QUATERNARY RESEARCH ASSOCIATION

FIELD MEETING GUIDE

SUFFOLK, May 7 - 9, 1982

Leaders :

P. ALLEN	City of London, Polytechnic
C.A. AUTON	Institute of Geological Sciences
M.R. CLARKE	Institute of Geological Sciences
P. COXON	Trinity College, Dublin

The leaders wish to thank the many landowners and quarry owners who have given permission to visit their property.

QUATERNARY RESEARCH ASSOCIATION

THE GIPPING VALLEY AND BURY ST EDMUNDS AREA — Saturday, 8 May, 1982

Section 1

Section 2

Contributors :

P. ALLEN

C.A. AUTON

J.A. CATT

M.R. CLARKE

D.T. HOLYOAK

A. STRAW

Edited P. Allen

These sections contain unpublished material which should not be quoted without the consent of the author(s).

1. INTRODUCTION

The Pleistocene deposits of south-east Suffolk rest on a bedrock surface principally of chalk, which, though irregular, inclines towards the south-east. On the eastern side of the Gipping Valley, Lower London Tertiaries overlie the chalk as far north as Barham. The succeeding fossiliferous Red Crag is now recorded as far north as Timworth Green (TL860680), north of Bury St. Edmunds (Clarke et al, 1980). Well sorted fine to medium sands, previously considered to be part of the Kesgrave Sands and Gravels by Rose and Allen (1977) are now interpreted as marine, regarded as unfossiliferous Red Crag by the (e.g. Allender and Hollyer, 1972) and grouped together as Creeting Beds (Dixon, 1978).

The oldest terrestrial deposits are the Kesgrave Sands and Gravels and the Ingham Sand and Gravel (Clarke and Auton, 1982), periglacial braided river deposits. The Kesgrave Sands and Gravels occur at at least three distinct altitudes, south of a chalk ridge trending east-west between Bury St. Edmunds and Wattisfield (TM 010742) (Figure 1) and represent a major river flowing south-west to north-east across southern east Anglia, an early Thames (Rose et al, 1976; Rose and Allen, 1977; Hey, 1980). The Ingham Sand and Gravel represents a separate major river system in the northern part of the area, possibly confluent with the early Thames east of Bury St Edmunds (Hey, 1980), though Clarke and Auton (1982) suggest that the situation is more complex.

The upper 1-2m of the Kesgrave Sands and Gravels are affected by complex pedogenic activity (Rose and Allen, 1977). An early phase of clay and iron enrichment, development of clay skins and rubification indicates temperate pedogenic activity and the formation of the Valley Farm Rubified Sol Lessivé. This temperate palaeosol is severely deformed by ground ice activity and the development of the skeletal Barham Arctic Structure Soil.

The succeeding Anglian glacigenic suite comprises sub-till gravels (Barham Sands and Gravels and Sandy Lane Gravels), tills (the Barham and Blakenham Tills) and intra- and super-till gravels (Haughley Park Gravels) (Rose et al, 1976, 1978; Rose and Allen, 1977).

Alternative interpretations of the deposits are put forward. The Kesgrave Sands and Gravels are not accepted as early Thames deposits and the clay and iron enriched layer as a palaeosol by Lake et al (1977), who regard the whole terrestrial sequence as part of the glacigenic suite. The major till sheet of East Anglia, and by implication its associated outwash, is regarded as Wolstonian in age by Bristow and Cox (1973), principally on the basis of the relationship of the till sheet to the terrace sequences of the area. The Haughley Park Gravels at the type site form part of a wide range of evidence used by Straw (1979a,b) to define the limits of a Wolstonian ice advance over East Anglia.

The stratigraphic sequence is summarised in Table 1.

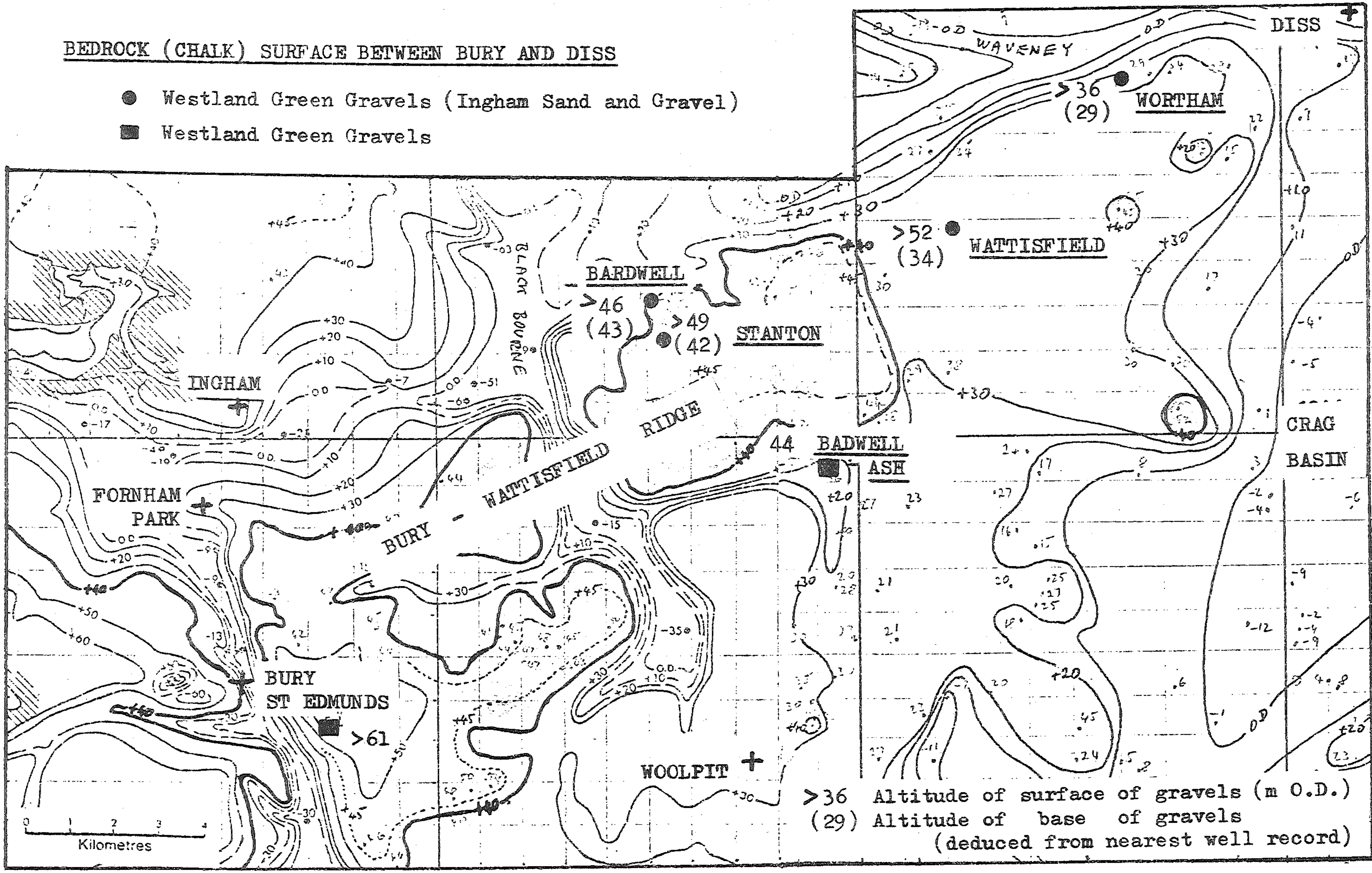


Figure 1. The Bury - Wattisfield Ridge.

Based on Woodland (1940-46), Harvey et al (1973), Hey (1980) and Clarke and Auton (1982).

Table 1. Middle Pleistocene lithostratigraphy and soil stratigraphy in Suffolk.

Deposits and structures	Lithostratigraphy: Formation	Lithostratigraphy: Member	Soil stratigraphy	Environment	Stage name
Coversand Head				Cold	
Chalky sands and gravels	Haughley Park Gravels			Glaciofluvial	Anglian
Flow till Lodgement till Flow till (non-calc) Flow till (calc) Chalky sands and gravels	Lowestoft Till	Blood Hill Till Blakenham Till Creeting Till Barham Till Sandy Lane Gravels		Glacial Glaciofluvial	
Sands and gravels Fluvial lag Unconformity	Barham Sands and Gravels			Glaciofluvial	
Loess Colluvium Involutions, sand and ice-wedge casts Coversand	Barham Loess Barham Colluvium Barham Coversand		Barham Arctic Structure Soil	Periglacial	
Rubification, clay and iron enrichment			Valley Farm Rubified Sol Lessive	Humid, warm temperate	Cromerian (Pastonian?)
Sands and gravels, intraformational ice-wedge casts	Kesgrave Sands and Gravels	Waldringfield Gravels		Periglacial	Beestonian
		Westland Green Gravels Baylham Common Gravels			Pre-Pastonian
Sands and gravels	Ingham Sand and Gravel			Periglacial	
Sands, silty-clay	Creeting Beds			Estuarine, marine	Prior to Pastonian

2. THE FORM AND EVOLUTION OF THE CHALK SURFACE (CAA, MRC)

Data from water wells, Chalk outcrops and recently drilled shallow boreholes has been used to reveal the nature of the concealed Chalk surface of 500 km^2 of the Norfolk-Suffolk borderlands between Bury St Edmunds and Diss (1:25,000 sheets TL 86, 96, TM 07, 17, 08 SW/SE and 18 SW/SE). In general the pre-Pleistocene bedrock surface is formed by the Upper Chalk, though Middle Chalk has been recorded in a few deep wells near the western margin of the area (Harvey et al, 1973).

Some 970 data points have been used to produce the computer generated contour map of the surface of the Chalk (Figure 2). This data has also been used to produce isometric views of the Chalk surface. Figure 3a shows the surface viewed from the south-west and 3b from the north-west. The Chalk is seen to be dissected by a network of over-deepened buried channels, the tunnel valleys described by Woodland (1970). The channels are thought to have been formed by meltwater, under hydrostatic pressure beneath an ice sheet, which excavated these features to a depth of several hundred feet below the base of the ice and partially infilled them with a thick sequence of fluvio-glacial drift. Figures 2 and 3 also show the elevation of the Chalk surface south of the Waveney Valley to be generally some 10 to 20m higher than to the north, which may indicate relatively less glacial erosion in the southern part of the area. The Chalk surface also falls south-eastwards, coinciding with the basin of Crag deposition in this area.

The position of the buried channels has clearly influenced the post-glacial drainage pattern of the area since the major present-day water courses, such as the River Lark, Black Bourn, Little Ouse and River Waveney have a similar trend to that of the network of buried channels. In detail, however, Figure 2 shows that the present-day rivers and streams cut across the alignment of the underlying channels. The amount of down-cutting associated with the formation of the buried channel system in this area can be envisaged by examining the elevation of the Chalk surface which ranges from +86.6m O.D. at TL 818600, to the south-west of Bury St. Edmunds to -44.8m O.D. in a well at TL 937695 sunk within the margins of the buried channel associated with the present-day course of the Black Bourn.

There is some controversy as to the shape of the buried channels themselves. This present work suggests that the channels are not the very narrow, steep-sided features previously proposed by Woodland (1970) and Notcutt (1978). This difference in interpretation is due the sparsity of data points available to them and to the small scale of the maps on which contour plots were made, which gave a large vertical exaggeration and a consequent apparent steepening of the channel sides. Cross-sections drawn through the channels of this area, such as Figures 4a and 4b, with a ten-fold exaggeration, show the channels to be funnel-shaped, at least in their upper part. This point is further emphasised when cross-sections a and b are redrawn at true scale (Figures 4c and 4d). The shape of the channel edge is confirmed by boreholes drilled in the peripheral areas which contain considerable thicknesses of poorly laminated glacial silts, typical of the fluvio-glacial channel infill, but which are largely absent in the glacial sequence of the surrounding till plateau.

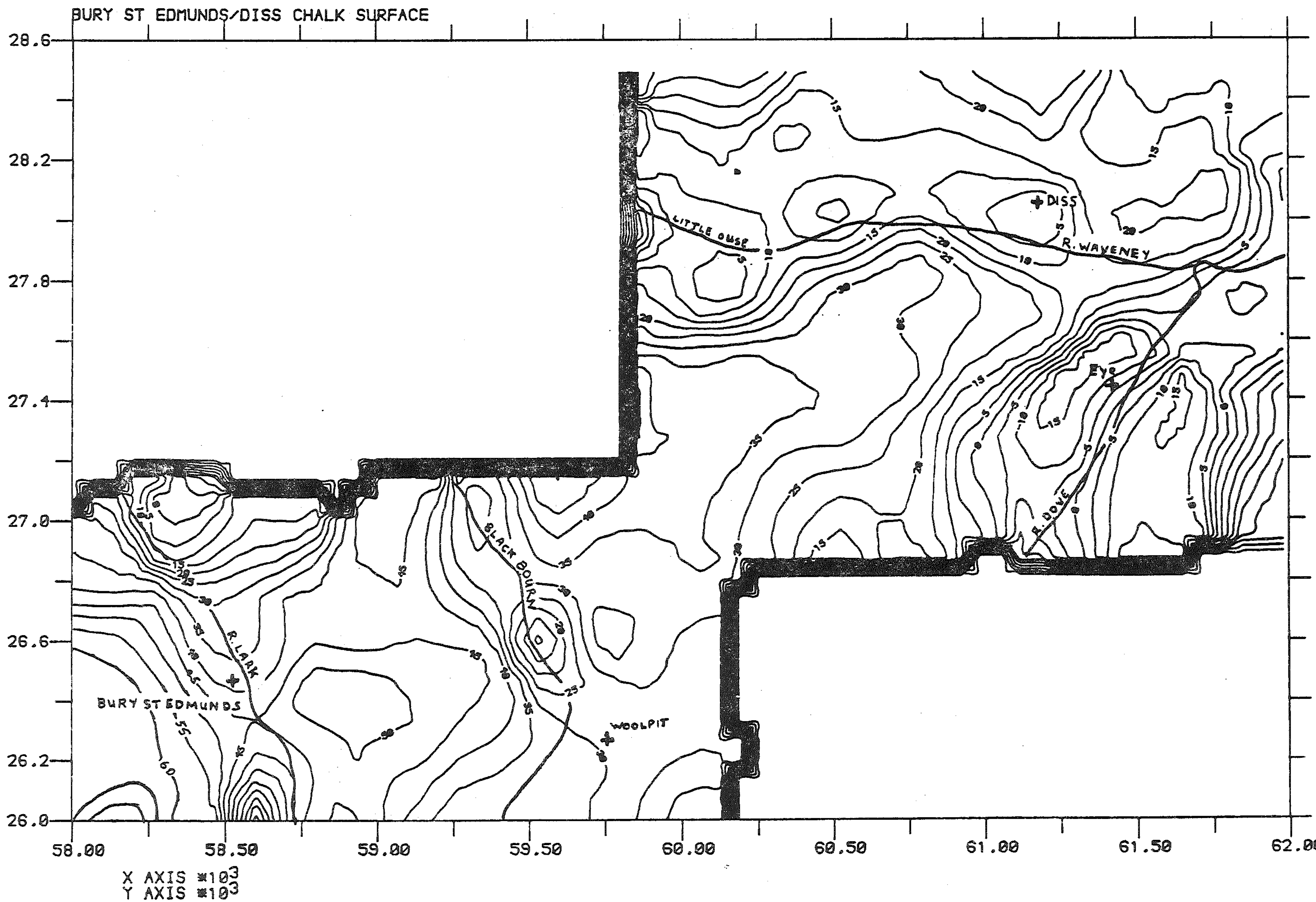


Figure 2. Bury St Edmunds - Diss Chalk Surface.

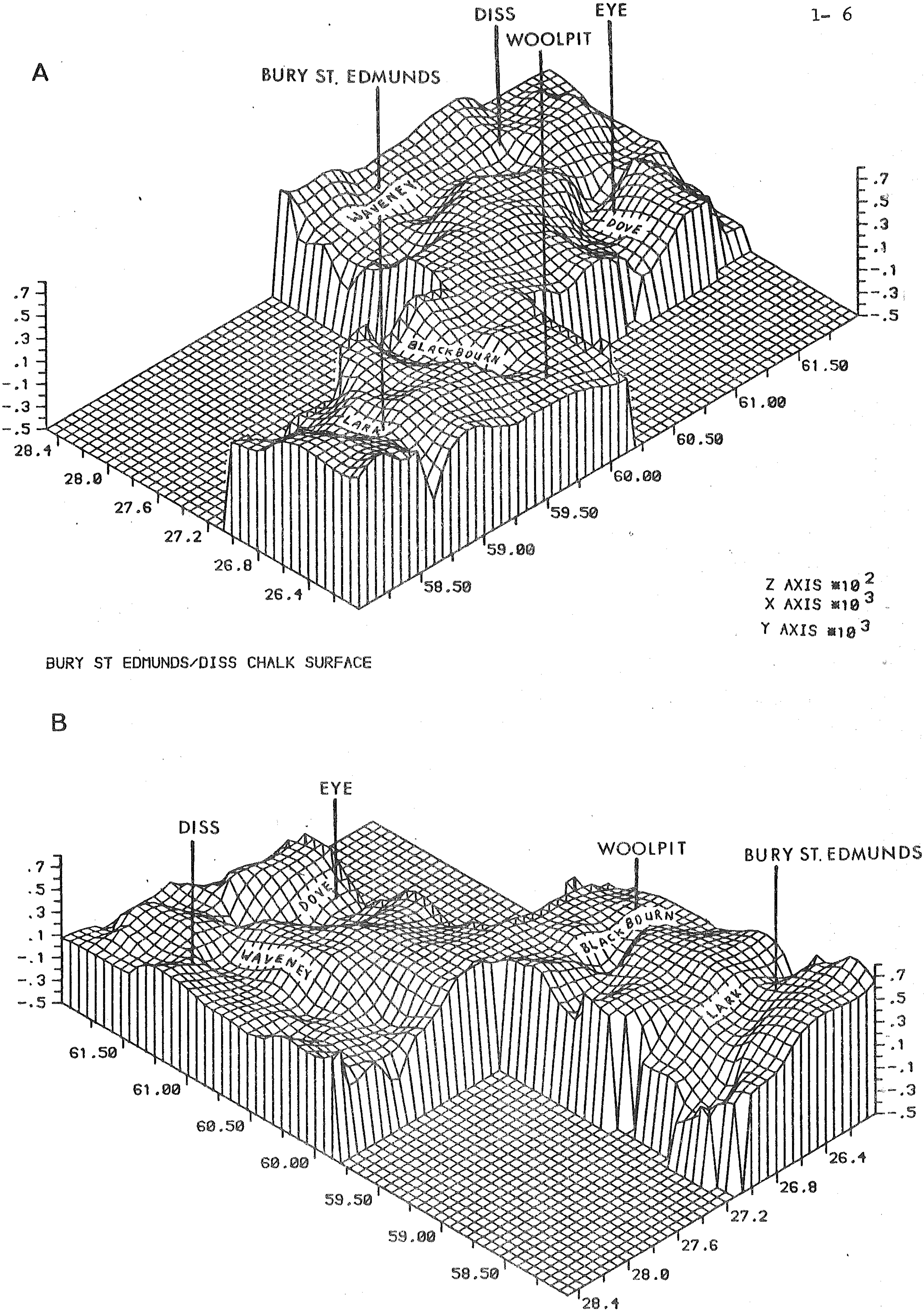


Figure 3. Isometric views of the Bury - Diss Chalk surface.

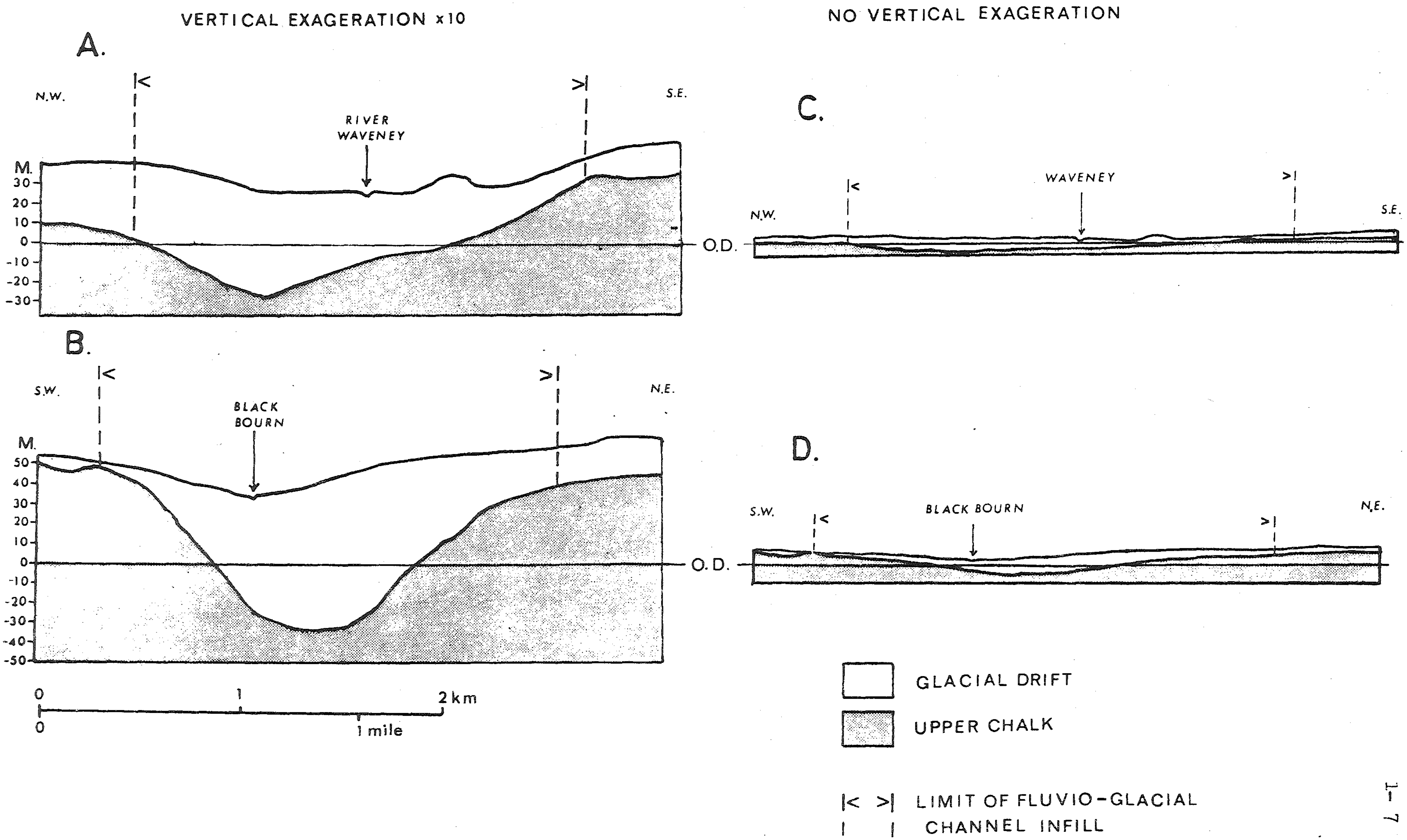


Figure 4. Cross-sections of the Waveney and Black Bourn.

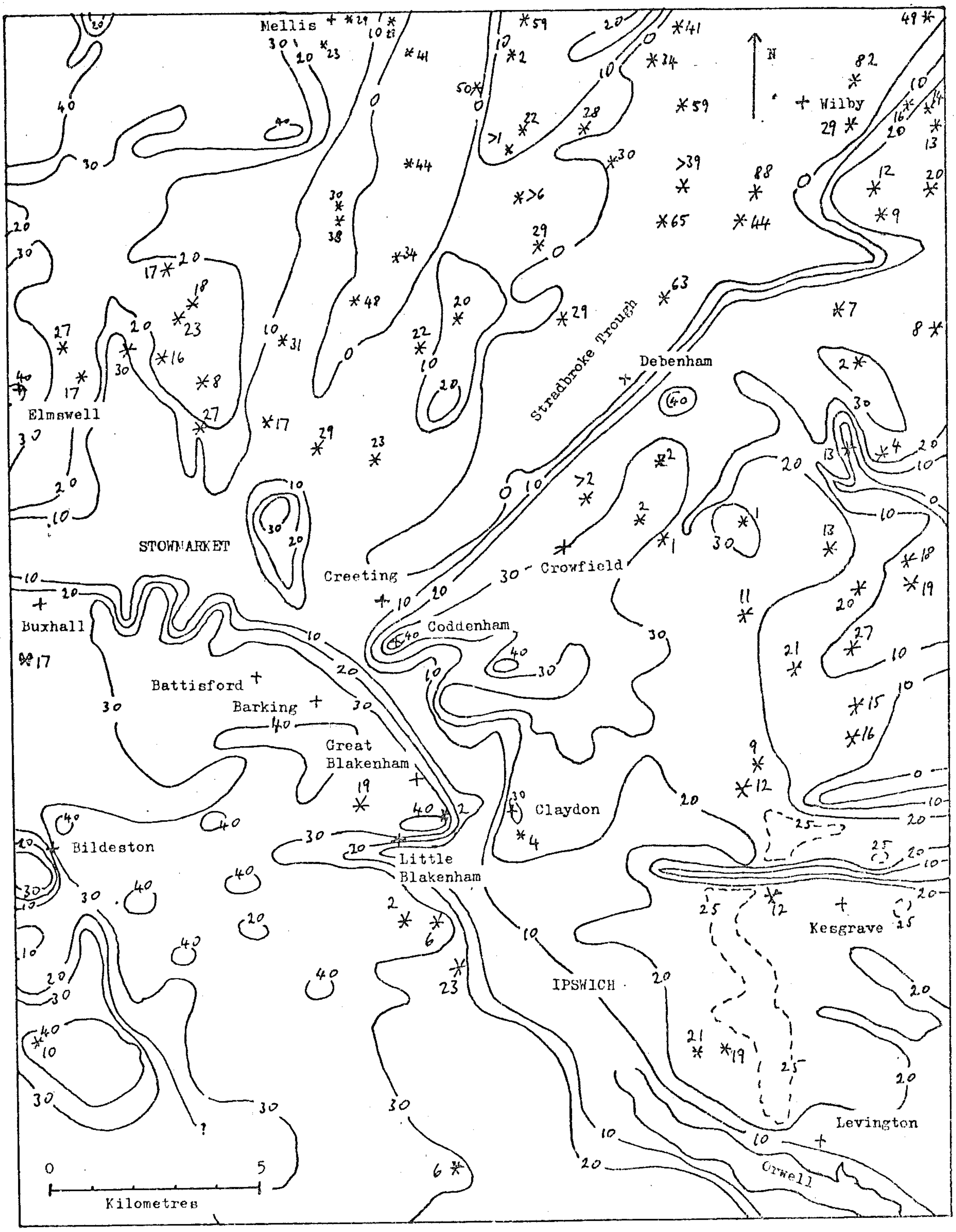
3. CREETING BEDS

The Creeting Beds consist of well-sorted fine or medium sands with occasional matrix-supported gravel beds. Spencer (1966) considered the main distribution of the Beds to lie between Creeting and Hollesley; Dixon (1978) considered the distribution to be between Stowmarket, Wickham Market and Grundisburgh. Well records suggest an even wider distribution with sub-till sands, as opposed to sand and gravel, being widespread north and east of the Gipping Valley in an area bounded on the south by Levington (TM 228392) and going at least as far north as Elmswell (TL 990640) and Mellis (TM 100746) and as far east as Woodbridge (Figure 5). The sands occur west of the Gipping Valley at Valley Farm, Copdock, Great Blakenham and in the Buxhall area and are absent east of the valley between Claydon, Creeting and Crowfield. The western limit of the Creeting Beds appears to be coincident with Boswell's (1915) anticlinal axis of instability, which trends north-west to south-east, approximately along the alignment of the Gipping, suggesting a tectonic control to the area of deposition. The area where the sands are absent east of the valley coincides with the presence of Chalk ridges while the sands west of the valley occur in basins.

The upper surface of the sands varies between 30 and 40m O.D., except in the west, between Elmswell and Old Newton and at Great Blakenham, where heights up to 50m O.D. are recorded, and in the north-east, around Eye, where heights below 30m O.D. are common. The main control on the thickness of the sands is the irregularity of the bedrock floor, with over 80m of sand and Crag being recorded in the Stradbroke trough at Wilby (borehole 190/215), contrasting with the area immediately to the south-east with less than 20m. The latter area lacks any record of underlying shelly Crag and appears to be an extension of the Claydon-Creeting-Crowfield area which has no record of the sands.

Where thicker sequences are exposed, as at Great Blakenham and formerly at Creeting St Mary, the lower parts, up to c12m thick, are sand dominated with minor amounts of silty-clay in flaser and lenticular bedding, while in the upper parts, up to 3m thick, have more silty-clay in interlayered silt and sand units or in massive silty-clay lenses up to 1m thick. A similar relationship occurs with the 'Chillesford Beds' overlying unfossiliferous Red Crag (e.g. Allender and Hollyer, 1972). The particle size characteristics do not allow an unequivocal interpretation of the data. The best match was found to be with beach deposits, using Passega's (1957) CM diagrams (Figure 6). The matrix-supported gravelly units are reasonably explained as fluvial debris flows into the littoral/shallow water area rather than storm or turbidity deposits as the former is not likely to be matrix-supported while the shallow water depths would not favour the latter.

Sedimentary structures in the sands consist of channel scours filled with gamma cross-lamination, horizontal bedding, tabular cross-sets and occasional trough cross-sets. Silty-clay occurs within the sands as seams, either polygonally fractured (mud-cracks) or as curled flakes and as flaser and lenticular bedding. Palaeocurrent measurements show local concentrations of readings but no particular concentrations overall. Deformation structures indicating biogenic disturbance occur, but infrequently. The sedimentary structures of the sands indicate deposition in sub-tidal or inter-tidal zones. The desiccation implied by the curled mud flakes and mud cracks suggests an inter-tidal rather than a sub-tidal environment. The paucity of biogenic structures is thought to reflect reduced biological activity, due either to rapid sedimentation or, less likely, to low temperatures.



(Woodland, 1940-46)

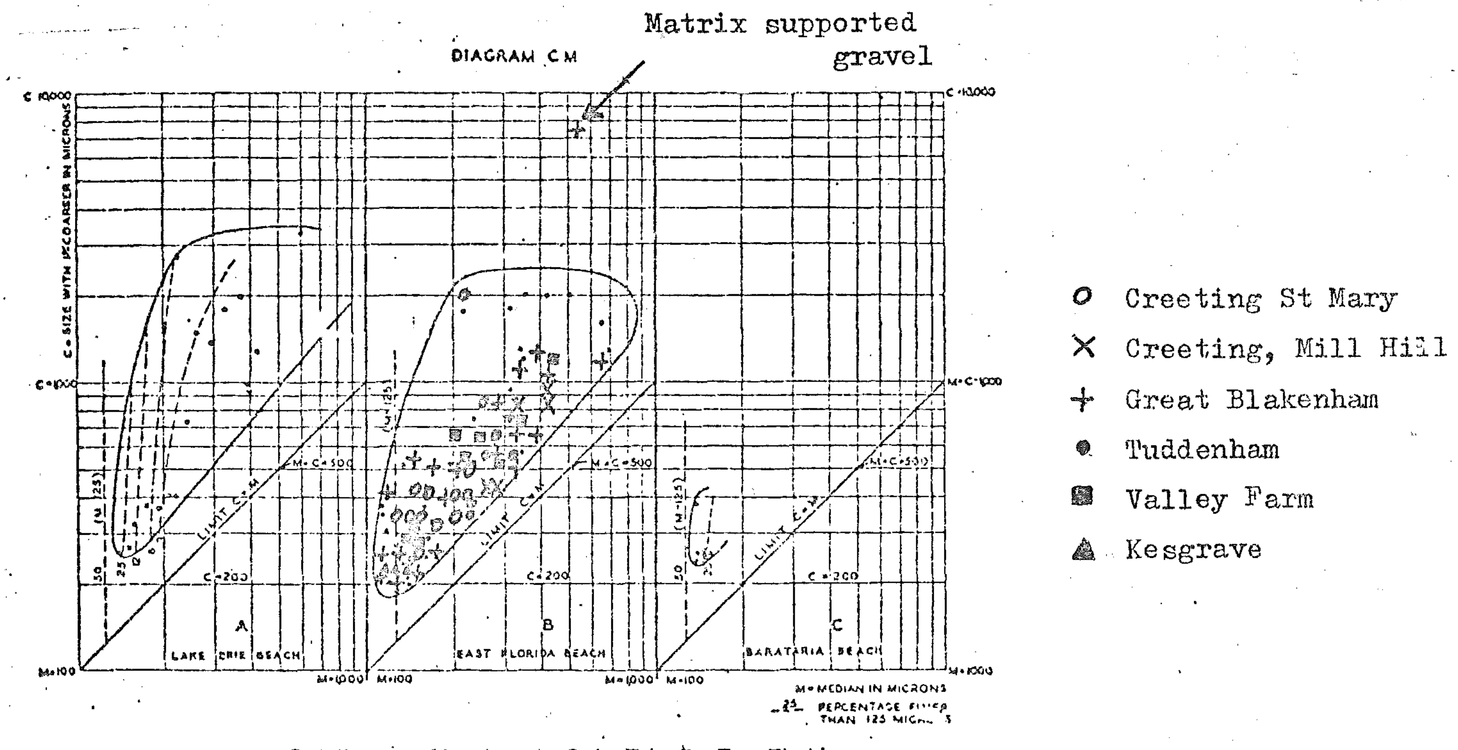
*20 Well or borehole at which sub-till sands are recorded. Thickness (in metres) of sands and Crag.

Figure 5. Gipping Valley, sub-drift contours (in metres O.D.), showing possible distribution of Creeting Beds.

Massive seams of silt in the upper part of the sands at Great Blakenham are seen to pass laterally into lenticular and interlayered bedding, similar to that found at Creeting St Mary. Oxidised and brecciated horizons are found, particularly in the higher parts. The silty-clay indicates deposition from water with high concentrations of suspended fine sediment in areas of low current or wave activity. The thickness of the accumulation suggests that such conditions obtained for a long time as such material is slow to accumulate. The thickness of the silty-clay, the presence of the lenticular bedding and the inter-bedding with inter-tidal sands suggests that the silty-clay is estuarine in origin.

Arboreal pollen obtained from the silty-clay include Pinus, Alnus, Betula, Quercus, Picea and Tsuga canadensis and shrubs, principally Ericacae. The non-arboreal pollen was mainly of Graminae, Cyperacea and Filicales. This spectrum suggests predominant woodland vegetation with areas of heathland of an age earlier than the Pastonian (Holyoak, pers. comm.).

Thus the Creeting Beds are established as shallow marine deposits of Lower Pleistocene age. Non-shelly shallow marine deposits of similar age occur along the Suffolk and Norfolk coasts (West, 1980), in bore-holes at Ludham (Funnell, 1961; West, 1961; Norton, 1967) and Stradbroke (Beck et al, 1972) and in association with Norwich Crag exposures, notably at Bramerton (Funnell et al, 1979). The preliminary state of the pollen work at Great Blakenham makes it impossible to correlate with a specific stage of the Lower Pleistocene or an specific sites and a further complication is that although the silts in the upper part of the sequence at Great Blakenham are interglacial, it does not follow that the sands below are also interglacial, as the intercalations of matrix-supported gravel suggest a periglacial origin. Similar climatic variations are recorded in the sedimentary sequences from the boreholes and coastal sections. However, the presence of shallow marine deposits of similar age in the coastal sections at or near present sea-level implies a relative uplift at (or downwarp from) Great Blakenham of c50m. If the Stradbroke trough is of tectonic origin, the difference may be as much as 80m. Thus, it is feasible that East Anglia was tectonically very active in the early Pleistocene.



CM diagram of beaches: A—Lake Erie; B—East Florida; C—Barataria, Gulf of Mexico.

Figure 6. Creeting Beds, CM diagrams (Passega, 1957)

4. INGHAM SAND AND GRAVEL (MRC, CAA)

Iron-stained sand and gravel, rich in 'liver-coloured', well rounded Bunter quartzite with a high proportion of vein-quartz pebbles have been proved in some IMAU boreholes in the northern part of the area surveyed. Sand and gravel of similar composition ... is also exposed in pockets at the base of a small pit (TL 851713) north of the village of Ingham (Figure 7).

The high proportion of well rounded Bunter quartzite pebbles, which at some localities is as much as 60% of the pebble-counted fraction, serves to distinguish this Bunter-rich gravel from other stratigraphic units in the region.

Bunter-rich gravels are also well known from north-west of the Wash, in Lincolnshire, where IMAU surveys have shown that the fluvial deposits of the proto-Witham contain abundant material derived from the Triassic deposits of the Midlands. The mean composition of Bunter-rich gravel proved in assessment boreholes in the Billinghay area of the Witham valley (Wild, in press), is flint 19%, vein quartz 21%, quartzite/sandstone 50%, limestone 7% and others 3%. It is remarkably similar to the mean composition of the Bunter-rich gravel exposed in Ingham pit ...; it would appear therefore, that both deposits have material derived from a similar source. Recently it has been suggested (Hey, 1980) that quartzite-rich gravels in this area are related to a tributary of an early glacial outwash stream which laid down the Kesgrave Sands and Gravels. However, the data presented here imply that the Bunter-rich gravels found in this area represent a separate fluvial event from that which led to the formation of the Kesgrave Sands and Gravels.

(From Clarke and Auton, 1982)

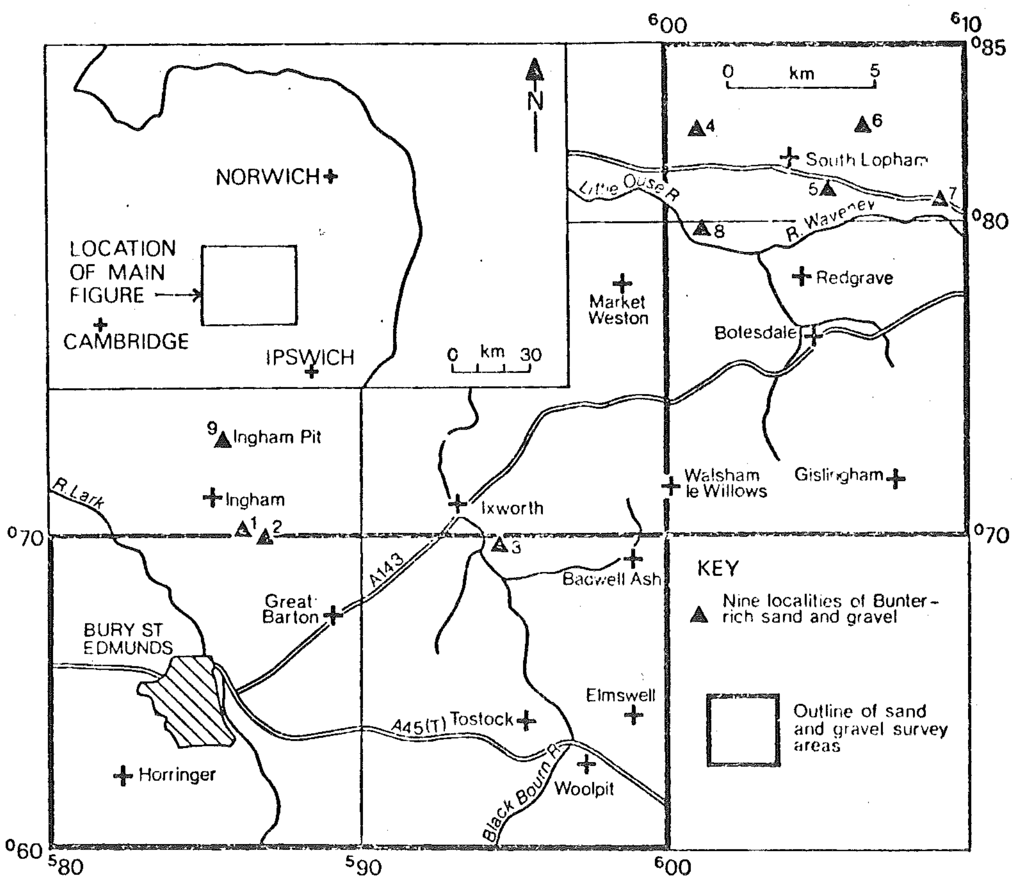


Figure 7. Ingham Sand and Gravel.

5. KESGRAVE SANDS AND GRAVELS (Figures 8, 9. Tables 2, 3.)

The Kesgrave Sands and Gravels can be divided on the criteria of altitude, lithology and sedimentary structures into :

BAYLHAM COMMON GRAVELS	c50m O.D., in the Gipping Valley
WESTLAND GREEN GRAVELS	40-44m O.D.
WALDRINGFIELD GRAVELS	24-28m O.D.

The sedimentary structures and lithological composition of the formation (Tables 2, 3) are typical of a braided river system, an early course of the Thames which flowed across south-eastern East Anglia (Rose et al, 1976; Rose and Allen, 1977; Hey, 1980)

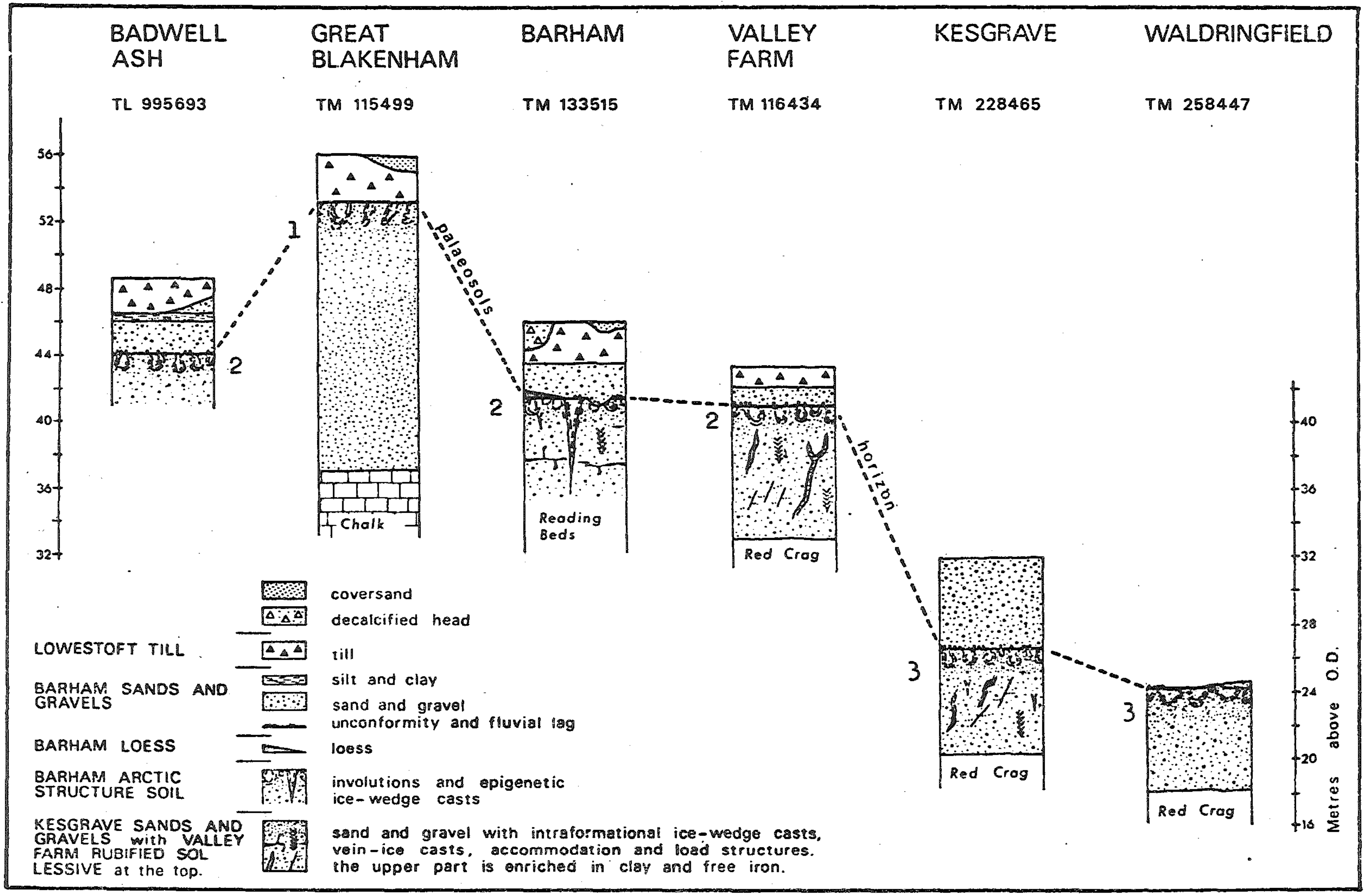
Field observations of these gravels can be supplemented by borehole evidence, though it must be stressed that the borehole records do not include lithological or bedding information, so correlations must be treated with caution.

a. BAYLHAM COMMON GRAVELS (Figure 8, 9. Tables 2, 3.)

