# Quaternary Research Association

# Norwich

# Easter-1970

To: Members of the recent QRA excursion to East Anglia

As the QRA Handbook may be referred to by leaders of future excursions to the area I give below the portion of the Scratby description which was accidentally omitted during duplication. This portion should be inserted at the end of page 3 of the Handbook:-

"No structural information to date.

4. Chalky Till (4) This till outcrops high in the cliffs to the north of California Gap. Normally, it has a dark-grey to blue-black clay matrix and numerous, relatively large chalk erratics. In its lower parts, and especially to the north, it becomes chalkier in matrix, the chalk erratics becoming correspondingly somewhat smaller and less numerous (see also Baden-Powell, 1948; Green et al., 1953).

Erratics (500: 100 from each of 5 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 3-20 | 10 |
| Chalk | 80-97 | 90 |
| Quartz & -ite | 0-1 | 0 |
| Exotics | 0-1 | 0 |
| Shells | 0-1 | 0 |

"

In addition, the following line should be inserted in the stratigraphic table on page 9:-

"4. Second Till 4m."

P. H. Banham

# QUATERNARY RESEARCH ASSOCIATION

## NORWICH - EASTER 1970

### Introduction

The excursion has been designed to take in some of the "classic" localities of the East Anglian Quaternary, and also those areas in which recent work has promised to yield valuable information both about chronology and process. Some of the ideas presented here are contentious and perhaps premature, but they have been explicitly stated in order to provoke discussion.

We shall investigate four main areas, each with their own problems, but all of which share a similar problem, that of inter-correlation over intervening ground in which there is little exposure.

The Waveney valley in the south provides most of the direct chronological evidence, containing as it does biogenic deposits of both Hoxnian and Ipswichian interglacials. The coastal sections display two elements, the Cromer Forest Bed Series in which ample organic material provides a correlative tool; and the overlying glacigenic sequence, sporadically exposed in 60 miles of coastal cliffs from Lowestoft to Weybourne, in which there are no organic remains and in which correlations are based entirely on studies of lithologic variation. The third area, that of north Norfolk, shows a variety of geomorphic features, moraines and sandar plains, for which distinctly different interpretations have been proposed, and which are difficult to relate to the deposits in the coastal cliffs. Fourthly, the interior of Norfolk, the area around Norwich, which has recently been mapped by IGS and for which much new data can be provided, although here again, correlation with the other three areas is a major difficulty.

The contributions of individual workers to this handbook are headed by their initials:- PHB - Peter Banham, GSB - Geoff Boulton, FCC - Frank Cox, NBP - N. B. Peak, CER - Colin Ranson, GGS - Gale Sieveking, AS - Alan Straw, RGW - Richard West.

GSB.

## DAY 1 SCRATBY - CORTON, HADDISCOE

## AND THE WAVENEY VALLEY (Homersfield, Wortwell, Hoxne)

The sites visited on this first day are of fundamental importance for the chronology of the glacigenic sequences of Norfolk. At Scratby and Corton, a relatively simple sequence of tills occurs, lying upon the Cromer Forest Bed Series. At Hoxne, on the south side of the Waveney Valley, an organic sequence, used for the type section of the Hoxnian interglacial, rests upon tills which are tentatively correlated with those at Corton, whilst above the Hoxnian interglacial beds there lie gravels which contain erratics characteristic of the Gipping tills of west Norfolk. The Waveney Valley appears to cut through the above-mentioned till sequence and some of the terraces lying within it are thought to carry outwash material from the glacier which deposited the Gipping tills. Stratigraphically above this outwash material, lying below a terrace at Wortwell, occur other organic beds which have been correlated with the Ipswichian Interglacial.

This data has been used as a key to the chronology of Norfolk; firstly by attempts to correlate the pre-Hoxnian post-Cromerian, Lowestoft tills at Corton and Scratby with those lying to the north (see day 2); secondly by the inference that the Gipping tills were deposited during a post-Hoxnian pre-Ipswichian glacial phase; and thirdly by using the fact that the cutting of the modern Waveney valley (and presumably therefore the valleys of other large eastward flowing rivers of Norfolk) seems to have initiated in Gipping times.

### LOCALITY 1 SCRATBY

(PHB)

#### Introduction

The sea-cliffs here did not become exposed on a large scale until after the heavy storms and floods of 1953. At this time they were first studied by Green et al. (1953). Recent (1969) observations on these still well exposed sections are generally in agreement with those of Green:

| Stratigraphy of Green et al. 1953 (max. thicknesses from p. 331) | | Provisional succession of PHB (max. thicknesses given) | | |
|---|---|---|---|---|
| Lower Chalky Boulder Clays (i.e. Chalky and Chalky Jurassic of Great Eastern Glaciation) | 10m+ | 4. | Chalky Till | 10m+ (4) |
| Corton Sands | 10m+ | No sands in this position in 1969 | | |

| | | |
|---|---|---|
| Norwich Brickearth | 10m | 3. Upper Brown Till 10m (3)<br>2. Sands (and silts/clays) 6m<br>1. Lower Brown Till 6m+ (1) |

Figures in brackets indicate possible lateral relations with the tills (1-3) of NE Norfolk (Banham, 1968).

Descriptions of the Beds

1. Lower Brown Till (1) Exposed at the base of the cliff to the north of Scratby Coast Road (TG 515154) and to the south of California Gap (TG 518148). It is soft, sandy and homogeneous with very few, small erratics.

Erratics (186: from 2 stations - 86 and 100)

| Lithology | Range | Average |
|---|---|---|
| Flint | 58-61 | 60 |
| Chalk | 5-9 | 7 |
| Quartz & -ite | 9-10 | 10 |
| Exotics | 12-16 | 14 |
| Shells | 8-12 | 10 |

Structures West & Donner (1956, p. 73) found that erratic pebble long axes were aligned at 320°, and concluded that the depositing ice had moved from this direction.

2. Sands (and silts/clays) These generally yellow, bedded sands are found between the Lower and Upper Brown Tills to the south of California Gap.

3. Upper Brown Till (3) This till has a large outcrop between Scratby Coast Road and California Gap; it also overlies the Sands (2) to the south of California. It consists of a brown, sandy matrix around numerous "rafts" and laminae of generally yellow sands. The whole deposit shows abundant (glacial tectonic) minor folds.

Erratics (300: 100 from each of 3 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 65-81 | 74 |
| Chalk | 0 | 0 |
| Quartz & -ite | 4-17 | 11 |
| Exotics | 11-17 | 14 |
| Shells | 0-1 | 1 |

Structures West & Donner (1956, p. 73) found a pebble lineation at 260° and concluded that the Chalky Till ice had moved into the area from this direction.

## LOCALITY 2 CORTON

(PHB)

### Introduction

Rapid cliff recession during recent years has caused the local authority to buttress the cliffs with a concrete sea-wall, thus obscuring exposures up to a height of approx. 6m OD. However, the upper portions of the cliff are now more easily examined, and two apparently previously unrecorded beds have been found (1969). This is the type locality for the Lowestoftian stage (West, 1963, 1968, e.g.), recently re-named the Anglian Stage (Shotton & West, 1969). Mapping of this section is not complete and the following succession may need (probably slight) revision in the future:-

| Baden-Powell 1950 | PHB Unpublished (Approx. max. thickness given) |
|---|---|
| ? Gipping Outwash Gravels | 7. Sands & Gravels 4m+ |
| 5 & 6 not given (? found by Blake 1890, p. 61, nearby inland) | 6. Upper Chalky ? Till 2m (5)<br>5. Grey Clays & Sands 3m |
| Lowestoft Boulder Clay | 4. Lower Chalky Till 6m (4) |
| Corton Beds (marine) | 3. Sands 7m |
| Cromer Till | 2. Brown Till 3m |
| Pebbly Series<br>Cromer Forest Bed<br>(or Chillesford Clay)) | 1. Cromer Forest Bed Series 1m+ |

Figures in brackets indicate inferred relations to NE Norfolk tills (1-3) (Banham 1968)

### Description of beds

(RGW)

1. Cromer Forest Bed Series

Below the glacial drifts can sometimes be seen exposures of the Cromer Forest Bed Series, as follows:

3. Grey estuarine silts (2-3 m.), penetrated by ice-wedge casts.
2. Freshwater drift muds (0.2m.), very compressed.

1. Blue-grey silty clay, containing race (0.2-3 m.); this is "Rootlet Bed" of Blake.

This sequence is probably related to the Cromerian transgression.