The Baylham Common Gravels of Darmsden and Great Blakenham have high percentages of gravel, 44-60% of the units sampled being sandy gravel and over 75% of the samples analysed contained clasts coarser than -3ϕ (8mm). The sedimentary sequences are dominated by matrix-supported gravels (Gms facies) with lesser amounts of horizontally or planar cross-bedded sands (Sh and Sp facies). Both sites, where the sediments are not affected by pedogenesis and ground ice activity, accord with the Donjek type of braided river profile of Miall (1977, 1978). The palaeocurrent direction, to the south-east, is unusual for the Kesgrave Sands and Gravels, but with only 14 measurements from one site, it is possible that the sample does not reflect the direction of flow truly.

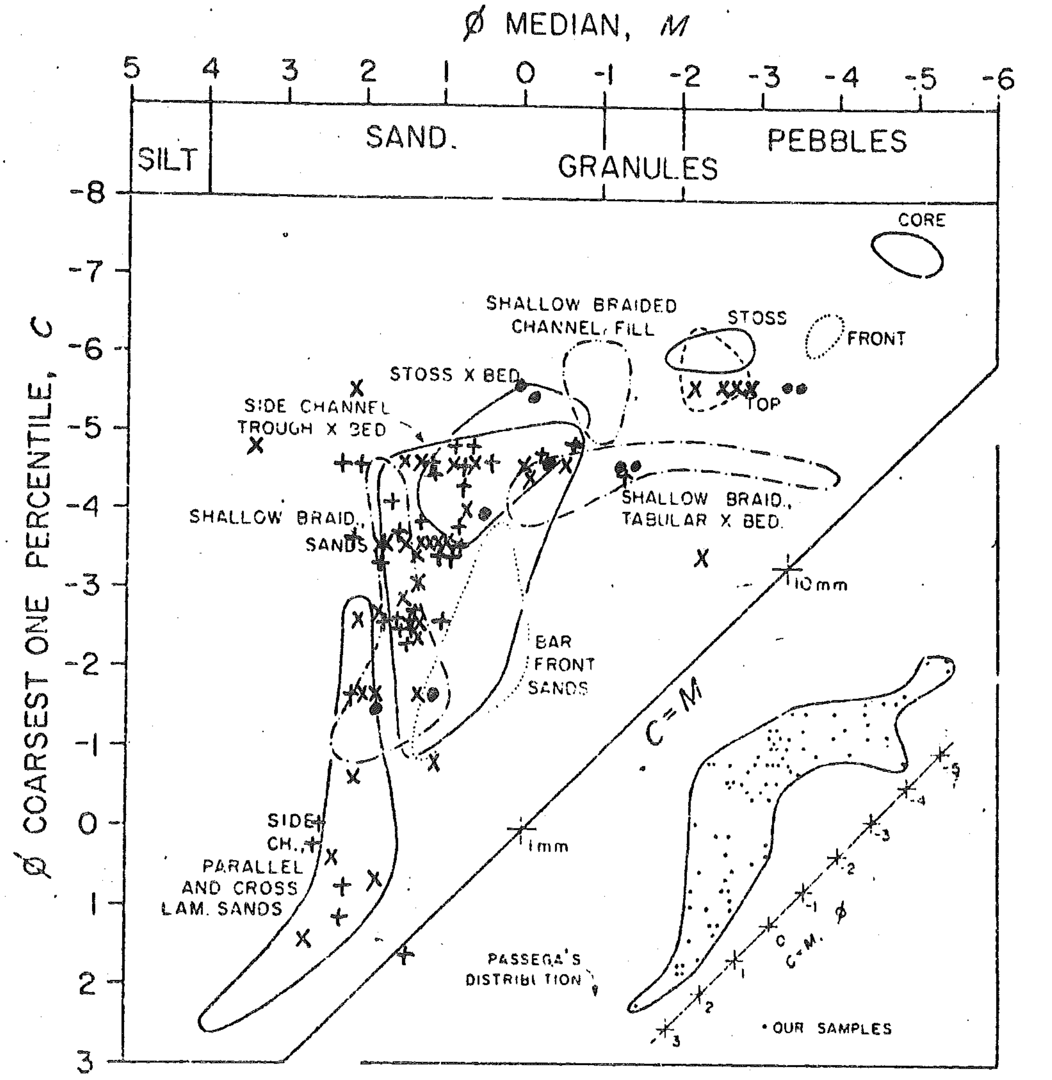
The gravels are dominantly composed of flint (up to 66%), most of which is angular (up to 43%). Quartz and quartzite are the next most important group (up to 32%), with quartz being more important than quartzite. Small amounts of Greensand and Carboniferous chert occur. Essentially the gravel suite is composed of durable lithologies, typical of the Kesgrave Sands and Gravels.

Using the criteria of height, the Baylham Common Gravels are distinctive in that they occur at altitudes up to 10m above the Westland Green Gravels. Similar high level gravels occur at 50m O.D. in the Gipping Valley in wells 207/50 and 51 and at Elmsett at 55m (207/33 and 39). Tentatively, the gravels can be traced back through Boxford at 60m (206/194 and 232 and 223/51) at least to Alphamstone at 70m (206/226, 223/31 and 28). If these gravels are correctly correlated, they form a gradient of c1m.km^{-1}. Extrapolation further west at this gradient would give a level of c120m O.D. in eastern Hertfordshire, which lies between the height of the Westland Green Gravels there (116m O.D.) and the '400 ft Gravels' (122m O.D.) (Hey, 1965). A correlation with the former is proposed on the basis of stone counts (Table 4).



1.	Baylham Common Gravels.	Surface height	c50m O.D.
2.	Westland Green Gravels.		40–44m O.D.
3.	Waldringfield Gravels.		24–28m O.D.

Figure 8. Kesgrave Sands and Gravels, altitudinal distribution.



Eynon and Walker 1974

● Baylham Common Gravels

+ Westland Green Gravels

x Waldringfield Gravels

CM diagram for braided river deposits

Figure 9. CM diagram, Kesgrave Sands and Gravels

SEDIMENTARY PROPERTIES.	No. samples per site	PARTICLE SIZE Gravel %	Sand %	Silt + Clay %	COARSEST CLASTS[1] >-5 %	-4 %	-3 %	-2 %	-1 %	0φ %	SANDY[2] GRAVEL %	PALAEOCURRENT DIRECTION n	x̄	AMPLITUDE OF CROSS-SETS n	x̄ m	max. m	FACIES ASSEMBLAGE
HAUGHLEY PARK GRAVELS																	
Haughley Park	10	37.3	58.6	4.1	40	20	20	20	0	0	50	25	115.5°	-	-	0.5	Scott
Woolpit	10	26.5	68.4	5.1	50	10	20	10	10	0	40	-	-	-	-	-	Scott
Little Blakenham	10	34.2	62.3	3.5	10	60	20	0	0	10	60	37	166.1°	30	0.28	1.0	Donjek
SANDY LANE GRAVELS																	
Badwell Ash	1	80.3	15.5	4.2	100	0	0	0	0	0	100 (gravel)	-	-	-	-	-	
BARHAM SANDS AND GRAVELS																	
Barham	49	17.5	81.8	0.7	21	19	25	23	12	0	24	50	121.4°	45	0.27	0.4	Donjek
Badwell Ash	10	20.3	78.2	1.5	10	30	30	10	12	10	30	50	109.7°	13	0.27	0.7	Donjek
Valley Farm	5	21.9	76.5	1.6	20	20	20	0	40	0	40	20	112.0°	1	-	0.25	Donjek
Kesgrave	7	9.4	89.8	0.8	0	28	0	28	43	0	14	25	70.2°	8	0.14	0.3	Donjek
Tuddenham	4	27.6	70.4	2.0	25	50	0	0	25	0	25	15	97.0°	10	0.24	0.3	Donjek
KESGRAVE SANDS AND GRAVELS																	
Baylham Common Gravels																	
Darmsden	10	37.0	57.4	5.6	40	30	10	0	20	0	60	14	135.7°	-	-	0.5	Donjek
Great Blakenham	16	23.0	59.2	17.8	38	19	19	12	6	6	44	-	-	-	-	-	Donjek
Westland Green Gravels																	
Badwell Ash	9	11.7	72.8	15.5	0	44	44	0	11	0	0	49	56.3°	1	-	0.5	South Saskatchewan
Barham	47	17.0	73.4	9.6	4	27	35	27	6	0	21	46	10.0°	8	0.30	0.7	Donjek
Valley Farm	9	14.3	81.9	3.8	0	44	33	0	11	11	11	50	41.7°	7	0.24	0.3	Donjek
Waldringfield Gravels																	
Kesgrave	7	4.1	90.0	5.9	0	0	43	14	29	14	0	50	18.0°	8	0.13	0.4	South Saskatchewan
Waldringfield	9	11.4	87.2	1.4	11	22	22	33	11	0	11	50	76.5°	6	0.22	0.4	Donjek
Foxhall Heath	12	22.1	73.9	4.0	33	17	25	8	17	0	25	20	66.0°	-	-	0.6	Donjek
Trimley	10	31.6	59.5	8.9	30	40	10	20	0	0	60	-	-	-	-	-	Donjek

1. Coarsest clast size in each sample as a percentage of all samples.

2. Percentage of samples classified as sandy gravel (Folk, 1974).

Table 2. Sedimentary properties of the sands and gravels of Suffolk.

STONE COUNTS

16–32mm
In percentages

		FLINT Non-Tertiary ANG.	ROUND	TOTAL	Tertiary ANG.	ROUND	TOTAL	All Flint ANG.	ROUND	TOTAL	QUARTZ GROUP QTZ	QTZ'ITE	COLOURLESS QTZITE	DURABLE SEDST.	TOTAL	CHERTS GREENSAND	CARBONIFEROUS	BARBELA	MISC.	TOTAL NON-GREENSAND	TOTAL
INGHAM SAND AND GRAVEL																					
Hardwell	H	—	—	—	—	—	—	—	—	23.9	32.7	41.6	—	—	74.3	0	—	—	—	1.8	1.8
Stanton	H	—	—	—	—	—	—	—	—	26.0	37.8	34.1	—	—	71.9	0	—	—	—	2.0	2.0
Wattisfield	H	—	—	—	—	—	—	—	—	36.9	28.6	33.3	—	—	61.9	0	—	—	—	1.2	1.2
KESGRAVE SANDS AND GRAVELS																					
Baylham Common Gravels																					
Great Blakenham		28.6	5.2	33.8	9.8	21.9	31.7	38.4	27.1	65.5	18.3	11.1	5.9	0	29.4	0.5	3.1	0	0.3	3.4	3.9
Darmsden		37.3	5.9	43.2	5.6	13.0	18.6	42.9	18.9	61.8	18.6	13.7	5.9	0	32.3	2.2	1.6	0	0	1.6	3.8
Westland Green Gravels																					
Badwell Ash (P)	A	24.8	4.0	28.8	16.8	16.8	33.6	41.6	20.8	62.4	16.4	16.4	14.4	0.4	33.2	0	3.6	0	0.4	4.0	4.0
	B	48.7	0.5	49.2	9.7	10.3	20.0	58.4	10.8	69.2	11.8	11.8	9.2	0.5	24.1	1.0	1.0	0	1.0	2.0	3.0
	H	—	—	—	—	—	—	—	—	70.2	18.1	10.6	—	—	28.7	0.3	—	—	—	0.3	0.6
Creeting St Mary		31.4	9.0	40.4	9.4	24.9	34.3	40.8	33.9	74.7	10.8	10.8	10.1	0	21.6	0.4	2.5	0	0	2.5	2.9
	H	—	—	—	—	—	—	—	—	65.3	20.3	10.6	—	—	30.9	2.5	—	—	—	1.0	3.5
Barham (P)	A	34.8	4.3	39.1	12.1	14.6	26.7	46.9	18.9	65.8	13.7	13.9	10.6	0.2	27.8	1.1	3.6	0	0.7	4.3	5.4
	B	46.1	2.6	48.7	11.8	7.8	19.6	52.9	10.4	68.3	13.6	12.2	5.9	0	25.8	1.5	4.4	0	0	4.4	5.9
	H	—	—	—	—	—	—	—	—	73.5	16.0	9.5	—	—	25.5	0.8	—	—	—	—	0.8
Bramford		45.6	7.2	52.8	5.8	10.5	16.3	51.4	17.7	69.1	16.5	12.3	4.4	0.2	26.9	0.2	1.8	0.2	1.0	3.0	3.2
	H	—	—	—	—	—	—	—	—	66.0	19.0	12.3	—	—	31.3	0.6	—	—	—	1.0	1.6
Valley Farm (P)	A	16.9	3.2	20.1	8.3	21.0	29.3	25.2	24.2	49.4	16.4	28.2	5.5	0.9	45.5	0.5	0.9	0.2	0.9	2.0	2.5
	B	36.6	2.1	38.7	12.8	12.3	25.1	49.4	14.4	63.8	15.2	16.0	7.0	0.8	32.0	0.4	2.5	0	0	2.5	2.9
	H	—	—	—	—	—	—	—	—	66.0	16.9	13.3	—	—	30.2	1.4	—	—	—	1.6	3.0
Tuddenham	H	—	—	—	—	—	—	—	—	73.0	14.0	9.0	—	—	23.0	1.0	—	—	—	2.0	3.0
Waldringfield Gravels																					
Kesgrave (P)		59.3	0.7	60.0	14.0	10.7	24.7	73.3	11.4	84.7	6.0	6.0	0.7	0.7	12.7	1.3	1.3	0	0	1.3	2.6
Foxhall Heath (P)		59.0	4.0	63.0	11.4	4.4	15.8	70.4	8.4	78.8	10.4	8.2	2.5	0.2	18.8	1.3	1.1	0	0	1.1	2.4
Waldringfield (P)	upper	55.2	3.7	58.9	12.2	9.4	21.6	67.4	13.1	80.5	8.4	7.9	3.7	0.2	16.5	1.4	1.2	0	0	1.2	2.6
	lower	55.7	4.6	60.3	9.3	8.4	17.7	65.0	13.0	78.0	9.8	8.2	1.0	0	18.0	1.6	1.5	0	0.8	2.3	3.9
Ipswich Airport (P)		65.5	3.5	69.0	10.6	6.6	17.2	76.1	10.1	86.2	4.4	5.3	0.0	0.4	10.1	0.9	0.9	0	0	0.9	1.8
Trimley		49.0	3.4	52.4	19.0	14.7	33.7	68.0	18.1	86.1	5.8	5.8	1.0	0.2	11.8	1.0	0.2	0.2	0.6	1.0	2.0

		SEDIMENTARY NON-DURABLES CHALK	LIMEST.	SANDST.	IRONST.	MISC.	IGNEOUS + METAM DURABLE	NON-DURABLE	UN-KNOWN DURABLE	NON-DURABLE	DURABLES	NON-DURABLES	% COLOURLESS QUARTZITES	RATIOS (n:1) ANG: ROUNDED FLINT	NON-TERT: TERT. FLINT	FLINT: QTZ GROUP	QUARTZ: QUARTZITE	n
INGHAM SAND AND GRAVEL																		
Hardwell	H	—	—	—	—	—	0.4	—	—	—	—	—	—	—	—	0.3	0.8	113
Stanton	H	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.4	1.1	296
Wattisfield	H	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.6	0.9	345
KESGRAVE SANDS AND GRAVELS																		
Baylham Common Gravels																		
Great Blakenham		0	0	0.8	0	0.3	0.3	0	0	0	98.9	1.1	53	1.4	1.1	2.2	1.6	388
Darmsden		0	0	0.9	0	0	0.6	0	0.6	0	99.1	0.9	43	2.3	2.3	1.9	1.4	322
Westland Green Gravels																		
Badwell Ash (P)	A	0	0	0	0	0	0.4	0	0	0	100.0	0	86	2.0	0.9	1.9	1.0	250
	B	0	0	2.1	0	0	0	0	0	0	97.9	2.1	69	5.4	2.5	2.9	1.0	195
	H	—	—	—	—	—	0.8	—	—	—	—	—	—	—	—	2.4	1.7	287
Creeting St Mary		0	0	0	0	0	0.4	0	0.4	0	100.0	0	93	1.2	1.2	3.5	1.0	277
	H	—	—	—	—	—	0.2	—	—	—	—	—	—	—	—	2.1	1.9	487
Barham (P)	A	0	0	0	0	0	0	0	0.9	0	100.0	0	76	2.5	1.5	2.4	1.0	445
	B	0	0	0	0	0	0	0	0	0	100.0	0	48	5.6	2.5	2.6	1.1	271
	H	—	—	—	—	—	0.4	—	—	—	—	—	—	—	—	2.9	1.7	254
Bramford		0	0	0.4	0	0	0.4	0	0	0.2	99.4	0.6	35	2.9	3.2	2.6	1.2	505
	H	—	—	—	—	—	1.0	0	—	—	—	—	—	—	—	2.1	1.5	310
Valley Farm (P)	A	0	0	0.5	0	0	0.9	0	0	0.2	99.3	0.7	20	1.0	0.7	1.1	0.6	433
	B	0	0	1.2	0	0	0	0	0	0	98.8	1.2	44	3.4	1.5	2.0	1.0	243
	H	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.2	1.3	362
Tuddenham	H	—	—	—	—	—	0.7	—	—	—	—	—	—	—	—	3.2	1.6	303
Waldringfield Gravels																		
Kesgrave (P)		0	0	0	0	0	0	0	0	0	100.0	0	11	6.4	2.4	6.7	1.0	150
Foxhall Heath (P)		0	0	0	0	0	0	0	0	0	100.0	0	31	3.7	4.0	4.2	1.3	473
Waldringfield (P)	upper	0	0	0.2	0	0	0.2	0	0	0	99.8	0.2	48	5.1	2.7	4.9	1.1	509
	lower	0	0	0	0	0	0.2	0	0	0	99.8	0.2	12	5.0	3.4	4.3	1.2	611
Ipswich Airport (P)		0	0	0.4	0.9	0	0.4	0	0	0	98.7	1.3	0	7.5	4.0	8.5	0.8	226
Trimley		0	0	0	0	0	0.2	0	0	0	100.0	0	17	3.8	1.6	7.3	1.0	504

P Palaeosols layer present H Hey (1980)

Table 3. Ingham and Kesgrave Sands and Gravels, stone counts.

TABLE 4

		Baylham Common Gravels	Westland * Green Gravels (Herts)	400 ft * Gravels
Flint -	rounded	19 -27 %	29 -54 %	66 -78 %
	angular	38 -43	17 -37	14 -20
	total	62 -66	65 -78	85 -92
Quartz		18.3-18.6	12.3-24.5	4.4-11.0
Quartzite		11.1-13.7	5.9-10.0	0.5- 3.0
Chert -	Cretaceous	0.5- 2.2	0.3- 0.8	0.3- 0.7
	Palaeozoic	1.6- 3.1	0.9- 4.7	0.5- 1.0
	Other	0.0- 0.3	0.3- 1.2	0.3- 0.5

* Hey (1965)   Size range 16-32mm.

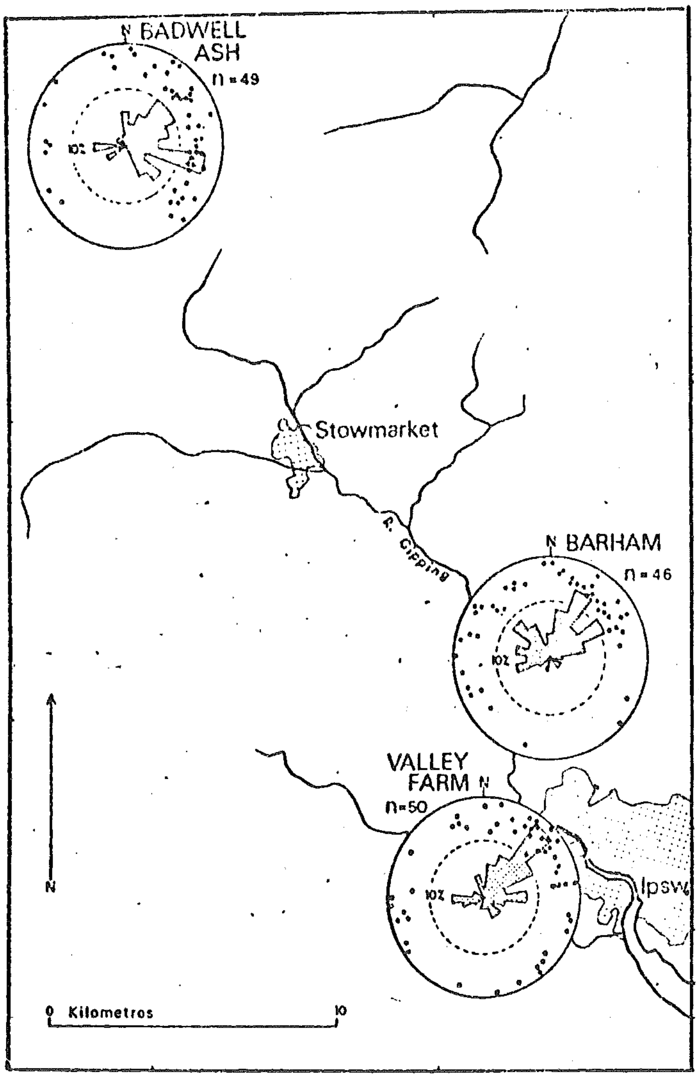


Figure 10. Palaeocurrent measurements of the Westland Green Gravels.

b. WESTLAND GREEN GRAVELS (Figures 8, 9. Tables 2, 3.)

Within the Westland Green Gravels, gravels, though important, occupy less than a quarter of the sections and the coarsest clasts encountered are mostly -4ϕ (16mm) or smaller. The matrix-supported gravels (Gms facies) are less important than the sands which are planar and trough cross-bedded or horizontally bedded (Sp, St and Sh facies). The maximum size of the cross-sets is 0.7m. At Valley Farm, a complex and well-developed sequence of 12 channel scours occur with amplitudes up to 2.8m. The channels are filled with sands and gravels bedded concentrically, parallel to the channel sides, indicating deposition as planar beds of the upper flow regime. Palaeocurrent measurements show flow directions to the east and north-east (Figure 10). The facies assemblages mostly correspond with Miall's Donjek type of braided river profile. Badwell Ash, having less gravel than the other two sites, has a South Saskatchewan type of profile.

The gravel suite is very similar to that of the Baylham Common Gravels, though with slightly more flint (62-75%). Two clasts of Rhaxella chert occurred (out of 2619 stones), thought to be derived from the underlying Red Crag. The counts are typical of the Kesgrave Sands and Gravels, except for one sample from Valley Farm, which had 28.2% quartzite (range for rest of Westland Green Gravels, 9.0-16.4%), most of which were coloured (80%), which again is unusual. A second sample from the site proved to be normal. No explanation for the aberrant sample is offered.

South and east of Bury St Edmunds, comparison of exposures with borehole and well sections indicates that these gravels were deposited in two distinct channels. The more northerly channel lies between the Bury-Wattisfield ridge and a complex of ridges between Barking and Little Blakenham. The second channel lies to the south of the latter ridge complex. The northern channel can be traced back, using both exposures and borehole and well sections to the Sudbury area. Immediately west of Sudbury, the gravels are replaced by till, though the bounding ridges can still be identified. The southern course can be traced back to Alphamstone. West of Sudbury, the well and borehole records have not yet been examined. Hey (1980) traces the gravels into Hertfordshire, correlating them with the Westland Green Gravels of the northern part of the London Basin. Eastwards the northern channel can be traced to Mendlesham and the southern channel to Debach. East of these points, the gravels cannot be separated into different channels. Hey (1980) traces the gravels to the Norwich area.

The occurrence of two gravel bodies at different heights, c50m and 40-44m O.D., in the Gipping Valley, both correlated with the Westland Green Gravels of the London Basin, is matched in Buckinghamshire and Hertfordshire by McGregor and Green (1978) who find Westland Green Gravels with a local altitudinal range of c35m. In the Gipping Valley, the gravels are obviously fluvial, occur in close proximity and are not sufficiently disturbed to suggest that they are not in situ, so they are considered to represent different phases of deposition and thus represent different terrace levels. So far, the Westland Green Gravels of the London Basin have not been divided.

c. WALDRINGFIELD GRAVELS (Figures 8, 9. Tables 2, 3.)

The Waldringfield Gravels lie south and east of Ipswich, with a surface height of 24-28m O.D. There is significant variation in the gravels for at Trimley, near Felixstowe, gravels dominate (60% of the units sampled comprised sandy-gravel), at Foxhall Heath they are still a significant fraction (25%), but at Waldringfield and Kesgrave they are far less important (11% and 0%, respectively). This pattern is repeated when examining the coarsest clasts. At Trimley, 70% of the samples had clasts coarser than -4ϕ (16mm), at Foxhall Heath 50%, Waldringfield 33% and Kesgrave 0%. This decline in gravel is complemented by an increase in the sand fraction of the samples rising from 59.5% at Trimley to 90.0% at Kesgrave. The particle size characteristics correspond to those expected of a braided river system (Figure 9).

Similarly, the sedimentary structures correspond to the Donjek and South Saskatchewan type of braided river profiles (Miall, 1977, 1978). Trimley was dominated by horizontally bedded, coarse, matrix-supported gravels (Gms facies). At Foxhall Heath, the Gms facies were important but various sandy facies, horizontally bedded, planar and trough cross-bedded (Sh, Sp, St facies) were of approximately equal importance. At Waldringfield and Kesgrave, the exposures were predominantly sandy (Sh, St, and Sp facies). The variation in the profiles would normally be attributed to downstream lessening energy in the braided river system. However, all the sites lie within 10 km and they are disposed transverse to the general flow direction. The variation may be explained by reference to the bedrock topography. To the west of the sites, an arcuate ridge of London Clay overlain by Red Crag trends north-south through Rushmere and east-west north of Kesgrave, reaching heights of 25-30m O.D. (Figure 11). Trimley lies to the south of the ridge, the other sites are contained within its arcuate form. The variations noted above are readily explained by Trimley being in the main flow path of the river while the other sites are protected by the ridge. Rust (1972) does describe cross-stratified sand, associated with transverse bars, in sheltered parts of the Donjek, but in general descriptions of lateral variation in braided rivers are lacking.

Palaeocurrent measurements, as with the Westland Green Gravels, show that flow was dominantly to the north-east (Foxhall Heath, $\bar{x} = 066^{\circ}$; Waldringfield, $\bar{x} = 076.5^{\circ}$; Kesgrave, $\bar{x} = 018^{\circ}$). The more northerly mean at Kesgrave may be due to the influence of the containing ridge.

The clast lithologies of the Waldringfield Gravels serve to distinguish them from the other members of the Kesgrave Sands and Gravels. The Waldringfield Gravels have high percentages of flints, the range being 78.0-86.2%, low proportions of quartz and quartzite (less than 20%) and few exotics (Table 3). The increase in flint is brought about by a significant input of angular and sub-angular non-Tertiary flint. This input is difficult to explain as the gravels lie south of the Chalk outcrop and within the limits of the Teriary beds. The angular nature of the flints suggests that cold conditions obtained at a later stage than for the deposition of the rest of the Kesgrave Sands and Gravels. However, considering the location of the gravels, periglacial conditions should give an input of angular Tertiary flint. A glacial input could selectively introduce angular non-Tertiary flint, but would also introduce exotics, but these, in fact, show a reduction.

The proportion of colourless quartzites is much lower in the Waldringfield Gravels (maximum 31%). Hey (1980) suggests that the lack of colour may be due to post-depositional weathering. This view is confirmed by the counts from Waldringfield where a near-surface sample had 48% of its quartzites colourless, but a deeper sample had only 12% colourless. This suggests that the Waldringfield Gravels are significantly younger than the rest of the Kesgrave Sands and Gravels.

Well and borehole records show that the gravels can be traced at least as far east as Tunstall Forest. Hey (1980) records the gravels running parallel with the coast into Norfolk. At Covehithe, the gravels are recorded in cliff sections (Hey, 1967), indicating that they formerly extended further east but have been destroyed by marine erosion. The stone count from Covehithe shows the flints in the northern part of the county to be far more rounded than in the Ipswich area, probably due to the incorporation of material from the underlying Westleton Beds. Westwards of Ipswich, the bedrock surface contours (Hollyer, 1974) show that the river depositing the Waldringfield gravels can have occupied only the south-eastern part of the Orwell-Stour interfluve, with its north bank trending north-east to south-west through the Tattingstone-Bentley area. Hey (1980) traces the gravels running parallel with the Westland Green Gravels at least to the Ongar area.

Correlation with the gravels of the London Basin is difficult as the published pebble counts of the gravels lower than the Westland Green Green Gravels there relate to the 11.2-16.0 mm size range (Green and McGregor, 1978). However, for this smaller fraction, the Higher Gravel Train does have more flint (55.0-82.5%) than the Westland Green Gravels 41.5-52.2%) and the flint is more angular (0.30-0.40 compared with 0.41-0.44) (Green and McGregor, 1978). The Lower Gravel Train shows a reduction in the amount of flint (37.7-74.3%) but a wide range of angularity values (0.31-0.46). On the basis of the quantity of the flint component, a correlation with the Higher Gravel Train is suggested.

d. CHRONOLOGY

The Kesgrave Sands and Gravels cannot be dated per se but they can be located relative to other deposits that have been biostratigraphically dated. The sands and gravels underlie the temperate Valley Farm Sol Lessivé which is Cromerian in age, at the youngest, for it in turn is overlain by till which can be dated as Anglian on the biostratigraphic evidence of its confining deposits. The sands and gravels overlie the Westleton Beds which were regarded as Pastonian in age (Turner, 1973) but which are now regarded as Bramertonian (Funnell et al, 1979). Whilst the Westleton Beds were regarded as Pastonian, the Kesgrave Sands and Gravels were, logically, assigned to the Beestonian (Rose and Allen, 1977), but with the revision of the dating, a wider time span is available.

A difficulty of dating the Kesgrave Sands and Gravels as Beestonian was that gravels of that age in north Norfolk, at the type-site and at West Runton, have a considerably higher flint content (91-92%) and less quartz and quartzite (7-9%) (Hey, 1980). Within the Weybourne Crag at Beeston and Sidestrand, a marine conglomerate, formerly regarded as Baventian in age (Hey, 1976) and now redesignated Pre-Pastonian (West, 1980), provides a better correlation for the Westland Green Gravels (Hey, 1980), with 74-77% flint and 14-25% quartz and quartzite. The differences between the conglomerate and the Westland Green Gravels values are probably due to the incorporation of flint from the Chalk and from the underlying Baventian gravels, increasing the flint and depressing the quartz and quartzite fractions.

The Waldringfield Gravels, being a lower fluvial sequence, are considered to be younger than the Westland Green Gravels. Hey (1980) suggests a correlation with the Beestonian of north Norfolk. Such a correlation with the Beestonian of Beeston and West Runton is feasible, entailing only a slight increase in the flint content (to 91-92%) and decrease in the quartz and quartzite values (to 7-9%) (Hey, 1976), as with the Westland Green Gravels. However, the Beestonian gravels of Sidestrand and Mundesley have lower flint values (50-63%) and more quartz and quartzite (33-49%).

The Baylham Common Gravels, being higher, are regarded as older than the Westland Green Gravels, but it is unlikely that they can be Baventian as stone counts from the type site and from Bramerton Common (Hey, 1976) have high flint (90%) and low quartz and quartzite (5-10%) values. On lithological composition, a Pre-Pastonian dating is more acceptable.

6. VALLEY FARM RUBIFIED SOL LESSIVE

At Badwell Ash, Barham, Great Blakenham, Kesgrave, Great Blakenham, Kesgrave, Valley Farm and Waldringfield Heath, the matrix of the uppermost 0.6m of the Kesgrave Sands and Gravels is reddened and iron and clay enriched. The colours of the matrix are 7.5YR 5/4 and redder and, except at Waldringfield, have a hue at least 2.5 redder than the reddest part of the lower part of the deposit.

The colours of the reddened horizon are accepted as rubified (hue of soil matrix redder than 10YR with a chroma of 4 or more; Avery, 1973). The rubification of the uppermost 0.6m of the Kesgrave Sands and Gravels indicates a concentration of iron in goethitic or haematitic form (Schwertmann and Taylor, 1977). Iron is at least 7.9 times more abundant in this layer.

The clay content of the horizon is at least 3.2 times greater than for the lower parts of the Kesgrave Sands and Gravels and for Barham the clay enrichment can be shown to be independent of mean particle size. The abundance of clay is also expressed by the presence of smooth clay skins (cutans) on the pebbles within the layer. The cutans occur both superposed on the stones and totally enveloping them.

These properties and their concentration in the uppermost part of the Kesgrave Sands and Gravels is characteristic of a soil (Richmond, 1959). The iron and clay enrichment and the cutans are typical of an illuvial horizon created by downward translocation of clay and free iron in a humid environment (Lamouroux, 1972). Although iron can be mobile in cold environments (Gravis and Lisun, 1973), in its haematitic form it 'appears to be absent in soils recently formed under a humid temperate climate such as in northern and mid-Europe and the northern part of the American continent' (Schwertmann and Taylor, 1977). As haematite is an anhydrous form of iron, its presence suggests that the iron may have crystallised out in an environment in which evaporation exceeded precipitation at least for part of the year, a situation more likely to occur in climates warmer or more continental than prevailing in Britain to-day. Rubification is also associated with older deposits (Gerasimov, 1971). This implies that if goethite is present in a deposit in its original form, it alters to haematite with time. This would still involve desiccation for the iron to change to its anhydrous form. However, as the palaeosol is thought to have been sealed beneath till at a relatively early stage at many sites, the opportunities for desiccation are considered to have been limited. Further, at Waldringfield, where the palaeosol has always been a ground-surface or near-surface feature, rubification has been subdued rather than enhanced.

The total assemblage of soil properties is attributed to pedogenic activity operating over a long period of time (Birkeland, 1974) in a humid, warm, temperate climatic regime. The colour and clay enrichment of the illuvial horizon can be described as a rubified sol lessivé (Aubert, 1965) or a rubified palaeo-argillite (Avery, 1973).

The age of the palaeosol can be determined only by its stratigraphic relationship to other deposits. From the arguments put forward for the Kesgrave Sands and Gravels, the palaeosol on the Waldringfield Gravels must be Cromerian in age, but that on the Westland Green Gravels could have been formed either in the Pastonian or the Cromerian. As the palaeosol is relatively fragile, the younger age is favoured.

7. BARHAM COVERSAND AND BARHAM LOESS

a. BARHAM COVERSAND (Table 5)

The Barham Coversand is recognised on the basis of its sedimentary characteristics and its stratigraphic position above the Valley Farm Rubified Sol Lessive, though it shares a history of deformation with the temperate palaeosol and is found only in sand wedges and in the cores of the involutions of the Barham Arctic Structure Soil.

In the Gipping Valley, the coversand shows primary sedimentary structures only in the sand wedges at Great Blakenham. These structures comprise bedding sub-parallel to the walls of the wedges and so is sub-vertical except where the irregular shape of the wedges causes rounded patterns. More frequently, the sand is found in a disturbed state, lacking bedding, in the cores of involutions.

Particle size analyses show the coversand to have a mean grain size of 1.93-2.30ϕ and to be moderately to poorly sorted (0.90-1.39ϕ). Although the sorting is not good, the deposit is interpreted as a coversand because it compares well with examples of coversand from the Netherlands (Maarleveld, 1960)(Figure 11). The median grain size is in the range expected of aeolian sands as summarised by Kukal (1970). Also occasional flint pebbles, the broken faces of which are polished, occur within the sands. The moderate to poor sorting of the sands is considered to be a function of the wide size range of sand clasts available for aeolian transport from the underlying Kesgrave Sands and Gravels and of a limited amount of transport.

Also in keeping with an aeolian origin, the sands are found at varying altitudes. Within south-east Suffolk, the sands occur at 53m O.D. at Great Blakenham, 41m at Barham and Valley Farm and 28m at Ipswich Airport, reflecting the terrace surfaces of the Kesgrave Sands and Gravels. The coversand has a wide regional distribution and is found as far west as Widdington (above 95m O.D.), as far south as Chelmsford, at Newney Green (58m) and Great Waltham (50m) and as far north as Denham, near Bury St Edmunds, (90m). This widespread occurrence of the coversand shows that it has regional significance and its wide altitudinal range, coinciding with the terraces of the Kesgrave Sands and Gravels, shows that those terraces were still a major sub-aerial morphological feature in the early Anglian.

The mineralogy of the coversand contrasts with that of the Kesrave Sands and Gravels. The latter is characterised by a residual assemblage dominated by tourmaline and zircon, while the coversand includes a wider range of heavy minerals, including apatite, chlorite and collophane, which are easily weathered (Catt, in Rose _et al_, 1978). The input of new minerals can be matched in large part from the Lowestoft Till which is relatively rich in epidotes, garnet and amphiboles (Perrin _et al_, 1979).

Thus the coversand indicates an important early Anglian dry periglacial phase. The sand wedges suggest that precipitation might have been less than 100mm per year (French, 1976).

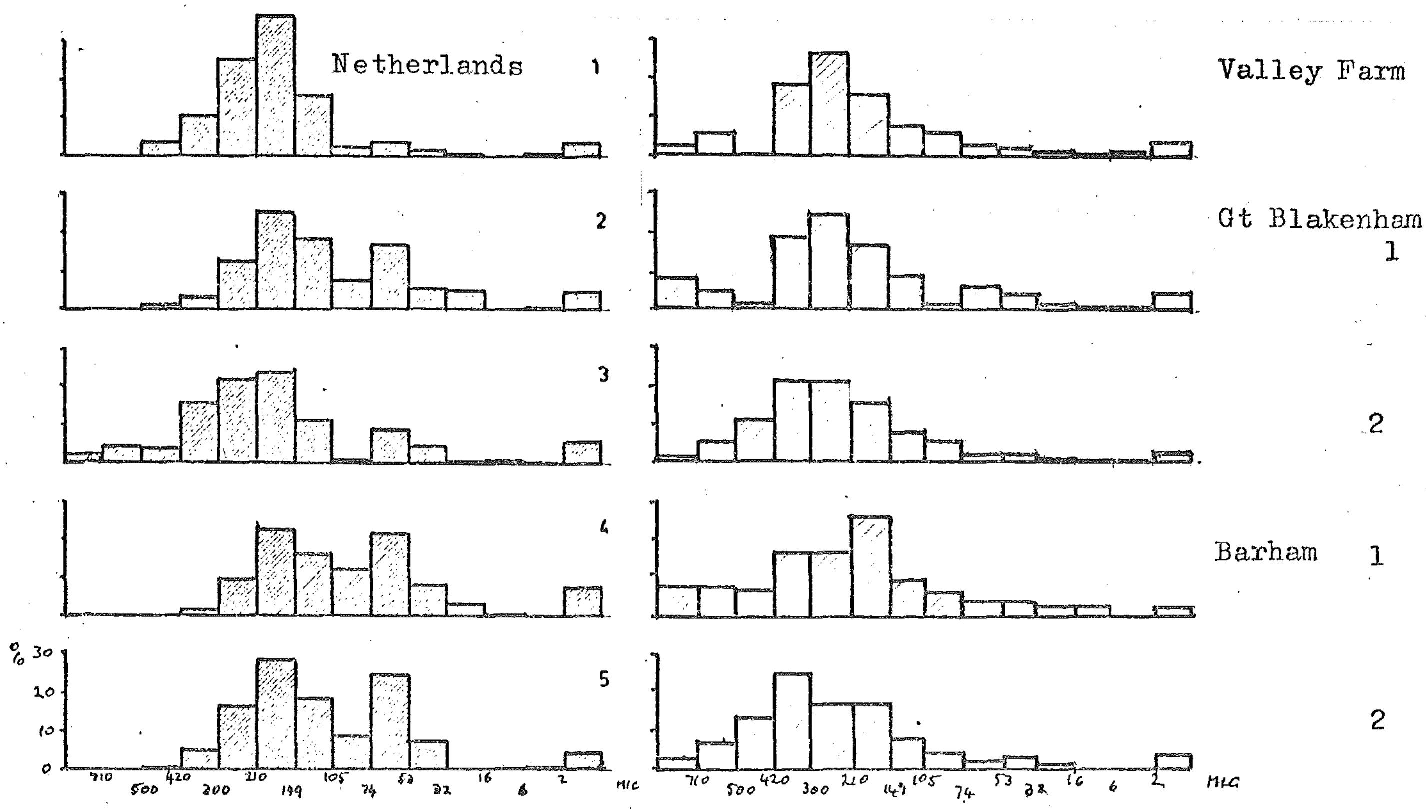
Figure 11. Barham and Netherlands coversands compared.

b. BARHAM LOESS (Table 5)

The Barham Loess is a calcareous silt found as a loess in the Gipping Valley only at Barham. Other calcareous silts occur within the Sandy Lane Gravels at Great Blakenham. The silt at Barham is characterised by having 5% sand, 85% silt and 10% clay (mean of 3 samples). The well-sorted nature of the silt, with a mode between 20 and 25 microns, is compatible with aeolian transport (Kukal, 1970) and within the sand fraction are fine carbonate tubules which are characteristic of many loess deposits (Catt, pers. comm.). Mostly the loess appears massive, but in places planar bedding and climbing ripples occur, indicating that the silt has been reworked by running water.

The heavy mineral assemblage, analysed by Dr J.A. Catt, contrasts with that of the Barham Coversand in that it is richer in epidote, chlorite, biotite, yellow rutile and anatase and relatively deficient in zoisite, zircon, tourmaline, garnet, brown rutile and apatite. The heavy mineral assemblage compares very well with calcareous silts from within the Sandy Lane Gravels, with the exceptions of being relatively deficient in chlorite and tourmaline and rich in garnet and brookite. The Sandy Lane Gravels, and its included silt, are argued to be genetically related to the Lowestoft Till. Thus, in turn, the loess is linked with the advance of ice into East Anglia during the Anglian.

At Barham, the loess and the coversand are not found in superposition, but the loess appears to be in a stratigraphically higher position as the coversand is found only in a disturbed state in the cores of involutions, while the loess is largely undisturbed, still showing primary sedimentary structures and lies on a surface cut through the involuted horizon of the Kesgrave Sands and Gravels. However, at Edwardstone, near Sudbury, the coversand does occur in superposition above the loess. If the loess post-dates the coversand, as is suggested at Barham, then it is likely to be only of local significance. However, if the loess pre-dates the coversand, it is possible that it has a regional significance, representing distal aeolian deposition, while the coversand, being of larger clasts, may be ice proximal. The wider range of heavy minerals in the coversand would support such a proposition.