2. Brown (Cromer) Till (PHB) Small exposure south of Corton village; i.e. around TM 546967. This till is homogeneous, sandy, generally unlaminated, and contains few small erratics.

(a) Erratics (300; 100 from each of 3 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 65-73 | 68 |
| Chalk | 0 | 0 |
| Quartz + -ite | 20-29 | 24 |
| Exotics | 6-11 | 8 |
| Shells | 0 | 0 |

(b) Glacial tectonic structures Minor folds - very few found in the Brown Till; in lower part, isolated, small, tight, flat folds trend 120 at 0 and close to SW. In upper few cms more open folds trend 100 at 0, with no clear sense of overturning. In upper 250 cms of CFBS below occur conjugate fractures which strike 105 and dip at 70 N (frequently) and 55 S (less frequently). With these are associated minor folds of similar (105) trend and with the dominant fractures axial planar. Lineation of erratic long axes - major peaks at three stations trend 095-105, 105 and 115 (from S-N); the intermediate station (105) has a secondary peak at 085 - these lineations coming mainly from the upper part of the till.

Provisional conclusion - ice-movement from NNE (005-030). (This is in disagreement with West and Donner, 1956, p. 73 - 310).

3. Corton Beds (Sands) Yellow-white-grey sands with some prominent clay beds. Problematical shell fauna (see West, 1961).

4. Lower Chalky (Lowestoft) Till Good exposure in upper part of cliff. Matrix generally grey-blue-black, sticky clay with numerous, relatively large, mainly chalk erratics.

(a) Erratics (700; 100 from each of 7 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 2-14 | 8 |
| Chalk | 77-97 | 91 |
| Quartz + -ite | 0-1 | 0 |
| Exotics | 0-9 | 3 |
| Shells | 0 | 0 |

(b) Glacial tectonic structures Apparently "structureless"; also, no folds found (so far) in upper part of underlying Corton Beds.

Lineation of erratic long axes - both stations measured show very clear peaks at 055.

Provisional conclusion - ice-movement from NE, SW, NW or SE (!) On similar evidence West & Donner (1956, p. 73) had ice from SW (approx.).

5. Grey clays and sands Clayey in lower part, sandy in upper; fragments of wood (?) found by RGW and CT; RGW has taken samples for pollen anlaysis - results?

6. Upper Chalky Till Much thinner than Lowestoft Till, with greyer, more chalky matrix and smaller, less chalky erratics.

(a) Erratics (200; 100 from each of 2 stations) (see also Baden-Powell, 1948)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 29-33 | 31 |
| Chalk | 66-71 | 69 |
| Quartz + -ite | 0 | 0 |
| Exotics | 0-1 | 1 |
| Shells | 0 | 0 |

(b) Glacial tectonic structures Intensely (chalky) laminated in places with numerous tight, flat folds - not studied to date.

Lineation of erratic long axes - the single station measured shows a broad major peak at 085 with a broad secondary peak at 125. Without the evidence of folds, particularly, no unambiguous ice-movement direction can be deduced.

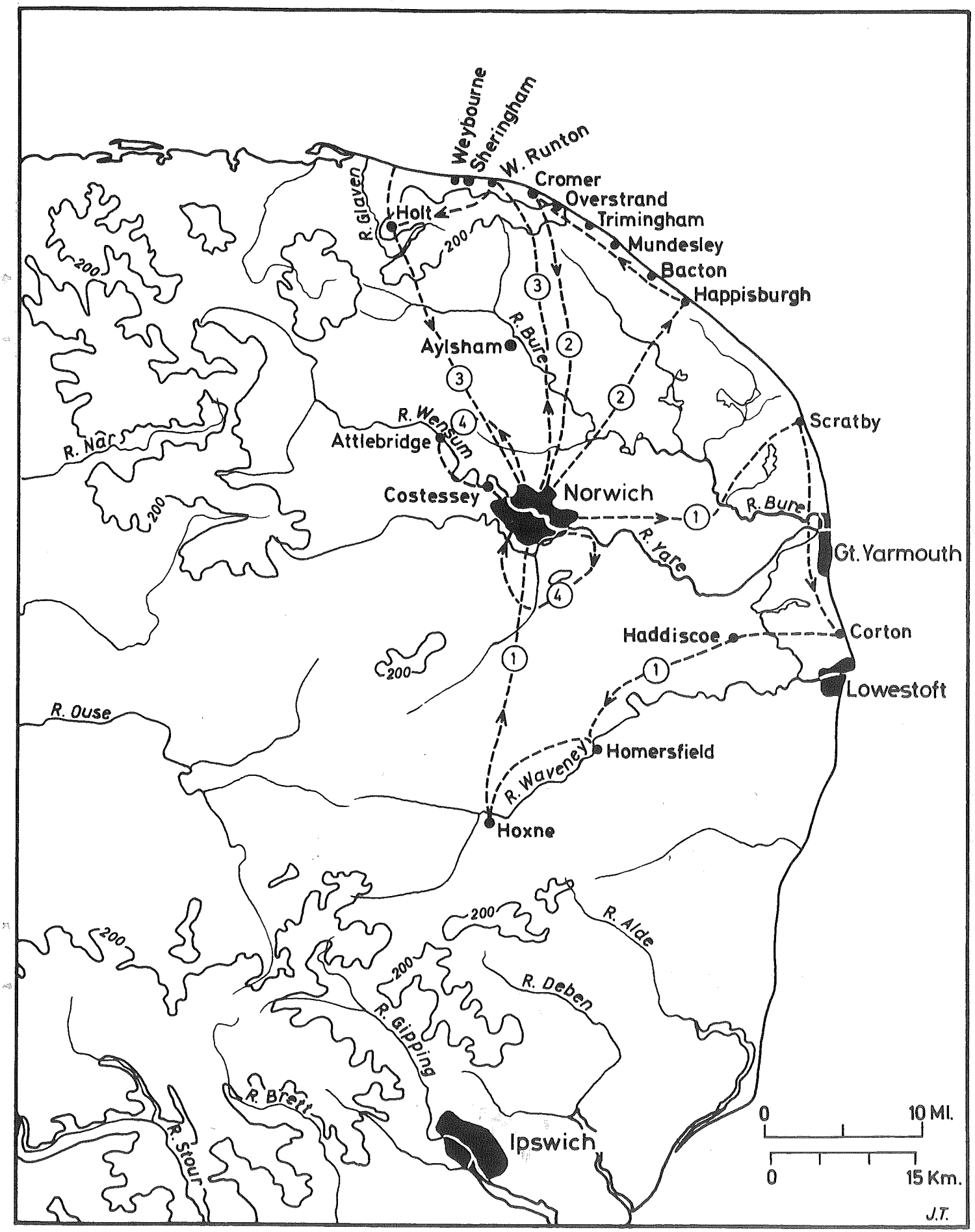
7. Sands and Gravels Bedded and current bedded, yellow, more or less iron-stained. (Blown sand overlies this succession, especially to the south.

Broad structure The beds at Corton are horizontal or nearly so; the coast section to the south of the village reveals a very broad anticline within the core of which the lower beds can still be seen above the new sea-wall.