	Barham (?) Coversand (Newney Green)	Barham Loess (Barham)	Sandy Lane Gravels - silt (Great Blakenham)
	n = 910	n = 582	n = 931
Epidote	21.5	35.4	27.6
Zoisite	3.1	1.2	0.5
Zircon	26.3	20.6	15.7
Tourmaline	7.9	0.9	6.0
Chlorite	5.5	9.5	19.5
Biotite	0.7	2.2	1.9
Green Hornblende	1.7	2.2	1.5
Brown Hornblende	0.0	0.0	0.0
Tremolite/ Actinolite	1.0	0.0	1.1
Garnet	11.5	6.9	2.6
Yellow Rutile	8.0	11.5	13.2
Brown Rutile	3.2	0.0	0.8
Red Rutile	0.2	0.0	0.1
Anatase	1.2	6.9	6.8
Brookite	0.3	2.1	0.2
Staurolite	1.4	0.0	0.3
Kyanite	1.5	0.0	0.3
Augite	0.0	0.0	0.0
Apatite	2.0	0.1	0.1
Collophane	2.0	0.5	1.7
Brown Spinel	0.8	0.0	0.0
Andalusite	0.2	0.0	0.0

Size range 16-63 microns   Analysed by Dr J.A. Catt.

Table 5. Silt mineralogy, Barham Coversand and Loess, Sandy Lane Gravels.

8. BARHAM ARCTIC STRUCTURE SOIL

The Valley Farm Rubified Sol Lessivé is disturbed by involutions at many sites, at Barham by an ice-wedge cast and at Great Blakenham by sand wedges. These periglacial disturbances brought about a reorganisation of the pedogenic features of the temperate palaeosol, e.g. the smooth faces of the cutans may be indicative of stress (Hodgson, 1974), such as could be brought about by the build up of ground ice. This reorganisation is considered to have created a skeletal arctic structure soil (Muckenhausen, 1963), the Barham Arctic Structure Soil.

The patterns formed by the involutions varied from being very irregular and with structures similar to those expected of loading to being more regular and approximating to the U-shapes decribed by Watson (1965). With the involutions at Badwell Ash, the clay-rich gravelly sand of the temperate palaeosol has retained its integrity to the extent that it could be traced, discontinuously, across 12m of exposure, though it is much disturbed and very irregular.
The upper 0.5m of the disturbed horizon is arranged into a series of lobes varying from being U-shaped with gravel cores to highly irregular with cores of sand from the underlying Kesgrave Sands and Gravels. Below this level the sand lacks bedding and occurs as upward rounded or sharp-crested projections, or in totally enclosed pockets, while the palaeosol projects downwards to form ball and pillow structures. The disturbed horizon has a well-defined lower limit, arranged in a series of lobes. The lack of bedding, the disruption of the gravel, the sharply crested antiforms and the ball and pillow structures suggest that the Kesgrave Sands and Gravels liquefacted and that the palaeosol foundered irregularly into it, forming ball and pillow structures. The downward movements were compensated by upward movements creating the sharp-crested antiforms, disrupting the palaeosol and forming the sand pockets and irregular surface lobes. Although the individual elements of the pattern at Badwell Ash can be described in terms of loading and liquefaction, the whole pattern is considered to be one of involutions created by ground-ice activity. The structures are confined to one horizon, disturbing and therefore post-dating the temperate palaeosol. The association with the palaeosol indicates that the structures were formed at or near the ground surface. The pressures required to induce movement of gravel would normally rquire a heavy overburden, but the indications are that such overburden was not available. It is argued that differential melting of ground-ice, particularly beneath the palaeosol, could build up unusually high pore water pressures, liquefacting the Kesgrave Sands and Gravels and requiring only the weight of the palaeosol to induce movement.

In contrast, at the other sites where involutions are present, at Barham, Valley Farm, Kesgrave, Waldringfield and Foxhall Heath, the structures are typically U-shaped and diminish with depth rather than having a well-defined base as at Badwell Ash. At Barham, which is typical of the sites listed above, the involutions are not uniform in spacing or dimensions, though they occur with a mean spacing of 1.6m (+/- 0.8m at 1σ range). The involutions with gravel cores are mostly wider and deeper (average width 0.98m, depth 0.53m, n = 10) and more frequent (less than 1.0m apart) than those with sand cores (average width 0.58m, depth 0.35m, n = 32) which are 1.5-3.0m apart. The involutions are round-bottomed and separated by sharp-crested antiforms which often penetrate through the palaeosols layer. Beneath the involuted layer, the Kesgrave Sands and Gravels lack primary sedimentary structures, indicating liquefaction. Clays inject downwards to form ball and pillow structures and, to a lesser extent, upwards, showing more typical load structures. Gravels lack their original horizontal bedding.

Again it is suggested that the structures are largely a response to loading stresses and liquefaction. The main body of the Kesgrave Sands and Gravels obviously experienced high pore water pressures and liquefacted, providing an incompetent base for the palaeosol. The heavier material sank to form U-shaped lobes while the underlying sand injected upwards to form sharp-crested antiforms. It is notable that where the density gradient is greater, the involutions are better developed, i.e. the gravel cored involutions are wider, deeper and more closely spaced. As at Badwell Ash, it is considered that the structures are involutions rather than simple load and liquefaction structures. They are best developed immediately beneath the unconformity marking the upper surface of the Kesgrave Sands and Gravels, disturb the temperate palaeosol and contain Barham Coversand in some of the cores, indicating that they formed in association with a ground surface. The structures involve the upward movement of gravel, which would require stresses greater than one would expect to develop under the limited, 0.5m, of overburden actually present.

One ice-wedge cast, at Barham, was found in association with the Barham Arctic Structure Soil. This wedge was not fully exposed, but had a vertical extent of at least 7.5m and a maximum width of 2.5m. The isolated nature of the wedge indicates that it does not form part of a properly integrated system of patterned ground.

Three sand wedges were observed, at Great Blakenham, penetrating 2.0-2.25m into the Kesgrave Sands and Gravels and in one case through into the Creeting Beds beneath. Two of the wedges were less than 0.5m wide, the third was 1.5m wide, possibly due to an oblique section being viewed. In vertical section, the wedges were relatively uniformly wide, rather than tapering, and in one case, the basal area widened to over 1.5m. Bedding of the contained coversand was parallel to the wedge walls and so was sub-vertical, except in the basal area of the last example, where it varied to accommodate the wider section. The infill of aeolian sand implies dry conditions, with a lack of moisture to fill the open cracks with ice and a lack of snow which, if it filled the crack, would also exclude aeolian sand. Such conditions are best matched in cold arid regions with less than 100mm of precipitation a year (French, 1976). It is also recognised that sand can be wind-blown and accumulate in open fissures in suitably dry topographic situations, such as exposed, unvegetated sand and gravel bars, in humid environments. However, the dimensions of the sand wedges and their implied longevity do not favour their being formed in such temporary situations.

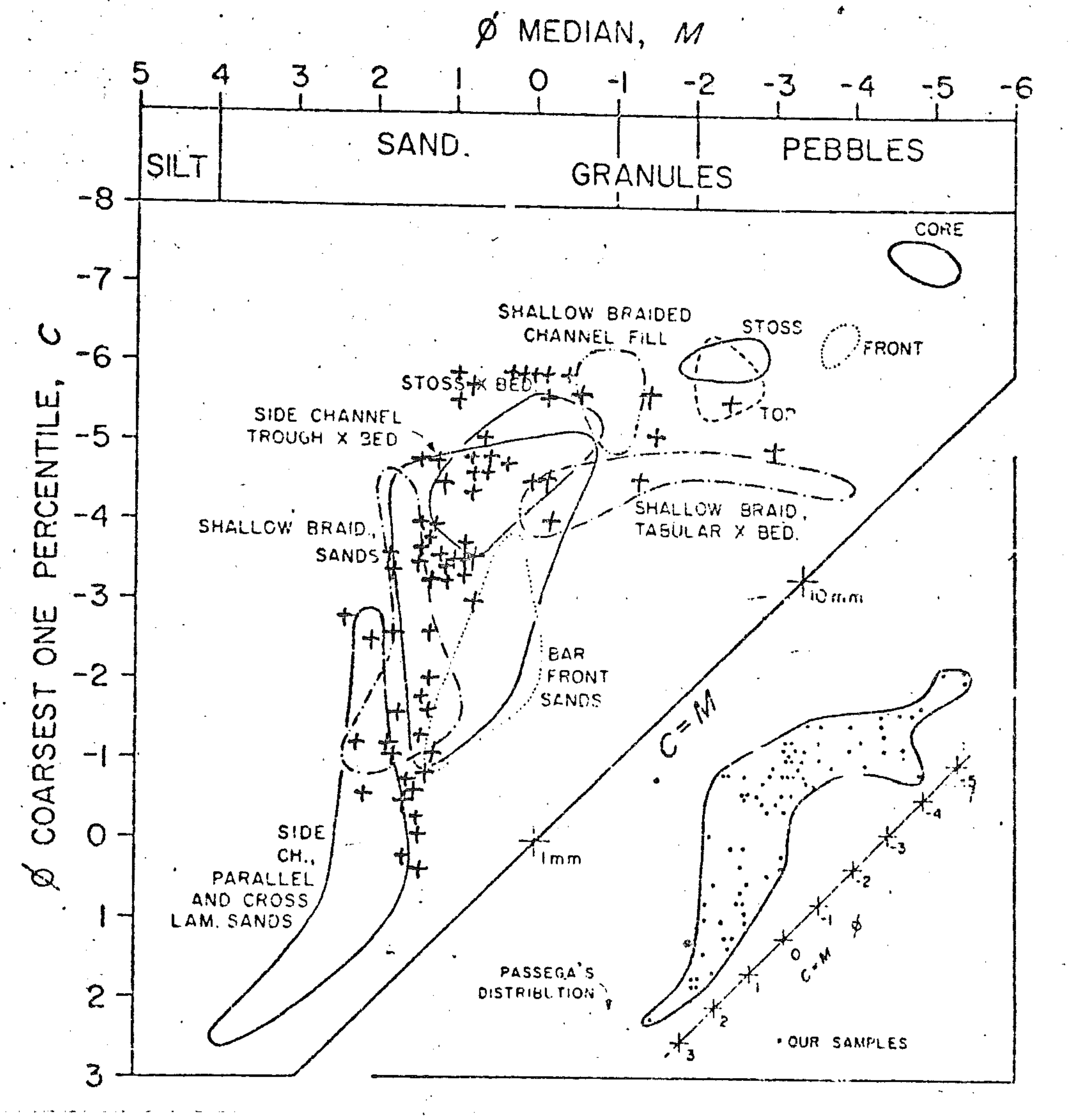
9. BARHAM SANDS AND GRAVELS (Figure 12. Tables 2, 6)

At Badwell Ash, Barham, Valley Farm and Kesgrave, the palaeosols are overlain unconformably by sand and gravel. At the base of the sequence there is often a concentration of pebbles, considered to represent a fluvial lag deposit, formed during the truncation of the upper part of the Kesgrave Sands and Gravels. Usually the lag is only one or two pebbles thick, which is what would be expected from the limited amount or erosion indicated by the survival of the illuvial palaeosol horizon and the involutions.

Above the lag are poorly sorted gravelly sands and moderately well sorted sand. Sedimentary structures consist predominantly of planar beds and small scale tabular and trough cross-sets (Sh, Sp and St facies) and the assemblage corresponds the Miall's (1977,1978) Donjek type of profile. Channels are small and infrequent, the largest cutting through the palaeosols layer at Barham. Cross-sets suggest flow to the south-east at Badwell Ash and Barham and to the east at Kesgrave. The sedimentary characteristics indicate deposition in the form of dunes and plane beds in a shallow braided river system.

The Barham Sands and Gravels are dominantly of flint (62.7-81.7%) mostly non-Tertiary and angular or sub-angular. Quartz and quartzite comprise between 14.7 and 31.9% of the gravels, the two being of approximately equal importance. The proportion of colourless quartzites varied from 20 to 55%. Within the cherts, Greensand varieties account for less than 1% and Carboniferous for between 0.2 and 3.3%. Rhaxella chert is present at all localities, except Badwell Ash, though in small quantities (0.2-0.8%). A variety of non-durable lithologies occur; Chalk, limestone, ironstone and friable sandstone, comprising up to 9.8% of the total.

Overall, the Barham Sands and Gravels are similar in composition to the Kesgrave Sands and Gravels, suggesting that the former is largely derived from the latter. However, in detail, significant differences are noted. The Barham Sands and Gravels have an input of angular, non-Teriary flint, Rhaxella chert and sedimentary non-durable clasts and a deficiency of quartz and quartzite and Greensand chert compared with the Baylham Common Gravels and Westland Green Gravels. This input can be matched from the Lowestoft Till and establishes the Barham Sands and Gravels as distal outwash of the Anglian ice-sheet.



Eynon and Walker 1974

CM diagram for braided river deposits

Figure 12. CM diagram, Barham Sands and Gravels.

STONE COUNTS

16–32mm
In percentages

		Flint: Non-Tertiary Ang.	Non-Tertiary Round.	Non-Tertiary Total	Tertiary Ang.	Tertiary Round.	Tertiary Total	All Flint Ang.	All Flint Round.	All Flint Total	Quartz Group: Qtz	Qtz'ite	Colourless Qtzite	Durable Sandst.	Total
HAUGHLEY PARK GRAVELS															
Haughley Park	upper	81.9	6.8	88.7	0.3	0.6	0.9	82.2	7.4	89.6	2.6	4.2	1.0	0	6.8
	lower	57.4	8.5	65.9	0	1.0	1.0	57.4	9.5	66.9	3.8	5.7	1.0	0.2	9.7
Woolpit		76.5	9.0	85.5	0	0.3	0.3	76.5	9.3	85.8	3.6	5.4	1.2	0	9.0
Great Blakenham		33.0	2.5	35.5	1.5	1.6	3.1	34.5	4.1	38.6	1.2	6.8	0.2	0.8	8.8
Little Blakenham	upper			49.0			3.2			51.2	2.4	4.0	0.8	0	6.4
	lower	17.7	1.2	18.9	0	0.2	0.2	17.7	1.4	19.1	0.2	1.2	0.3	0	1.4
SANDY LANE GRAVELS															
Badwell Ash	A	66.3	6.3	72.6	3.4	1.4	4.8	69.7	7.7	77.4	4.8	10.1	1.0	0.5	15.4
	B	61.0	7.2	68.2	0	0.6	0.6	61.0	7.8	68.8	5.8	10.4			
	C	54.4	4.4	58.8	1.2	2.4	3.8	55.6	6.8	62.4	11.7	12.4	1.2	0.2	24.3
Barham		39.0	1.1	40.1	0.5	0.5	1.0	39.5	1.6	41.1	0.9	2.0	0.4	0	2.9
BARHAM GRAVELS															
Barham (P)	A	35.1	3.7	38.8	13.5	19.1	32.6	48.6	22.8	71.4	11.7	11.7	6.5	0	23.4
	B	55.4	3.2	58.6	9.0	7.3	16.3	64.4	10.5	74.9	11.5	11.2	2.2	0	22.7
Darmsden		35.5	7.1	42.6	14.1	25.0	39.1	49.6	32.1	81.7	8.5	6.2	2.3	0	14.7
Badwell Ash (P)		31.4	5.2	36.6	13.7	12.4	26.1	45.1	17.6	62.7	15.7	13.7	6.5	0	29.4
Valley Farm (P)		54.4	5.9	60.3	11.3	5.4	16.7	65.7	11.3	77.0	8.9	8.7	2.0	0	17.6
Kesgrave (P)		43.4	4.5	47.9	8.6	10.2	18.8	52.0	14.7	66.7	17.7	14.2	4.3	0	31.9
Ipswich Airport (P)		49.5	7.6	57.1	10.5	10.0	20.5	60.0	17.6	77.6	7.0	8.4	2.3	0.6	16.0
Creeting St Mary		57.6	4.8	56.4	14.3	7.2	21.5	65.9	12.0	77.9	6.9	10.1	2.7	0	17.0
Tudderham		47.7	5.9	53.6	5.9	8.9	14.8	53.6	14.8	68.4	9.2	9.7	2.4	0	18.9

		Cherts: Greensand	Carboniferous	Rhaxella	Misc.	Total Non-Greensand	Total	Sedimentary Non-Durables: Chalk	Limest.	Sandst.	Ironst.	Misc.	Igneous + Metam: Durable	Non-Durable	Unknown: Durable	Non-Durable	Durables	Non-Durables	Ratios (n:1): % Colourless Quartzites	Ang.: Rounded Flint	Non-Tert.: Tert. Flint	Flint: Qtz Group	Quartz: Quartzite	n
HAUGHLEY PARK GRAVELS																								
Haughley Park	upper	0	0	1.0	0	1.0	1.0	0	0	0.6	0.3	0	0	0	0	0	99.1	0.9	23	11.1	98.6	13.2	0.6	310
	lower	0	1.2	1.0	0.2	2.4	2.4	17.3	2.8	0.7	0.2	0.7	0.2	0	0	0	78.3	21.7	17	6.0	65.9	6.9	0.7	420
Woolpit		0	0.6	1.5	0.9	3.0	3.0	0	0	0.3	0.7	0	0	0.9	0.3	0	98.1	1.9	22	8.2	285.0	9.5	0.7	332
Great Blakenham		0	0.2	0.8	1.5	2.5	2.5	35.5	0.8	0.6	8.5	2.5	1.2	0	0.6	0	52.1	47.9	3	8.4	11.5	4.4	0.2	482
Little Blakenham	upper	0	0	1.2	0.8	2.0	2.0	27.7	2.0	1.2	2.0	3.6	2.4	0	0	0	63.5	36.5	20		15.3	8.0	0.6	251
	lower	0	0.2	0.5	0	0.7	0.7	71.5	1.2	2.2	1.7	1.7	0.3	0	0.2	0	21.7	78.3	29	12.6	94.5	13.6	0.2	586
SANDY LANE GRAVELS																								
Badwell Ash	A	0	0	0.5	0	0.5	0.5	1.4	1.4	1.4	0.5	1.0	1.0	0	0	0	94.3	5.7	10	9.1	15.1	5.4	0.5	208
	B	0	3.2	0	0	3.2	3.2	3.9	1.2	3.2	0.6	1.9	0.6	0	0	0	89.2	10.8		7.8	113.7			154
	C	0	0	0	0	0	0	4.4	3.4	0.7	3.4	0.2	1.5	0	0	0	87.9	12.1	42	8.2	15.5	2.6	0.9	410
Barham		0	0	0.5	0.5	1.0	1.0	51.0	1.9	0.6	0.3	0.5	0.7	0	0.3	0	45.7	54.3	22	24.7	40.1	14.2	0.5	892
BARHAM GRAVELS																								
Barham (P)	A	0	2.5	0.3	1.2	4.0	4.0	0	0	0.6	0	0	0	0	0	0.6	98.8	1.2	55	2.1	1.2	3.1	1.0	325
	B	0.3	1.3	0.3	0.3	1.9	2.2	0	0	0	0	0	0	0	0	0	100.0	0	20	6.1	3.6	3.3	1.0	312
Darmsden		0.4	1.2	0.6	0.4	2.2	2.6	0	0	0.2	0.4	0	0.6	0	0	0	99.4	0.6	38	1.5	1.1	5.6	1.4	519
Badwell Ash (P)		0.7	3.3	0	0.7	4.0	4.7	0	0	0	0	0	0.7	0	0	0	100.0	0	48	2.6	1.4	2.1	1.1	153
Valley Farm (P)		0.7	1.3	0.2	0.4	1.9	2.6	0.9	0	0.7	0.7	0	0.7	0	0	0	97.7	2.3	23	5.8	3.6	4.4	1.0	461
Kesgrave (P)		0.6	0.2	0.2	0.2	0.6	1.2	0	0	0	0	0	0.2	0	0	0	100.0	0	30	3.5	2.5	2.1	1.2	491
Ipswich Airport (P)		0.4	2.5	0.6	0.2	3.3	3.7	0	0	0.4	1.6	0	0.4	0	0.4	0	98.0	2.0	28	3.4	2.8	4.9	0.8	513
Creeting St Mary		0.3	1.9	0.5	0.3	2.7	3.0	0	0	0	0.5	0	1.1	0	0.5	0	99.5	0.5	26	5.5	2.6	4.6	0.7	376
Tudderham		0	0.8	0.8	0.3	1.9	1.9	6.5	0.5	0.3	1.9	0.6	0.8	0	0.3	0	90.2	9.8	25	3.6	3.6	3.6	0.9	371

P Palaeosols layer present

Table 6. Barham Sands and Gravels, Sandy Lane and Haughley Park Gravels, stone counts.

10. SANDY LANE GRAVELS (Tables 2, 6)

At Tostock, Great Blakenham, Barham and Valley Farm, chalk-rich gravels sands and silts occur beneath till. The gravels occur in lenses and lack discernible bedding. The sands appeared massive except at Tostock where they were cross-bedded, dipping to the south-west. The silts are massive. The bedded nature of the sequence and the range of sediments present indicates deposition in a variable energy fluvial regime.

The gravels are of variable composition (Table 2), and characterised by chalk, including Red Chalk (1.4-51.0%) and flint (41.0-82.4%), mostly angular and sub-angular and non-Tertiary (39.0-66.3%), with quartz and quartzite (2.9-24.3%) and lesser amounts of friable sandstone, ironstone, fossil fragments (particularly belemnites and gryphea), limestone, igneous clasts. This suite is comparable with the Barham Sands and Gravels in terms of the lithologies represented, but differs in that non-durable clasts are far more highly represented (5.7-54.2%), particularly chalk. As with the Barham Sands and Gravels, it is argued that the Sandy Lane Gravels were deposited as outwash genetically linked with the Lowestoft Till. The high percentage of non-durable clasts indicate a very short distance of transport, particularly as the gravels represent high energy flow. Thus the sequence is regarded as an ice-proximal one.

The heavy minerals of the silt (Table 5), analysed by Dr J.A. Catt, show a suite that could not have been derived from the Kesgrave Sands and Gravels, but does bear affinities to those derived from the Lowestoft Till (Perrin et al, 1979). Thus the link with the till is supported.

At Great Blakenham, the sequence occurs in channels and is overlain by till. The channels are cut into the Chalk surface to depths of 12m, so deposition is likely to have been sub-glacial. At the other locations, there is nothing to indicate deposition other than sub-aerially in a pro-glacial environment.

11. TILL

The till of Suffolk has long been subject to debate. Recent work (Perrin et al, 1979) suggests that there is a major till sheet, the Lowestoft Till, of Anglian age, in the county. This view is challenged by Straw who considers that Wolstonian ice advanced into the northern part of the county.

LOWESTOFT TILL

The Lowestoft Till has been studied on a regional basis by Perrin et al (1979) who establish that there is a single major till in Suffolk, deposited by ice entering East Anglia through the Wash and crossing the county from north-west to south-east. This pattern is confirmed by local studies in Suffolk, though variants are noted. The major till member is a lodgement till, the Blakenham Till. This is often underlain by a flow till which may be calcareous (the Barham Till) or non-calcareous (the Creeting Till). A further flow till, the Blood Hill Till, is stratigraphically higher than the Blakenham Till and is associated with ice wastage. The tills are associated, and may be interbedded, with calcareous gravels, the Sandy Lane and Haughley Park Gravels.

Summary			
	3	Blood Hill Till	Flow till
	2	Blakenham Till	Lodgement till
	1b	Creeting Till	Flow till, non-calcareous
	1a	Barham Till	Flow till, calcareous

i. Barham Till Member

The Barham Till is a banded till lying beneath a massive till, the Blakenham Till, at Barham and Great Blakenham. At Valley Farm only the Barham Till occurs. The banded till is chalky, yellowish-brown (10YR5/6 - 10YR6/4) and made up of units up to 0.3m thick, of slightly different colours. At Barham, the bands are intercalated with sand. The banded nature of the till and its intercalation with sand suggests that it is flow till. At each site, the statistically significant (at the 95% level or better) trends of the macrofabrics are north-west to south-east, suggesting flows forward from the advancing ice sheet which is known to have approached from the north-west (Perrin et al, 1979).

ii. Creeting Till Member

At Badwell Ash and Creeting St Mary crudely bedded brown and brownish-yellow (7.5YR5/6 - 10YR6/6) tills occur beneath chalk-rich gravels which in turn are overlain by the Blakenham Till. In contrast with the Barham Till, the Creeting Till is non-calcareous and has thicker units, up to 0.5m. At Badwell Ash, there are two flow tills, the lower having a silty matrix and the majority of its stones dipping to the north, while the upper is clayey and has dips to the south. At Creeting, the till is sandy and the majority of stones dip to the west. Only flint pebbles have been found in the tills. The lack of chalk is difficult to explain, particularly because of the adjacent chalk-bearing gravels, which at Badwell Ash lie between the two tills. The nearest non-calcareous tills are the First and Third Cromer Tills of Norfolk, but these are characterised by Scandinavian erratics and low percentages of flint. As the tills overlie Barham Sands and Gravels and are associated with chalky Sandy Lane Gravels at both sites, correlation with the Lowestoft Till is proposed.

iii. Blakenham Till Member

The Blakenham Till is a chalky, predominantly very dark grey (5YR3/1) till identified as a lodgement till on the basis of its massive nature and the frequent occurrence of macrofabric vector trends in keeping with the direction of regional ice movement. The macrofabrics are of variable strength and most of those with vector magnitudes significant at the 95% level or higher are in accord with or at right-angles to the direction of regional ice movement. Similar trends could often be detected in those macrofabrics which did not reach the 95% level.

In the uppermost 2m, with no detectable sedimentological break, the colours of the till are mostly lighter (5Y5/1 - 5Y6/1, grey) or browner (2.5Y4/2 - 10YR5/6, dark yellowish brown to yellowish brown). The brown variants correspond to descriptions of the Gipping Till. However, this till and the underlying Blakenham Till show similar macrofabric patterns suggesting that the two were deposited in similar circumstances. In places, the 'Gipping' till is deficient in gravel and rich in silt or sand, which may assist weathering and encourage the browner colours, but this characteristic is not always present.

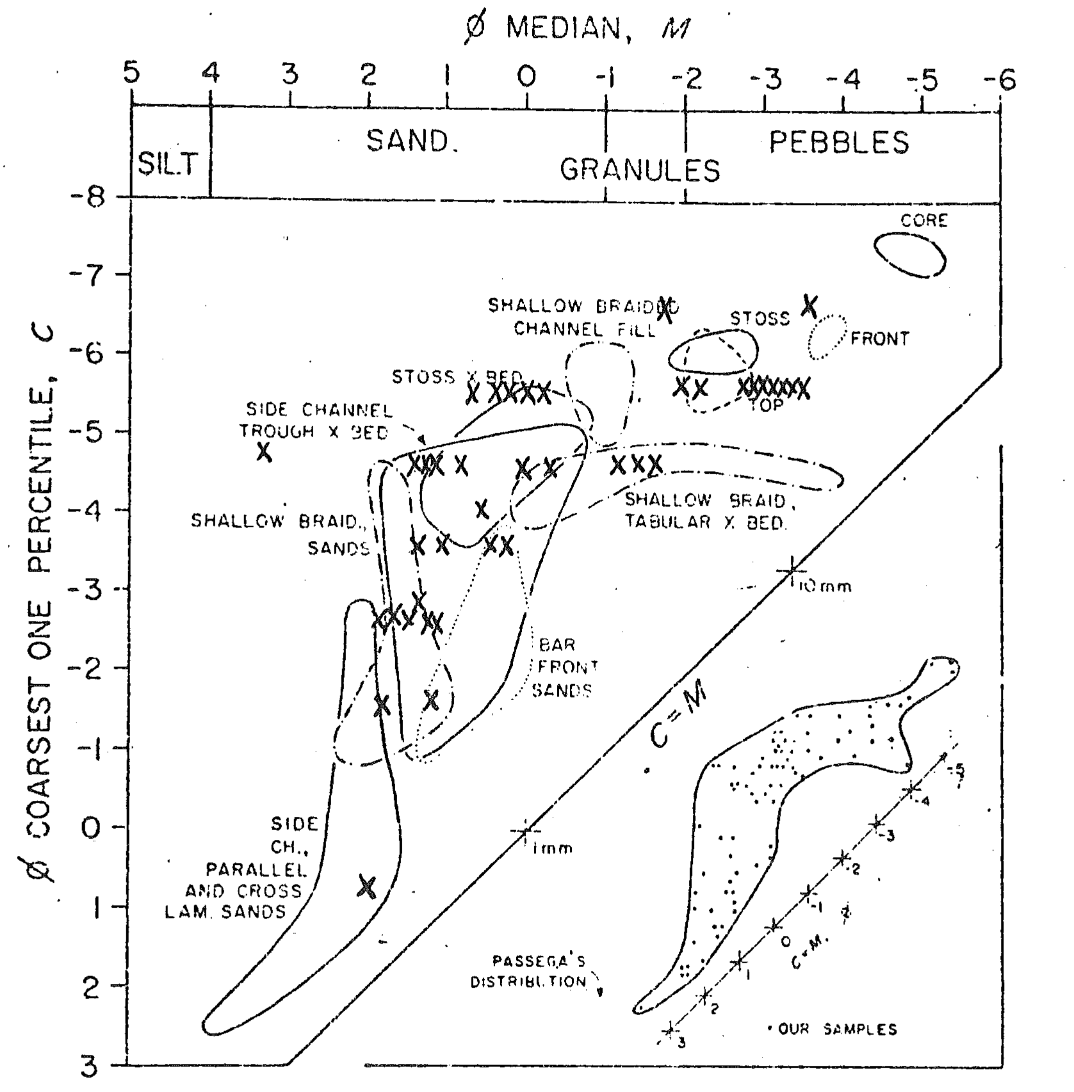
iv. Blood Hill Till Member

At Little Blakenham (Blood Hill) a chalky, banded till occurs overlying chalky Haughley Park Gravels which in turn overlie Blakenham Till. The banded till, The Blood Hill Till, has a variable light olive brown matrix (2.5Y5/4 - 10YR5/6), the colour variations showing the banding. Four macrofabric analyses carried out were significant at the 99% level or better, showing a north-east to south-west trend. This till is interpreted as a flow till on the basis of its banding and anomalous vector trend. Its high stratigraphic position and association with outwash gravels suggests that the till is associated with decay of the ice sheet.

12. HAUGHLEY PARK GRAVELS (Figure 13, Tables 2, 6)

Lying above the till at Haughley Park, Woolpit and Great and Little Blakenham are gravels associated with ice wastage. At all the sites, coarse, poorly sorted, matrix-supported gravels (Gms facies) dominate, but at Haughley Park and Little Blakenham, planar and trough cross-bedded sands (Sp and St facies) occurred in sufficient quantity to establish that the direction of flow was east and south respectively, i.e. in accord with the present Gipping drainage system. The facies assemblage corresponds with Miall's (1977,1978) Scott type of profile at at Haughley Park and Woolpit and the Donjek type at Little Blakenham.

The composition of the gravels is very similar to the Sandy Lane Gravels (Table 3). Chalk, including Red Chalk (17.3 -71.5%, except where decalcified) and flint (19.1-89.6%), mostly non-Tertiary and angular (18.9-88.7%) dominate. Quartz and quartzite comprise 1.1-9.0% of the total, with lesser amounts of friable sandstone, ironstone, limestone, fossil fragments and igneous and metamorphic clasts. Rhaxella chert is consistently present (up to 1.5%). Again a genetic link with the Lowestoft Till is proposed. At Little Blakenham, the Blood Hill Till member of the Lowestoft Till occurs within the sand and gravel complex. The coarse texture of the gravels and their high non-durable content (up to 77.4%) indicate that they are ice-proximal outwash gravels. Their stratigraphic position, immediately above the Blakenham Till, indicates an association with ice wastage, in contrast with the ice advance environment of the Sandy Lane Gravel.



Eynon and Walker 1974

CM diagram for braided river deposits

Figure 13. CM diagram, Haughley Park Gravels.

13. THE WOLSTONIAN GLACIATION IN EAST ANGLIA (AS)

The reasons for supporting a Wolstonian ice advance over central and west Norfolk and the Brecklands depend on considerable fieldwork in Norfolk, Lincolnshire and the East Midlands, and on much thought about drift composition, drainage pattern evolution and stratigraphic relations of interglacial deposits over the whole of eastern England (Straw, 1979a, 1979b).

The postulated limit of Wolstonian glaciation in East Anglia is a generalized line, and as published it should not be regarded as precise in location. Rather, it approximates to a marginal zone within which the real limit is deemed to lie. Various reasons have prevented me from making a detailed field survey over the past seven years, but the limit is a serious proposal put forward for testing.

Discussion is under four headings:

1. Regional considerations bearing on a limit within East Anglia
2. Observations in Norfolk where the limit is fairly closely defined
3. Extrapolation of the limit SW of Diss
4. Difficulties of establishing the precise location

1. Regional considerations (Dates refer to publications by the writer where points are developed more fully)

i) The older Lincolnshire tills comprise one stratigraphic unit deposited by ice moving generally from the north, and are continuous with the chalky tills of Leicestershire, Northamptonshire, Bedfordshire and Buckinghamshire (1969). Along the eastern Lincolnshire Wolds and in the Ancholme valley they are separated from Devensian tills by a single phase of valley development, and are in contact only at Welton-le-Wold (1976). At Welton mammal remains including *Equus* and several Acheulian artefacts have been recovered from beneath the Welton and Calcethorpe Tills. At Tattershall, Bardney and Wing the tills are overlain directly by Ipswichian deposits. NW of Louth, the Calcethorpe Till caps bluffs of the old marine cliff, and in the S. Wolds, this cliff (Ipswichian deposits at Sewerby) actually cuts across the Till at Revesby.

ii) In N. Norfolk, Devensian tills lie in valley floors cut into Chalk below the Marly Drift, with no intervening glacial drifts. Only one phase of valley development is apparent (1960, 1965).

iii) In W. Norfolk, dark Jurassic till, intermixed with Marly Drift, is regarded as equivalent to the Wragby Till (Gallois, 1978). The close relations of the Marly Drift from the Calcethorpe Till, and of the W. Norfolk till with the Wragby Till (1967, 1979c) demonstrate that no Wolstonian limit is located within the Fen basin.

iv) All superincumbent fossiliferous drifts and drifts within valleys cut through the tills W. of the limit are of Ipswichian or later date (the only exceptions are Kirmington and the Nar Valley where the stratigraphic relationships are far from clear).

v) Terrace sequences on the tills are relatively simple, for example the Witham terraces, and artefacts are extremely rare in terrace materials, and generally, compared with Suffolk and the Thames basin.

vi) Widespread evidence for much bedrock erosion by the ice (matrix and fresh clasts) and therefore for incorporation of all pre-existing drifts explains the rarity of discoveries of interglacial materials beneath the tills (1977).

2. Norfolk

The following considerations allow a limit to be defined fairly closely in Norfolk.

i) Geomorphological and stratigraphical discontinuities separate the Holt-Kelling sandar and the Marly Drift from the Cromer Ridge drifts (1965, 1973, 1979a). I believe a gradation occurs between Marly Drift with inclusions of Contorted Drift, and Contorted Drift with crushed Chalk (raft) inclusions. Banham has demonstrated two phases of tectonic disturbance (Banham and Ranson, 1965).

ii) The Telegraph Hill/Aylsham Gravels NW of Norwich are an E-grading, compound outwash plain derived from Wolstonian ice to the west. The actual limit is somewhere within the gravel zone (much inter-leaving of till and gravel, but the gravels mostly overlie Norwich Brickearth). I discount Cox and Nickless' claim (1972) of a barrier of North Sea ice to further progress of Chalky BC ice. On their admission, the ice masses never actually met, the gravels have no character either of an interlobate moraine or of ice-walled spillway gravels with drainage to the south.

iii) If the limit NW of Norwich was not against an obstruction then a more logical continuation is S. of Norwich, not E. to the coast. I consider (1974) it is represented by the complex till/gravel zone noted by Nickless (1971).

iv) The anomalous course of the Tas (compared with the alignment of the Yare and Wensum) could have been initiated by submarginal meltwater streams.

v) There are some contrasts in pattern of minor drainage N. of Diss compared with E. of the A140.

vi) Meltwaters seem to have passed down the short Starston (Pulham) valley and down the Waveney from somewhere in the Diss area. They were responsible for the Broome terrace but possibly also the Homersfield terrace. I accept the latter might be Anglian, but it should be noted that Homersfield aggradation had to succeed considerable erosion first of the lower Waveney valley.

vii) Ice has never overridden the Hoxne IG deposits, but overlying glacifluvial gravels came down the Dove valley. Note the similarity of alignment of the Dove to that of the Tas, and this too could represent a meltwater movement close to an ice margin.

3. Extrapolation

i) If the postulated limit, Weybourne to Diss, represents the unobstructed extent to which the Wolstonian ice could move, then it follows that it had insufficient energy to surmount the Suffolk scarp (this squares with its failure to override the Cromer Ridge).

ii) Substantial differences in stratigraphy, lithology and in landform and stream patterns have been reported between the Brecklands and areas to the E. and SE (Holmes, 1971).

iii) The gravel mass in Woolpit Wood (east of the village) could mark the limit, with meltwaters coursing down the Gipping valley. The 60 m gravel terrace S. of Bury St Edmunds, and some of the lower gravels around Ixworth, Kentford and Tuddenham could represent glacifluvial activity (with ice-contact features) during early stages of recession of Wolstonian ice, or slight readvances.

4. Difficulties in determining the precise location

Real difficulties attach to separating Anglian and Wolstonian deposits

i) because lithological similarities seem inevitable between tills E. and W. of the proposed limit. The Wolstonian ice followed broadly the same track as Anglian ice across the Fen basin into the Breckland region, and most likely incorporated Anglian drifts en route. Matrix materials, clasts and far-travelled erratics will be qualitatively identical, and there is the strong probability that quantitative between-site variations within both sets of drifts will overlap.

ii) because stratigraphic superimposition is likely only in zones close to the actual limit. Wolstonian ice seems almost everywhere to have achieved basal erosion, with destruction of what remained of earlier drifts. Local oscillation of the Wolstonian margin could also produce layered tills.

iii) because glacifluvial deposits of Wolstonian meltwaters could directly overlie or be channelled into Anglian glacifluvial materials. Further, Wolstonian meltwaters could easily erode and rework Anglian materials into its own deposits. Thus it may be very difficult to separate glacifluvial deposits genetically related to a Wolstonian limit from those marking a recessional Anglian position, if the two coincided.

iv) because if Wolstonian ice stagnated at its maximum limit, no morainic features would form. Subsequent fluvial dissection and periglaciation of the marginal zone would render detection even more difficult. Hence a careful geomorphological investigation is necessary.

Conclusions

I do not consider paragraph 4, i-iv to be special pleading but as such realistic problems of interpretation that I doubt if lithological and stratigraphic techniques alone will reveal conclusive contrasts on either side of the limit. In this situation the broader spatial contrasts reviewed in paragraph 1 become especially significant.

I strongly believe that such broad contrasts exist between areas E. and W. of the proposed Wolstonian limit, and it would be interesting to examine IG sites and archaeological materials on the same basis.

I am convinced that 'Breckland' Wolstonian ice was mainly of 'Vale of York' origin that crossed central and west Lincolnshire, with relatively small contributions from the Bain valley and the Wash (flowing S.). Coastal ice moved over central and north Norfolk.

I am equally convinced that Anglian ice flowed, perhaps from a rather more NW direction, over the lower Trent valley and Lincolnshire into S. Norfolk and Suffolk, bringing some Keuper and Liassic material.

It is because of these similar tracks, I suggest, that Perrin et al (1979) failed to separate Wolstonian and Anglian tills on matrix data. Further, their suggestion that ice surged massively SW through the Wash gap, and only in the Anglian, seems to ignore every piece of field evidence that has been presented from the Geological Survey of the 1870's and 1880's to the present day.

REFERENCES

Alabaster, F.J. and Straw, A. (1976), The Pleistocene context of faunal remains and artefacts at Welton-le-Wold, Lincolnshire. Proc. Yorks. Geol. Soc., 41, 75-93.

Allender, R. and Hollyer, S.E. (1973), The sand and gravel resources of the country around Shotley and Felixstowe. Description of 1:25 000 resource sheet TM23. Rep. Inst. Geol. Sci. No. 73/13.

Aubert, G. (1965), La classification pedologique utilisee en France. Pedologie, Symp. intern., 3, 25-56.

Avery, B.W. (1973), Soil classification in the Soil Survey of England and Wales. J. Soil Sci., 24, 324-338.

Banham, P.H. and Ranson, C.E. (1965), Structural study of the Contorted Drift and disturbed Chalk at Weybourne, north Norfolk. Geol. Mag., 102, 164-174.

Beck, R.B., Funnell, B.M. and Lord,,A.R. (1972), Correlation of Lower Pleistocene Crag at depth in Suffolk. Geol. Mag., 109, 137-139.

Birkeland, P.W. (1974), Pedology, weathering and geomorphological research. Oxford Univ. Press, New York.

Boswell, P.G.H. (1915), The stratigraphy and petrology of the Lower Eocene deposits of the north-eastern part of the London Basin. Q. J. Geol. Soc. London, 71, 536-591.

Bristow, C.R. and Cox, F.C. (1973), The Gipping Till: a reappraisal East Anglian glacial stratigraphy. J. Geol. Soc. London, 129, 1-37.

Clarke, M.R., Graham, D.K. and Hawkins, M.P. (1980), New information from the Pleistocene deposits in the Bury St Edmunds area. Rep. Inst. Geol. Sci. No. 80/1, 39-42.

Clarke, M.R. and Auton, C.A. (1982), The Pleistocene depositional history of the Norfolk-Suffolk borderlands. Rep. Inst. Geol. Sci. No. 82/1, 23-29.

Cox, F.C. and Nickless, E.F.P. (1972), Some aspects of the glacial history of central Norfolk. Bull. Geol. Surv. No. 42, 79-98.

Dixon, R.G. (1978), Deposits marginal to the Red Crag basin. Bull. Geol. Soc. Norfolk, 30, 92-104.

Eynon, G. and Walker, R.G. (1974), Facies relationships in Pleistocene outwash gravels, Southern Ontario: a model for bar growth in braided rivers. Sedimentology, 21, 43-70

French, H.M. (1973), The Periglacial environment. Longmans, London.

Funnell, B.M. (1961), The Palaeogene and Early Pleistocene of Norfolk. Trans. Norfolk and Norwich Nat. Soc., 19, 340-364.

Funnell, B.M., Norton, P.E.P. and West, R.G. (1979), The Crag at Bramerton, near Norwich, Norfolk. Phil. Trans. R. Soc., B, 287, 489-534.

Gallois, R.W. (1978), The Pleistocene history of west Norfolk. Bull. Geol. Soc. Norfolk, 30, 3-38.

Gerasimov, I.P. (1971), Nature and originality of palaeosols. In: Palaeopedology. Origin, nature and dating of palaeosols. Ed. Yaalon, D.H., International Society of Soil Science and Israel Univ. Press, Jerusalem.

Gravis, G.F. and Lisun, A.M. (1973), Palynological research in cryopedology. In: Methodical problems in palinology, Proc. III Int. Palynological Conf., Moscow.

Green, C.P. and McGregor, D.F.M. (1978), Pleistocene Gravel Trains of the river Thames. Proc. Geol. Assoc., 89, 143-156.

Harvey, B.I. et al. (1973), Records of wells in the area around Bury St Edmunds: Inventory for one-inch geological sheet 189, new series. Well Inventory Ser. (Metric Units) Inst. Geol. Sci.

Hey, R.W. (1965), Highly quartzose pebble gravels in the London Basin. Proc. Geol. Assoc., 76, 403-420.

Hey, R.W. (1967), The Westleton Beds reconsidered. Proc. Geol. Assoc., 78, 427-445.

Hey, R.W. (1976), Provenance of far-travelled pebbles in the pre-Anglian Pleistocene of East Anglia. Proc. Geol. Assoc., 87, 69-82.

Hey, R.W. (1980), Equivalents of the Westland Green Gravels in Essex and East Anglia. Proc. Geol. Assoc., 91, 279-290.

Hodgson, J.M. (1974), Soil Survey field handbook. Soil Survey Tech. Monog. No. 5.

Hollyer, S.E. (1974), The sand and gravel resources of the country around Tattingstone, Suffolk. Description of 1:25 000 resource sheet TM13. Rep. Inst. Geol. Sci. No. 74/9.

Holmes, S.C.A. (1971), The geological mapper and the employment of his results, as illustrated in some areas of southern England. Proc. Geol. Assoc., 82, 161-186.

Kukal, Z. (1970), Geology of recent sediments. Academia, Prague.

Lake, R.D., Ellison, R.A. and Moorlock, B.S.P. (1977), Matters arising: Middle Pleistocene stratigraphy in southern East Anglia. Nature, 265, 663.

Lamouroux, M. (1972), Etude de sols formes sur roches carbonatees. Pedogenese ferisiallitique au Liban. Mem. O.R.S.T.O.M., Paris.

Maarleveld, G.C. (1960), Wind directions and cover sands in the Netherlands. Biul. Peryglac., 8, 49-58.

McGregor, D.F.M. and Green, C.P. (1978), Gravels of the river Thames as a guide to Pleistocene catchment changes. Boreas, 7, 197-203.

Miall, A.D. (1977), A review of the braided-river depositional environment. Earth Sci. Revs., 13, 1-62.

Miall, A.D. (1978), Lithofacies types and vertical profile models in braided river deposits: a summary. In: Fluvial sedimentology. Ed. Miall, A.D., Canad. Soc. Pet. Geol. Mem. 5.

Muckenhausen, E. (1962), Enstehung, Eigenschaften und Systematik der Boden der Bundesrepublik Deutschland. D.L.G. Verlag, Frankfurt.

Nickless, E.F.P. (1971), The sand and gravel resources of the country south-east of Norwich, Norfolk. Description of 1:25 000 resource sheet TG20. Rep. Inst. Geol. Sci. No. 71/20.

Norton, P.E.P. (1967), Marine molluscan assemblages in the Early Pleistocene of Sidestrand, Bramerton and the Royal Society bore-hole at Ludham, Norfolk. Phil. Trans. R. Soc., B, 253, 161-200.

Notcutt, G.J. (1978), The concealed Chalk surface of mid-Suffolk. Trans. Suffolk Nat. Soc., 17, 346-356.

Passega, R. (1957), Texture as characteristic of clastic deposition. Bull. Am. Assoc. Petrol. Geol., 41, 1952-1984.

Perrin, R.M.S., Rose, J. and Davies, H. (1979), The distribution, variation and origins of pre-Devensian tills in eastern England. Phil. Trans. R. Soc., B, 287, 535-570.

Richmond, G. (1959), Application of stratigraphic classification and nomenclature to the Quaternary. Bull. Am. Assoc. Petrol. Geol., 43, 663-675.

Rose, J., Allen, P. and Hey. R.W. (1976), Middle Pleistocene stratigraphy in southern East Anglia. Nature, 263, 492-494.

Rose, J. and Allen, P. (1977), Middle Pleistocene stratigraphy in south-east Suffolk. J. Geol. Soc. London, 133, 83-102.

Rose, J., Allen, P. and Wymer, J.J. (1978), Weekend field meeting in south-east Suffolk. Proc. Geol. Assoc., 89, 81-90.

Rose, J., Sturdy, R.G., Allen, P. and Whiteman, C.A. (1978), Middle Pleistocene sediments and palaeosols near Chelmsford, Essex. Proc. Geol. Assoc., 89, 91-96.

Rust, B.R. (1972), Structure and process in a braided river. Sedimentology, 18, 221-245.

Schwertmann, U. and Taylor, R.M. (1977), Iron oxides. In: Minerals in soil environments. Ed. Dixon, J.B. and Weed, S.B., Soil Sci. Soc. Am.

Spencer, H.E.P. (1966), A contribution to the geological history of Suffolk. Part 2. The geological history of the Orwell-Gipping system. Trans. Suffolk Nat. Soc., 13, 290-313.

Straw, A. (1960), The limit of the 'Last' Glaciation in north Norfolk. Proc. Geol. Assoc., 71, 379-390.

Straw, A. (1965), A reassessment of the Chalky boulder clay or Marly Drift of north Norfolk. Zeit. fur Geom., 9, 209-221.

Straw, A. (1967), The Penultimate or Gipping Glaciation in north Norfolk. Trans. Norfolk and Norwich Nat. Soc., 21, 21-24.

Straw, A. (1969), Pleistocene events in Lincolnshire: a survey and revised nomenclature. Trans. Lincs. Nat. Union, 17, 85-98.

Straw, A. (1973), The glacial geomorphology of central and north Norfolk. East Mid. Geogr., 5, 333-354.

Straw, A. (1974), The glacial geomorphology of central and north Norfolk: a reply to comments. East Mid. Geogr., 6, 95-98.

Straw, A. (1979a), Eastern England. In: Eastern and Central England. Straw, A. and Clayton, K.M., Methuen.

Straw, A. (1979b), The geomorphological significance of the Wolstonian glaciation in eastern England. Trans. Inst. Brit. Geogr., 4 (N.S.), 540-549.

Straw, A. (1979c), Age and correlation of Pleistocene deposits in west Norfolk. Bull. Geol. Soc. Norfolk, 31, 17-30.

Turner, C. (1973), Eastern England. In: A correlation of Quaternary deposits in the British Isles. Geological Society of London, Special Report no. 4. Ed. Mitchell, G.F., Penny, L.F., Shotton, F.W. and West, R.G.

Watson, E. (1965), Periglacial structures in the Aberystwyth region of central Wales. Proc. Geol. Assoc., 76,443-462.

West, R.G. (1961), Vegetational history of the Early Pleistocene of the Royal Society Borehole at Ludham, Norfolk. Proc. R. Soc., B, 155, 437-453.

West, R.G. (1980), The pre-glacial Pleistocene of the Norfolk and Suffolk coasts. Cambridge Univ. Press.

Wild, J.B.L. (in press), The sand and gravel resources of the country around Billinghay, Lincolnshire. Miner. Assess. Rep. Inst. Geol. Sci., No. 100.

Woodland, A.W. (1940-46), Water supply from underground sources of Cambridge-Ipswich district. Parts I-VI. Wartime Pamphlet No. 20. D.S.I.R., Geol. Surv.

Woodland, A.W. (1970), The buried tunnel-valleys of East Anglia. Proc. Yorks. Geol. Soc., 37, 521-578.

Wymer, J.J. and Straw, A. (1977), Hand-axes from beneath glacial till at Welton-le-Wold, Lincolnshire, and the distribution of palaeoliths in Britain. Proc. Prehist. Soc., 43, 355-360.

GREAT BLAKENHAM TM 102500 - 117500

Exposures at this site are in a quarry complex, 1.5 km (east-west) by 0.5 km (north-south) on the west side of the Gipping Valley. A plan of part of the quarry complex and a schematic cross-section are shown in Figures 1 and 2.

Table 1.

Sediments present	Bed no.	Maximum observed thickness
Coversand	7	2.5m
Haughley Park Gravels	6	1.8
Blakenham Till Barham Till	5	13.0
Sandy Lane Gravels	4	1.8
Barham Arctic Structure Soil Barham Coversand Valley Farm Sol Lessive Kesgrave Sands and Gravels (Baylham Common Gravels)	3	4.0
Creeting Beds	2	14.9
Crag	1	0.25
Chalk		

Creeting Sands

Up to 15m of Creeting Beds overlie occasional pockets of Crag and a basal lag of nodular flint pebbles and phosphatic nodules. The bottom 11m is predominantly a well sorted micaceous sand with occasional matrix-supported gravel beds and a small amount of silty clay. The lower 5m of sand is predominantly white (2.5Y8/2) but the upper 6m is variable in colour, being commonly very pale brown (10YR7/3 to 10YR8/4), yellowish-red (5YR5/8) or reddish-yellow (7.5YR6/8, 7.5YR7/6) with subordinate white (2.5Y8/2) amd pale yellow (2.5Y7/4). The silty-clay varies from light grey (5Y7/2) to red (10R4/8) and strong brown (7.5YR5/8).

The primary sedimentary structures (Figure 3) range from ripples through tabular and trough cross-sets, up to 1.3m thick, to horizontally bedded units up to 1.6m thick. Some beds appear structureless. Silty-clay occurs as curled flakes in the structureless beds and tabular cross-sets and thin seams in simple and wavy types of flaser bedding. Although the cross-sets appear to give a herringbone pattern, 12 cross-sets measured showed a wide range of readings with only a slight concentration between 300 and 340° (Figure 4).

The upper 4m is dominated by silty-clay which may occur as massive or brecciated beds up to 1.2m thick and interbedded with well sorted sand, or as interlayered sand-silty-clay bedding in units up to 1m thick.

The bedding is disturbed by small, cylindrical, U-shaped structures up to 4cm in vertical extent, thought to be of biogenic origin. Numerous small-scale reversed faults and low-angle thrusts, associated with nappe-like flexing of the beds, occur (Figure 5). Seven measurements taken show that the faults and thrusts incline towards 105-125° and 285-300°, i.e. into a concentrated symmetrically opposed bimodal pattern (Figure 10).

The particle size distributions suggest that the sands are beach or near-shore deposits (Section I, Figure 6). The horizontal bedding and its associated grain sizes indicate deposition in the upper flow regime with water velocities of 60 $cm.sec.^{-1}$, probably in channels. The tabular and trough cross-sets are associated with the lower flow regime and their amplitudes suggest water depths up to 9.8m (Allen, 1970). The flaser bedding indicates low energy conditions with ripples forming in fine sand during periods when water velocities were between 10 and 60 $cm.sec.^{-1}$, the silty-clay being deposited in periods of quiesence. The interlayered bedding and massive silty-clay beds are associated with prolonged quiet water conditions, with current velocities below 20 $cm.sec.^{-1}$ in areas with high concentrations of fine suspended sediment. Such conditions are met in sub-tidal water with depths of 20-40m (Reading, 1978), near the high water mark in estuaries or inshore of an extensive tidal flat. The curled and flaked silty-clay indicates desiccation, so at times the deposits were subaerially exposed. Thus an intertidal environment is suggested, in an estuary or inshore of a tidal flat.

The random pattern of palaeocurrent readings was not anticipated for in a shallow tidal environment a clear bipolar distribution is to be expected, reflecting the tidal currents. Possibly some of the structures were created by wind-induced currents. However, the low number of readings (12) may not be truly representative.

Pollen (DTH)

A sample of the organic-rich silt from Great Blakenham was found to contain pollen. Some of this pollen was corroded, so that 23.8% of the 361 grains counted were not identified, but much of the pollen was in fairly good condition. The tree pollen (33.9%) was dominated by Pinus (18.0%) and Alnus (8.0%) with a few grains of Betula, Quercus and Picea and two of Tsuga canadensis-type. Shrubs totalled 17.9%, principally Ericaceae (14.2%), while the 24.4% of non-arboreal pollen was mainly of Graminae, Cyperaceae and Filicales.

More detailed palynological study is in hand. The pollen spectrum summarised above suggests predominant woodland vegetation, with areas of heathland. It does not closely resemble Pastonian or Cromerian pollen spectra from the Norfolk coast and might represent a cool period of the early Pleistocene, but any hope of a proper correlation must await further study.

The palaeosols layer

(Kesgrave Sands and Gravels(Baylham Common Gravels), Valley Farm Sol Lessive, Barham Coversand and Barham Arctic Structure Soil)

Above the silty-clay, there are up to 4m of sand and gravel which is markedly rich in silt and clay, 15 out of 18 samples having more than 11% silt and clay. Most pebbles have a clay skin. The colour of the deposits is very varaiable. The basal deposits vary from brownish-yellow (10YR6/8) to yellow-red (5YR5/8). The higher parts involve well developed red colours (10R4/8 to 2.5YR5/8), strong brown (7.5YR5/8) and yellow-greys (2.5Y7/4 to 5Y7/2).

Primary sedimentary structures are seen only in the lowest 1.5m of the sequence, such structures invariably being horizontally bedded sands and gravels. The uppermost part of the sequence is severely deformed, essentially into lobes and irregular wedges, up to 2m in vertical extent, often with a core of yellow (10YR7/6), clay-deficient, sand bedded sub-vertically, parallel to the wedge walls, and occasional polished flint pebbles (Figure 5). This pattern is often inclined to the east, at times in a very complex manner, and in places beds are repeated due to thrusting. Measurement of the attitude of the thrust beds show inclinations to the west (Figure 6).

Kesgrave Sands and Gravels (Baylham Common Gravels). The pebble suite of the gravels (Section I, Table 3) is dominated by flint (65.5%) and quartz and quartzite (29%) with minor amounts of Greensand (0.5%) and Carboniferous (3%) chert. This suite is typical of the higher members of the Kesgrave Sands and Gravels.

Valley Farm Rubified Sol Lessive. The relatively high percentages of silt and clay in the sand and gravel, even in the lowermost, undisturbed beds, suggests that the particle size distributions are not original. The high clay content and the clay skins on the stones indicate a pedogenic concentration of clay at this level and the red colours a concentration of haematitic iron. Such a concentration of clay and iron is characteristic of the illuvial horizon of a humid temperate soil. The absence of the eluvial horizon indicates post-formational erosion. Similar horizons are found locally at Barham and Valley Farm.

Barham Coversand. The yellow sands found within the lobes deforming the temperate palaeosol are considered to be aeolian because the particle size distributions compare well with coversand from the Netherlands (Maarleveld, 1960) (Section I, Figure 11), the included flints are polished and the sand has sub-vertical bedding typical of sand wedges.

Barham Arctic Structure Soil. The lobate deformations of the temperate palaeosol and coversand are typical involutions. The disturbance has also to a degree homogenised the gravels. This reorganisation by ground ice activity has produced the Barham Arctic Structure Soil.

Sandy Lane Gravels.

In the eastern part of the quarry complex, the sequence so far discussed is not present. Up to 1.8m of calcareous silt, sand and gravel are found beneath till at the bottom of channels, up to 13m deep, cut into the Chalk. The sand and gravel is usually cemented. The gravels are dominantly of chalk with subordinate amounts of flint and quartz. The heavy minerals of the silt are listed in Section I, Table 5. The dominance of chalk in the gravels suggests local erosion of the bedrock. The depth of the channels, the presence of the gravels and the sub-till situation suggest deposition was by powerfully flowing sub-glacial meltwater. The silt indicates periods of still or very slow moving water.

Blakenham Till.

The till is very variable in thickness. In the plateau area, around TM 103502, it is 13m thick; it thins to 1m around TM 110503 and thickens again to 13m in the channels and on the valley side around TM 118499.

In the plateau area, 18 samples were examined. The particle size properties of the till are remarkably uniform (Figure 7). The colour, apart from the uppermost 2m, is also uniform (Figure 8), very dark grey (5Y3/1) or dark olive grey (5Y3/2). In the uppermost 2m, the colours are mostly lighter (5Y5/1, 5Y6/1, grey) or browner (from 2.5Y4/2, dark yellowish brown, to 10YR5/6, yellowish brown). Of the 11 macrofabric analyses showing a significance level of 95% or greater, 9 showed a limited range of vector means with trends between 098-278° and 174-354°, while two samples were notably aberrant at 083-263° and 086-266°. Between these last two samples were chalk rich lenses, approximately 5cm thick and 2m long.

Apart from the lighter and browner colours of the uppermost 2m, interpreted as post-depositional weathering, the uniformity of the colour and of the particle size properties indicate deposition in conditions that varied little. The consistency of the statistically significant preferred orientations and the accord with the regional direction of ice movement (Perrin et al, 1979) suggests a lodgement till, deposited by ice moving from north-west to south-east. When compared with a similar study from the Hertford area (Rose, 1974), it is notable that the resultant vectors from Great Blakenham are more variable and that the vector magnitude does not reach the 95% significance level as frequently. This is attributed to the ice being less controlled on the plateau at Great Blakenham than in the valley at Hertford.

In order to compare tills that would have been classified as 'Lowestoft' and as 'Gipping' Boulder Clay by Baden-Powell (1948), samples were taken from the plateau area. The tills were chosen on the basis of colour and their identification in one case was confirmed by Mr H.E.P. Spencer in 1974. The 'Gipping' type tills were sampled 1.5m below the ground surface and the 'lowestoft' type from directly beneath in dark grey till. Direct comparison of the two types of till shows remarkably similar macrofabric patterns with low vector magnitudes and highly variable dips. Both types of till appear to have been deposited in similar circumstances. Particle size analyses show the 'Gipping' till to be notably deficient in gravel and rich in silt in some cases, but this was not always the case. 'Gipping' type till from elswhere in the quarry was noted to be sand rich when compared to the 'Lowestoft' till.

No clear basis for distinguishing between the types of till was established. The higher quantities of silt and sand in some samples of 'Gipping' type till may encourage weathering and lead to browner colours, but this characteristic is not essential.

Glacier related sediment deformation.

A number of both major and minor disturbances to the primary sedimantary structures, considered to be related to glacier advance, have been noted.

Large-scale trough structures, seen in Face 2, (Figure 9) may be due to saturation, loading and consequent diapirism and may be similar, though smaller in scale, to structures described from north Norfolk (Banham, 1975). The structures are noted to coincide with the occurrence of the interlayered sand and silty-clay. Meltwater could have penetrated the sands very readily, giving the whole sequence a high potential to diapir. The weight of the overlying sediment or possibly ice itself could provide the necessary loading to bring about diapirism. The till itself is not involved in these structures and where present is spread equally over the troughs and diapirs, indicating that the activity occurred before the till was deposited, but possibly when ice was nearby.

The large-scale thrusts of Face 3 (Figure 6) may also have analogies in north Norfolk. The thrusting is similar to that described by Banham (1975) as occurring when sediments are subjected to lateral compression at an active ice front. Measurement of the attitudes of the thrust beds show low angle dips, principally to the west (Figure 6).

Detailed examination of the interlayered sand and silty-clay showed a number of thrusts and minor reverse faults (Figure 5), again indicating lateral pressure and shortening of the beds. The inclination of the faults and thrusts towards 105-125^{o} and 285-300^{o} in a concentrated bipolar pattern (Figure 10) is in keeping with the direction of ice movement.

Eastward deflection of the involutions in the palaeosols layer again reflect lateral pressure from the west. As the involutions are immediately beneath the till, the deflection may be due to ice drag.

The glacitectonic data is summarised in Figure 10, showing a range of pressure directions from 250 to 340^{o}, i.e. from west to north, in keeping with ice movement from the north-west. It is notable that these disturbances were caused by ice crossing from the plateau area into the Gipping Valley and not by ice moving down the valley deforming spurs and promontories as earlier authors have suggested.

<u>Haughley Park Gravels.</u>

Immediately above the till in the eastern part of the quarry complex are coarse, matrix-supported gravels. The clasts are set sub-horizontally in a reddish-brown (5YR4/4) matrix. The dominant durable lithology is flint (39%), mostly sub-angular and non-Tertiary (35.5%), with subordinate quartz and quartzite (9%) and chert (2.5%), including Rhaxella chert (0.8%) but totally lacking in Greensand chert. The non-durable lithologies comprise 48% of the total and include chalk (35.5%) and limestone, including fossils, (1%). The coarseness of the gravels, the high percentage of non-durable lithologies and the super-till position indicate that this is an ice proximal deposit associated with glacier decay.

Sketch of Chalk Quarry, Great Blakenham (1979)

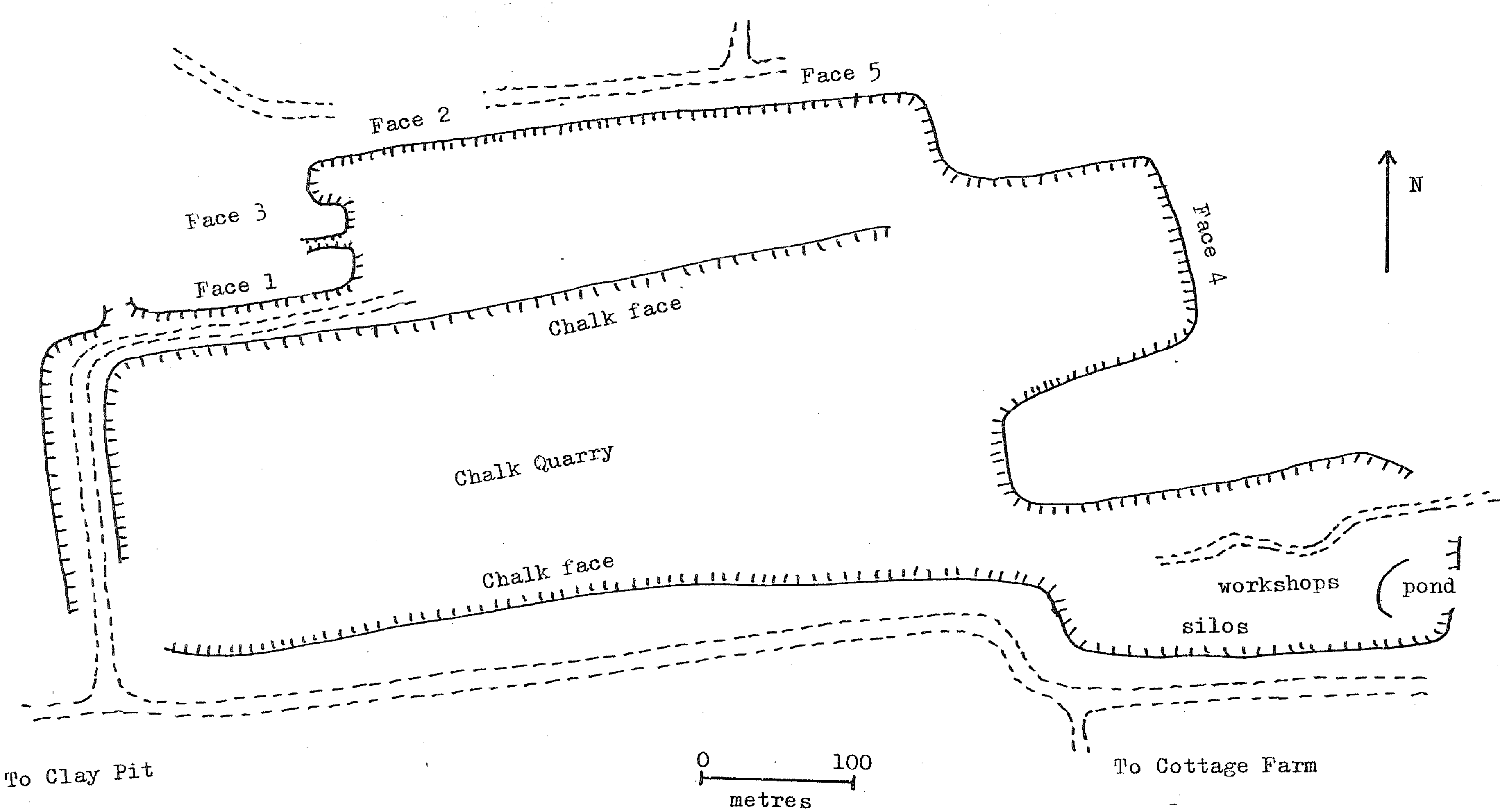


Figure 1. Great Blakenham, Chalk quarry.

Great Blakenham, schematic cross-section (east-west)

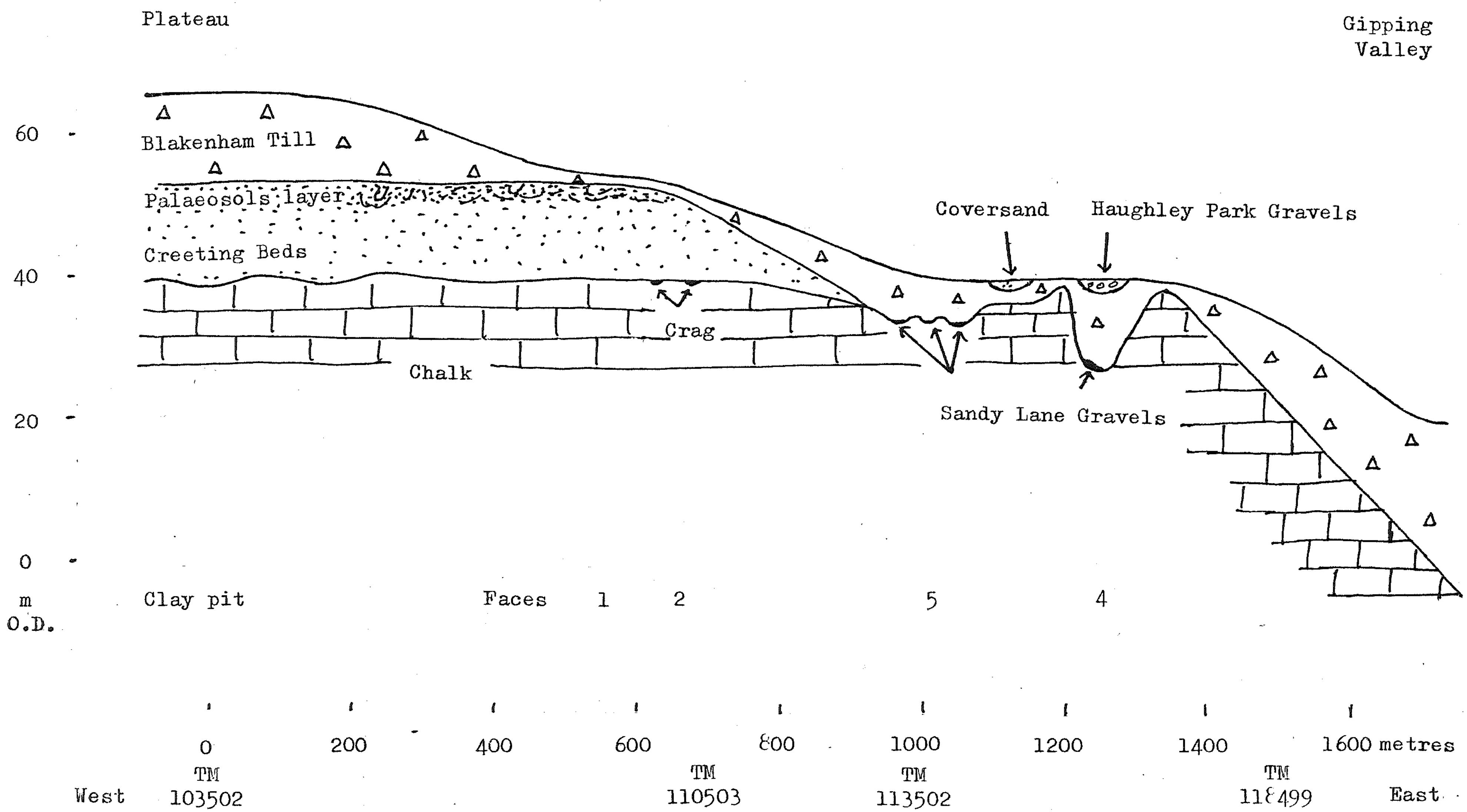
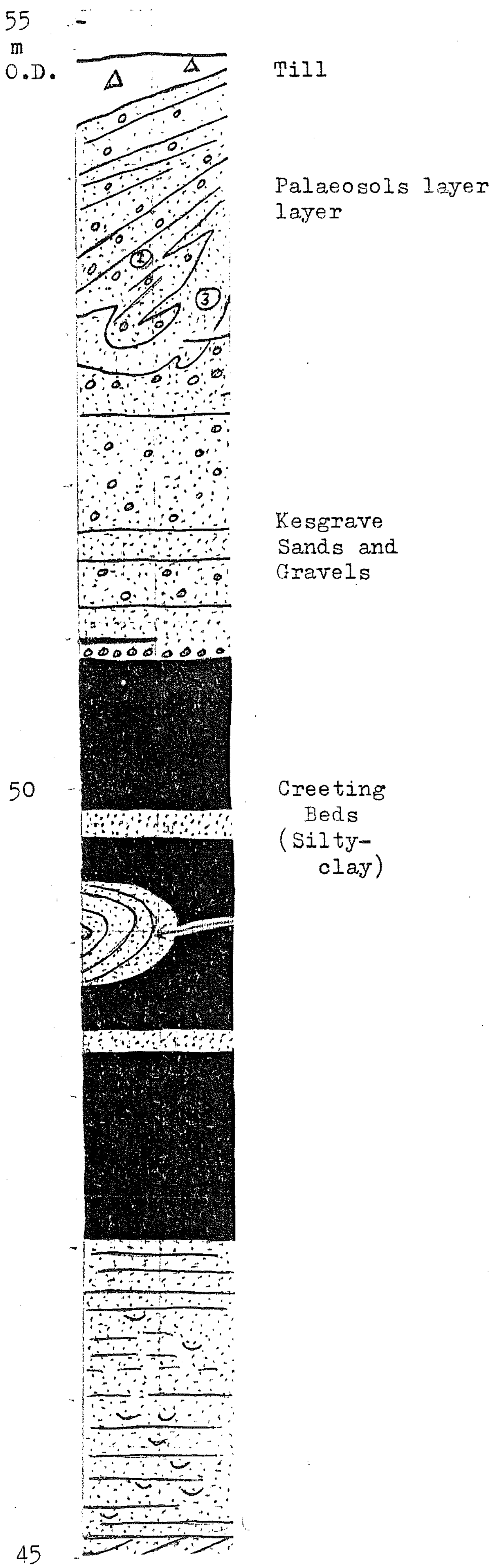


Figure 2. Great Blakenham, schematic cross-section.



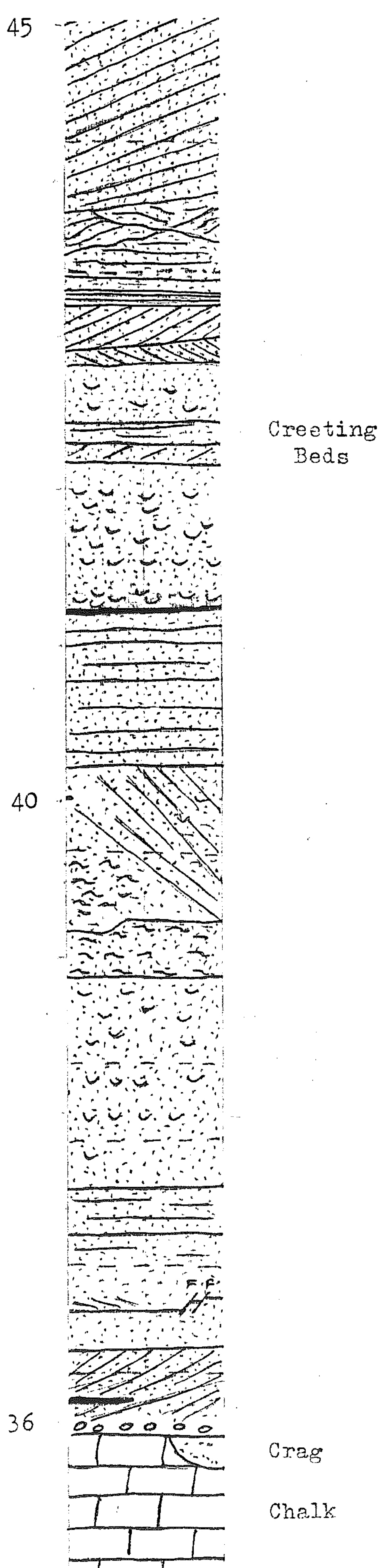


Figure 3. Great Blakenham,
Face 1.

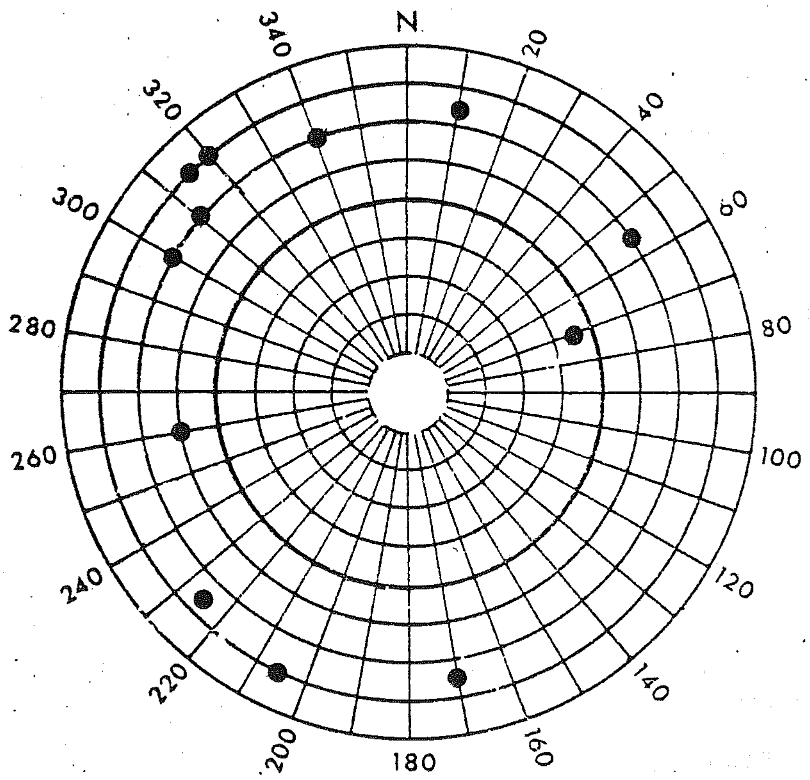
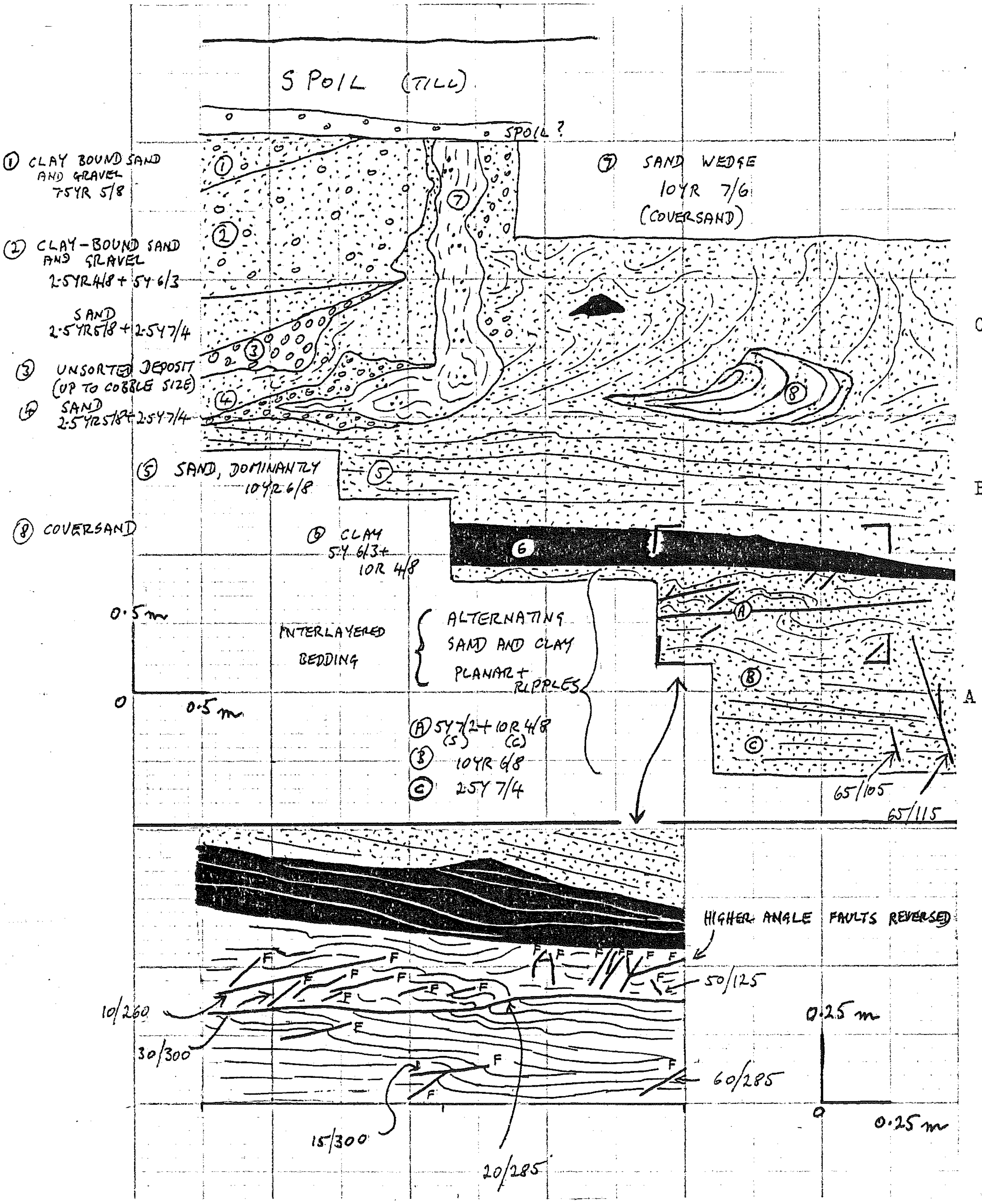


Figure 4. Great Blakenham, Creeting Beds, palaeocurrent measurements.

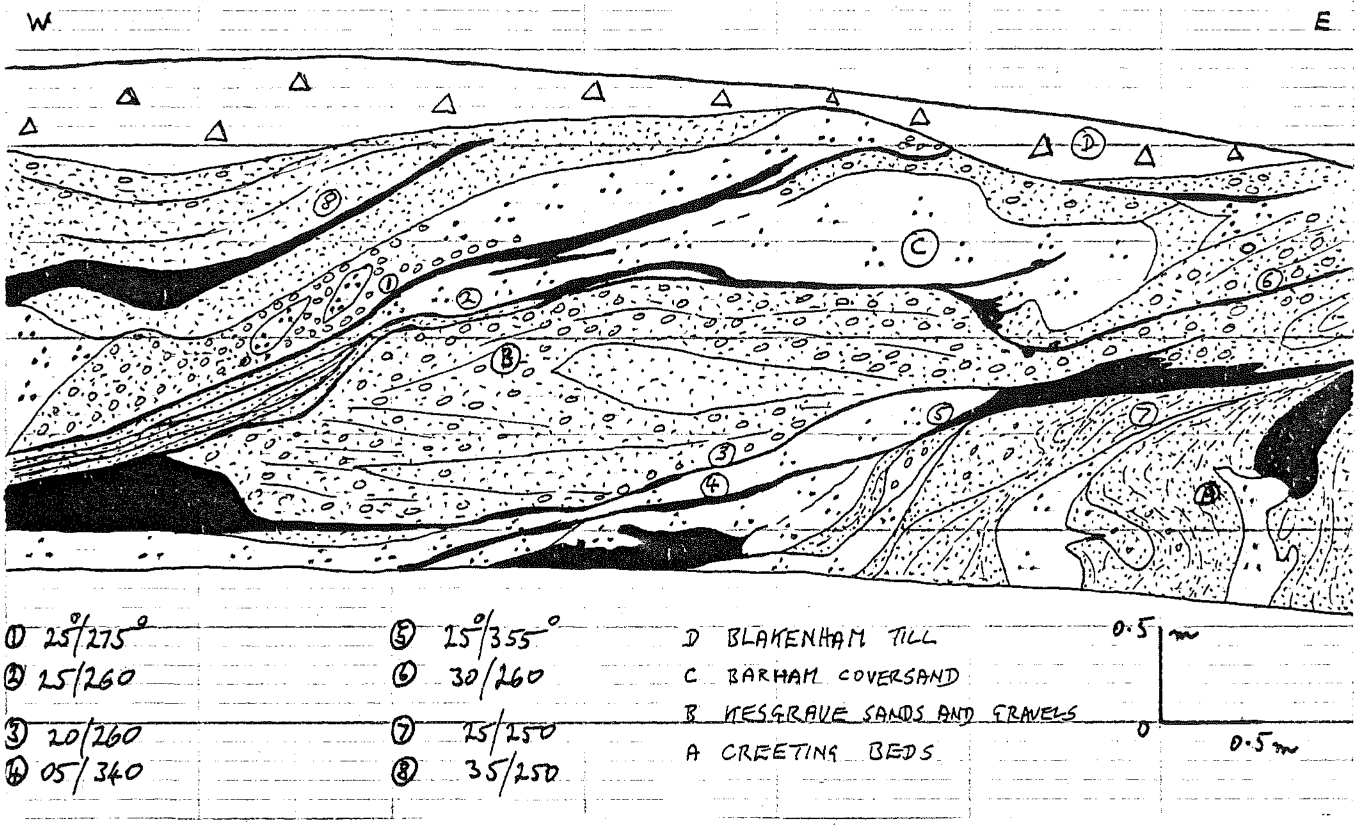


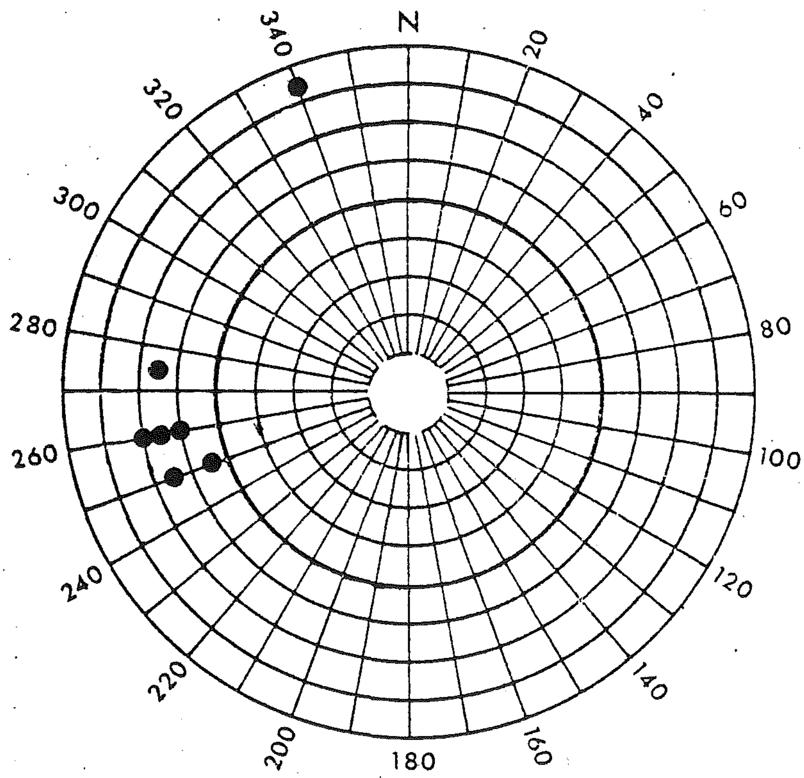
C Palaeosols layer

B Kesgrave Sands and Gravels

A Creeting Beds

Figure 5. Great Blakenham, Face 2.





Attitudes of thrust beds.

Figure 6. Great Blakenham, Face 3.