## LOCALITY 3 HADDISCOE

(RWH)

In parts of south-east Norfolk and north-east Suffolk (fig. 2) large areas of gravels occur which are thought to be older than the Lowestoftian tills and younger than Baventian deposits (Hey, 1967). On the basis of grading, sedimentary structures and distribution, it has been suggested that these gravels, termed Westleton beds, were laid down as beach-plain deposits, similar to those at Dungeness, on a shoreline which was prograding from north-west to south-east. These beds, consisting of an


Weybourne
Sheringham
W. Runton
Cromer
Overstrand
Trimingham
Mundesley
Bacton
Happisburgh
Holt
R. Glaven
200
Aylsham
R. Bure
Scratby
R. Wensum
Attlebridge
R. Nar
Costessey
Norwich
R. Bure
R. Yare
Gt. Yarmouth
Haddiscoe
Corton
Lowestoft
R. Ouse
Homersfield
R. Waveney
Hoxne
R. Alde
R. Deben
R. Gipping
R. Brett
R. Stour
Ipswich
0
10 Ml.
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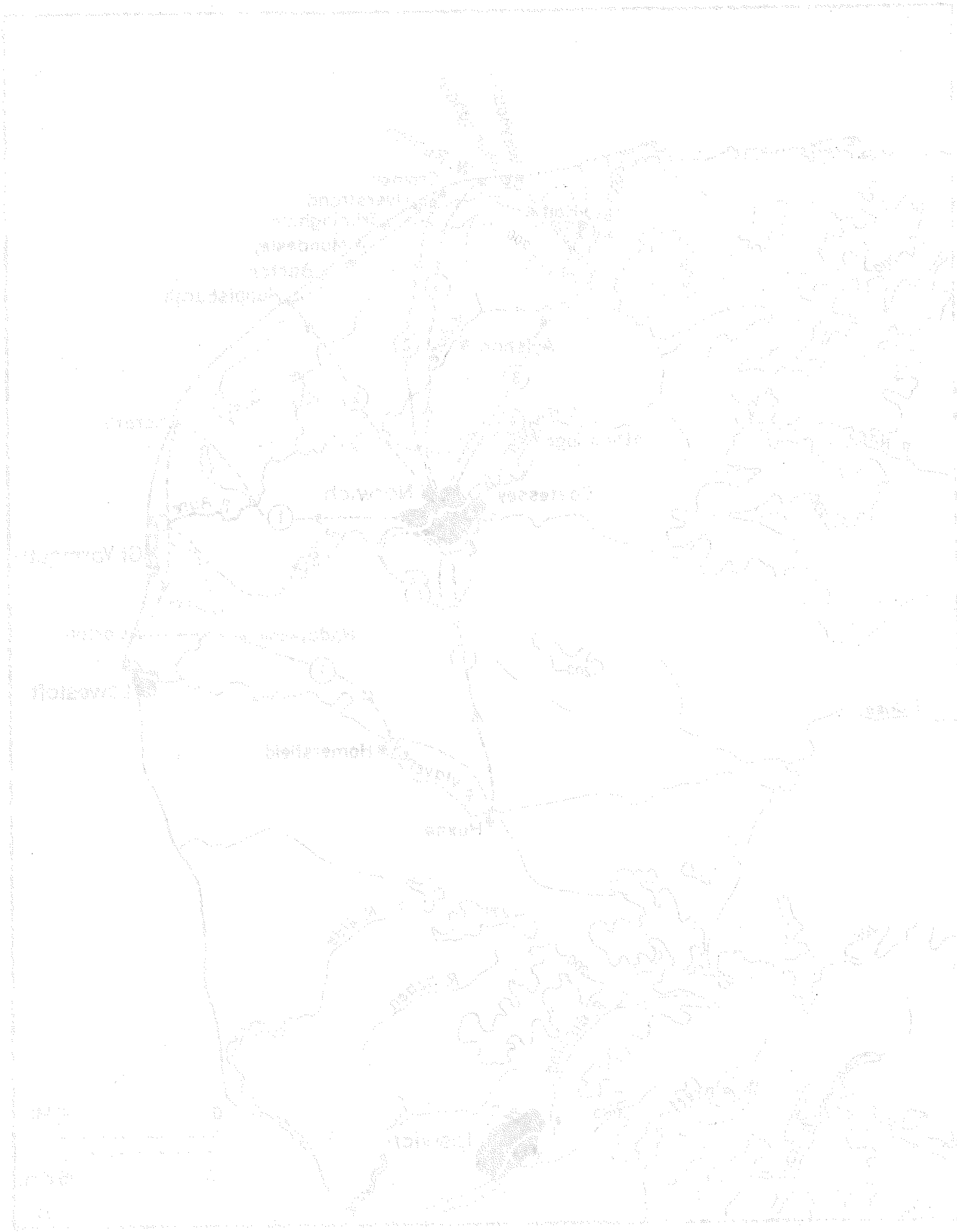
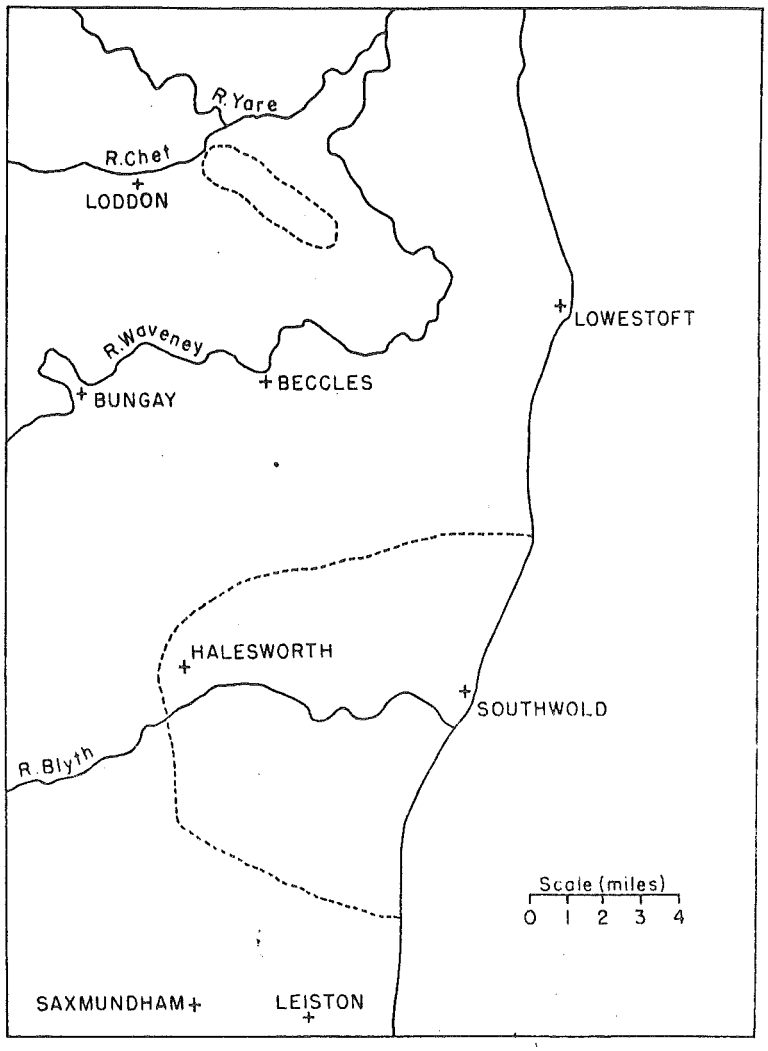
15 Km.
J.T.

Fig. 1






The areas in which outcrops of the Westleton Beds have been found. The broken lines show the outermost limits of each group of outcrops

**FIGURE 2.**

abundance of rounded flint pebbles, together with lesser quantities of quartz, quartzite and sponge-spicule cherts, are thought to have been derived from the Tertiary in the western parts of the London Basin.

One of the most interesting exposures is to be found in a large pit at Haddiscoe (444967) which lies on the higher ground between the rivers Waveney and Yare. The following section was recorded in 1963 in its south-east corner:

| Bed | | ft. | in. |
|---|---|---|---|
| 7 | Brown chalky boulder-clay | 6+ | |
| 6 | White current-bedded sand | 1 | 3 |
| 5 | Brown sand and gravel | 0 | 9 |
| 4 | Brown unbedded clay with scattered flints and rare quartz pebbles | 1 | 0 |
| 3 | Gravelly sand, poorly bedded | 1 | 3 |
| 2 | Brown and grey silt, laminated and contorted | 6 | 0 |
| 1 | Pebbly flint gravel | 30+ | |

The exposure of Bed 1 was large enough to show that it was identical in every detail with the more pebbly parts of the Westleton Beds of the type-area. The proportions of the different kinds of pebbles were almost the same, as was the distribution of particle-sizes. Moreover, the entire visible thickness of the deposit showed large-scale oblique bedding dipping at 5° to the east-south-east.

Of the overlying beds, the uppermost could safely be identified as the Lowestoft Till. Beds 5 and 6 strongly resembled the Corton Beds at their type-locality, a significant point being the presence in Bed 5 of large angular fragements of basic igneous rocks and a few of mica-schist. The most interesting of all, however, was Bed 4, which was lithologically identical with the Norwich Brickearth of adjoining areas. In other parts of the pit it expanded to a thickness of 6ft. or more without showing any internal bedding-planes. Hence, though the state of the sections was unsuitable for the determination of stone-orientations, it was concluded that this must be the Norwich Brickearth itself. Over most of its outcrop admittedly, the Norwich Brickearth is much thicker, but Haddiscoe lies very close to its extreme southern limit as determined by Boswell (1914, pl. 24).

The base of Bed 1 is nowhere exposed, and from the geological maps it can only be said to lie above the Norwich Crag. Dr. R. G. West, however, has kindly informed the writer that deposits of Baventian age are exposed at Aldeby, only two miles south of Haddiscoe, at levels near Ordnance Datum. Hence it seems almost certain that Bed 1 is largely or wholly post-Baventian.

## LOCALITY 4 THE WAVENEY VALLEY

This valley is cut into a series of tills generally thought of as equivalent to the Lowestoftian tills of Corton. Within the valley, in the vicinity of Bungay, between Ellingham and Wortwell, two major terrace levels occur. A high (Homersfield) terrace, and a low (Broome) terrace (figs. 3 and 4). Biogenic deposits are known at both Wortwell and Broome Heath. At Wortwell, the deposits occur at about floodplain level, below the level of the Homersfield terrace and the probable equivalent of the Broome

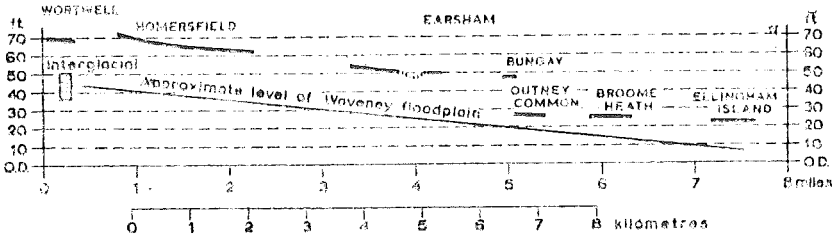
terrace, and are thought to represent pollen zones Ia and IIb of the Ipswichian interglacial. Both the terrace surfaces are probably pre-Ipswichian in age, and it has been suggested that they mark outwash episodes in the retreat of the Gipping glacier lying to the west, and are not separated by any great span of time. The biogenic deposits below the Broome terrace at present under study, indicate a full-glacial flora and thus fit with the above interpretation.

## LOCALITY 5 HOXNE

(RGW)

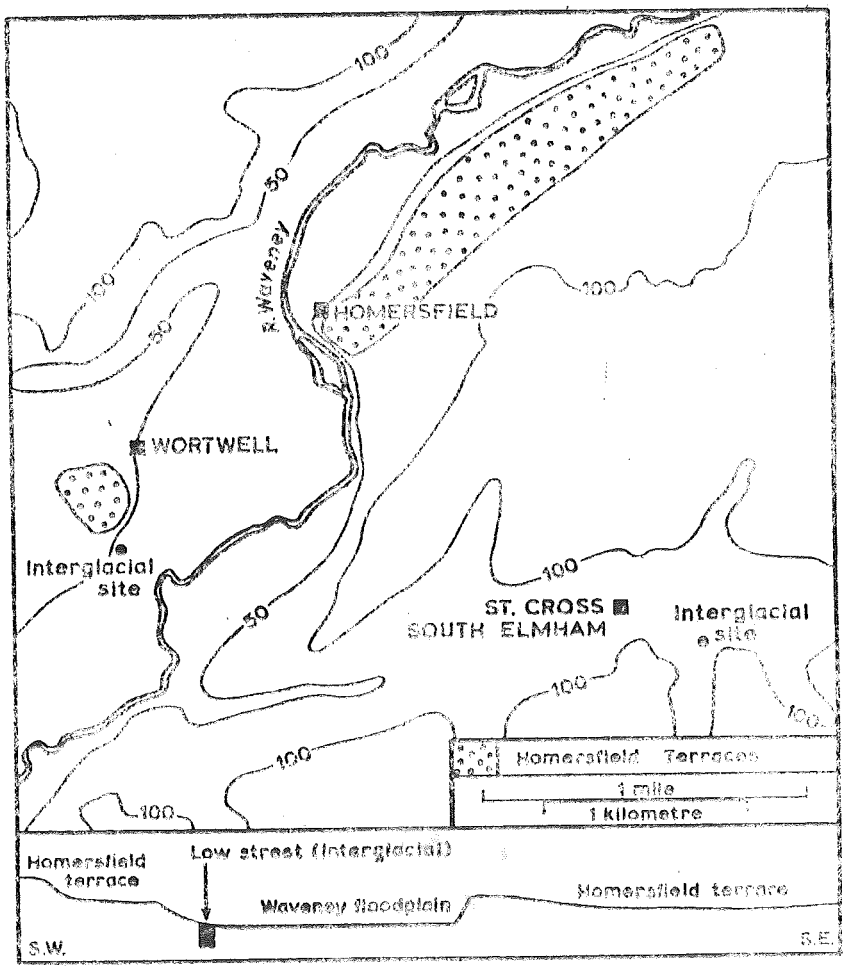
This site, the type site for the Hoxnian interglacial, is at the Old Brickfields on the Eye-Hoxne road. The pits on either side of the road are still worked intermittently. Fig. 5 gives the E-W section across the road, fig. 6 the general stratigraphy, and figs. 7 and 8 the pollen diagram obtained from a deep boring in the centre of the lake basin, just E of the road. The pollen diagram shows the complete vegetational development up to the middle of zone Ho IIIa; there is a hiatus above this, with deposition of reworked deposits over it. The reworked deposits contain a flora of species indicative of both cold and warm climates. The famous Hoxne hand axe industry is associated with a late part of zone Ho II, during the mixed oak forest period of the interglacial. Elephas antiquus teeth were also found at a similar level; otherwise the fauna at the site is poor.

The interglacial deposits lie over the bluish chalky boulder clay of the Lowestoft ice advance. They underlie a bed of clay, silt, sand and gravel which contains erratics thought to be characteristic of the Gipping ice advance. The origin of this covering deposit has been the subject of much argument. At the meeting in April 1969 of the Inqua Stratigraphic Commission it was concluded that it was partly aeolian, partly solifluction, and formed near an ice front. Be that as it may, the covering horizon with its erratics must belong to a later cold period than the interglacial, and formed before the present valleys were deeply excavated, i.e. by comparison with the Waveney last interglacial deposits, before the last interglacial.



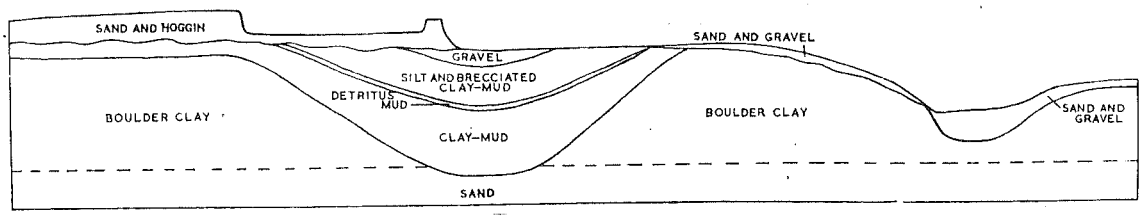

—Diagrammatic long profile of R. Waveney and outwash terraces near Bungay, Suffolk.