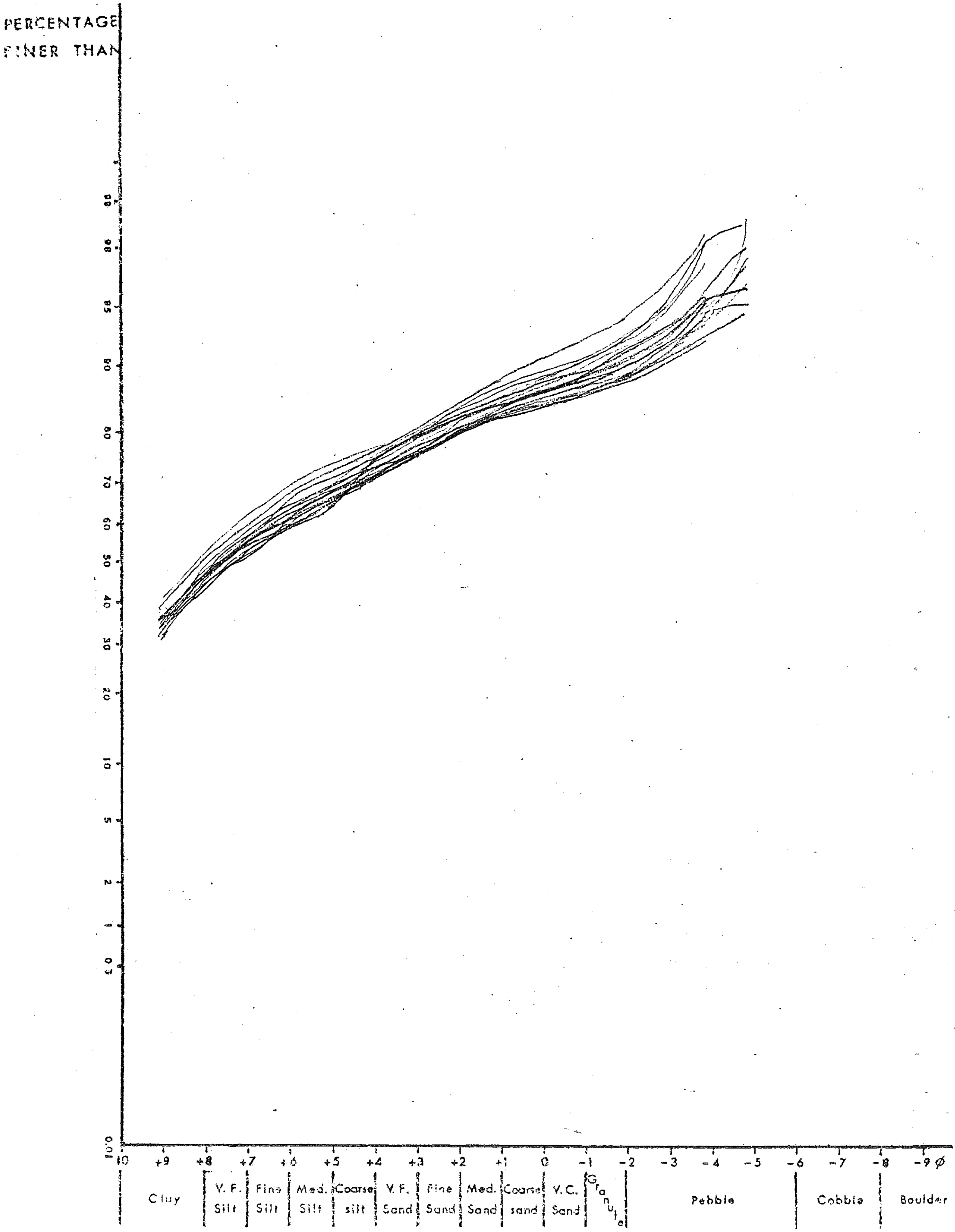


Figure 7. Great Blakenham, Blakenham Till, particle size distributions.

1 5Y4/3	2 5Y3/2 + 2.5Y4/4	3 5Y5/1 + 2.5Y4/4	4 10YR5/6 + 5Y5/1	5 10YR5/6 + 5Y6/1	6 2.5Y4/2
7 5Y3/1	8 5Y3/1	9 5Y3/1 + 5Y3/2	10 5Y3/1	11 2.5Y3/2	12 5Y3/1
13 5Y3/2	14 5Y3/1	15 5Y3/2	16 5Y3/1	17 5Y3/1	18 5Y3/1

a. Munsell colours.

1 160-340° **	2 174-354° *	3 83-263° **	4 86-266° **	5	6
7	8	9	10	11 117-297° *	12 113-293° **
13 98-278° **	14 133-313° **	15 126-306° *	16 149-329° **	17	18 167-347° **

b. Vector trends. * 95% ** 99% Significance level

Figure 8. Great Blakenham, Blakenham Till.

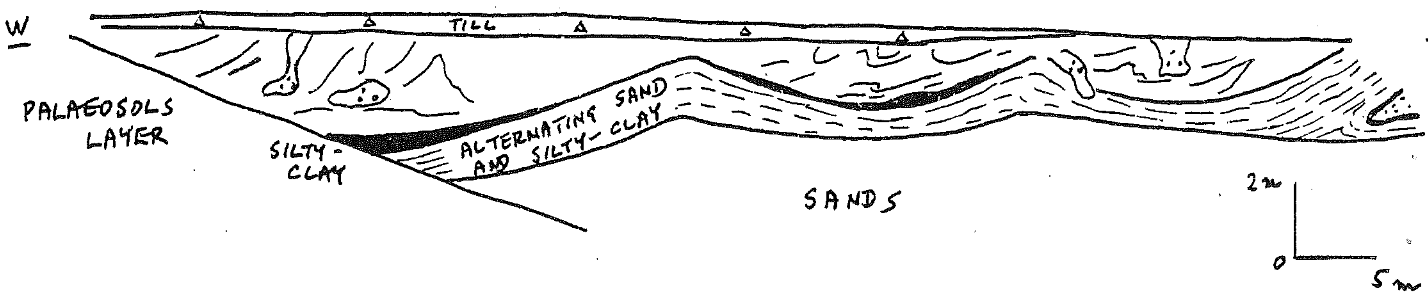


Figure 9. Great Blakenham, Face 2, structures.

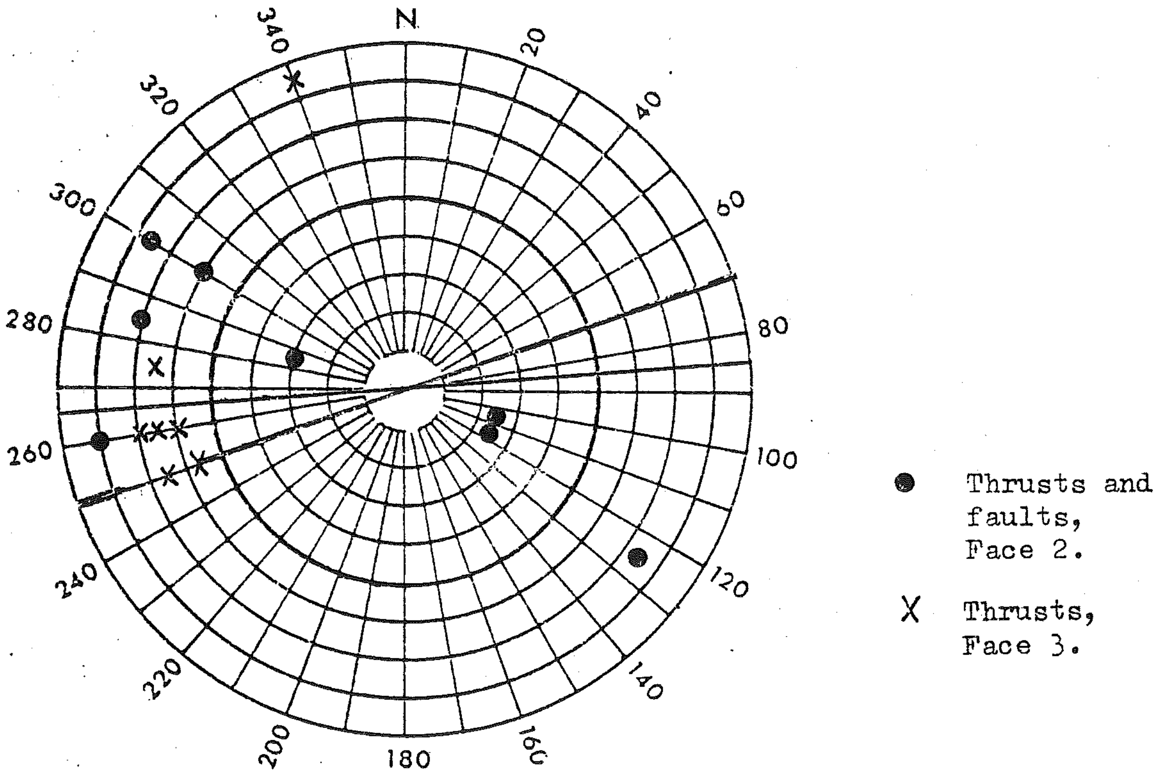


Figure 10. Great Blakenham, summary of glacitectonic data.

CREETING ST MARY   TM 095555

A series of quarries, worked for their sand, occur on an interfluve reaching 46m O.D. between the Gipping Valley and a minor east bank tributary near Needham Market. The layout of the quarries is given in Figure 11. The purpose of this visit is only to briefly compare the Creeting Beds here with those at Great Blakenham, hence only those beds will be described.

Creeting Beds.

Up to 15m of Creeting Beds have been exposed in the complex of quarries. The lowermost 11m are composed of unimodal, well sorted (σ = 0.32-0.51 ϕ, n = 11) sands, though clay flakes are common in some areas and occasional matrix-supported gravel lenses were noted in pit 2. Occasional pebbles, of flint, vein quartz and quartzite, are found throughout the sands. The uppermost part of the beds, reaching a mazimum thickness of 4.2m, is composed of horizontally bedded, laminated silty-clay.

Within the sands are undulating clay bands, usually 1-2mm thick and displaying desiccatiom cracks. These bands are infrequent, though in pit 3 they were more common and in pit 2 they were up to 5 cm thick and finely bedded towards the top of the unit. The uppermost 0.5m of sand are ferruginous and at the very top there is an iron-pan 1-2mm thick.

Sedimentary structures typical of the sands are shown in Figure 12. The structures are dominantly horizontal, with planar bedding of the upper flow regime, small scale ripples, tabular cross-sets up to 0.3m thick and occasional trough cross-sets of the lower flow regime. Into these are cut scours. Palaeocurrent measurements often show a relatively strong clustering on a local scale, but there is great variability from pit to pit. When the measurements are amalgamated, a polymodal distribution is noted, with a slight preponderance of readings to the north-east and south-west and fewer to the north-west and south-east, especially the latter (Figure 13). The weakly developed north-east to south-west trend is in accord with the alignment of the Stradbroke trough.

The particle size properties of the sands are typical of beach and near-shore sediments (Section I, Figure 6). The intercalation of clay seams within the sands is typical of tidal flats, the clays relating to slack water periods and the sands to deposition from tidal currents (Reineck and Singh, 1975). The matrix-supported nature of the gravel lenses is thought to indicate occasional inputs of fluvial sediments. The range of sedimentary structures is consistent with a sandy tidal flat. The ripples represent the surface of the flat and the tabular and trough cross-sets, dunes within the channels (Reineck and Singh, 1975). Water depths appear to have been shallow, the cross-sets indicating water depths in the channels of 2.9m (Allen, 1970). The desiccation of the clay laminae indicate that the deposits were at times exposed and dried out. Laminated silty-clay beds are frequently associated with intertidal deposits and are related to mudflats occurring near the high water mark (Reineck and Singh, 1975). Thus their presence may suggest a slight shallowing of the sea,or a shift of the main channels.

The sequence is possibly part of a widespread distribution of sands (see Section I) and deposition at Creeting may be related to the Stradbroke trough, a view also considered by Dixon (1978). Immediately to the south, the Creeting Beds are absent (Section I, Figure 5), so the beds at Great Blakenham were deposited either in a separate basin or have been cut off by post-depositional activity.

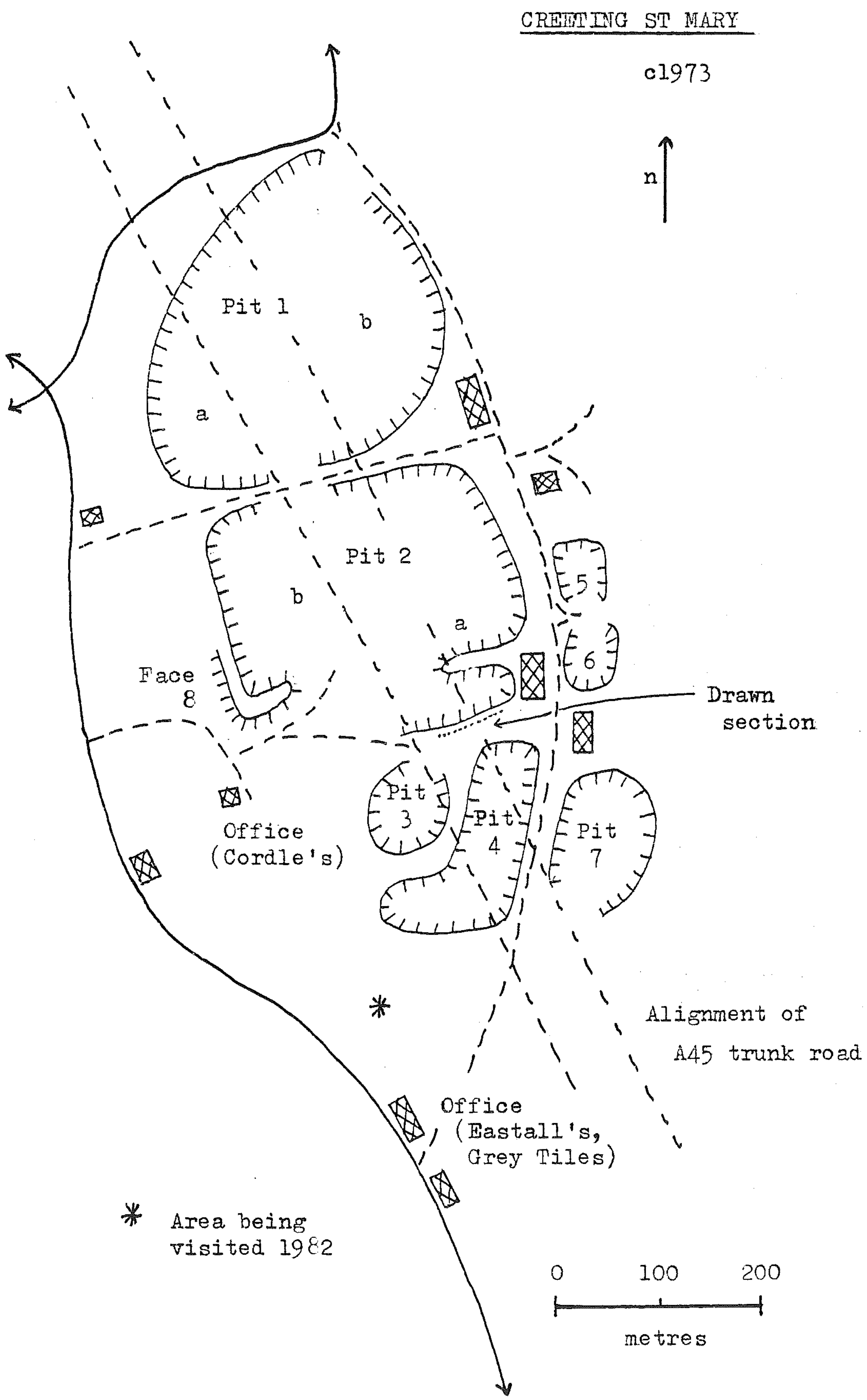


Figure 11. Creeting St Mary, layout of the quarries.

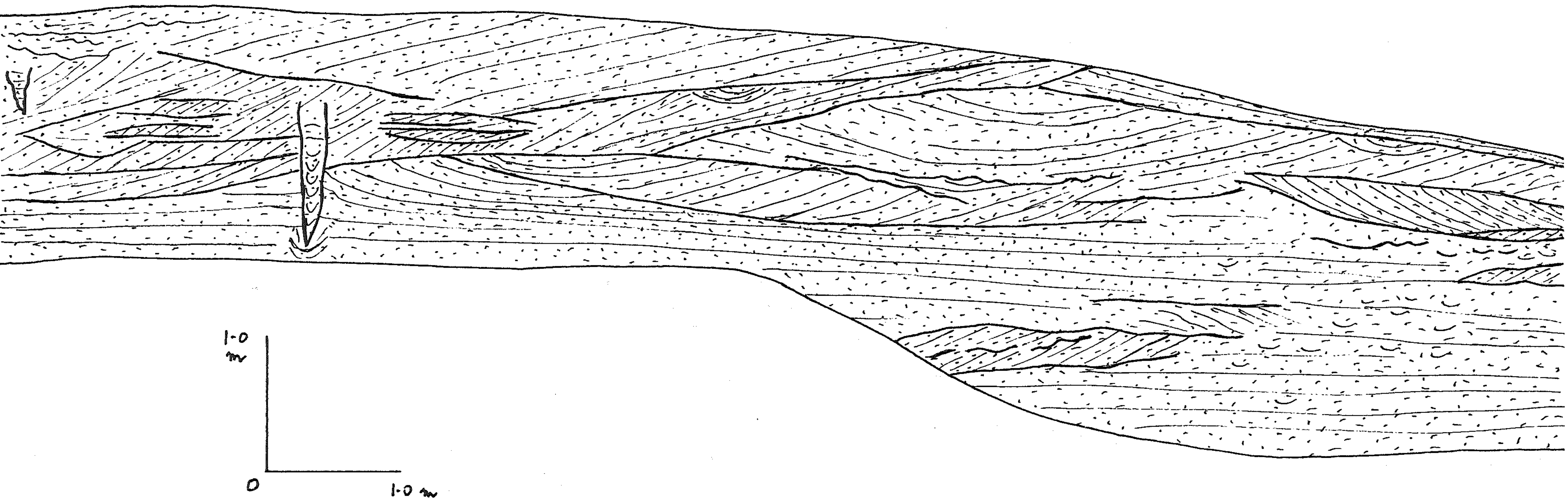


Figure 12. Creeting St Mary, Creeting Sands, sedimentary structures.

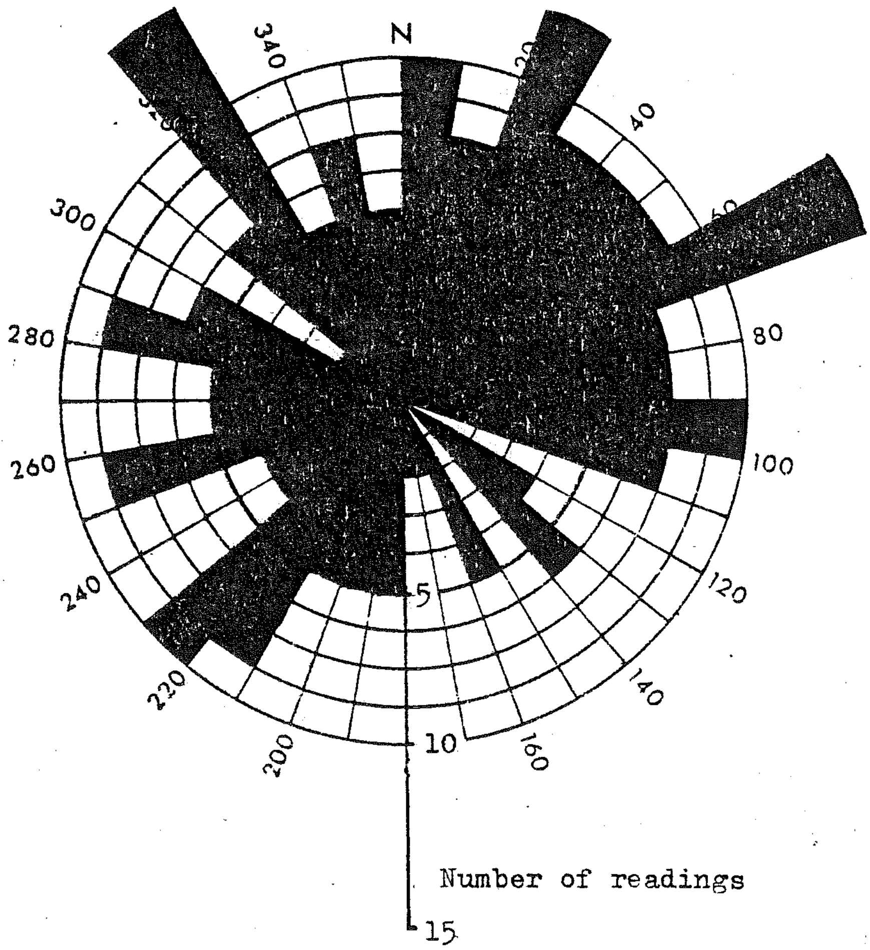


Figure 13. Creeting St Mary, Creeting Sands, palaeocurrent measurements.

BADWELL ASH   TL99/69 and TL 988687

The following descriptions relate to a series of quarries that occur east of the village, north and south of Back Lane (TL99/69). These quarries are no longer worked and the most important section, south of Back Lane, has been filled in. The remaining exposures (May 1982), north of the lane, do show Kesgrave Sands and Gravels in the bottom part of the quarry and Sandy Lane Gravels, Creeting and Blakenham Tills in the middle and upper parts of the face on the north side. The palaeosols layer and the Barham Sands and Gravels do not appear to be present. A better section may be available in a recently reworked small quarry (belonging to Shackerland Hall Farm) c0.25 km south-west of the church and south of the road to Hunston at TL 988687. If Back Lane quarries are visited, activity must be confined to the dry-bottomed quarry furtherest east on the north side of the lane.

Table 2.   Back Lane Quarries.

Sediments present	Bed no.	Maximum observed thickness
(Surface elevation		c49.0m O.D.)
Blakenham Till	7	3.3m
Creeting Till II	6	0.8
Sandy Lane Gravels	5	1.0
Creeting Till I	4	0.6
Barham Sands and Gravels	3	1.2
Barham Arctic Structure Soil } Valley Farm Sol Lessivé }	2	c1.0
Kesgrave Sands and Gravels (Westland Green Gravels)	1	3.0+

The sequence is represented in a section drawing (Figure 14) and stone counts are presented in Table 3.

Table 3.   Badwell Ash, stone counts (derived from Section 1, Table 3)

		FLINT			QTZ GROUP		CHERTS			NON-DURABLES		
		Ang.	Rnd.	Tot.	Qtz.	Q'te	Cret	Carb	Rhax	Chlk	Lmst	Other
Sandy Lane Gravels	A	69.7	7.7	77.4	4.8	10.1	0.0	0.0	0.5	1.4	1.4	2.9
	B	61.0	7.8	68.8	5.8	10.4	0.0	3.2	0.0	3.9	1.2	5.7
	C	55.6	6.8	62.4	11.7	12.4	0.0	0.0	0.0	4.4	3.4	4.3
Barham Sands and Gravels		45.1	17.6	62.7	15.7	13.7	0.7	3.3	0.0	0.0	0.0	0.0
Kesgrave Sands and Gravels	A	41.6	20.8	62.4	16.4	16.4	0.0	3.6	0.0	0.0	0.0	0.0
	B	58.4	10.8	69.2	11.8	11.8	1.0	1.0	0.0	0.0	0.0	2.1
	Hey 1980	-	-	70.2	18.1	10.6	0.3	-	-	-	-	-

Shackerland Hall Quarry

Sandy Lane Grav.	57.6	3.9	61.5	2.7	4.7	0.0	0.4	1.6	16.3	3.9	3.1
Barham S & G (?)	41.3	24.5	65.8	21.9	9.7	0.0	1.9	0.0	0.0	0.0	0.0
Kesgrave S & G	45.6	15.6	61.2	20.5	12.8	0.5	2.7	0.0	0.0	0.0	0.0

<u>Kesgrave Sands and Gravels</u> (Westland Green Gravels).

The Kesgrave Sands and Gravels consist dominantly of sand with an upper surface showing an unconformable relationship with the overlying Barham Sands and Gravels. The sands, and gravelly sands, have less than 5% silt and clay. Bedding is mostly horizontally bedded units with subordinate tabular cross-sets, up to 0.5m thick, and occasional trough cross-sets. The mean direction of dip of the foresets was 56°. The gravelly units were matrix-supported. The colour of the sands varied from yellow (10YR7/8) to pale yellow (5Y7/3). The lithologies of the 16-32mm fraction (Table 3) were dominantly flint and quartz and quartzite, with small quantities of sandstone and Greensand and Carboniferous cherts. The whole assemblage was almost exclusively of durable clasts.

The particle size distribution is typical of braided river deposits (Figure I-9) and the dominance of planar bedded sands (Sh facies), with subordinate tabular cross-bedding (Sp) and gravel (Gms), fits best with Miall's (1977, 1978) South Saskatchewan type of profile, suggesting the environment of deposition was that of the distal part of a shallow braided river. The cross-sets, up to 0.5m thick, indicate water depths up to 4.4m. The composition and durable nature of the clasts is typical of the Kesgrave Sands and Gravels and is in keeping with an early course of the Thames flowing to the north-east.

<u>Palaeosols layer</u> (Valley Farm Rubified Sol Lessivé and Barham Arctic Structure Soil).

The uppermost 1.0m of the Kesgrave Sands and Gravels has between 20 and 35% silt and clay (compared with 5% below 1.0m). Two samples, collected at 0.47 and 1.50m below the unconformity marking the surface of the Kesgrave sands and Gravels, showed that the clay content of the fraction finer than 0ϕ was 0.89% for the lower sample and 10.97% for the upper. For the same two samples, Dr J.A. Catt determined the iron content to be 825 p.p.m. for the lower sample and 4760 p.p.m. for the upper. The silt and clay was disseminated rather than occurring discretely or was in the form of cutans. The colour of the uppermost 0.6m consistently reached a hue and chroma of brown (7.5YR5/4) that is considered rubified (Avery, 1973) and which is particularly significant when compared with the colour of the parent material.

The clay and iron enrichment, the development of cutans and redder colours at one specific level are diagnostic pedogenic features (Richmond, 1959), the rubified colours indicating a temperate environment and the clay enrichment an illuvial horizon. The characteristics are typical of the Valley Farm Rubified Sol Lessivé.

The layer lacks primary bedding and is deformed irregularly by ground ice activity into load structures and involutions. The particle size distributions (Figure 15) show exceedingly poor sorting, due partly to the input of silt and clay and partly to the sediments being homogenised by the ground ice so that the gravel fraction is more evenly spread, making the coarse fraction of the samples more poorly sorted. This reorganisation is characteristic of the Barham Arctic Structure Soil.

Barham Sands and Gravels.

The Barham Sands and Gravels rest on a gravel lag and, compared with the Kesgrave Sands and Gravels, are more gravelly and significantly deficient in silt and clay (Table 2, Section 1). The formation consists of tabular cross-sets up to 0.7m thick. The foresets show a spread of direction measurements (Figure 16) with a mean of 110°. Planar beds and matrix-supported gravels occur subordinately. In the lithologies of the 16-32mm size fraction (Table 3), flint and quartz + quartzite dominate (63% and 29%, respectively) and there is an unusually high proportion of Carboniferous chert (3.3%).

The particle size distributions accord with those expected of a braided river (Figure I-12). The gravel units are interpreted as Gms facies of Miall (1977,1978), indicating deposition as longitudinal bars in a braided river; the planar bedded sands as Sh facies of the upper flow regime and the tabular and trough cross-sets as Sp and St facies of transverse and linguoid bars in the lower flow regime. The assemblage fits well with Miall's Donjek type of profile, indicating deposition in the distal part of a braided river system. The maximum height of the tabular cross-sets, 0.7m, indicates a water depth of 5.8m and the palaeocurrents, flow to the east-south-east. The composition of the gravels is very similar to that of the Kesgrave Sands and Gravels, suggesting extensive reworking of the latter, and lacks the input of Rhaxella chert and non-durable lihologies usually associated with the Barham Sand and Gravel.

Creeting Till.

Two units of Creeting Till occur, separated by Sandy Lane Gravels. The lower till is a stony silt, brownish-yellow (10YR6/6) below and brown (7.5YR5/5) in its upper parts. Macrofabric analysis showed a strong preferred orientation with a vector trend of 177-357°, significant at the 99% level. The upper unit was a strong brown (7.5YR5/6) stony clay, with a vector trend of 176-356°, significant at the 99.9% level. (Figure 17).

The strong preferred orientations of the stones indicate deposition by flow, while the poorly sorted nature of the deposits, ranging from gravel (greater than 10mm) to silt and clay, is typical of till. These characteristics and the association of the deposits with the Sandy Lane Gravels suggests that they are flow tills.

Sandy Lane Gravels.

This unit consists of 1.0m of poorly sorted, coarse, matrix-supported gravel. The clasts show a strong preferred orientation dipping particularly to the north-west, between 315 and 335° (Figure 18). The dominant lithology is angular, non-Tertiary flint (62-74%) (Table 3), with 15-24% quartz and quartzite. Chalk (1.4-4.4%) and limestone, including fossils, (1.2-3.4%) and other non-durable lithologies particularly distinguish these gravels from the Barham and Kesgrave Sands and Gravels.

The gravel is interpreted as Gms facies (Miall, 1977, 1978) deposited as a longitudinal bar in a braided stream flowing north-west to south-east. The pebble suite includes many new lithologies which are also found in the Lowestoft Till, while the soft lithologies indicate deposition in proximal situation. The unit is interpreted as an ice-proximal deposit.

Blakenham Till.

The Blakenham Till is strong brown (7.5YR5/6) in its lower part (basal 1.0m) and very dark grey (5Y3/1) above. Macrofabric analyses from nine points showed a consistent north-west to south-east trend, significant at the 95% level or better (Table 4). The massive nature of the till and the consistent preferred orintations, in alignment with the regional direction of ice movement (Perrin et al, 1979) indicates that this is a lodgement till. Its colour is typical of the Lowestoft Till.

Table 4. Badwell Ash, Blakenham Till, vector properties.

Sample no.	Vector trend	Significance level
1	138-318	99 %
2	117-297	99.9
3	118-298	95
4	161-341	99
5	133-313	99
6	100-280	95
7	100-280	99
8	123-303	99
9	117-297	99

The macrofabric data from sample 2 is illustrated in Figure 18.

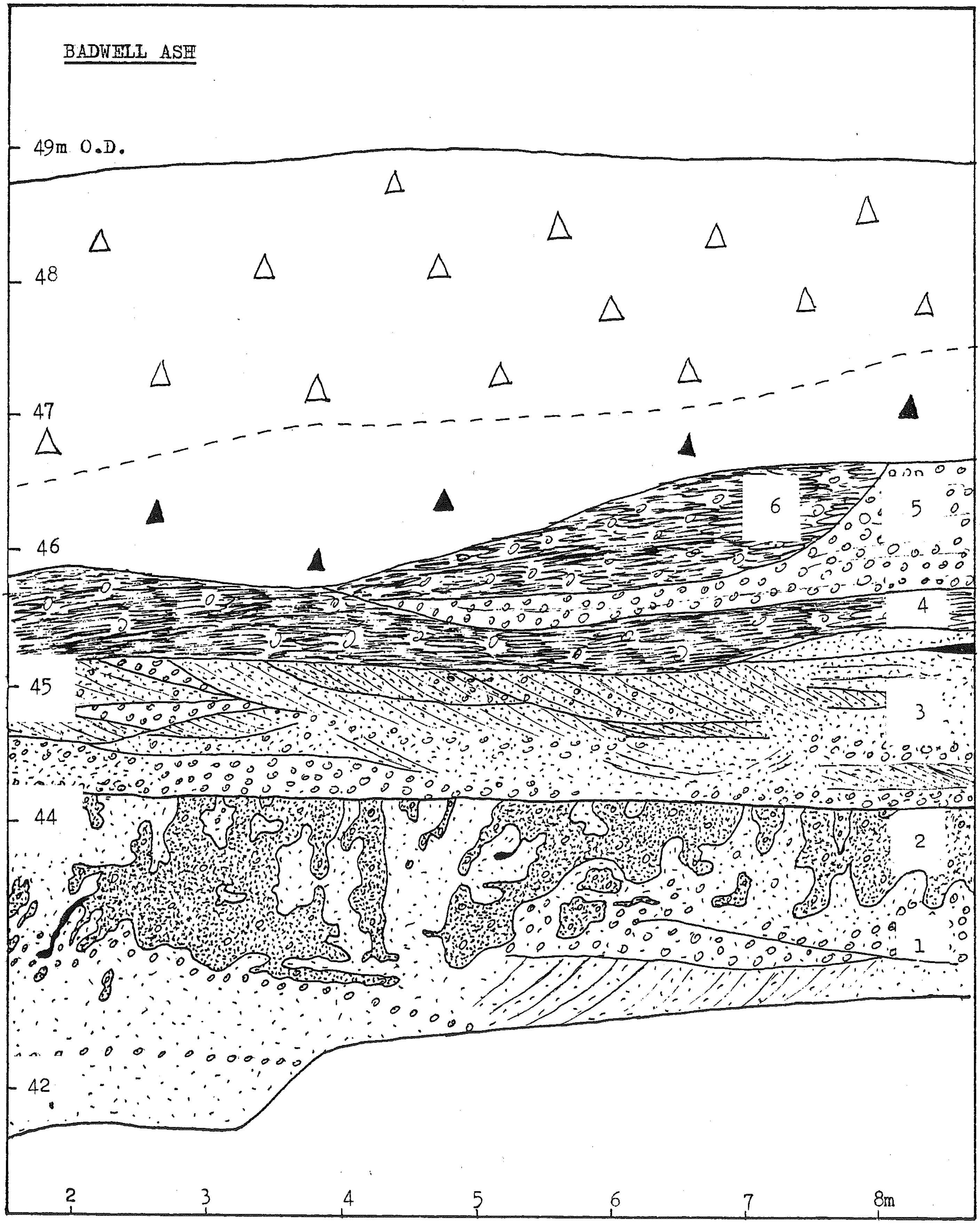
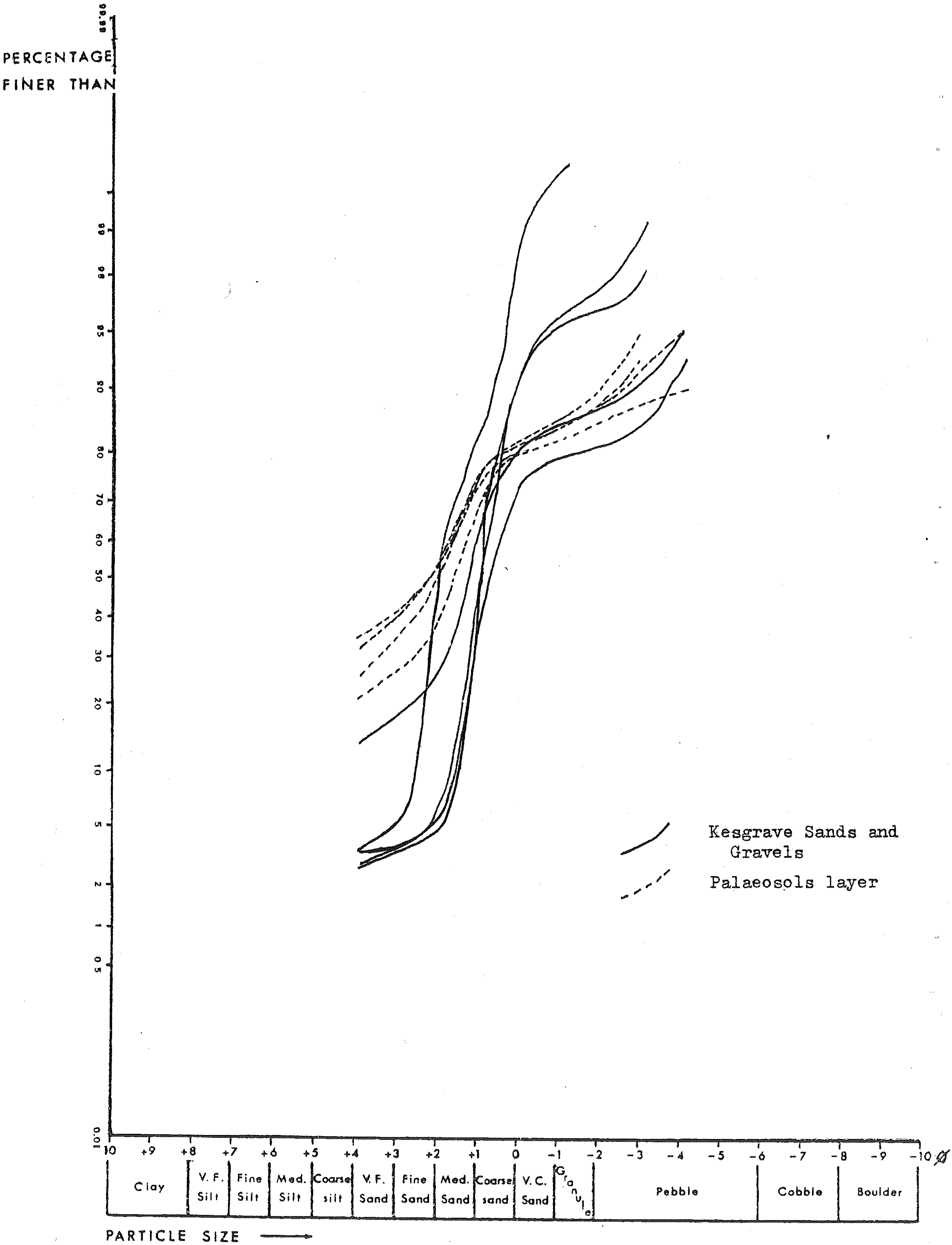
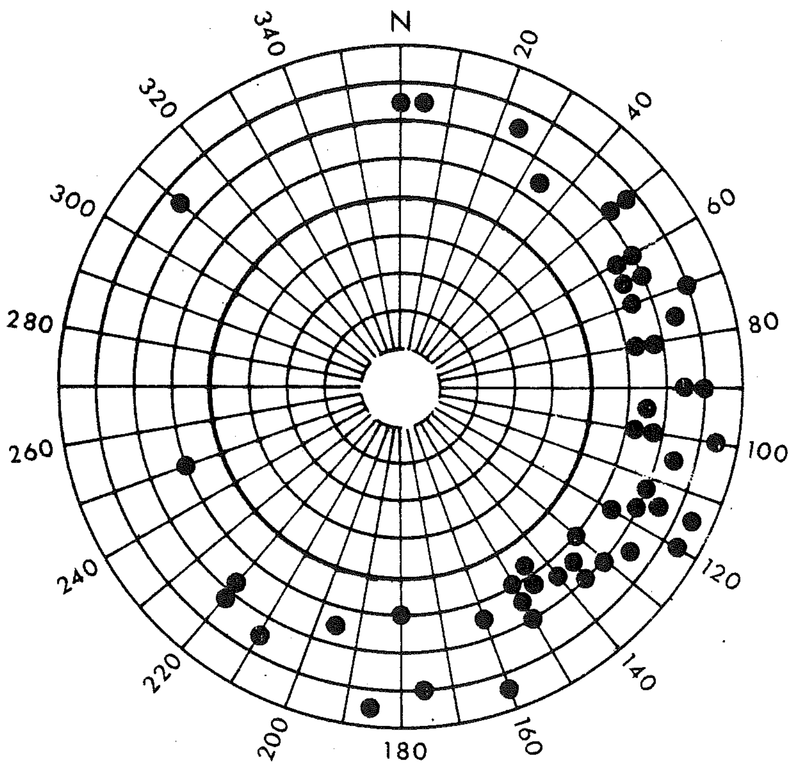


Figure 14. Badwell Ash, Section. Bed numbers as in Table 2.

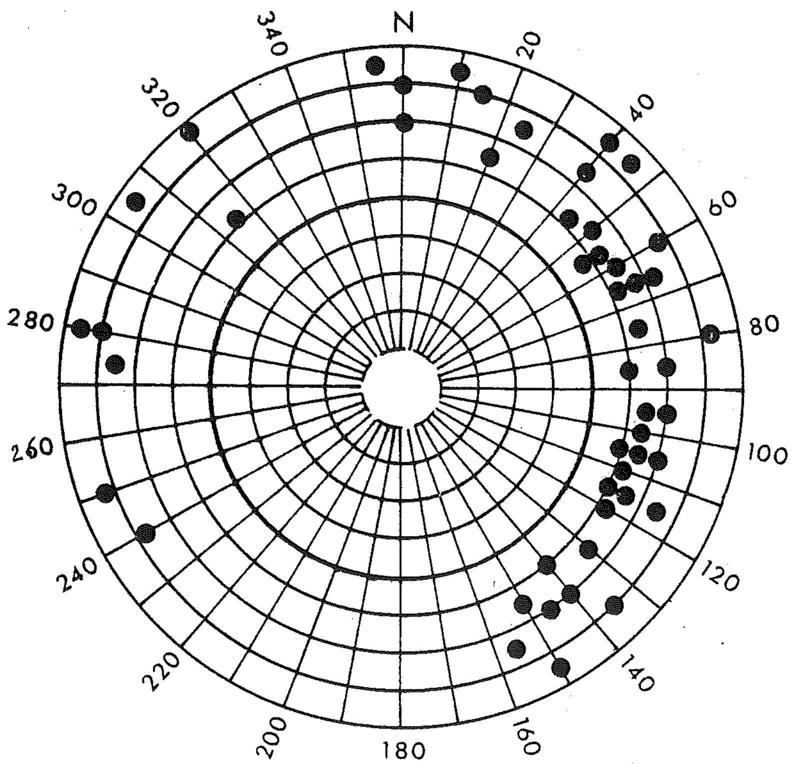
Figure 15. Particle size distributions from the Kesgrave Sands and Gravels and Palaeosols layer.





Barham Sands and Gravels

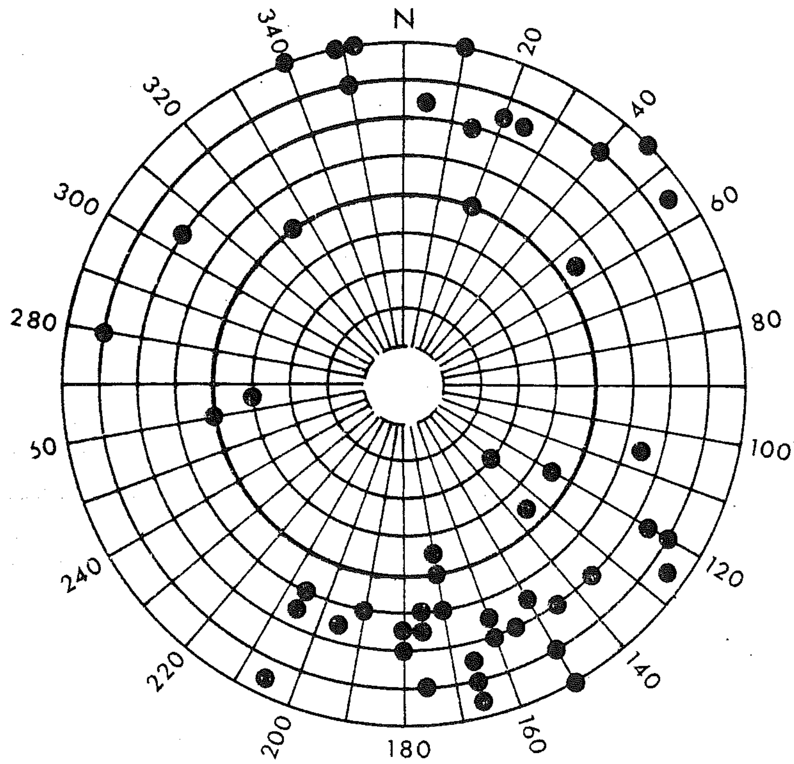
n = 50 $\bar{x}$ = 110°



Kesgrave Sands and Gravels

n = 50 $\bar{x}$ = 056°

Figure 16. Palaeocurrent Measurements, Kesgrave and Barham Sands and Gravels.