FIGURE 3



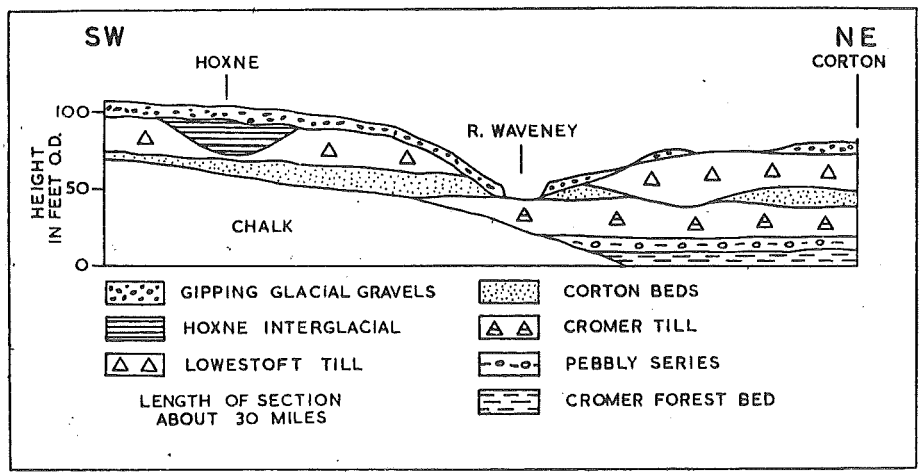

—Location map and section of Wortwell interglacial site.

FIGURE 4



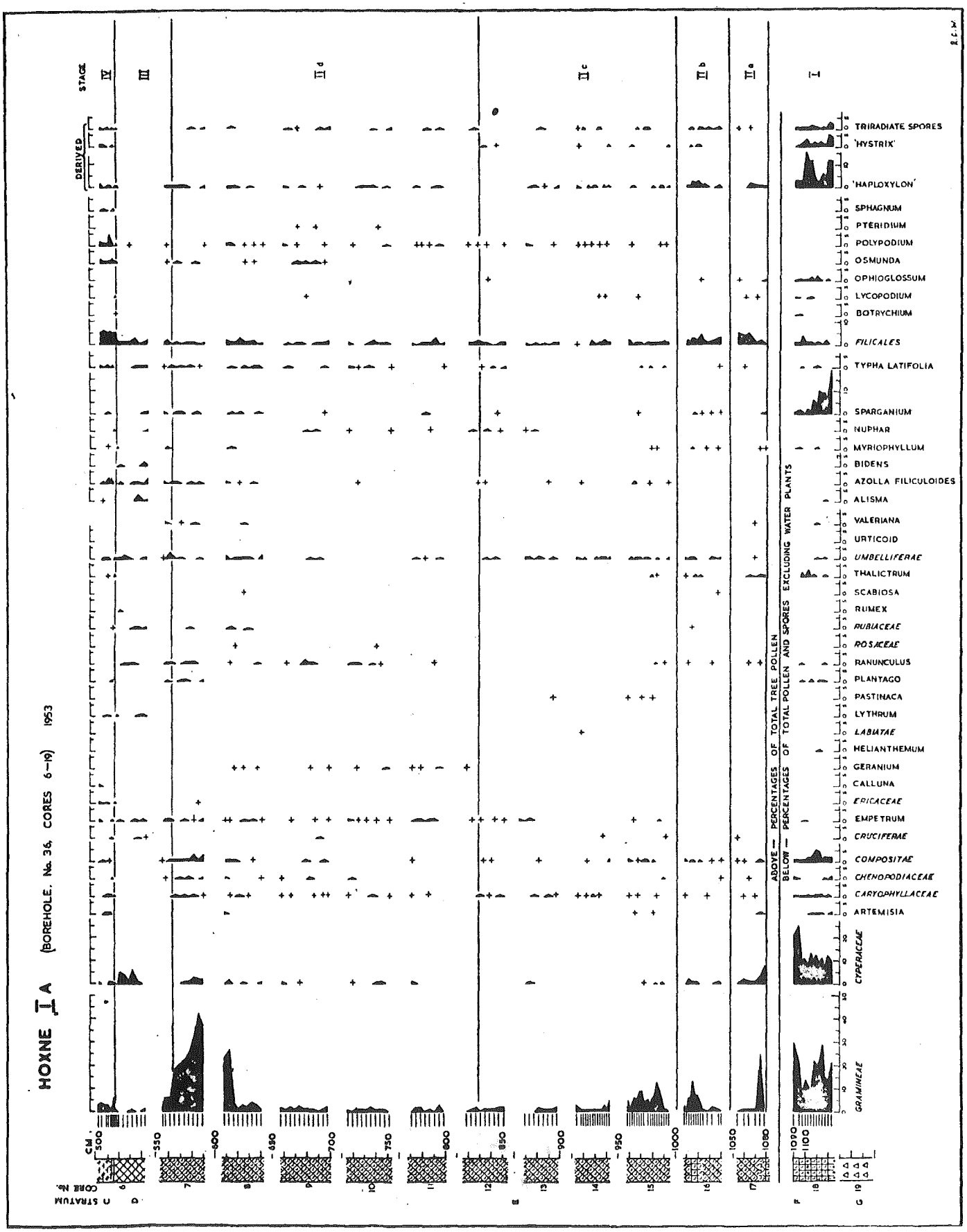

| | deposit | designation of strata | approximate maximum thickness found |
|---|---|---|---|
| 1 | (River alluvium) | | |
| | Fine sand with flints | A1 | 1 m |
| | Valley fill and hill-wash of clay, sand and gravel | H | 2½ m |
| 2 | Unstratified clay and sand, and till of Gipping Glaciation | A2 | 2½ m |
| 3 | Stratified clay, sand and gravel | B | 2 m |
| | Brecciated clay-mud with interbedded silt and drift mud | C | 3½ m |
| | Detritus mud | D | 40 cm |
| | Brown-green clay-mud | E | 6½ m |
| | Grey clay-mud and marl | F | 50 cm |
| 4 | Chalky boulder clay of Lowestoft Glaciation | G | 7½ m |

**FIGURE 5**



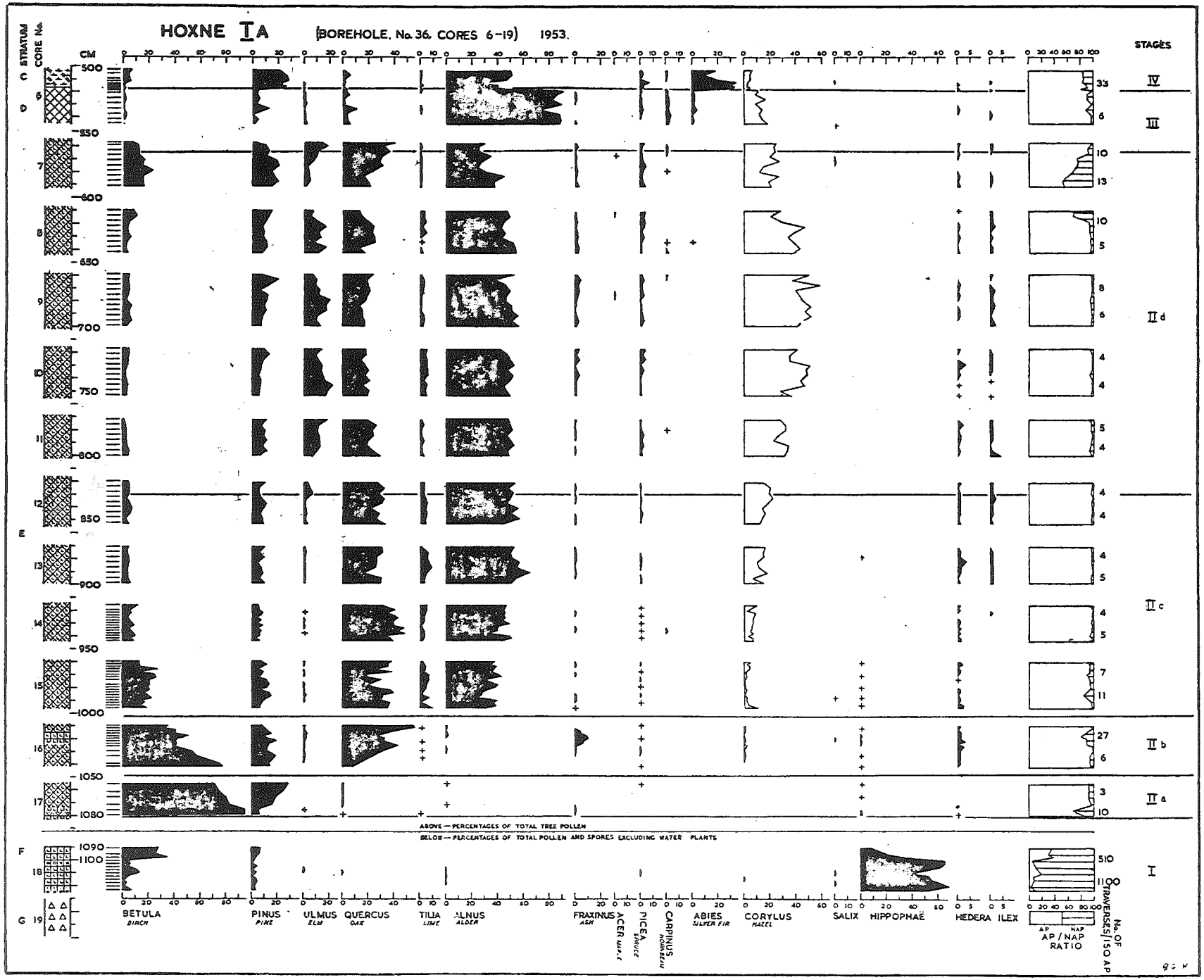

Geological sketch-map across East Anglia showing the succession of Quaternary deposits (after Baden-Powell).

**FIGURE 6**




The main non-tree pollen diagram from the centre of the lake basin.

FIGURE 7




The main tree-pollen diagram from the centre of the lake basin.

FIGURE 8

## DAY 2 COASTAL CLIFFS FROM HAPPISBURGH TO CROMER

Most of the cliff-line in this zone is made up of glacigenic sediments. In the south, in the Happisburgh area, these comprise a relatively simple undisturbed sequence. Progressing north, however, between Bacton, Mundesley and Trimingham, the intensity of deformation within the sequence increases until, in the vicinity of Sidestrand, massive chalk rafts are incorporated within the sequence, and much of the cliff section is made up of "Contorted drift".

There are three major problems in this zone; firstly, the compilation of a stratigraphic sequence, and the unravelling of this sequence in the zone of intense glacitectonics; secondly, the correlation of the deposits with those of the Scratby-Corton area and an assessment of the chronology involved; and thirdly, the problem of the origin of the "stratified" tills and of the chalk rafts and other tectonic structures.

The most recent detailed stratigraphy is that of Banham (1968) who has largely used erratic content as a means of correlation both within this zone and with the Corton-Scratby area to the south. The stratigraphy of this zone according to Banham is summarised in Figure 29.

### LOCALITY 1 HAPPISBURGH

(PHB)

This is the most southerly of the sections of "NE Norfolk", (Reid, 1882; Solomon, 1932; West & Banham, 1968). It is the "type area", at least for the lower part of the succession, because the simple, approximately horizontal, relations of the beds are largely undisturbed by later glacial tectonic structures. Recent interpretations of the stratigraphy of this section (Banham, 1968) are in agreement with those of Reid (1882).

Succession (approx. maximum thicknesses given)

7. Sands (etc.) (Gimingham ??, Valley?) 4m+
6. Third Till 2-3m
5. Mundesley Sands 4m
3. Intermediate Beds 6m
2. First Till 4m+
1. Cromer Forest Bed Series (now very rarely seen).

Description of the Beds

1. Cromer Forest Bed Series

(RGW)

Below the glacial drift can sometimes be seen laminated estuarine

silts (2-3m.) and below this a peat bed (0.5 m.) containing logs. These deposits are of Pastonian age, with a temperate woodland flora, and reflect the Pastonian marine transgression.

2. First Till Brown, soft, sandy, homogeneous, generally unlaminated. Pebble lineations at one site, single peak bearing 055°.

Erratics (300: 100 from each of 3 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 55-63 | 59 |
| Chalk | 3-9 | 6 |
| Quartz & -ite | 8-12 | 10 |
| Exotics | 15-24 | 21 |
| Shells | 4-9 | 6 |

3. Intermediate Beds Inter-laminated clays, silts and sands; no pollen (good exposures between Happisburgh and Walcott).

4. The Second Till is well exposed to the north of Happisburgh and to the south of Ostend (TG382312 - TG368324 approx.). It is a hard, grey, creamy weathering chalky till. Pebble lineation at one site, trend 040°.

Erratics (300: 100 from each of 3 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 32-34 | 33(54) |
| Chalk | 49-59 | 54(33) |
| Quartz & -ite | 6 | 6 (5) |
| Exotics | 3-13 | 8 (8) |
| Shells | 0 | 0 (0) |

The figures in brackets are for a presumably leached sample from the northern feather edge outcrop just below the soil.

5. Mundesley Sands White-yellow, current bedded sands.

6. Third Till Now not so well exposed as when Reid mapped; dubious remnant only north of Happisburgh (at TG375318).

7. Sands (etc.) occupying a valley feature to the south of Happisburgh Coast Guard Station (TG 388308) rest unconformably upon beds below (and including ?) the Second Till (cf. the Bacton Valley Gravels, West & Banham, 1968, p. 495).