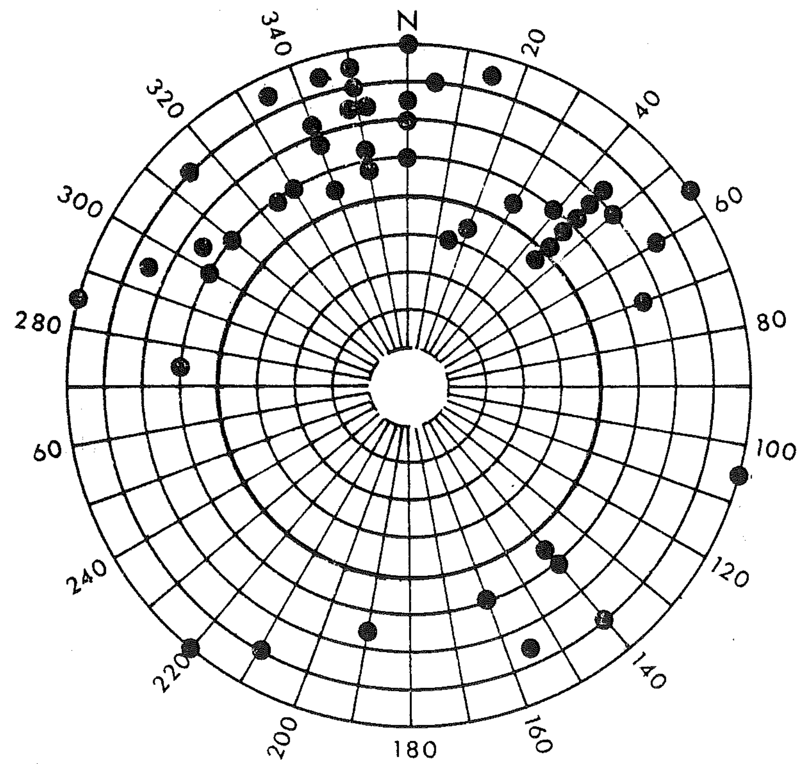


<u>Upper</u>

n = 50

Vector trend 176-356°

Significance level 99.9%



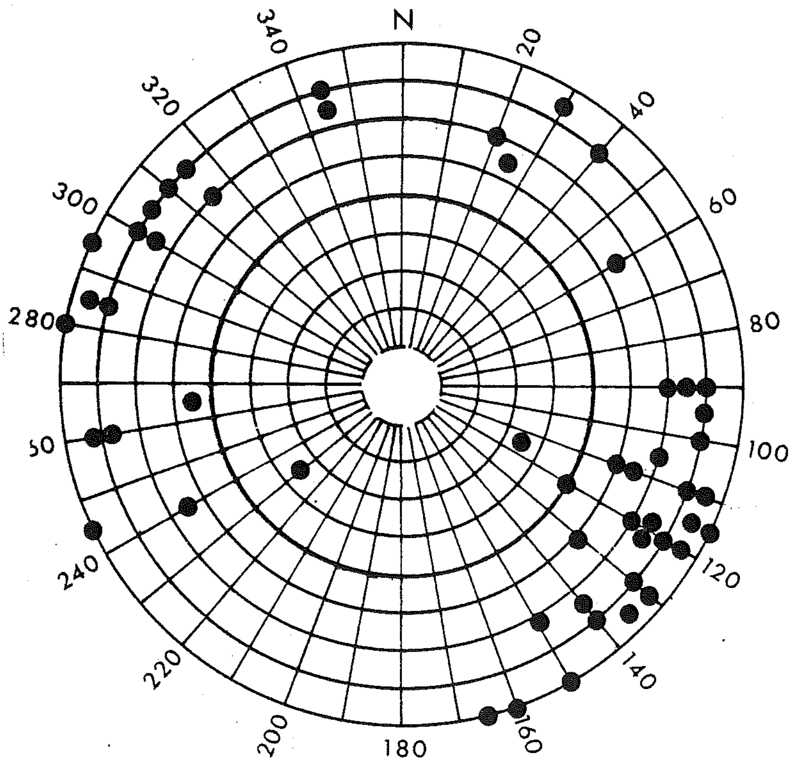
<u>Lower</u>

n = 50

Vector trend 177-357°

Significance level 99%

Figure 17. Vector data, Creeting Till.



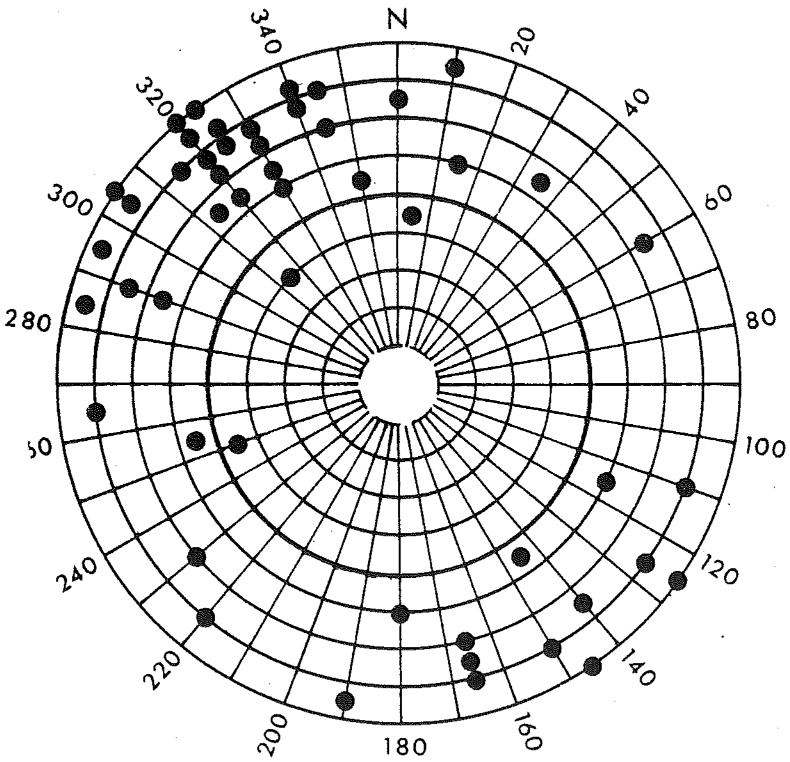
Blakenham Till

Sample 2

n = 50

Vector trend 177-297°

Significance level 99.9%



Sandy Lane Gravels

n = 50 $\bar{x}$ = 275°

Figure 18. Sandy Lane Gravels and Blakenham Till, directional data.

INGHAM TL 851713 (MRC, CAA)

Recent workings in a pit near Ingham, north of Bury St Edmunds, have exposed a sequence of iron-stained Bunter-rich sands and gravels, now formally named the Ingham Sand and Gravel. The deposits are characterised by a high proportion (generally over 40%) of pebbles of well rounded, liver-coloured quartzites, typical of pebbles from the Sherwood Sandstone Group (Bunter Pebble Bed) of the Midlands (for example, samples Ing 6 and 9 in Table 5).

Detailed examination of the sequence in Ingham pit shows that these Bunter-rich gravels are preserved in hollows in the base of the pit, and within solution pipes that have formed in the bedrock (Chalk) surface, to depths of several metres. The Ingham Sand and Gravel is overlain by later, glacial sands and gravels, often containing chalk debris (for example, samples Ing 3, 7 and 8) which are in turn overlain by a chalk-rich till. In some parts of the pit, the Bunter-rich gravels are directly overlain by this till (Figure 19), which contains Cretaceous and Jurassic erratics and is similar to the Chalky Boulder Clay seen elsewhere in the area.

Compositional analyses of the 8-16mm fractions (Table 5) show that the pebble content of the Ingham Sand and Gravel is quite different from that of the overlying glacial deposits, but is strikingly similar to the compositions of fluvial deposits formed by an early course of the River Trent in Lincolnshire.

More recently, deposits similar in composition to the Ingham Sand and Gravel have been recognised in boreholes drilled further to the west, towards Woolpit (TL 975623) and Redgrave (TM 048780) (see Figure 4 from Clarke and Auton, 1982). It seems likely that these Bunter-rich sands and gravels represent remnants of formerly more extensive fluvial deposits whose source lay either to the north (in Lincolnshire) or to the west (in Leicestershire). It is thought that they represent a separate, earlier phase of fluvial activity to that which laid down the Kesgrave Sands and Gravels in this area.

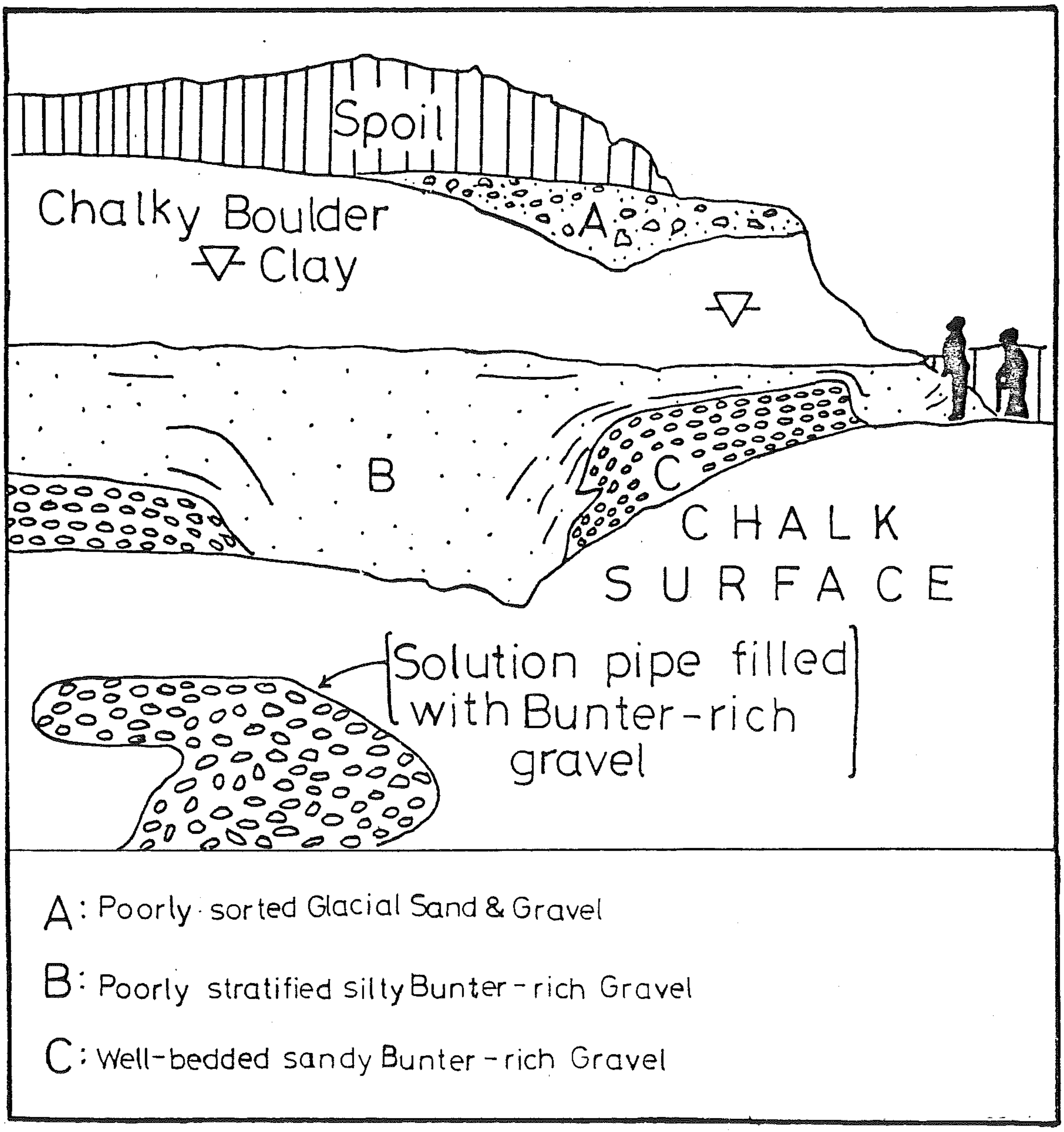


Figure 19. Sketch of the northern face of Ingham pit (summer 1981) showing the stratigraphic relationship between the Ingham Sand and Gravel and the glacial deposits.

Table 5. Composition of sands and gravels in north Suffolk.

Figure 20. Grading characteristics of the Ingham Sand and Gravel.

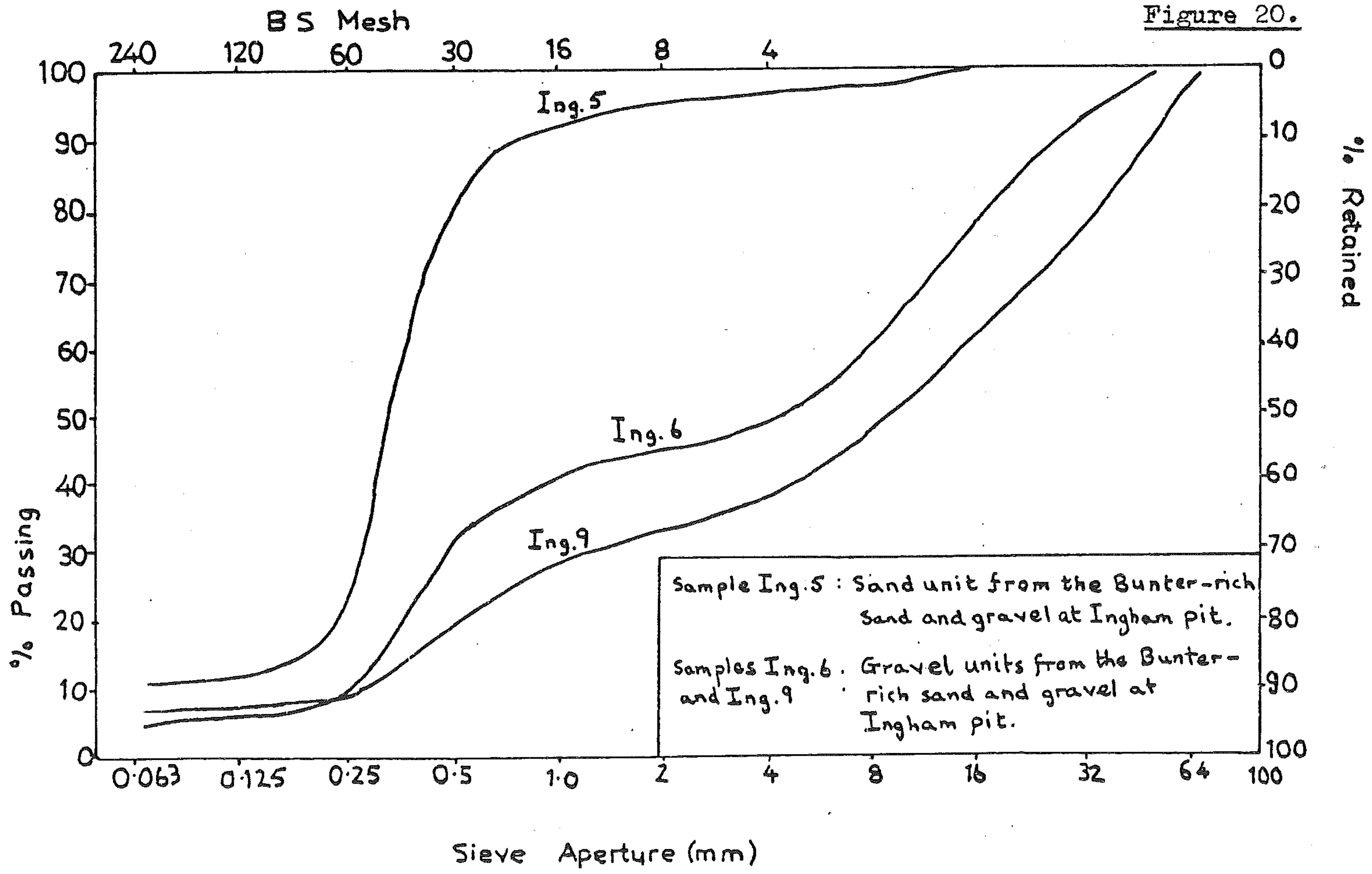
Table 5.

a) Ingham Sand and Gravel (Ingham Pit)

Percentage by weight of the +8-16 mm fraction

	Flint	Quartzite	Vein-Quartz	Chalk	Sst	Others
Ing 6	14	47	22	-	12	5
Ing 9	18	46	25	-	2	9
Esp 1	35	48	15	-	-	2
Esp 3	27	45	23	-	1	4
b) Glacial Sand and Gravel (Ingham Pit)						
Ing 3	60	6	4	24	4	2
Ing 8	48	7	3	39	3	trace
Ing 7	52	2	3	38	3	2
c) Kesgrave Sands and Gravels						
Woolpit area (n = 9)	57	14	26	-	-	3
Redgrave area (n = 148)	43	36	18	-	-	3

Figure 20.



HAUGHLEY PARK TL997624

The site lies on the watershed between the Gipping and Black Bourn drainage systems. An alternative name used is Woolpit Woods.

Table 6.

Sediments present	Maximum observed thickness
(Surface elevation	c76.0m O.D.)
Haughley Park Gravels	c12.0m
Blakenham Till	2.0m

The quarry floor was irregular, implying that the till surface was also, so greater thicknesses of gravel may have occurred, though these were not observed. The thickness of the till is not known as it was exposed only occasionally and because it formed the lower working limit of the quarry.

Blakenham Till

The till was very dark grey (5Y3/1). Of two macrofabric analyses carried out (Figure 21), one had a vector trend of 137-317° with a significance level greater than 95%. The second macrofabric, taken at a slightly higher level, did not have a statistically significant preferred orientation. The majority of stones, in the second case, dipped to the north and 16 of the 50 stones had dips of more than 40° which is unusual for the till of the area. The first till is typical of the Blakenham Till, being massive and having a preferred orientation in accord with the regional direction of ice movement (Perrin *et al*, 1979). The second till is thought to be disturbed.

Haughley Park Gravels

The Haughley Park Gravels (Figure 22), above the till, are matrix-supported gravels varying in size from pebbles to boulders (Gms facies). Horizontally bedded and tabular cross-bedded sands (Sh and Sp facies) are subordinate. Palaeocurrent measurements show a mean flow direction to the south-east (115.5°, n = 25). The whole facies assemblage accords with Miall's (1977, 1978) Scott type of profile from a proximal braided river. Particle size analyses are in keeping with such an interpretation (Section I, Figure 13).

In the lower part of the gravels, of the lithologies of the 16-32mm fraction (Section I, Table 3), angular non-Tertiary flint is dominant (67%) and chalk the next important (17%). Quartz and quartzite make up only 10% of the total. The cherts lacked any examples from the Greensand but had 1% of Rhaxella chert. Non-durable lithologies, including Cretaceous and Jurassic fossils and limestones, comprised 22% of the total. The upper part of the gravels lack chalk, limestone and fossils, so the non-durable fraction drops to 1%, but the proportion of quartz and quartzite remains low (7%), Greensand chert is absent and Rhaxella chert remains at 1%, while angular non-Tertiary flint dominates (90%). The durable lithologies of both samples are essentially the same. The lack of chalk, limestone and fossils in the upper sample is attributed to decalcification rather than to any other cause such as increased distance of transport before deposition as non-calcareous non-durable clasts, such as sandstone and ironstone, are still present.

The suite of pebbles, relatively rich in non-Tertiary angular flint, chalk, limestone and fossils and Rhaxella chert, and deficient in quartz and quartzite and Greensand chert, is compatible with a derivation from the Lowestoft Till. The high proportion of non-durable lithologies suggests that deposition was in an ice proximal environment.

Straw (Section I, page 38) specifically mentions these gravels, at Woolpit Woods, and suggests that they could locally mark the Wolstonian limit. The stone counts from Haughley Park/Woolpit Woods are not significantly different from those of the Haughley Park Gravels 12 and 14 km further south at Great and Little Blakenham (Section I, Table 3). Thus the stone count evidence and their position above the Lowestoft Till suggests that it is correct to correlate these gravels. Straw, however, argues that if Wolstonian ice followed a similar track to that of the Anglian ice, the two till sheets, and by implication, their associated outwash, would have similar lithologies.

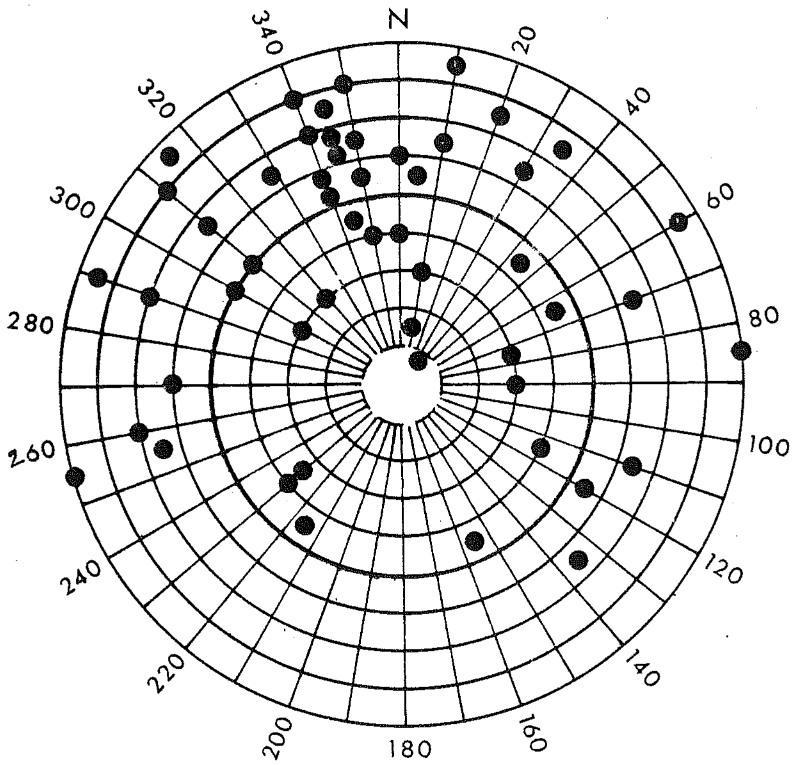
THE WOLSTONIAN LIMIT IN THREE DIMENSIONS (CAA, MRC)

Boreholes drilled between Bury St Edmunds and Diss have provided new information on the nature and distribution of Glacial Sand and Gravel in an area which corresponds with the western margin of the Wolstonian ice-limit proposed by Straw (1979a, b). Straw's assertion is based on the assumption that many of the 'high level' spreads of sand and gravel in this area represent glacial outwash lying within an ice-marginal zone. However, much of the Glacial Sand and Gravel (shown on the 1:625,000 Quaternary map of the United Kingdom) in the Bury St Edmunds - Diss area (notably those on sheet TL 96 around the village of Woolpit) have been recently remapped and subsequently recognised as thin spreads of coversand or as outcrops of Crag (see inset map, Figure 23). In many cases this remapping has been verified by the IMAU borehole surveys in the area. These surveys indicate that the patches of Glacial Sand and Gravel (shown by the horizontal line ornament on the inset map) are less extensive than shown previously, a factor which has an important bearing on the position of any presumed ice-limit.

Additional information about the vertical and lateral disposition of these sands and gravels is provided by the IMAU boreholes which have been used to draw a series of cross-sections through the Boulder Clay plateau (Figure 23). These show that, in general, the Glacial Sand and Gravel occurs as discrete beds within the Chalky Boulder Clay sequence. Individual surface occurrences of Glacial Sand and Gravel can be traced laterally beneath the Boulder Clay, with no evidence of glacitectonic disturbance. Thus few of the outcrops can be thought of as remnants of marginal morainic or outwash material corresponding to the limit of the Wolstonian ice advance.

It is, therefore, suggested that a simpler explanation of the distribution of Glacial Sand and Gravel, shown by the boreholes drilled in the area, is that it forms a series of lenticular masses within the glacial drift sequence. Some of these gravelly beds have been exposed on the plateau surface by later denudation, whilst others, which occur within and beneath the Boulder Clay, crop out on the sides of the present-day river valleys.

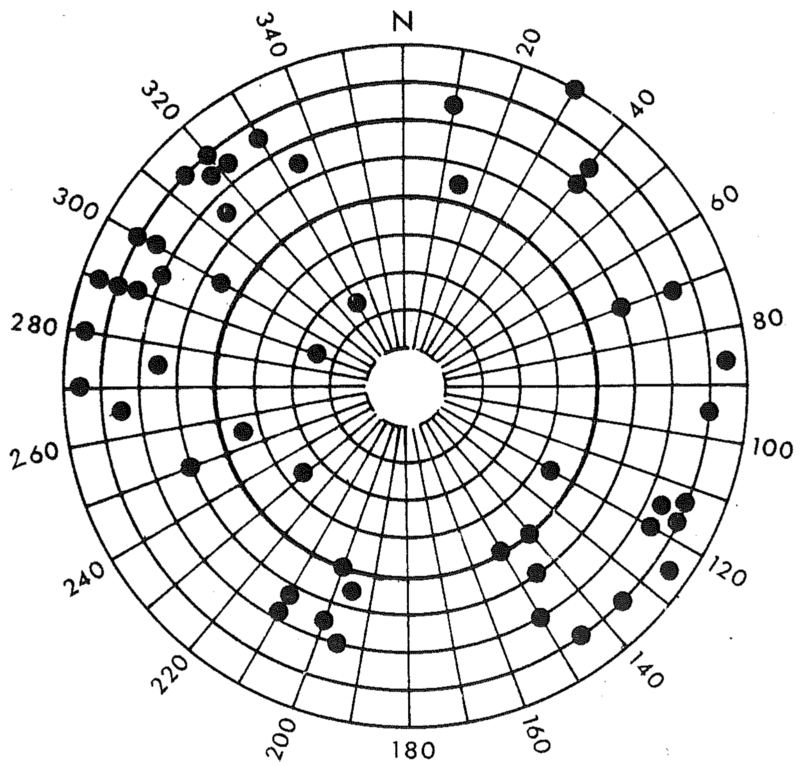
Thus, the results of recent borehole drilling give little geological evidence to support the concept of an ice marginal zone in the area between Bury St Edmunds and Diss.



1.

n = 50

Significance level N.S.



2.

n = 50

Vector trend 137-317°

Significance level 95%

Figure 21. Haughley Park, Blakenham Till, vector data.

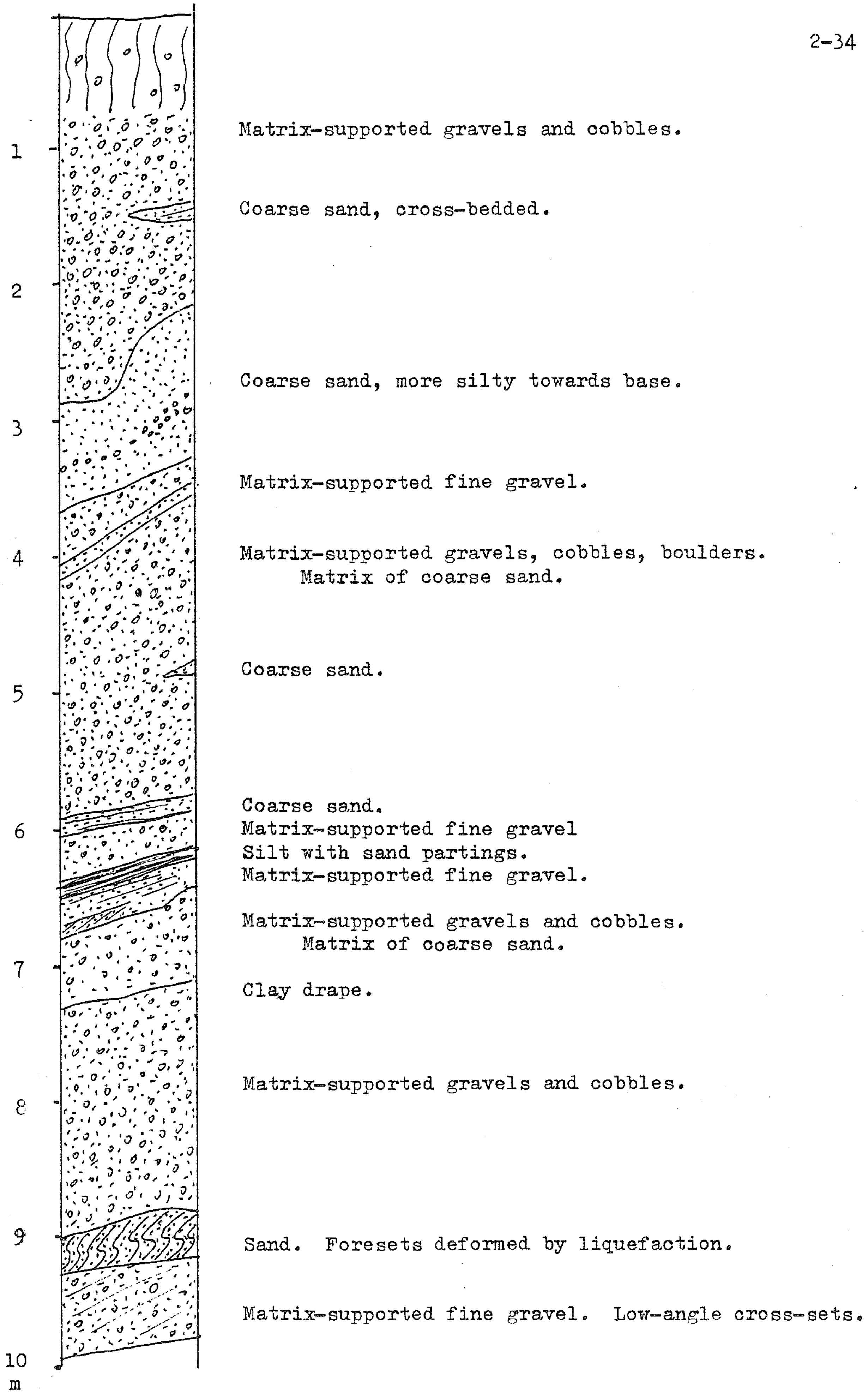


Figure 22. Haughley Park, Haughley Park Gravels, section.

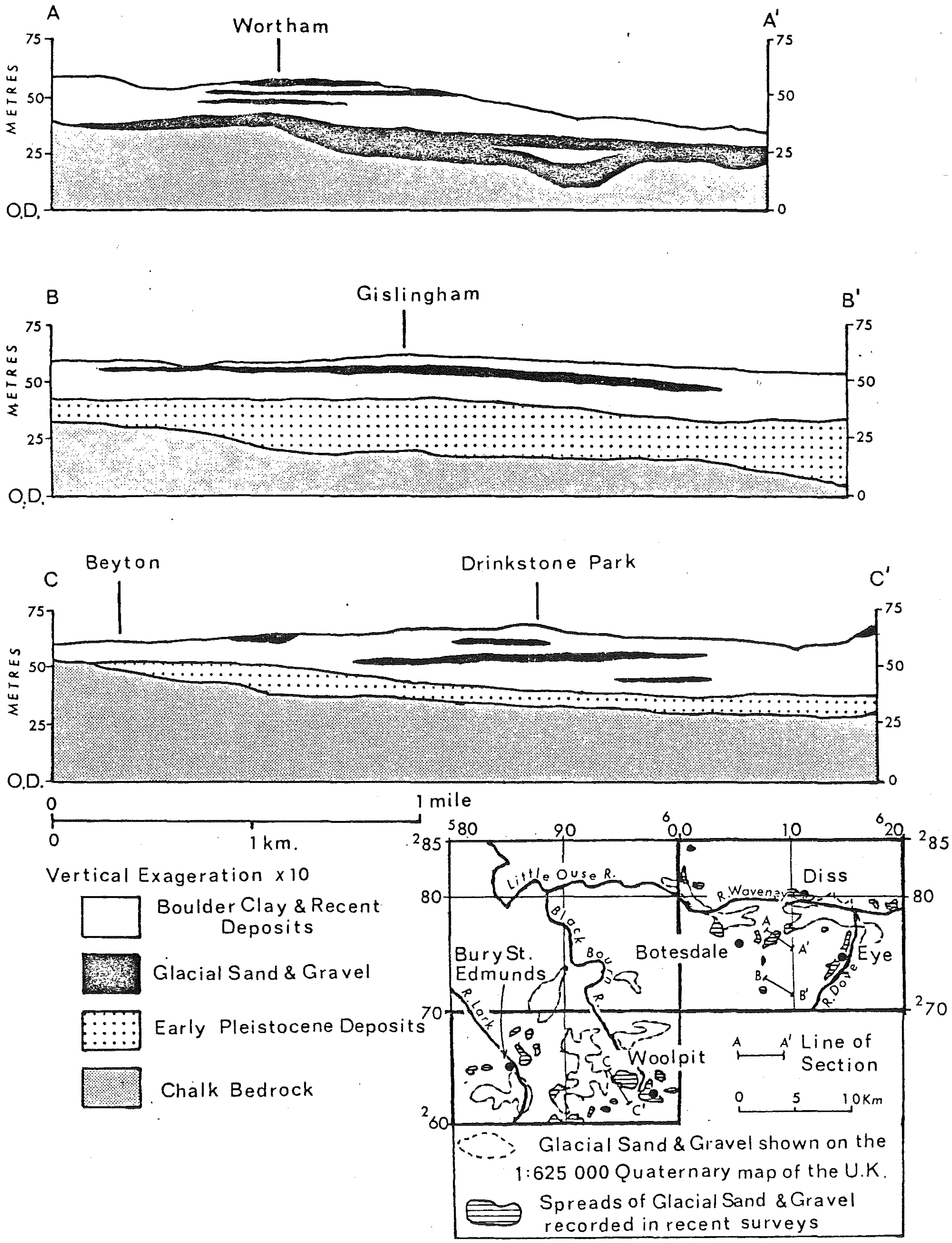


Figure 23. Cross-sections, based on recent borehole information, showing the stratigraphic relationship of the glacial deposits between the Lark and Waveney Valleys.

REFERENCES

Additional to those in Section I

Allen, J.R.L. (1970), Physical processes of sedimentation. Allen and Unwin.

Baden-Powell, D.F.W. (1948), The chalky boulder clays of Norfolk and Suffolk. Geol. Mag., 85, 279-296.

Banham, P.H. (1975), Glacitectonic structures: a general discussion with particular reference to the contorted drift of Norfolk. In: Ice Ages: Ancient and Modern, Ed. Wright, A.E. and Moseley, F., Seel House Press, Liverpool.

Reading, H.G., Ed. (1978), Sedimentary environments and facies. Blackwell Sci. Pubs.

Reineck, H-E. and Singh, I.B. (1975), Depositional sedimentary Environments. Springer-Verlag, Berlin.

Rose, J. (1974), Small scale variability of some sedimentary properties of lodgement and slumped till. Proc. Geol. Assoc., 85, 239-255.

QUATERNARY RESEARCH ASSOCIATION

THE WAVENEY VALLEY — Sunday, 9 May 1982

Section 3

Contributors :

P. COXON

M.R. CLARKE

A. HORTON

C.W. WILCOX

Edited P. Allen

1. INTRODUCTION

The Waveney Valley forms a distinct geomorphological feature running through the eastern part of central East Anglia. The valley cuts through the till plateau that rests on the Crag to the east and the Chalk to the west of the region and the head of the valley links with that of the Little Ouse River at Lopham (TM 039790) (Figure 1).

The Waveney flows north-eastwards for some 89km to Great Yarmouth where, in conjunction with the River Yare, it meets the sea. The present day channel has been much altered by drainage projects.

The present day valley is incised into the till surface of the surrounding landscape by between 20 metres near the source and 30-35 metres around Bungay. The till is the equivalent of the Lowestoft Till.

Since the original surveys by Bennett (1884) and Whitaker and Dalton (1887) the valley has attracted some attention on account of its structure, till deposits and interglacial deposits as well as preliminary work on terraces.

The author worked along 51km of the river valley between Lopham and Beccles (TM 425905) and the area adjacent to the valley and its tributaries was also included. The work was carried out between 1976-1979 (Coxon, 1979). The study concentrated on the physical characteristics of the deposits and the geomorphological interrelationships between deposits of different ages. The main object of this approach has been the correlation of the datable interglacial deposits with the terrace sequence and other glacial deposits in the valley, hence clarifying the succession of deposits and the major periods of landscape change.

It is hoped that we can visit some or all of the sites outlined below. Unfortunately some of the sites were studied using borehole evidence and are worth noting only to visualize geomorphic implications whilst others, especially the sand and gravel pits, have altered considerably since I visited them.

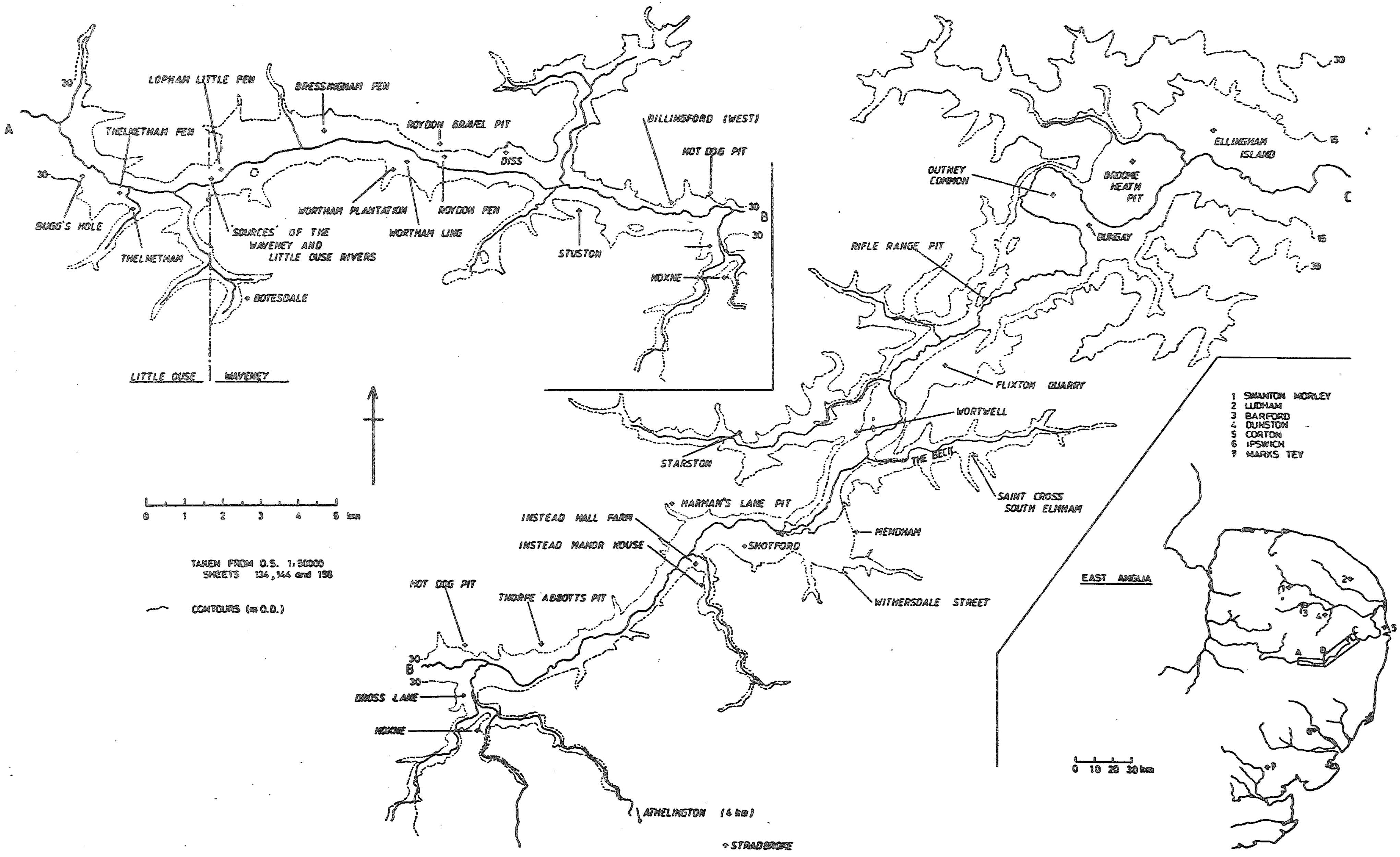


Figure 1. The Waveney Valley. Location Map.

2. THE TERRACES OF THE RIVER WAVENEY

The mapping of terrace remnants within the valley was subject to several difficulties not the least of which was the lack of adequate exposure.

Where possible sections were logged and samples taken for pebble count analysis. This approach was taken in order to attempt a lithostratigraphic correlation of the remnants. Where sections were not available the terrace surfaces were levelled and a morphostratigraphic correlation produced (with attendant problems as discussed by a number of authors, e.g. Gibbard, 1981).

The net result was the production of a diagram showing the long profiles of the major terrace remnants. This diagram (Figure 2) as well as showing the major terrace remnants also marks the relative location of the biostratigraphically important sites.

As the diagram shows, there are four main terraces or gravel spreads present in the area :

4. High Level Gravels
3. Homersfield Terrace
2. Broome Terrace
1. Waveney Floodplain.

a. THE HOMERSFIELD TERRACE

i. Introduction

The quarry at Flixton provides the best sections in the terrace remnants assigned to the Homersfield Terrace and was chosen as the 'type locality' for that particular terrace.

The Homersfield Terrace is the highest recognizable terrace within the main Waveney Valley and was recognised by Sparks and West in 1968 who traced the remnants of this outwash terrace from Wortwell (TM 243847) to Bungay (TM 335898).

To the south-west of Homersfield Church (TM 28568540), there are several other morphological expressions of Homersfield Terrace remnants (these are upstream of the Flixton Quarry site). These remnants are between 5-7 metres above the Waveney Floodplain and they grade into the Homersfield Terrace as can be seen in Figure 2.

The Flixton Quarry sections are within the portion of the terrace labelled 'Flixton' on Figure 2 and the steep north east gradient of the terrace at this point is obvious. At Homersfield Church the proximal end of the terrace remnant is found at 21.2m O.D. and here the terrace falls steeply with a gradient of greater than 2m km^{-1}. The terrace along this section reaches a width of 800m.

Downstream of Flixton the terrace remnants level out to a gradient of around 0.5 km^{-1}.

ii. Flixton Quarry TM 293862 Figure 3

Investigations pre-1979 (P.C.)

To aid description and short range correlation informal lithostratigraphic units were defined within the terrace deposits.

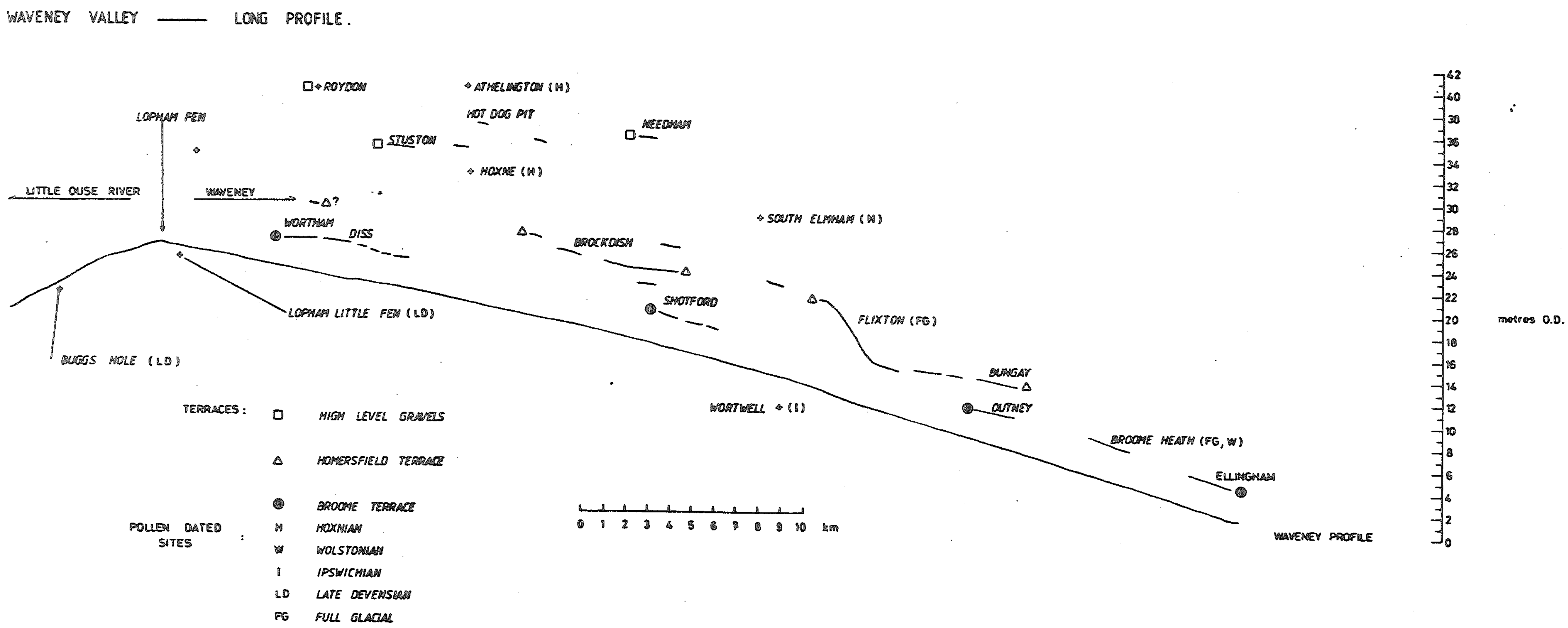


Figure 2. Terraces of the Waveney Valley.

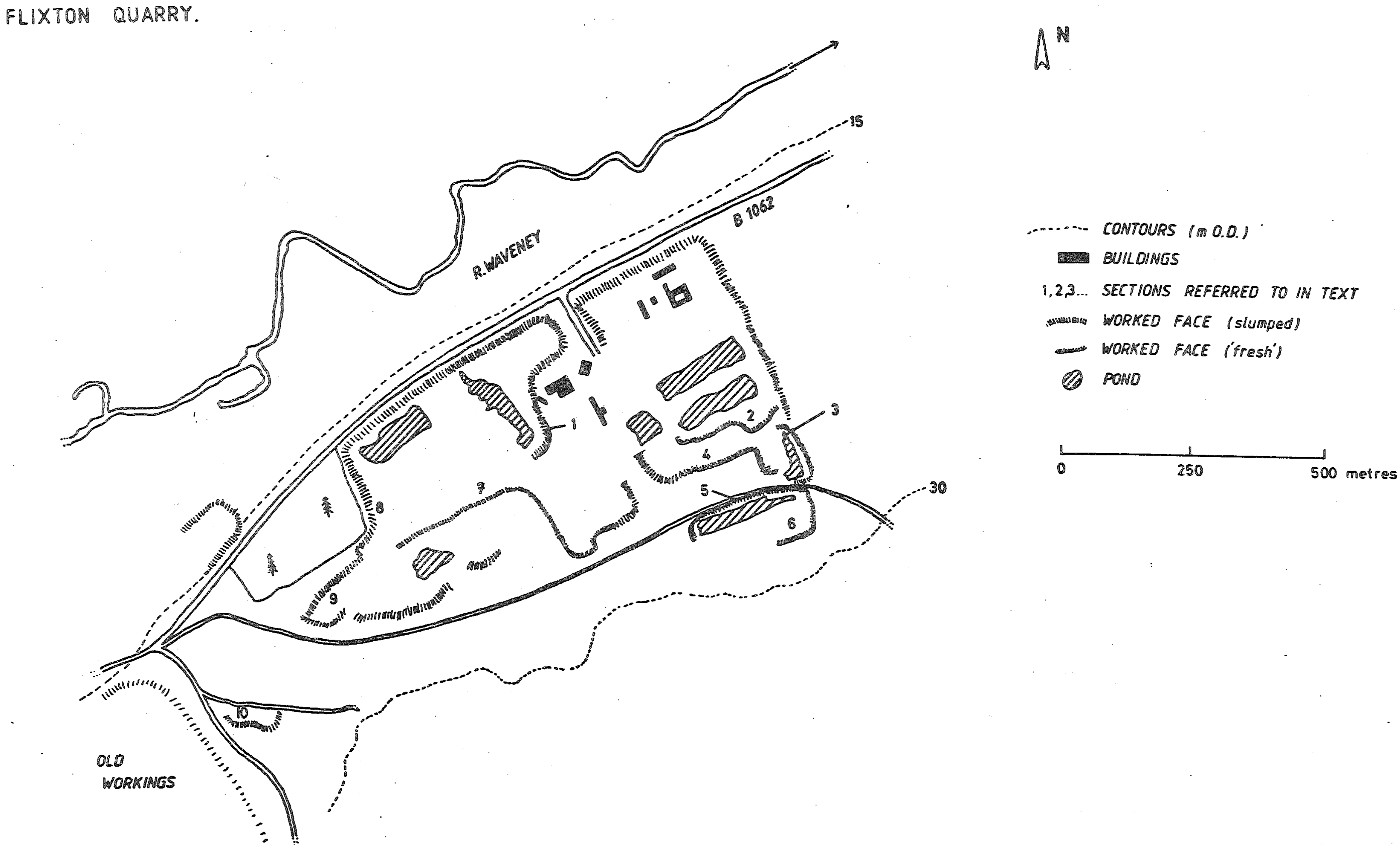


Figure 3. Flixton Quarry.

In Flixton Quarry these units were as follows :

4. Upper sands and gravels

3. Flixton sands and erosional inclusions

2. Lower sands and gravels

1. Chalky till.

Since this original description further interesting sections have been revealed in the central portion of the pit (ca. TM 296862) revealing a number of facies previously unobserved. (West, personal communication; Horton, personal communication).

The original work, using the units outlined above, described the following features of the various units :

1. Chalky till.

Found at base in central section of the quarry. Blue-grey chalky clay, similar to the Lowestoft Till of the area.

2. Lower Sands and Gravels.

Found only in central parts of the quarry. This facies is the one that would require re-examining in the light of new evidence.

3. Flixton sands and erosional inclusions.

The sands are found in the eastern (TM 299862) and central parts of the pit.

The sand is well-sorted and proved to be a complex of different bedding types including climbing ripples, planar cross-bedding and trough cross-bedding. The major portion of the deposits include planar laminated beds of sand with clay horizons which have been cut into erosionally by large channel fill cross-beds up to 1.5.-2.0 metres deep. (Figure 4). The sands contained interesting water escape structures.

The sands appear to be characteristic of lower energy deposition, perhaps a slow meandering channel complex with clay horizons indicating quiet water depositon.

The erosional inclusions are found cut into the Flixton sands and they comprise of :

a. Channel fill deposits interdigitated with flow till. The flow till is composed of lenses and lobes of chalky clay (Section 2, Figure 3).

b. Ice — collapse structures. Including oversteepened beds and an unsorted heterogenous fill. (Section 3, Figure3).

c. Mass transport diamicton including large flint cobbles in a matrix of sand and small pebbles. (Section 1, Figure 3).

4. Upper sands and gravels.

These deposits are found throughout the pit and have similar characteristics at each exposure. The sands and gravels are poorly sorted heterogenous sediments. They show a variety of facies and appear to have been formed during periods of rapid lateral channel migration and during a wide variation of energy conditions.

The deposits are characteristic of a braided stream system in which there is rapid and continuous shifting of sediment

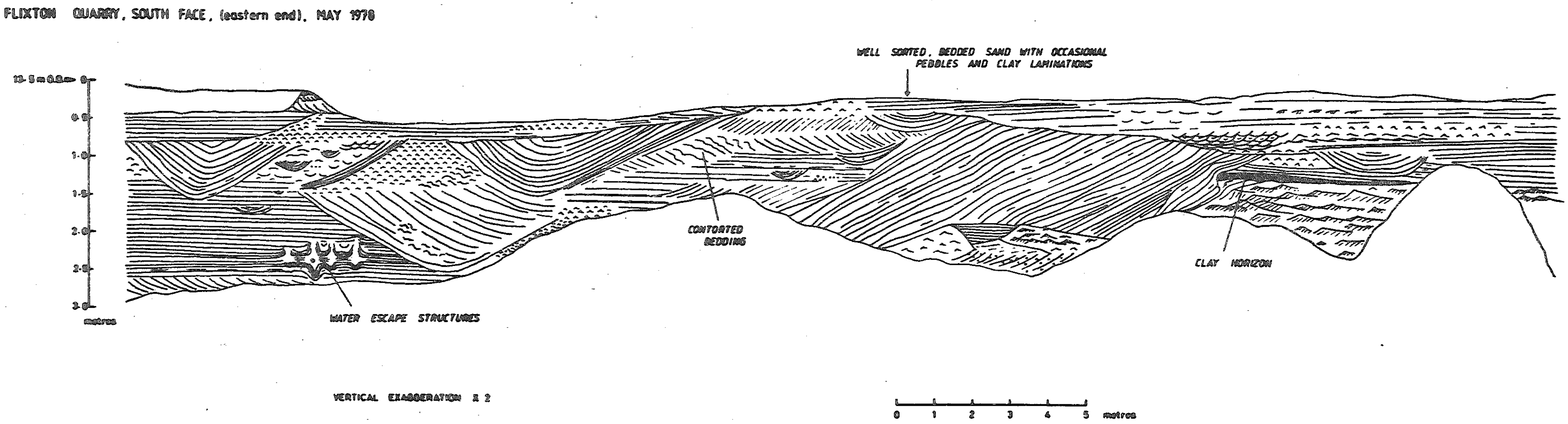


Figure 4. Fixton Quarry, South Face.

deposition and channel position as described by Doeglas (1962), Williams and Rust (1969) and Rust (1972) among others.

The braided deposits of the upper sands and gravels contain many slump structures, possibly due to loading or to melting out of ice blocks, as well as ice wedge casts, both contemporaneous with deposition and post-depositional.

Pebble Counts

(Samples estimated to contain over 300 pebbles in the 8-32mm size range).

Samples were taken from the Flixton Quarry as well as from other sites correlated with the Homersfield Terrace on morphological grounds.

The abbreviated results are shown on Table 1, below. The full results are given in Table 6 (Appendix).

The similarity of these samples was tested statistically and the results of one test are shown in Figure 5. The sample numbers are as in Table 6. The symbols refer to the subjective classification of the terrace remnants on morphostratigraphic grounds.

The groupings of samples appear to contain high % of flint, samples from Flixton Quarry containing an average value of 86% flint, 7% quartz, 4% quartzite and 3% erratic pebbles.

Samples 2 and 10 (from Flixton Quarry), and 43 (from a correlated pit) were grouped elsewhere. This separation appears due to a higher % of quartz and quartzite. In the light of subsequent exposures this material has probably been removed from quartz-quartzite rich gravels lower in the sequence.

Samples from morphostratigraphically correlated terrace remnants at Shotford (TM 244814, Sample 21) and Bungay (TM 335898, Sample 28) were grouped statistically with the Homersfield Terrace.

Palaeozoology and palaeobotany. Flixton Quarry.

Mammal remains, (Funnell, 1955) :

Elephas primigenius

Diceros antiquitatus

Megaceros giganteus

Bos primigenius.

Stuart (personal communication) studied further bones held by Norwich Castle Museum (labelled Homersfield Gravel Pit) :

Mammuthus primigenius (mammoth). 12 molars, 2 tusk fragments and bits of limb bones.

Coelodonta antiquitatis (woolly rhinoceros). 2 molars and a fragment of humerus.

Equus caballus (horse). metapodial and tibia (both fragments).

Table 1. Pebble counts, Homersfield Terrace.

Sampling site reference number	Location	Flint	Quartz	Quartzite	Chalk	Others
		(percentage total stones counted)				
1	FQ/LSG/E	96	1	2	0	1
2	FQ/USG/E	81	10	4	0	5
3	FQ/USG/E	85	7	4	+	4
4	FQ/USG/C	88	7	4	0	1
5	FQ/USG/W	85	7	4	+	4
6	FQ/USG/C	84	8	4	0	4
7	FQ/USG/W	85	7	4	+	4
8	FQ/USG/W	87	8	3	0	2
9	FQ/USG/W	94	1	3	0	2
10	FQ/USG/W	76	12	11	0	2
11	FQ/USG/E	88	6	3	0	3
12	FQ/USG/E	85	7	4	0	4
21	Shotford (upper terrace)	85	8	4	0	3
28	Bungay (upper gravels)	88	3	4	0	5
43	Rifle Range Pit	76	13	7	0	8

FQ = Flixton Quarry

USG = Upper sand and gravel

LSG = Lower sand and gravel

E = Eastern end of Quarry

C = Central part of Quarry

W = Western end of Quarry

Pebble Count Data —— Dendrogram for Minimum Variance Clustering.

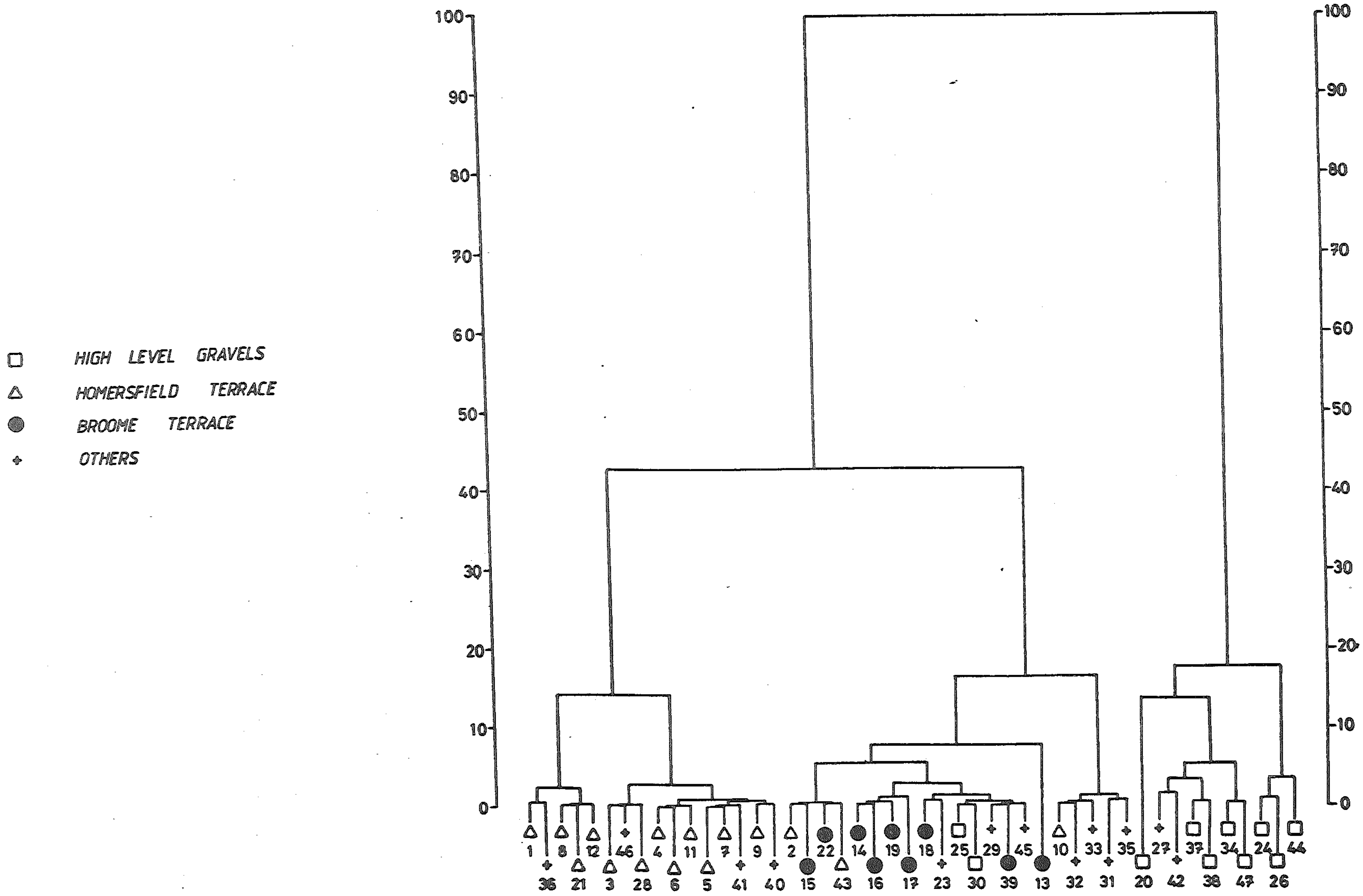


Figure 5. Dendrogram of pebble counts, Homersfield Terrace.

Rangifer tarandus (reindeer). antler (basal part)

Bison sp. or *Bos* sp. (bison or aurochs). metapodial fragments, part of horn core, and a fragment of tibia.

Palaeobotany :

The author sampled a variety of clay and silt facies especially within the central area of the quarry but failed to find plant fossils. In 1980 and 1981 samples sent by Professor R.G. West and by the I.G.S. have also proved to be barren. However, a sample taken by Funnell in 1954 (and found in a basement in Cambridge!) was found to contain both micro and macro-fossil remains. The pollen assemblage was briefly as follows :

Pinus	10%
Picea	3%
Betula	11%
Salix	3%
Gramineae	22%
Cyperaceae	24%
Caryophyllaceae	17%
Others	10%

Summary

The Homersfield Terrace was produced during a cold period and can be identified as a series of remnants that grade into one another.

The form of the terrace with its steep central section and high western and lower eastern parts suggests that during its formation conditions controlling aggradation were varied along the length of the terrace. The proximity of ice within the valley itself could explain such a steeper central portion with the ice providing a greater sediment load and hence a steeper gradient. Supporting evidence for ice proximity comes from the terrace sediments, flow tills and ice collapse structures.

Investigations post-1979 (M.R.C., A.H., C.J.W.)

As part of the recent remapping of part of the Waveney valley, IGS staff have been able to observe a number of new sections that have become available during the recent workings of the gravels. Of particular importance has been the recognition of what appears to be an organic silt/clay unit within the gravel sequence (Figure 6). This clay unit, which is up to 2.5m thick, is dark grey in colour, becoming orange-brown at its contact with the adjacent sandy beds. Recent palynological examination of the clay has yielded somewhat disappointing results (Coxon, pers. comm.), as pollen is almost entirely absent.

However, the stratigraphic position of the clay has shown itself to be very significant. Pebble-count studies (Table 2) show that the clay separates two quite distinct gravel facies. The lower gravel unit, which lies beneath the clay, is up to 3m in thickness and is characterised by a high proportion of well-rounded white quartzite pebbles, similar to those found in the Kesgrave Sands and Gravels.

The upper gravel unit, lying above the clay, contains appreciably less white quartzite and proportionately larger amounts of angular and subangular flint.

These results show that the lower-most gravel, which overlies green Crag Sands (seen in the base of the pit) has obvious affinities with, and may be contemoraneous with, the quartzite-rich deposits of Middle to Lower Pleistocene age, recognised by Rose and Allen (1977) and Hey (1980) as the Kesgrave Sands and Gravels. The silt/clay unit probably represents a much later cold-phase (glacial) infill, although it is not known to which event it relates. The upper gravel unit is considerably younger than the other deposits and is similar in composition to the river terrace sands and gravels seen elsewhere in the area. Thus the base of the Homersfield Terrace lies at the base of the upper gravel unit, that is, at about +12m OD. It is this altitudinal level which should be used for correlation with the other terrace deposits found in the Waveney Valley.

Table 2.

THE COMPOSITION OF THE SANDS AND GRAVELS IN FLIXTON PIT

a) Lower Gravel unit (?Kesgrave Sands and Gravels)

Percentage by weight of the +8-16 mm fraction

	Flint	Quartzite	Vein-Quartz	Chalk	Sst	Others
Ton 1	59	31	9	-	-	1
Ton 2	60	35	5	-	-	trace
Ton 3	47	45	8	-	-	trace
Ton 6	53	33	11	-	-	3

b) Upper Gravel unit (Homersfield Terrace)

Ton 7	81	14	5	-	-	trace
Ton 8	75	20	5	-	-	trace
Ton 9	74	15	8	1	-	2

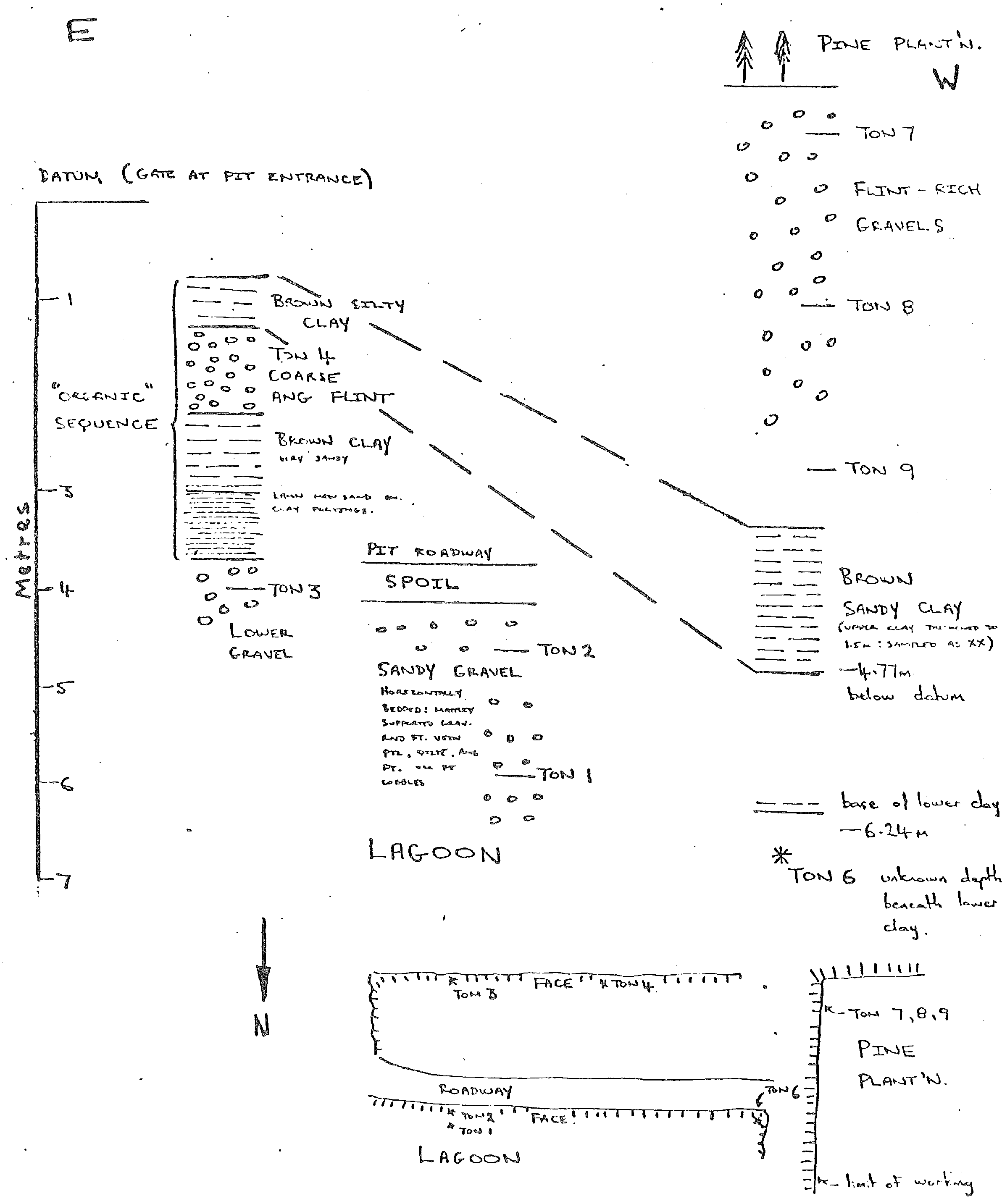


Figure 6. Flixton Quarry, schematic section. November 1981.

b. THE BROOME TERRACE

i. Introduction

The gravel pits at Broome Heath provide the type locality for the Broome Terrace, again recognised by Sparks and West (1968).

The Broome Terrace is at a lower elevation than the Homersfield Terrace (3-4m above the floodplain) and its remnants can be traced over a 45 km distance, maintaining a 0.5m.km^{-1} gradient (Figure 2).

The type locality provides the only sections in the Broome Terrace and they are rather poor. Other remnants are found at Shotford (TM 246813), Diss (TM 115797) and Wortham Ling (TM 089798).

ii. Broome Heath Pit TM 348915 Figure 7

As at other sites, the deposits at Broome Heath were grouped under unit headings. At this site they are used descriptively only.

3. Sorted, current-bedded gravel with sand (1m)
2. Coarse, poorly-sorted, bedded gravel and sand (3-4m)
1. Current-bedded sand with gravel and clay lenses (1m)

The three units at Broome Heath were not laterally consistent and all appear, with minor variations, to have been produced under braided channel conditions. Clay lenses within the lowermost deposits suggest the preservation of lower energy deposits.

The upper deposits (1) and middle deposits (2) contain both penecontemporaneous ice-wedge casts and post-depositional casts as well as having been disturbed by cryoturbation in places.

Pebble Counts

Table 3. Abbreviated results.

Table 6 (Appendix). Full results.

As with the Homersfield Terrace the similarity of these samples was tested. The results on Figure 5 show a strong internal homogeneity within samples placed within the Broome Terrace group with all of the samples being placed together.

The average content was as follows : 71% flint,
14% quartz, 10% quartzite, and others 5%

A high degree of homogeneity in such samples is to be expected where sampling is localised. Due to spatially varying percentages of lithologies the technique begins to suffer from other problems when sampling is carried out over wide areas.

The pebble counts from these samples of the lower terrace show higher % of quartz and quartzite possibly due to the reworking of these lithologies from gravels of early Pleistocene age in the valley floor.

Samples from Broome Terrace remnants at Stratford (TM 246813) and Outney Common (TM 325905) gave similar % of lithologies to the Broome Heath site.

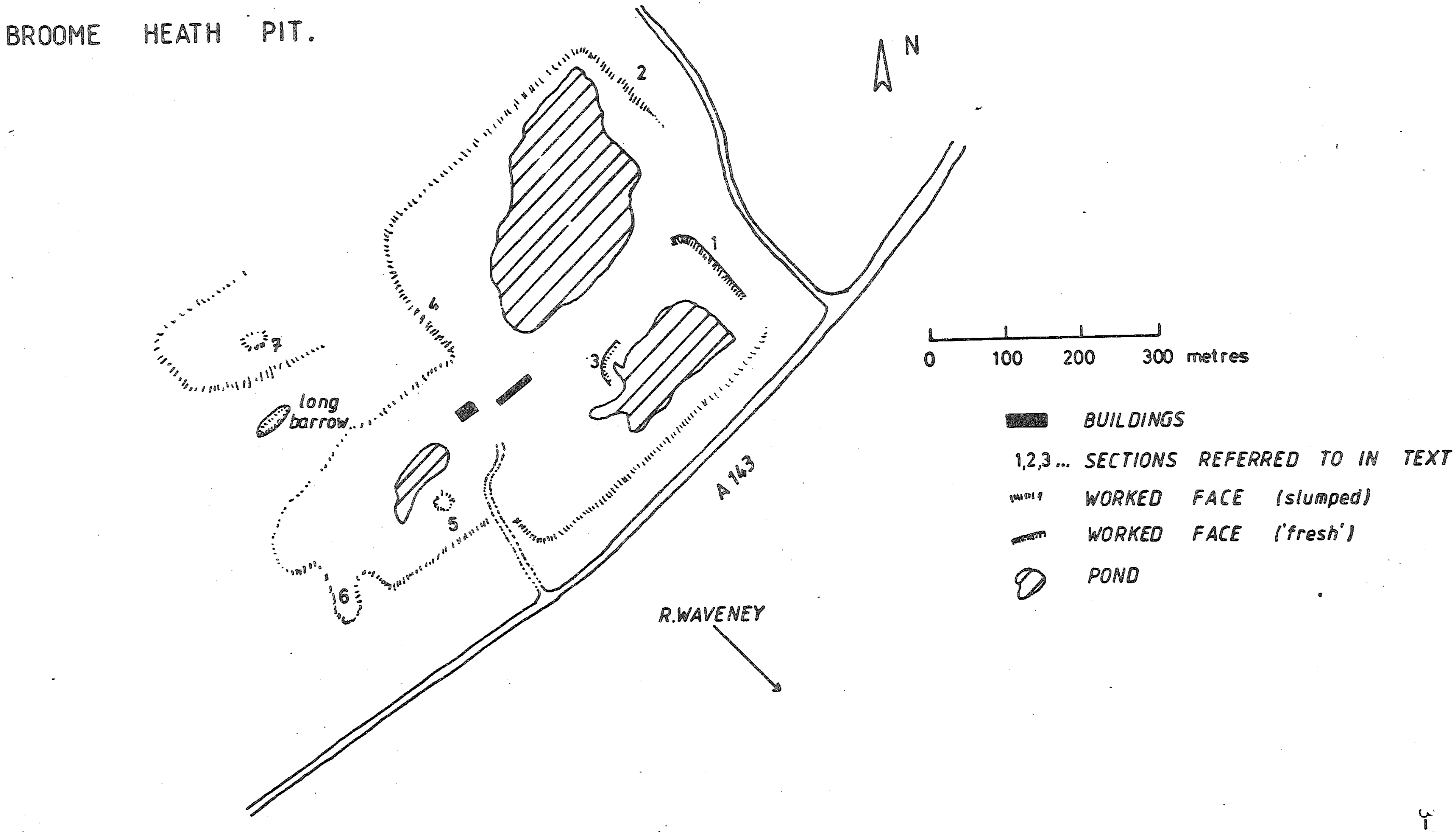


Figure 7. Broome Heath Pit.

Table 3. Pebble counts, Broome Heath Pit.

Sampling site reference number	Location	Flint	Quartz	Quartzite	Chalk	Others
		(percentage total stones counted)				
13	BHP/L/W	63	11	7	0	19
14	BHP/U/W	70	15	8	0	7
15	BHP/U/C	78	16	15	0	1
16	BHP/L/C	70	17	11	0	2
17	BHP/L/C	72	8	15	+	5
18	BHP/U/E	72	13	10	0	5
19	BHP/L/E	67	16	14	0	3
22	Shotford (TM 246813)	81	12	4	0	3
39	Outney Common (TM 325905)	72	16	8	0	4

BHP = Broome Heath Pit.

L = Lower sand with gravel.

U = Upper gravel and sand.

E = eastern end of pit.

C = central part of pit.

W = western end of pit.

Palaeozoology, palaeobotany and archaeology.

Palaeozoology.

Records of shelly crag from below water level (3m O.D. in July 1978) - R.G. West (personal communication). Mineralised antler from pit (Funnell, 1955).

Stuart (personal communication) has identified the following specimens held by Norwich Castle Museum:

Mammuthus primigenius 13 molars + fragment of pelvis

The N.C.M. Catalogue also records

Bison.

Palaeobotany.

The Broome Heath Pit has in the past yielded an arctic flora (R.G. West, personal communication, Lambert, C.A., unpubl.)

The author analysed several organic lenses in coarse unsorted gravel at Section 3 (Figure 7). The sandy, silty material suggests a small area of quiet water deposition within a braided channel.

The material (after much treatment) yielded pollen but no macro-fossil plant remains.

The pollen diagram (Figure 8) contains the results which are briefly outlined below :

a. Herb pollen predominates. Gramineae and Cyperaceae reaching 23% and 45% P respectively.

b. Tree and shrub taxa are diverse.

c. The palynomorph Type X is present at levels of up to 2% (P + type X).

Conclusions.

1. The depositional environment (with ice wedge casts truncating these organic lenses) and the presence of herbs and Betula and Pinus in moderate frequencies suggest a cold climate deposition.
2. The thermophilous taxa are reworked from older deposits.
3. The presence of Type X, restricted to the Hoxnian Interglacial (Turner, 1970; Phillips, 1976), is another strong indicator of reworking and important stratigraphically as it suggests the reworked material is of Hoxnian age.

Archaeology.

One flint flake was found in Unit 2, 3m below the surface by the author. The flake is a primary flake of black flint in a rolled condition, its unpatinated striking platform of cortex also forms over half of the reverse side. The flake has a greatest length of 9cm and width of 3.5cm (J.J. Wymer, personal communication).

Summary .

The Broome Terrace with its consistent height and gradient lacks features indicating ice proximity in contrast with the Homersfield Terrace. The deposits appear to have been produced in a braided channel system and during a cold climatic regime. The terrace also appears to have a distinctive lithological content at least along part of its length.

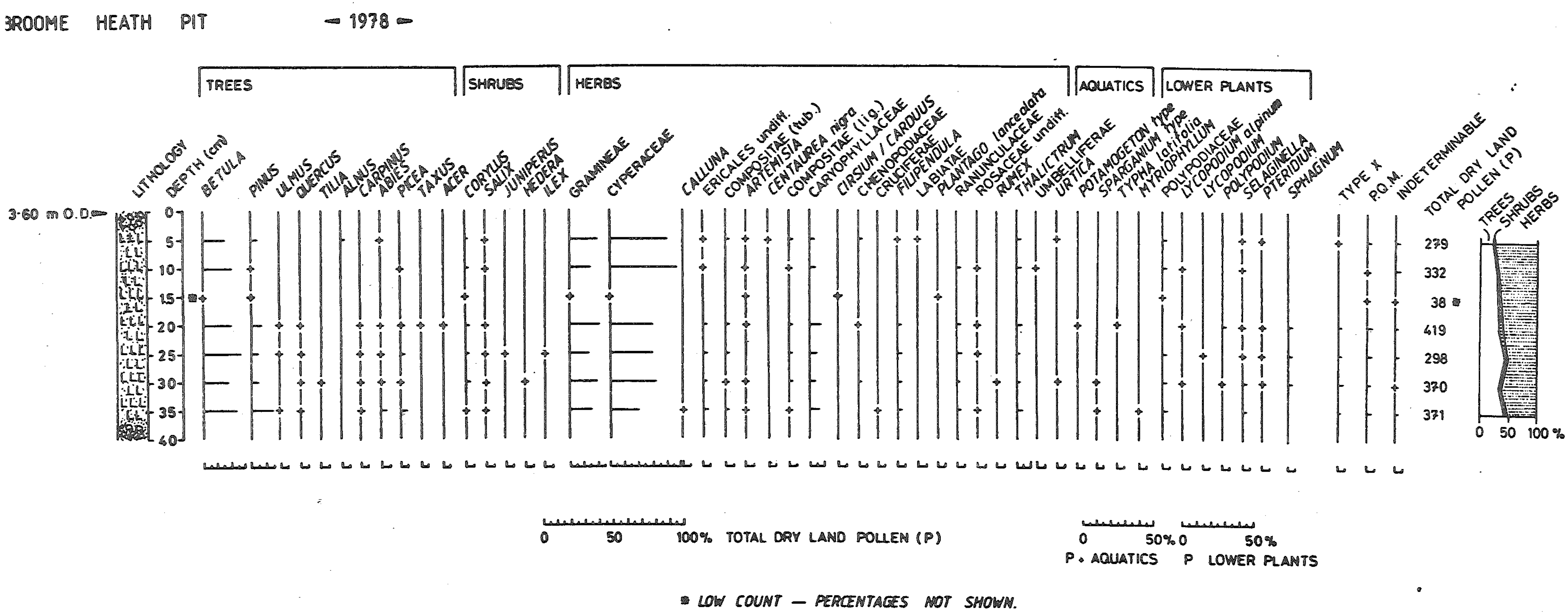


Figure 8. Pollen diagram, Broome Heath Pit.

The sites in these 2 divisions are rather poor, the former being badly exposed, the latter under water. However, sites may be available and a general introduction follows.

i. HIGH LEVEL GRAVELS

This term is firstly a relative one for the area and secondly is used to describe a variety of deposits of sand and gravel along the upper edges of the Waveney Valley and its tributaries.

The deposits cover a number of different depositional environments and were grouped to facilitate description. (Some sites in this section were referred to by Gladfelter, 1975, as "Upper Terrace".) The sands and gravels along the upper edge of the valley have been referred to as High Level Gravels because of their discontinuous, varied and sometimes uncertain nature. They also are dissimilar to the other terrace deposits in the valley.

Examples:

Roydon Gravel Pit (TM 099802)

40 metres O.D. (14 metres above floodplain).

Fluvioglacial, including frozen transport, till inclusions, ice contact.

Billingford (West) (TM 161780)

Spread of sand and gravel. No exposure. 35-40 metres O.D.

Hot Dog Pit (TM 17187886)

37 metres O.D. Poor exposure. Current bedded sands and sands and gravels with chalky till inclusions.

Harman's Lane Pit (TM 226824)

36 metres O.D. Coarse sand and gravel overlain by bedded sand and laminated clays. Fluvioglacial outwash with till inclusions followed by ponding of water within the tributary.

The pebble count analysis from the sites grouped in this division are given in Table 4.

The lower % of flint, high quartz and high chalk and erratic content has separated this group out from the other sand and gravel deposits (Figure 5).

There is however some overlap between the groups.

The High Level Gravels include a variety of deposits, many ice proximal and their diversity is probably due to their being proximal outwash deposits and ice contact features.

Table 4. Pebble counts, High Level Gravels.

Sampling site reference number	Location	Flint	Quartz	Quartzite	Chalk	Others
		(percentage	total	stones	counted)	
20	Shotford	52	6	32	2	8
24	Hot Dog Pit (upper)	57	7	6	20	10
25	Hot Dog Pit (lower)	77	12	6	+	5
26	Hot Dog Pit (lower)	53	12	4	24	7
27	Broadwash Farm*	64	27	4	0	4
34	Harman's Lane Pit	57	12	14	11	6
36	The Beck	94	1	1	0	4
37	Thorpe Abbotts (upper)	51	22	10	13	6
38	Thorpe Abbotts (lower)	51	27	7	10	5
42	Dross Lane	55	23	9	3	10
44	Roydon Gravel Pit	46	6	4	33	11
47	Harman's Lane Pit	54	12	13	11	10

*Broadwash Farm, road cutting TM 273856

ii. THE WAVENEY FLOODPLAIN

The present day river flows across its floodplain which between Lopham and Ellingham maintains an average gradient of 0.45 $m.km^{-1}$.

The morphology of the floodplain is similar to other present day river systems in the regions and the floodplain itself represents a valley fill of sand and gravel overlain by an accumulation of clay and silt. The floodplain varies in width between 0.5km and 3km.

The sand and gravel lying below the alluvium of the floodplain have yielded a cold climate fauna at Shotford (TM 246813) :

Coelodonta antiquitatis

Mammuthus primigenius

Organic remains in hollows within the floodplain sands and gravels at Lopham Little Fen (TM 042794) have been shown to be Late Devensian in age (Tallantire, 1953). Other organic remains, just within the Little Ouse Valley, west of Lopham, have also been found to be Late Devensian (Coxon, 1978, Bradshaw, Coxon, Greig and Hall, 1981).

The sands and gravels of the Waveney Floodplain had been deposited before the Late Devensian, the accumulation of alluvium is Post Glacial.

One sample taken for pebble counts taken from below water level at Shotford was found to have a similar composition to the Broome Terrace gravels. This sample (Sample 23, Figure 5) indicates reworking of material and the problems in using pebble counts for such correlations.

3. INTERGLACIAL DEPOSITS

The Waveney Valley and its tributaries contains biogenic sites of both Hoxnian and Ipswichian age and these datable sites are of considerable importance when reconstructing changes in the geomorphology of the area.

Sites and small sections may be available in these deposits.

a. SAINT CROSS SOUTH ELMHAM TM 303840 Figure 9.

The interglacial deposits are on the south side of a small tributary of the Waveney (The Beck) 2½km from the Waveney itself, 15km north east of Hoxne and 3km east of Wortwell. The site was first described by Candler, 1889, and was the subject of a preliminary investigation by West, 1961.

It was Candler, as long ago as 1889, who noted the position of the lake deposits relative to the surrounding land; "they (the interglacial deposits) now occupy a ridge or tongue of land between 2 depressions".

The lacustrine deposits at South Elmham lie in a basin some 300 metres across and the basin probably was produced as a kettle hole in the Lowestoft Till.

The location of the basin in the landscape can be seen on Figure 9 and the lithological and biostratigraphical subdivisions are shown in more detail on Figure 10. The location of this site is very similar to the location of the Hoxnian type site at Hoxne and also to the other Hoxnian site analysed by the author at Athelington. (Athelington, Figures 11 and 12, TM 222710, 9.5km from the Waveney on a tributary and 9km south of Hoxne).

All three Hoxnian sites lie on tributaries of the Waveney and are positioned out of the present tributary valleys. In the case of Athelington (Figure 11) which is near the head of the tributary stream the lake basin is within the valley, whilst Hoxne and South Elmham are alongside the present valleys.

The lacustrine deposits at South Elmham are varied and it was not possible to divide them into defined strata as at Hoxne (West, 1956).

In general terms the lower sediments are clay-muds (dark grey - olive green) which are very compact. These lacustrine deposits contain some sandy horizons probably indicating higher energy deposition within a quiet low energy depositional environment. Towards the upper levels of the interglacial deposit (Figure 10) the clay becomes mottled and contains higher levels of sand. The top of the deposit contains an erosional unconformity, with soliflucted chalky till from the surrounding slopes cut into the lake deposits.

The longest continuous pollen record from the sites came from boreholes 4 and 5. These proved the basin to be 11 metres deep and contain the pollen record shown on Figure 13.

The local pollen assemblage biozones are summarised here :

SAINT CROSS SOUTH ELMHAM. ——— PLAN / GEOLOGY.