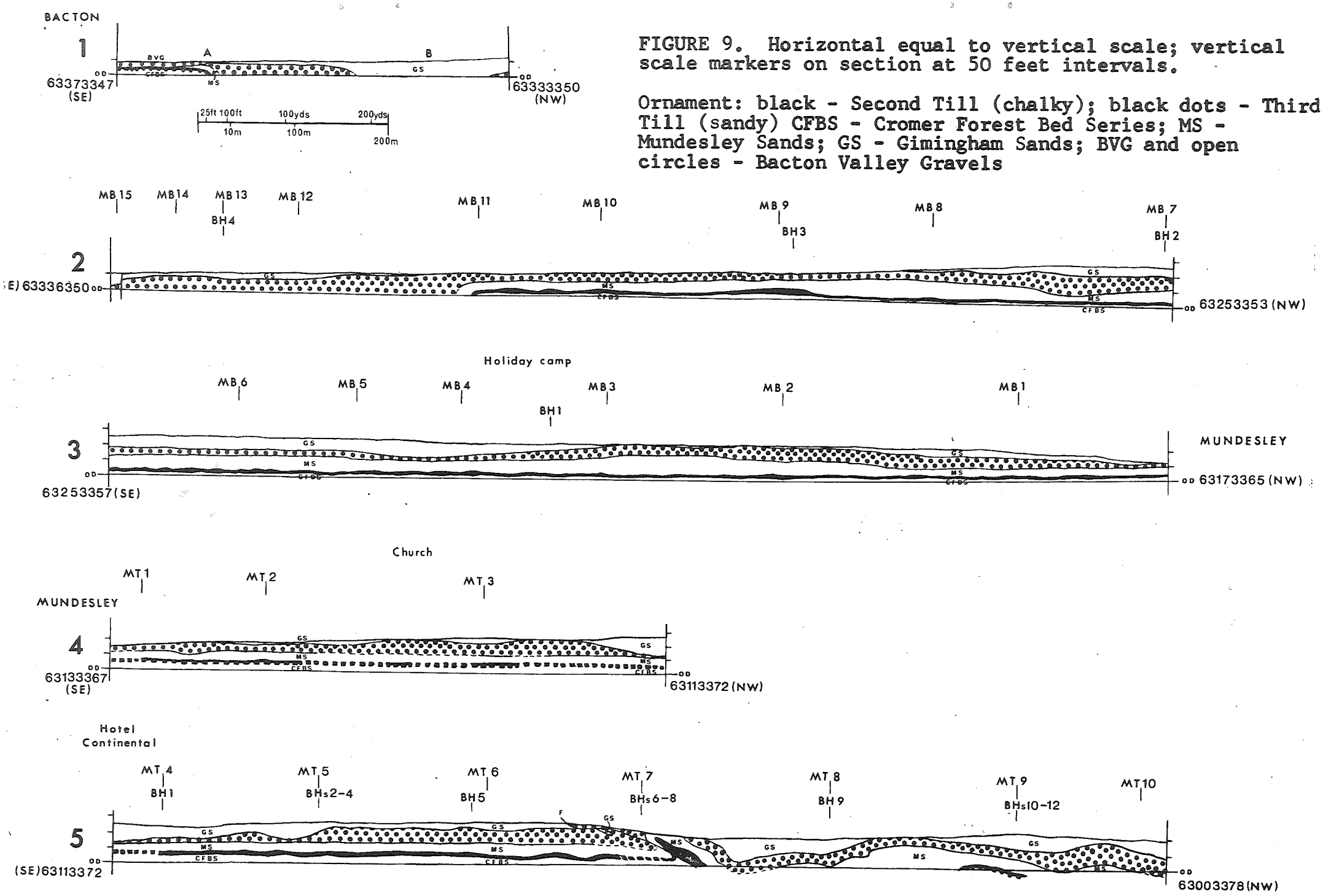



FIGURE 9. Horizontal equal to vertical scale; vertical scale markers on section at 50 feet intervals.

Ornament: black - Second Till (chalky); black dots - Third Till (sandy) CFBS - Cromer Forest Bed Series; MS - Mundesley Sands; GS - Gimingham Sands; BVG and open circles - Bacton Valley Gravels

## LOCALITY 2 MUNDESLEY

(Bacton - Trimingham: TG340345 - TG300378)

(PHB)

The instructive cliff-sections immediatley to the north of Bacton (West & Banham, 1968, p. 495) are now unfortunately largely obscured by artificially seeded grass in the region of the Bacton North Sea Gas Terminal. The sections to the north of Mundesley show the same succession, somewhat deformed by glacial tectonics. Recent interpretations of the stratigraphy (Banham, 1968; Banham & Ranson, in press) generally agree with those of Reid (1882).

Succession (approx. maximum thicknesses given) (see fig. 9)

6. Bacton (& Mundesley) Valley Gravels 9m+
5. Gimingham Sands 17m+
4. Third Till 14m
3. Mundesley Sands 13m
2. Second Till 5m
1. Cromer Forest Bed Series 4m+

NB: The First Till and Intermediate Beds (of Happisburgh, etc.) are absent in this area.

Descriptions of the Beds

1. Cromer Forest Bed Series

(RGW)

The Cromer Forest Bed sections were well exposed a few years ago before the sea wall was built. The succession is similar to that at Bacton, except that freshwater peats of Cromerian age were exposed above the Elephant Bed.

North-west of Bacton the following succession can sometimes be seen:

3. Arctic Freshwater Bed of Reid
   Plant-rich bluish silts (Lowestoftian) 1-3 m.
2. Laminated estuarine silts (Cromerian transgression) 2-3 m.
1. The so-called Elephant Bed, a ferruginous gravel and clay conglomerate, containing bone fragments. The deposit contains reworked clay lumps of Pastonian age.

A borehole on Mundesley foreshore showed some 6 m. of grey marine or estuarine silts, then Chalk. The silts are of Baventian age, and are to be correlated with the basal beds on the Chalk below the Pastonian between West Runton and Sheringham.

(PHB)

2. The Second Till is a hard, grey, chalky till, lensoid in vertical outcrop, especially south of Mundesley.

Erratics (975: 100+ from each of 9 stations between Mundesley and Bacton)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 33-56 | 43 |
| Chalk | 22-56 | 42 |
| Quartz & -ite | 4-20 | 9 |
| Exotics | 3-8 | 6 |
| Shells | 0 | 0 |

Structures Infrequent flat, tight minor folds within the Second Till plunge at low angles to both the NW and SE quadrants. Much more numerous, open folds with steep axial planes developed in places immediately below the till in the upper 1m+ of the CFBS also plunge NE-SW and, moreover, are consistently overturned to the SE.

Associated with the larger of the folds (both within and below the till) occur approximately axial planar shears which strike NE-SW and dip at low-moderate angles (30°-60°) to the NW.

Erratic pebble lineations (831: at least 50 from each of 14 stations between Bacton and Trimingham) trend very consistently NE-SW (strong, single peak in each case) with an average direction of 052° (-040° at M-T).

It is concluded that the second till ice moved into the area from the NW, i.e. the pebble lineation is transverse (Banham, 1966), West & Donner, 1956, p. 72 also concluded that this ice had moved from the NW (approx.) on the basis of a pebble diagram with a peak at 300°.

(CER)

3. Mundesley Sands

Extent

The Mundesley Sands are seen only in cliff sections between Bacton (TG336347) and Beeston Regis (TG170435). Well records from near the coast indicate that the Sands extend at least four or five kilometres inland south of Cromer. The maximum known thickness of the Sands is 18m.

It would seem that the Mundesley Sands had a much wider distribution at the time of deposition: none of the exposures shows any marginal features or significant variations in lithology.

Exposures

(a) From Bacton to Mundesley (TG300378) the Mundesley Sands are seen lying on the eroded surface of a grey chalky boulder clay (Reid's 1882 Second Till, Solomon's (1932) Lower Till, Banham's (1968) Second Till). South of Mundesley it is relatively undisturbed, but north of Mundesley,

it and the rest of the sequence is often folded and in many places the depositional features have been disturbed.

The base of the sands is usually pebbly and the lowest metre or so is often rich in small chalk pebbles and grains. From the base to the top the Sands are almost entirely cross-stratified with numerous erosion surfaces. At intervals, beds of finer sands and silt occur.

Micro-cross-lamination (nu cross-stratification) and ripple drift bedding (kappa cross-stratification) with some laminar bedding occur throughout the Sands. These features are made conspicuous in sections by the concentration of carbonaceous grains on their foresets.

Sets of cross-stratified sands extend to 8m. thick and 50 m. long, but individual units range from 2 - 8 cm high and up to 30 cm long.

The finer silty beds occasionally show grading from sand at the base to fine silt and even clay near the top.

In several places, the finer, silty horizons are associated with ice-wedge casts and apparent croyoturbation. Except for one very large cast, they are entirely contained within the Sands.

(b) Where there has been more extensive disturbance, for example at Overstrand (TG247412) and Cromer (TG230417), the lithological features can still be seen quite clearly. Here, far fewer beds of silty sand are seen.

(c) At Beeston, only dislocated fragments of the Sands, not more than 2 m by 5 m, are seen in the grossly distorted and reconstituted glacial sequence, though they still retain the chief characteristics seen further south.

Petrology and Microscopic Features

Table 1 shows analyses of pebble samples from the Sands.

Solomon (1932) has published the results of his minerological studies of the Sands.

In addition to sand grains, there is a significant proportion of carbonaceous matter, apparently coal, with occasional spores from pteridophyte tetrads. There are also frequent shell fragments. A fauna of derived foraminifera has been collected and it is composed of U. Cretaceous, late Tertiary and Quaternary forms. The Chalk pebbles yield a fauna identical with that of the B. mucronata Zone of the Chalk.