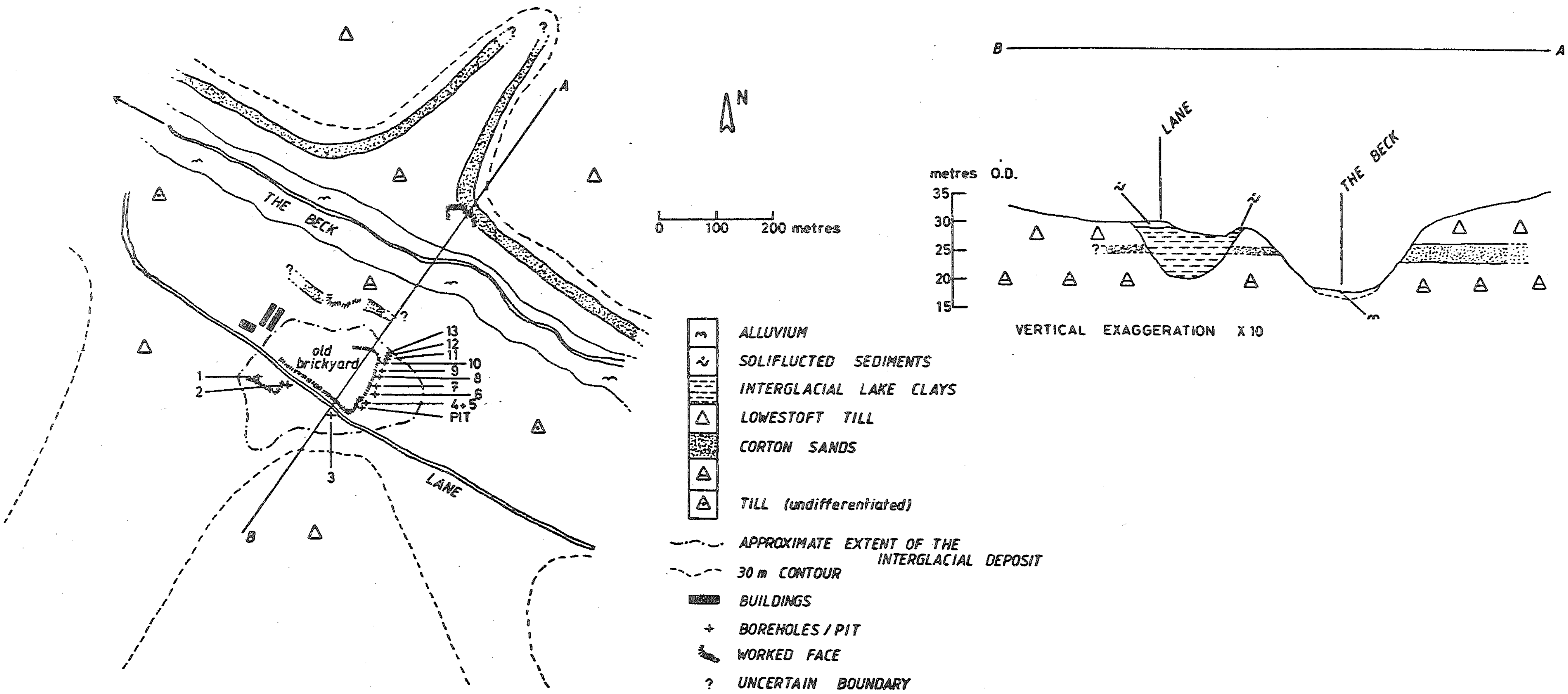


Figure 9. St. Cross South Elmham brickyard.

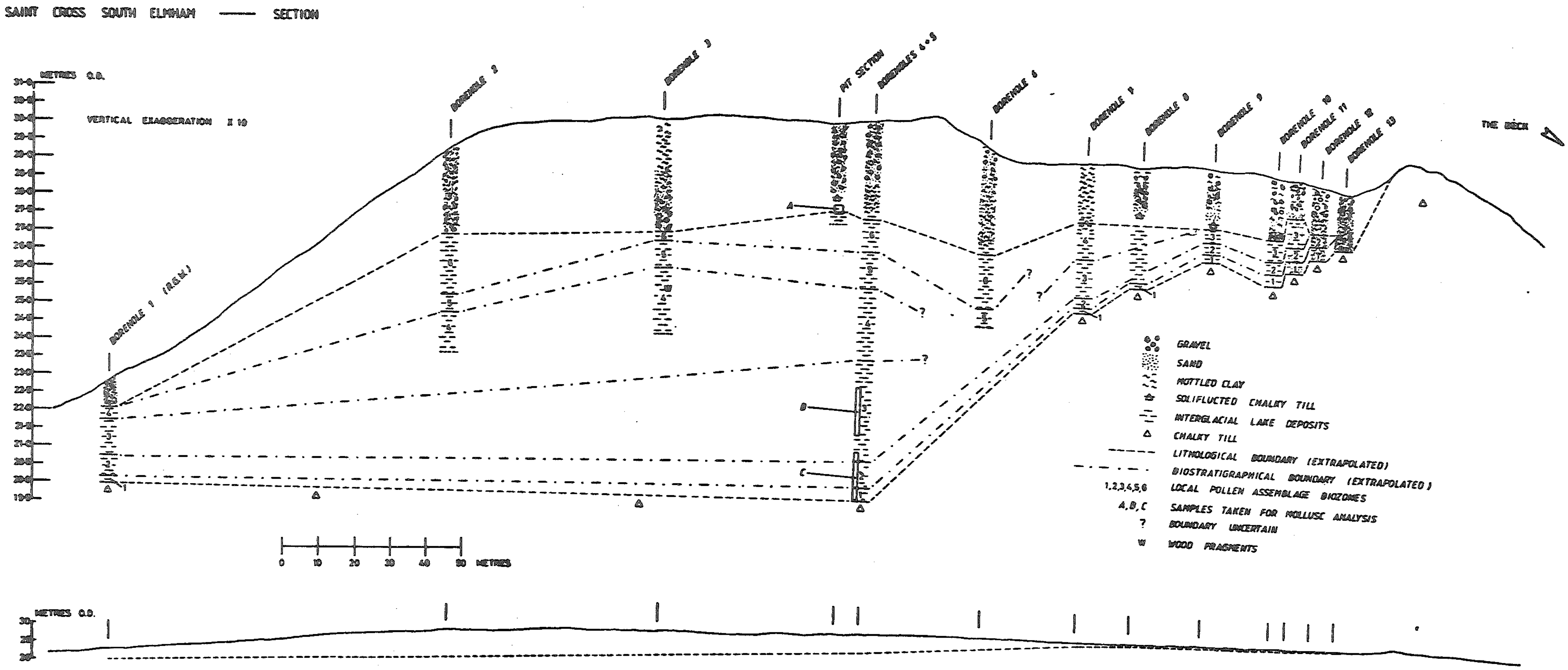


Figure 10. St. Cross South Elmham, section.

ATHELINGTON. —— PLAN / GEOLOGY.

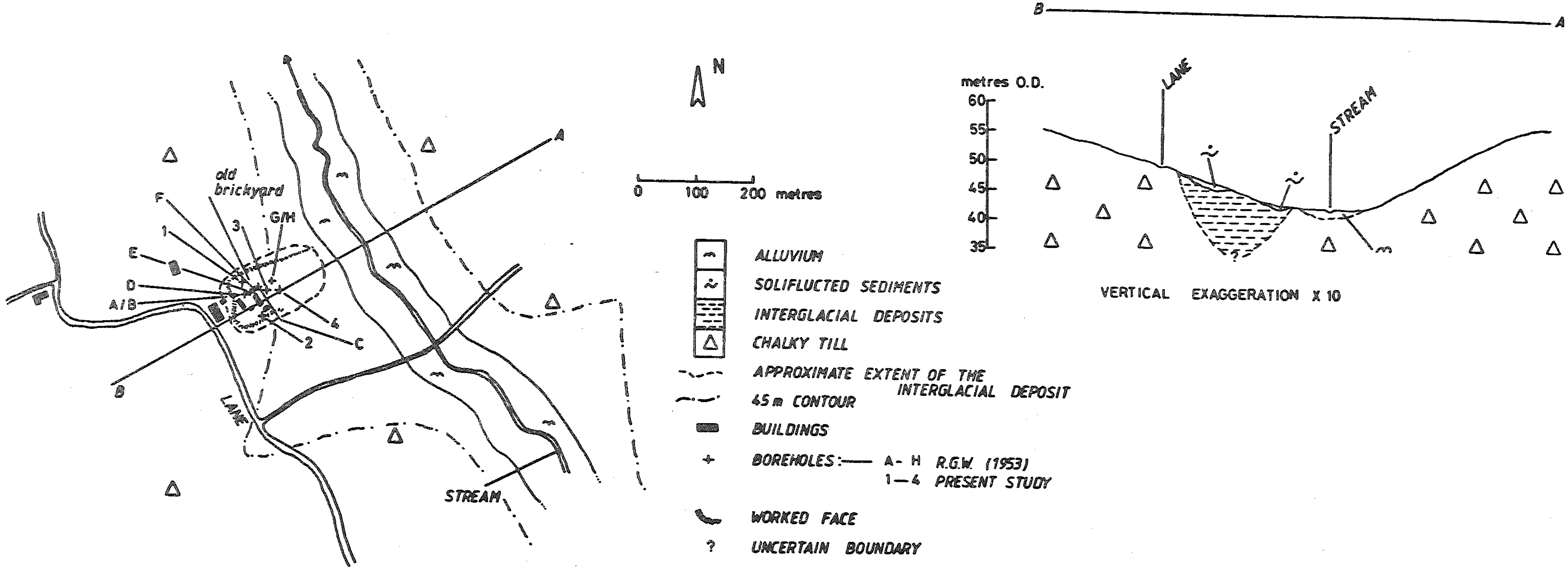


Figure 11. Athelington brickyard.

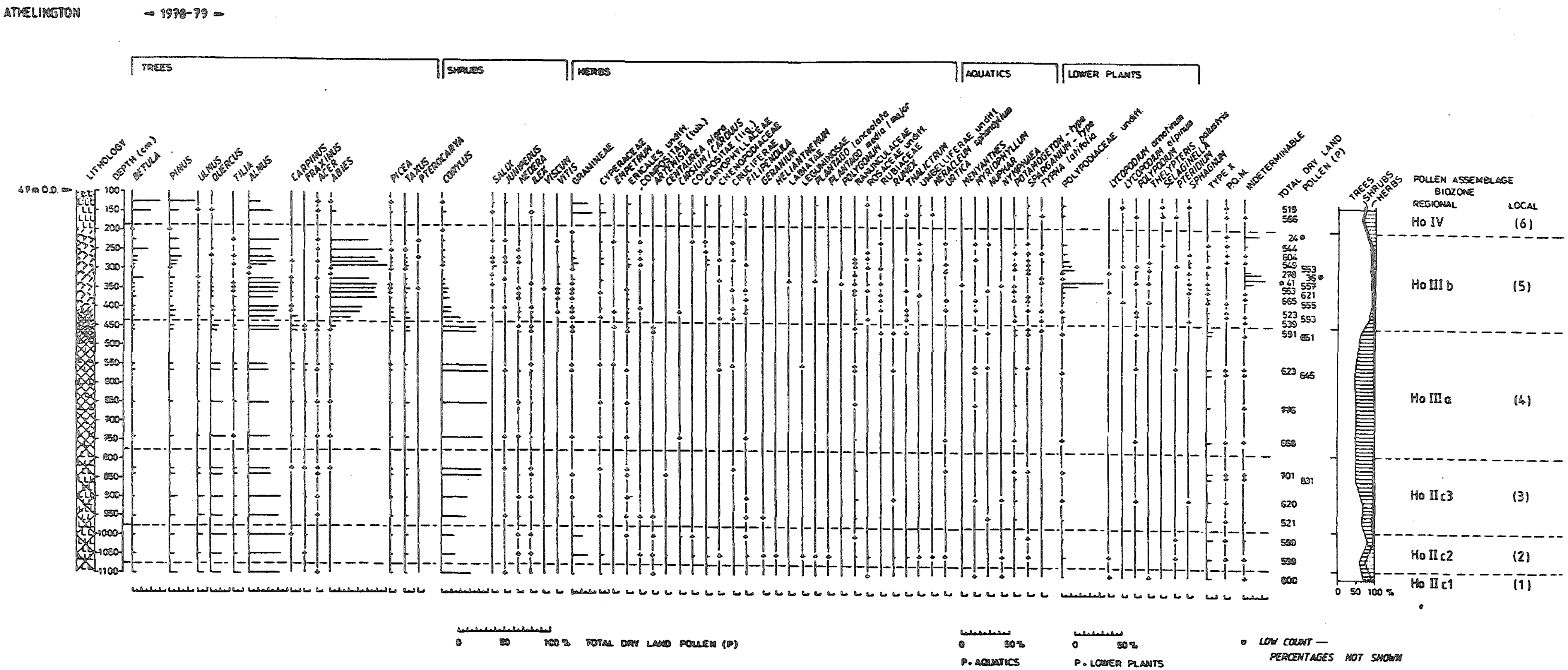


Figure 12. Athelington, pollen diagram.

SAINT CROSS SOUTH ELMHAM (boreholes 4 and 5) — 1978 —

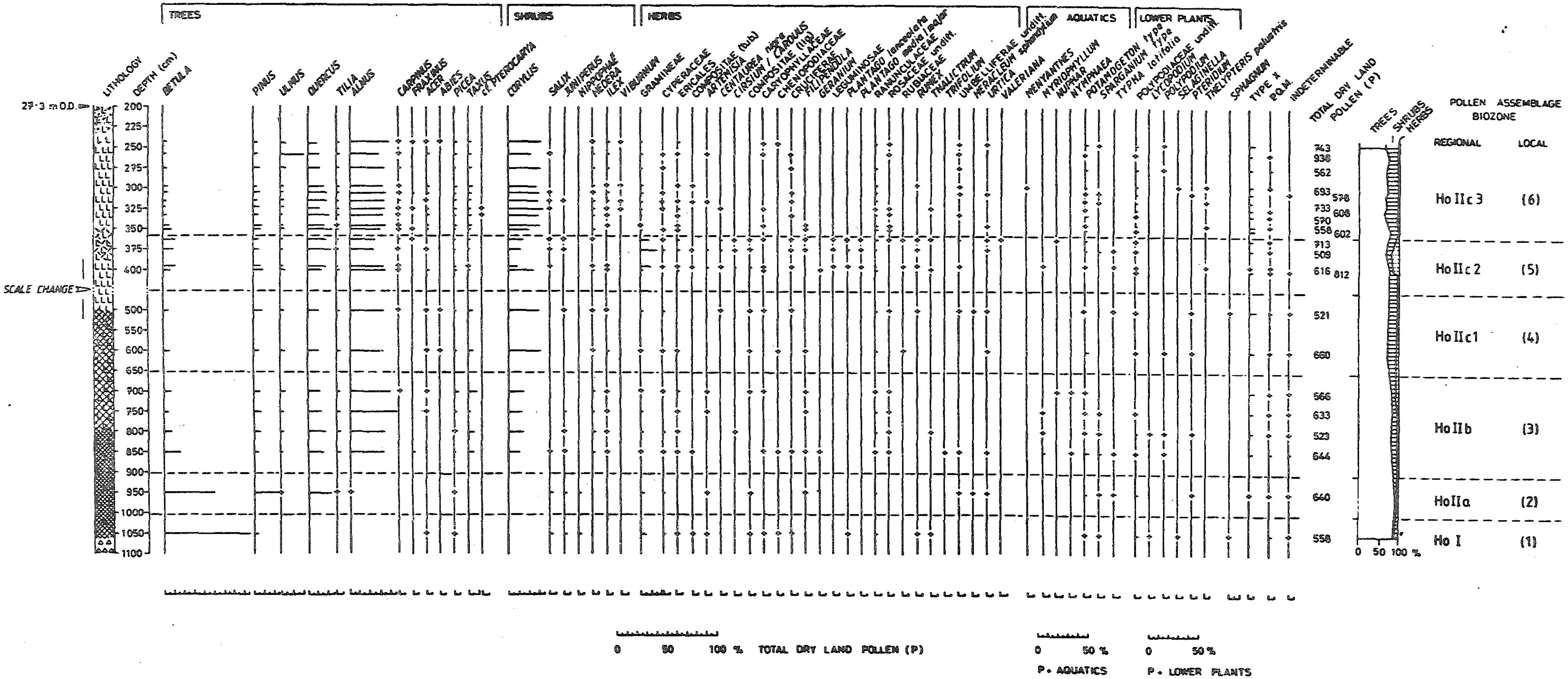


Figure 13. St. Cross South Elmham, pollen diagram.

6. Alnus-Corylus p.a.b.

5. Alnus-Gramineae-Corylus p.a.b.

4. Alnus-Corylus-Quercus p.a.b.

3. Alnus-Quercus p.a.b.

2. Betula-Pinus-Quercus p.a.b.

1. Betula-Gramineae

The regional pollen assemblage biozones to which the local p.a.b. are best correlated are clearly those of the Hoxnian Interglacial.

The local p.a.b. were correlated with the sub-stages of Marks Tey, Essex (Turner, 1970) and the type site at Hoxne (West, 1956) as follows :

Pollen assemblage biozones

Local	Regional
6. Alnus-Corylus p.a.b.	Ho IIc3
5. Alnus-Gramineae-Corylus p.a.b.	Ho IIc2
4. Alnus-Corylus-Quercus p.a.b.	Ho IIc1
3. Alnus-Quercus p.a.b.	Ho IIb
2. Betula-Pinus-Quercus p.a.b.	Ho IIa
1. Betula-Gramineae p.a.b.	Ho I

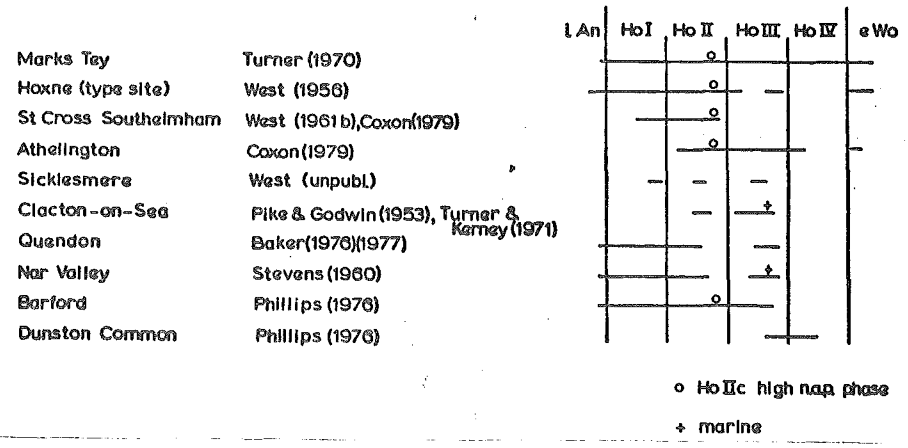
Major and interesting factors involved in this correlation include the following :

1. The presence of Type X throughout the pollen record

2. The rapid rise of pollen values of Quercus during Ho IIa, other thermophilous taxa then appearing.

3. The decline of Quercus, Alnus becoming dominant and Corylus steadily increasing throughout Ho IIb.

4. The high non-arboreal pollen values during Ho IIc (subdivided by this author into Ho IIc1, Ho IIc2 and Ho IIc3). This n.a.p. phase has been shown to be widespread in Hoxnian deposits :



Turner, 1970, favoured grazing by animals or a regional forest fire as a cause for this marked horizon in Hoxnian pollen diagrams.

The Hoxnian sites in the Waveney Valley now lie on the edges of the low order tributaries that have cut down beside them. The proximity of the basins to the tributary system of the Waveney suggests these basins may have been linked to the drainage network during their infilling. There are post-Hoxnian fluviatile deposits at Hoxne itself that cap the interglacial like sediments (Gladfelter, 1975).

The degree of post-Hoxnian erosion marked by these tributaries is large for the area, around 10 metres for South Elmham and Hoxne and 5 metres at Athelington. The present tributaries are graded to the level of the floodplain.

If the Hoxnian sites were linked to the drainage system of the Waveney then presumably the streams were graded to a higher level in the main valley. This point is discussed in detail elsewhere (Coxon, 1979).

b. WORTWELL TM 27528437

The interglacial site at Wortwell is unfortunately below gravel (and by now probably under a house!). During 1966 an excavation for a sewer trench in Low Street revealed the remains of an elephant (Elephas antiquus, NCM, 877.967) within organic deposits. The site was investigated by Sparks and West (1968) who analysed samples retrieved from the trench for plant macrofossils, pollen and molluscs. The organic sediments were assigned to the Ipswichian Interglacial on the basis of their fossil content. The deposit's importance was recognised as a biostratigraphical marker horizon especially with respect to its relationship to the Waveney terraces and its proximity to Hoxnian Interglacial sites at Hoxne and South Elmham. Unfortunately the lack of stratigraphic context and a complete profile of the interglacial has led to doubt in the literature (Cox, 1981).

The author reinvestigated the site and used a series of 5 boreholes and also auger tests to determine the stratigraphy of the deposits at Low Street. The results show the interglacial deposit thinning out upslope (Figure 14) eventually disappearing.

The interglacial sediments are underlain by sand and gravel which rises upslope. Overlying the interglacial are 1-2 metres of sand and gravel which form the floodplain terrace. The interglacial appears to be contained between the sands and gravels of the side of the valley slope and the Waveney Floodplain sands and gravels.

The interglacial deposits are composed of a sandy, silty clay and silty mud containing organic material and freshwater molluscs. The sediments and their contained fauna suggest a quiet, low energy depositional environment characterised by the sedimentation of clay and silt. Occasional higher energy flow is indicated by the presence of sandy layers with pebbles. The environment was probably one of a backwater on a floodplain providing an unstable environment and one found at other Ipswichian sites (e.g. Coxon, Hall, Lister and Stuart, 1980).

The pollen record of the organic deposits is recorded in Figure 15 and can be seen to be just over 2 metres in length.

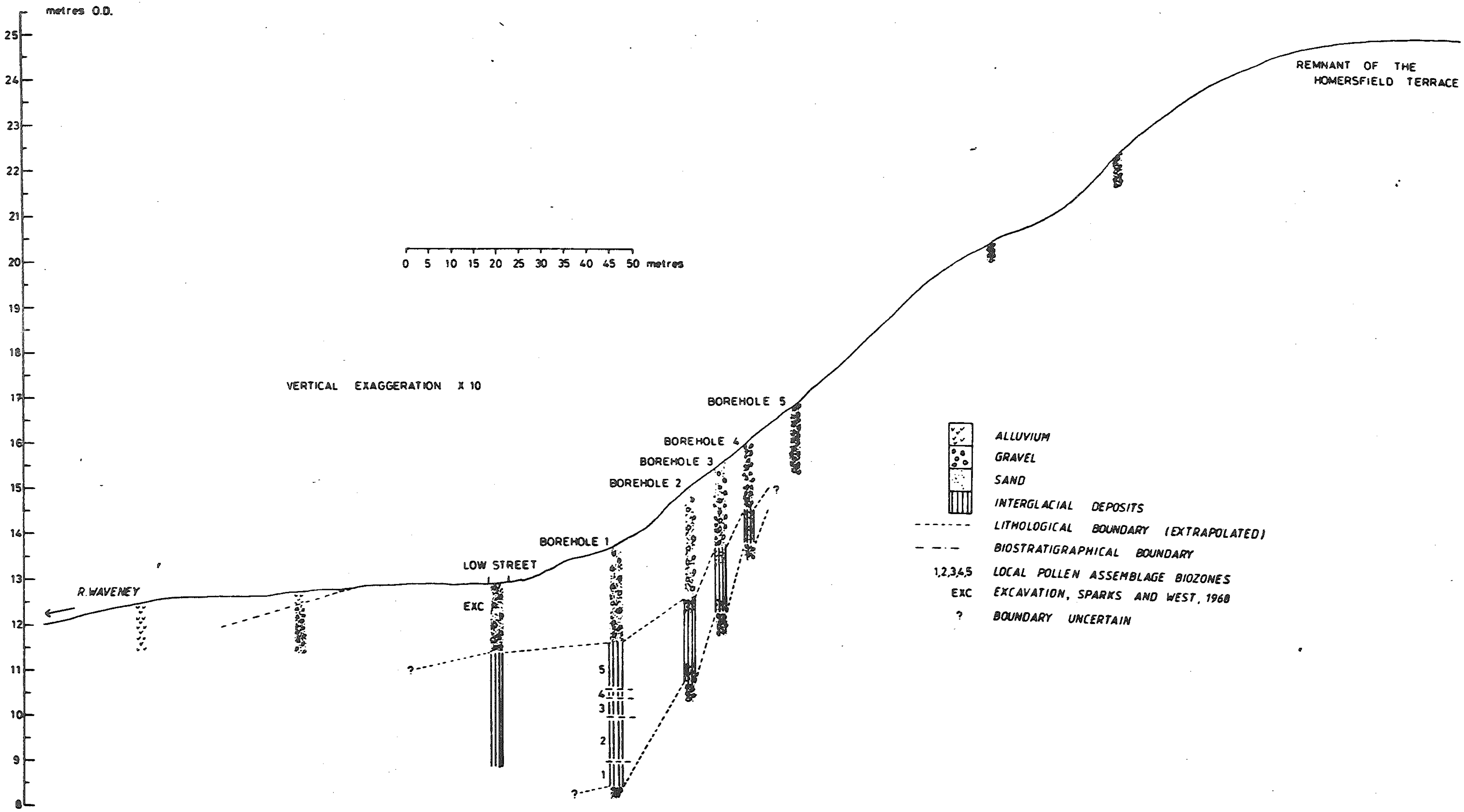


Figure 14. Wortwell, section.

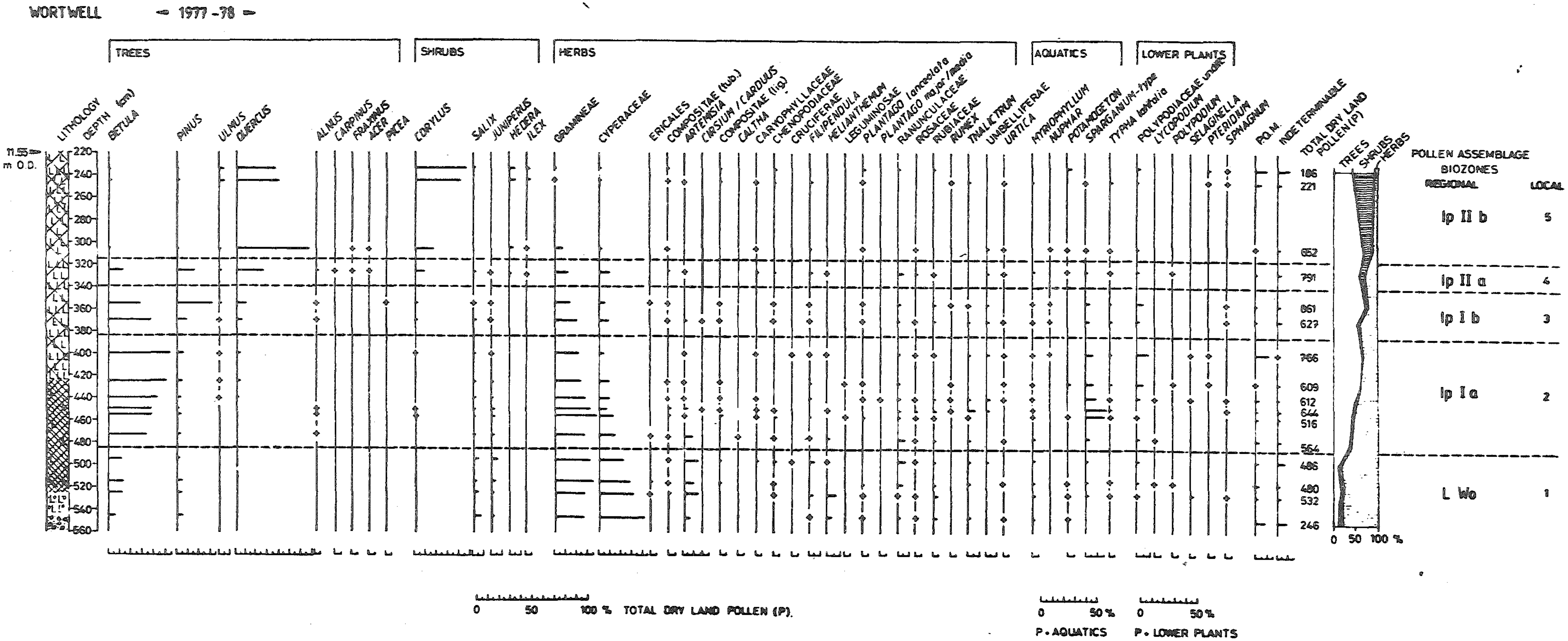


Figure 15. Wortwell, pollen diagram.

The local pollen assemblage biozones are summarised here :

5. Corylus-Quercus p.a.b.

4. Quercus-Pinus-Betula p.a.b.

3. Betula-Pinus-Gramineae p.a.b.

2. Betula-Gramineae-Cyperaceae p.a.b.

1. Gramineae-Cypreraceae-Betula-Artemisia p.a.b.

The regional p.a.b. to which the local p.a.b. are best correlated are those of the Ipswichian Interglacial. The local p.a.b. were correlated with the sub-stages of the Ipswichian type site at Bobbitshole, Ipswich, 47km to the south south west (West, 1957).

Pollen assemblage biozones.

Local		Regional
5.	Corylus-Quercus p.a.b.	Ipllb
4.	Quercus-Pinus-Betula p.a.b.	Iplla
3.	Betula-Pinus-Gramineae p.a.b.	Iplb
2.	Betula-Gramineae-Cyperaceae p.a.b.	Ipla
1.	Gramineae-Cyperaceae-Betula-Artemisia p.a.b.	lWo

Major and interesting factors involved in this correlation include :

1. The absence of Hippophae, Tilia, Taxus and Type X
2. The scarcity of Alnus pollen.
3. The rapid expansion of Corylus in Ipllb
4. The importance of Quercus in Ipllb.

The correlation with other Ipswichian diagrams including the type site is good.

Another interesting point is that the pollen diagrams from Wortwell and South Elmham are very different and both sites would favour a regional representation of the pollen 'rain'. The sites are only 5km apart and both represent the first part of an interglacial. These points underline the clear division between Hoxnian and Ipswichian sites and the validity of using biostratigraphy to subdivide these interglacials..

The Ipswichian deposit at Wortwell appears to be a floodplain backwater deposit that clearly post-dates the Homersfield and Broome Terraces as it lies within the valley and banked up against the valley side. The interglacial also lies below sands and gravels that belong to the Waveney Floodplain Terrace.

The geomorphological position of the deposit shows that the main valley must have been in existence at the beginning of the Ipswichian interglacial and that the Ipswichian floodplain was in much the same position as the present day one.

4. THE GEOMORPHOLOGICAL HISTORY OF THE WAVENEY VALLEY

The main points used in determining the dating of the landscape change within the valley are outlined.

i. The High Level Gravels.

These deposits are linked with the chalky Lowestoft Till over the entire area and as this till can be correlated to the Anglian type section at Corton (Mitchell, Penny, Shotton and West, 1973) and as most authorities now accept this Anglian age the High Level Gravels probably represent Anglian fluvioglacial deposits.

ii. The Homersfield Terrace

The sands and gravels of the Homersfield Terrace partly fill the Waveney Valley. They were produced in cold conditions and the morphology of the terrace and its contained sedimentary structures suggest ice proximity. The Homersfield Terrace also contains a flow till with very similar appearance to the Lowestoft Till (i.e. very chalky, blue-grey) suggesting that the Lowestoft Till was being deposited penecontemporaneously with the Homersfield Terrace. This would mean the Homersfield Terrace was produced as outwash sands and gravel from the Anglian ice.

iii. The Broome Terrace.

The Broome Terrace contains no evidence of ice proximity although it was clearly laid down in cold climatic conditions. The presence of reworked pollen which strongly suggests a Hoxnian age would mean this terrace postdated the Hoxnian Interglacial. Ipswichin deposits on the valley floor at Wortwell show that the terrace must predate the Ipswichian. The Broome Terrace therefore was produced between these 2 interglacials within the Wolstonian Glaciation.

There is no evidence along the length of this terrace of glacial ice.

iv. The Waveney Floodplain.

The Floodplain sands and gravels lie on the floor of the valley. They cover the Ipswichian deposit at Wortwell and lie below Late Devensian sites at Lopham and Thelnetham (TM 005972). The Waveney Floodplain also appears to have been laid down under cold climatic conditions, during the Devensian.

v. The importance of the interglacial sites.

The biostratigraphic marker horizons of Hoxnian and Ipswichian age are of considerable importance. The Hoxnian sites :

a. Place the chalky till as Lowestoft Till

b. Show the degree of erosion since the Hoxnian lake deposits formed in hollows on the Anglian till surface.

c. Show that if the Hoxnian sites were linked to the Waveney drainage system by tributary streams then these streams were probably graded to a higher valley floor than exists at present. The valley floor could then have been at the height of the Homersfield Terrace.

The Ipswichian site :

a. Post-dates the Homersfield and Broome Terraces.

b. Shows the level the river had cut down to following the deposition of the terrace deposits.

c. Pre-dates the Waveney Floodplain Terrace.

vi. Summary.

Taking all of the information together it is possible to reconstruct a sequence of events that shaped the Waveney Valley area. There are bound to be gaps in such a sequence but the biostratigraphic evidence enables key points to be stratigraphically place objectively.

Table 5 summarises the main geomorphic events :

TABLE 5.

Summary of the Pleistocene history of the Waveney Valley.

Stage	Events
Flandrian	Anthropogenic effects including peat cutting and drainage. Aggradation of floodplain clays and organic deposits
Devensian	Production of open pools in hollows left by melted ice. Deposition of sandy clays. Aggradation of sands and gravels on the flood-plain.
Ipswichian (Substages Ipla-Ipllb)	Deposition of channel backwater sediments along floor of main valley.
Wolstonian	Downcutting Aggradation of Broome Terrace Downcutting Aggradation of sands and gravels on surface of Hoxnian deposits at Hoxne. Solifluction of till onto surface of Hoxnian deposits at South Elmham.
Hoxnian (Substages HoI-HoIV)	Sedimentation in hollows in the Lowestoft Till.
Anglian Lowestoft Substage	Outwash using valley as a channel and filling it producing the Homersfield Terrace. Retreat of Lowestoft ice, production of High Level Gravels and associated deposits. Tunnel valley formation. Advance of Lowestoft ice.
Corton Substage	Formation of Corton Sands.
Gunton Substage	?Till below Corton Sands at South Elmham.
Pre-Anglian	Deposition of Crag on Chalk.

5. APPENDIX

Table 6a. Waveney Valley, stone counts.

Pebble lithology count data matrix (relative frequency). All figures shown are percentages of the total pebbles counted for that sample. A + indicates a value of less than 0.5%.

Sample reference number	Locality	Sample reference number	Locality
1	Flixton Quarry	26	Hot Dog Pit
2	" "	27	Corton Sands (TM 273855)
3	" "	28	Bungay (TM 335898)
4	" "	29	Mendham (TM 273822)
5	" "	30	"
6	" "	31	"
7	" "	32	"
8	" "	33	Instead Hall Farm (TM 233810)
9	" "	34	Harman's Lane Pit
10	" "	35	Instead Manor House (TM 235805)
11	" "	36	The Beck
12	" "	37	Thorpe Abbotts
13	Broome Heath Pit	38	" "
14	" " "	39	Outney Common (TM 325905)
15	" " "	40	Dross Lane
16	" " "	41	" "
17	" " "	42	" "
18	" " "	43	Rifle Range Pit
19	" " "	44	Roydon Gravel Pit
20	Shotford	45	Starston (TM 243844)
21	"	46	Hoxne (upper gravel)
22	"	47	Harman's Lane Pit
23	"		
24	Hot Dog Pit		
25	" " "		

SAMPLE REFERENCE NUMBER *	FLINT	QUARTZ	QUARTZITE	CHALK	RED CHALK	LIMESTONE	DECALCIFIED LIMESTONE	OOLITIC LIMESTONE	CALCITE	CHERT	GRYPHEA	BELEMNITE	AMMONITE	GRIT
1	96	1	2			✦								
2	81	10	4				1		1	✦				
3	85	7	4	✦			✦			1				
4	88	7	4			1	✦			✦				
5	85	7	4	✦			✦			✦				
6	84	8	4				1	✦		1				
7	85	7	4	✦		✦				1				
8	87	8	3			✦				1				
9	94	1	3			✦								
10	76	12	11							1				
11	88	6	3							1				
12	85	7	4				✦			2				
13	63	11	7											
14	70	15	8				1		✦	✦				
15	78	16	5				✦							
16	70	17	11											
17	72	8	15	✦			1			✦				
18	72	13	10			✦	1		✦	1				
19	67	16	14				1							
20	52	6	32	2		2	1				✦		✦	
21	85	8	4						✦	1				
22	81	12	4			✦				1				
23	68	14	5	2					✦	1				
24	57	7	6	20	✦				✦		1	✦		
25	77	12	6	1			✦							
26	53	12	4	24	✦	1	1							✦
27	64	27	4							1				
28	88	3	4				1							
29	75	14	9				1			✦				
30	79	15	6	✦										
31	75	10	11	✦						1				
32	81	10	7							✦				
33	81	11	7	✦						✦				
34	57	12	14	11		1	1				1			
35	74	15	7							2				
36	94	1	1				✦			1				
37	51	24	6	12		2				1				1
38	51	27	7	10			2			1				1
39	72	16	8				1			1				
40	91	6	1	✦			✦			2				
41	87	4	4							1				✦
42	55	23	9	3	✦		✦		✦	2				
43	76	13	7						1	1				
44	46	6	4	33				✦	1	1	✦			✦
45	76	12	11							1				
46	85	4	5				✦		1	1		✦		
47	54	12	13	11		1	1			2	✦			

SAMPLE REFERENCE NUMBER *	SANDSTONE	IRON SANDSTONE	MICA SANDSTONE	CALCAREOUS SANDSTONE	GREEN SANDSTONE	BUNTER SANDSTONE	MUDSTONE	c.f. MUDSTONE	CALCAREOUS MUDSTONE	IRONSTONE	OOLITIC IRONSTONE	CHALKY TILL
1	1		✦									
2	1				1							
3	1		✦				✦					
4	✦	✦										
5	2					✦						
6	1											
7	2					✦						
8	1									✦		
9	1		✦				✦					
10	✦											✦
11	2											
12	1									✦		
13												
14	3		✦			1	✦			✦		
15	1		✦									
16	1		✦							✦		
17	1	✦	✦									
18	1		✦				✦					
19	1		✦									
20	2											
21	1	1	✦							✦		
22	2						✦					
23	4											
24	5		1			✦	✦					
25	3											
26	2	1	1	✦		✦			✦		1	
27	1	1					✦					
28	1	1	✦				✦					
29												
30	✦											
31												
32	1	1						✦				
33												
34	3		✦			✦						
35												
36	2											
37	2						✦					
38	1		✦									
39	1					✦						
40	1				✦							
41	2											
42	2					✦	✦		✦			1
43	1	✦	✦									
44	1	✦	✦		✦		1		1			✦
45		1	✦									
46	1	✦					✦			✦		
47	3	✦					1					✦

SAMPLE REFERENCE NUMBER *	IGNEOUS	METAMORPHIC	GRANITE	DOLERITE	VOLCANIC GLASS	SCHIST	COAL	CLAY	IRON CONCRETION	JASPER	DOLOMITE	BONE	UNKNOWN	TOTAL
1														495
2	✦													503
3	✦	✦							✦					367
4														764
5		✦						✦		✦			✦	667
6														555
7	✦	✦						✦						670
8														782
9	✦	✦												762
10		✦												790
11	✦	✦												467
12														336
13									19					888
14	✦	✦	✦						✦	✦				875
15		✦								✦				746
16	✦													487
17		✦												870
18									✦	✦		✦		822
19	✦									✦				876
20		✦		1	✦									222
21	1	✦					✦		✦					568
22			✦					✦						457
23	✦	✦						5						376
24	1	1											✦	824
25		✦							✦					349
26		✦											✦	580
27	1	✦		✦										282
28	1	✦											✦	471
29			✦										✦	390
30														682
31	✦													279
32	1	✦				✦				✦				392
33									✦					614
34	✦	✦												500
35	✦												✦	294
36		✦												682
37	1	✦												325
38	✦													401
39	1	✦							✦			✦		814
40		✦												562
41	✦	✦						✦						413
42	✦	✦												452
43	✦	✦												560
44	✦	✦							2	✦		✦		651
45	✦													486
46	1	✦								✦				377
47	✦	✦		✦							✦			503

Table 6b.

* Sample reference numbers as in previous tables.

REFERENCES

Bennett, F.J. (1884), The geology of the country around Diss, Eye, Botesdale and Ixworth. Mem. Geol. Surv. U.K.

Bradshaw, R.H.W., Coxon, P., Greig, J.R.A., and Hall, A.R. (1981), New fossil evidence for the past cultivation and processing of Hemp (Cannabis sativa L.) in Eastern England. New Phytol. 89, 503-510.

Candler, C. (1889), Observations on some undescribed lacustrine deposits at Saint Cross, South Elmham in Suffolk. Q.J. Geol. Soc. London. 45, 504-510.

Cox, F.C. (1981), The 'Gipping Till' revisited. in 'The Quaternary in Britain'. Ed. Neale, J. and Flenley, J., Pergamon Press, 267pp.

Coxon, P. (1978), The first record of a fossil naled in Britain. Quaternary Newsletter, 24, 9-11.

Coxon, P. (1979), Pleistocene environmental history in central East Anglia. Unpublished Ph.D. thesis, University of Cambridge.

Coxon, P., Hall, A.R., Lister, A. and Stuart, A.J. (1980), New evidence on the vertebrate fauna, stratigraphy and palaeobotany of the interglacial deposits at Swanton Morley, Norfolk. Geol. Mag., 117, 525-546.

Doeglas, D.J. (1962), The structure of sedimentary deposits of braided rivers. Sedimentology, 1, 167-190.

Funnell, B.M., (1955), An account of the geology of the Bungay district. Trans. Suff. Nat. Soc., 9, 115-126.

Gibbard, P.L. (1981), Views on the Pleistocene of the River Thames. Quaternary Newsletter, 34, 32-35.

Gladfelter, B.G. (1975), Middle Plesitocene Sedimentary sequences in East Anglia (United Kingdom). In: After the Australopithecines. Ed. Butzer, K.W. and Isaac, G.Ll., Monton, The Hague.

Hey, R.W. (1980), Equivalents of the Westland Green Gravels in Essex and East Anglia. Proc. Geol. Assoc., 91, 279-290.

Mitchell, G.F., Penny, L.F., Shotton, F.W. and West, R.G. (1973), A Correlation of Quaternary deposits in the British Isles. Geological Society of London, Special Report no. 4, 99pp.

Phillips, L. (1976), Pleistocene vegetational history and geology in Norfolk. Phil. Trans. R. Soc. B, 275, 215-286.

Rose, J. and Allen, P. (1 77), Middle Pleistocene stratigraphy in south-east Suffolk. J. Geol. Soc. Lond., 133, 83-102.

Rust, B.R. (1972), Structure and process in a braided river. Sedimentology, 18, 221-245.

Sparks, B.W. and West, R.G. (1968), Interglacial deposits at Wortwell, Norfolk. Geol. Mag. Vol. 105, 471-481.

Tallantire, P.A. (1953), Studies in the Post-glacial history of the British Vegetation. XIII, Lopham Little Fen, a Late-glacial site in Central East Anglia. J. Ecol., 41, 361-373.

Turner, C. (1970), The Middle Pleistocene deposits at Marks Tey, Essex. Phil. Trans. R. Soc., B, 257, 373-440.

West, R.G. (1956), The Quaternary deposits at Hoxne, Suffolk. Phil. Trans. R. Soc., B, 239, 265-356.

West, R.G. (1957), Interglacial deposits at Bobbitshole, Ipswich. Phil. Trans. R. Soc., B, 241, 1-31.

West, R.G. (1961), The glacial and interglacial deposits of Norfolk. Trans. Norfolk Norwich Nat. Soc., 19, 365-375.

West, R.G. (1980), Pleistocene forest history in East Anglia. New Phytol., 85, 571-622.

Whitaker, W. and Dalton, W.M. (1887), The geology of the country around Halesworth and Harleston. Mem. Geol. Surv. U.K.

Williams, P.F. and Rust, B.R. (1969), The sedimentology of a braided river. J. Sediment. Petrol., 39, 649-679.