Sedimentary Environment

There seems little doubt that the basal part of the Sands is composed of material eroded from the underlying boulder clay. The sedimentary structures throughout the Sands are essentially fluviatile in character. The bulk of the Sands probably came from the retreat of

# TABLE 1

## PETROLOGICAL DATA FROM THE WATER-LAIN STRATA OF MUNDESLEY CLIFFS

1. Petrology of the pebbles of each of the beds (intermediate diameter between 8 and 32 mm.) excluding chalk.

| Bed | No. of Pebbles | No. of Samples | Flints % | Quartz % | Quartzite % | Others % |
|---|---|---|---|---|---|---|
| Paston Sands = Sands & Gravels = Gimingham Sands | 266 | 4 | 88.0 | 6.4 | 3.7 | 1.9 |
| Mundesley Sands | 370 | 10 | 81.3 | 6.4 | 7.5 | 4.8 |
| Cromer Forest Bed Series | 673 | 2 | 51.4 | 23.8 | 22.6 | 2.2 |

2. Rock types, excluding flint and chalk, in the samples analysed from the table above.

| Bed | No. of Pebbles | Quartz % | Quartzite % | Sandstone % | Igneous % | Metamorphic % | Others % |
|---|---|---|---|---|---|---|---|
| Paston Sands = Sands & Gravels = Gimingham Sands | 32 | 53 | 31 | 0 | 10 | 0 | 6 |
| Mundesley Sands | 70 | 35 | 40 | 14 | 4 | 2 | 5 |
| Cromer Forest Bed Series | 328 | 49 | 46 | 0 | 0 | 0 | 4 |

the ice-front which produced the underlying boulder clay. Measurement of palaeocurrent directions in the Sands show that the water flow was almost exlcusively from southwest, west or northwest.

The siltier beds are probably deposits laid down in abandoned channels and other quiet water in what was otherwise a wide pro-glacial alluvial plain.

4. Third Till (PHB) Brown, sandy till with numerous sand "rafts" and laminae much folded. The upper part of this till contains more and larger sand rafts, fewer chalk erratics and more quartz and quartzite erratics than the lower part.

Erratics (1110: 100 from each of 11 stations, Mundesley-Bacton only)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 43-73 | 63 |
| Chalk | 0-9 | 5 |
| Quartz & -ite | 3-26 | 13 |
| Exotics | 5-23 | 16 |
| Shells | 0-10 | 5 |

Structures Folds: within the till, tight folds with axial planes within the normally sub-horizontal lamination are often re-folded by much larger more open folds with generally steep axial planes. Both fold sets plunge at low angles N-S (approx.). Below the till in places in the upper 1-2 m of the Mundesley Sands occur a few open folds of similar trend (i.e. N-S approx.) and these are normally overturned to the E.

Erratic pebble lineations (604: at least 50 from each of 11 stations between Bacton and Trimingham), represented on rose diagrams normally show either a good simple peak near N-S, or a clear cross with peaks near N-S and E-W. There is a special relationship between pebble long axis orientations and the positions of the pebbles in the flat folds (Banham, 1966). Briefly, pebbles in fold axial plane zones are lineated parallel to the fold axes (i.e. N-S), whereas those in limb zones are lineated normal to the fold axes (i.e. E-W).

It is concluded that the Third Till ice moved into the area from the W. (although the evidence for this is not substantial and a movement from the E is an alternative possibility).

5. Gimingham Sands (CER)

Extent

These beds lie at or near the top of the glacial sequence in northern and eastern Norfolk. They, or other indistinguishable deposits, are seen in the cliffs between Happisburgh (TG390306) and Cromer (TG230417) and inland in pits and on heaths; and they have recently been exposed in the continuous trenches excavated for the gas pipe lines radiating westward from Bacton. From these various sources, it is evident that the Sands and Gravels extend west and south at least as far as Oulton (TG150290) and Honingham (TG110125). The maximum known thickness of the beds is 30m.

Exposures

(a) In the cliffs between Happisburgh and Cromer these sands and gravels lie on the eroded surface of the Boulder Clay, Stony loam and Contorted Drift of Reid (equivalent to the Upper Till and Great Chalky Boulder Clay of Solomon and the Third Till of Banham). Above the thin pebbly basal bed with occasional boulders are large scale sets of cross-stratified sands (mainly beta and chi types. 10-20 cm thick).

On the erosion surfaces beneath many of the sets of cross-strata scatterings of small pebbles often occur. These are virtually the only pebbles found in the sands away from the base.

At a few horizons within the Sands and Gravels, there are thin (1-5cm) continuous (up to 30m) laminae of silty sand or silty clay.

However, within the Sands and Gravels between Mundesley (TG305375) and Sidestrand (TG258404), there is a more or less continuous bed of laminated fine sands, silts and clays, varying between 3m and 5m in thickness. These laminated beds have a considerable amount of calcium carbonate mud in them. They are best seen in situ at Mundesley, but fallen blocks are usually found on the beach at Sidestrand: at Mundesley, frost wedges occur within the laminated beds and at least one penetrates the underlying lower part of the Sands and Gravels.

The clays are mainly illite and kaolinite.

(b) Inland, there are numerous exposures within a few miles of the coast, for example, North Walsham (TG291288), Swafield (TG298329), Bryant's Heath (TG258294). These all show the same characters as the coastal section except the base is not seen and there is no thick sequence of silts and clays.

(c) To the west of Cromer and along the Cromer-Edgefield-Holt ridge there are a number of exposures of sands and gravels in the cliffs and inland. These are dealt with separately.

Petrology and Microscopic Features

Table 1 shows analyses of pebble samples from the Sands and Gravels. Solomon (1932) has published the results of his minerological studies of the Sands and Gravels.

There is very little other than pebbles, sand and clay in these beds. Occasional fragments of unidentified organic matter have been found. A high proportion of the sand grains is rounded.

Sedimentary Environment

There is no direct evidence of the origin of the Sands and Gravels. The underlying Boulder Clay is extremely sandy in places, and even contains numerous lenses of sands, probably derived from the Crag.

Solomon (1932) recorded a similarity between the heavy minerals of the Boulder Clay (Great Chalky Boulder Clay) and the Sands and Gravels (Chalky Outwash Sands and Gravels).

It would seem that the Sands and Gravels are either derived from or belong to the same glacial event as the underlying Boulder Clay.

Palaeocurrent measurements on the coast indicate a northerly source for the sands. Inland measurements show a generally north-easterly origin.

It would seem that the Sands and Gravels are essentially glacio-fluvial outwash, much the same as the Mundesley Sands, but laid down by more vigorously flowing water. The occasional thin seams of silt and clay accumulated in slack water possibly below ice and the thick sequence of laminated silts and clays probably accumulated in a lake at least 5 km across.

6. Bacton Valley Gravels (PHB) These fill a valley feature under the parish of Bacton and rest unconformably on all the lower members of the succession in this area (with the possible exception of the CFBS). The highly fossiliferous "Mundesley River Bed" (Reid, 1882) has not been exposed for many years.

Later Structures Generally weak, post-Gimingham Sands folding to the south of Mundesley appears to have been about axes which trend very approximately N-S (as does a normal fault with a downthrow of 3m, West & Banham, 1968 p. 497 and gig. 1). However, to the north of Mundesley, near Trimingham, the first of a series of large, overturned, isoclinal folds which affect the entire succession, plunges at a low angle to 110°. Within a short distance to the north, Peake & Hancock (1961, fig. 9) found three similar, even larger folds, which also affect the underlying chalk; these have trends of 96°, 118° and 122°. Overturning to the south seems general, and it is concluded that it is possible that later ice movements from the N (approx.) caused the deformation of the beds in this area (i.e. north of Mundesley).
NB: No post-Gimingham Sands Till has been found here or in NE Norfolk as a whole.

## LOCALITY 3 OVERSTRAND - CROMER

This section is well within the "Contorted Drift" defined by Reid (1882 p. 92) as outcropping to the NW of Trimingham. The normal succession (of Happisburgh, Mundesley, i.e.) has been tentatively identified, as, indeed, Reid predicted might be possible after detailed work.

Succession (approximate maximum thicknesses are given for undeformed portions of the beds)

8. Brick Kiln Dale Gravels 9m+ (part of "Plateau Gravels" of early workers (?) )
7. Gimingham Sands 13m
6. Third Till 13m
5. Mundesley Sands (?) 6m
4. Second Till 2m
3. Intermediate Beds(?) 2m+
2. First Till 3m
1. Cromer Forest Bed Series 2m+

Descriptions of the Beds

(RGW)

1. Cromer Forest Bed Series

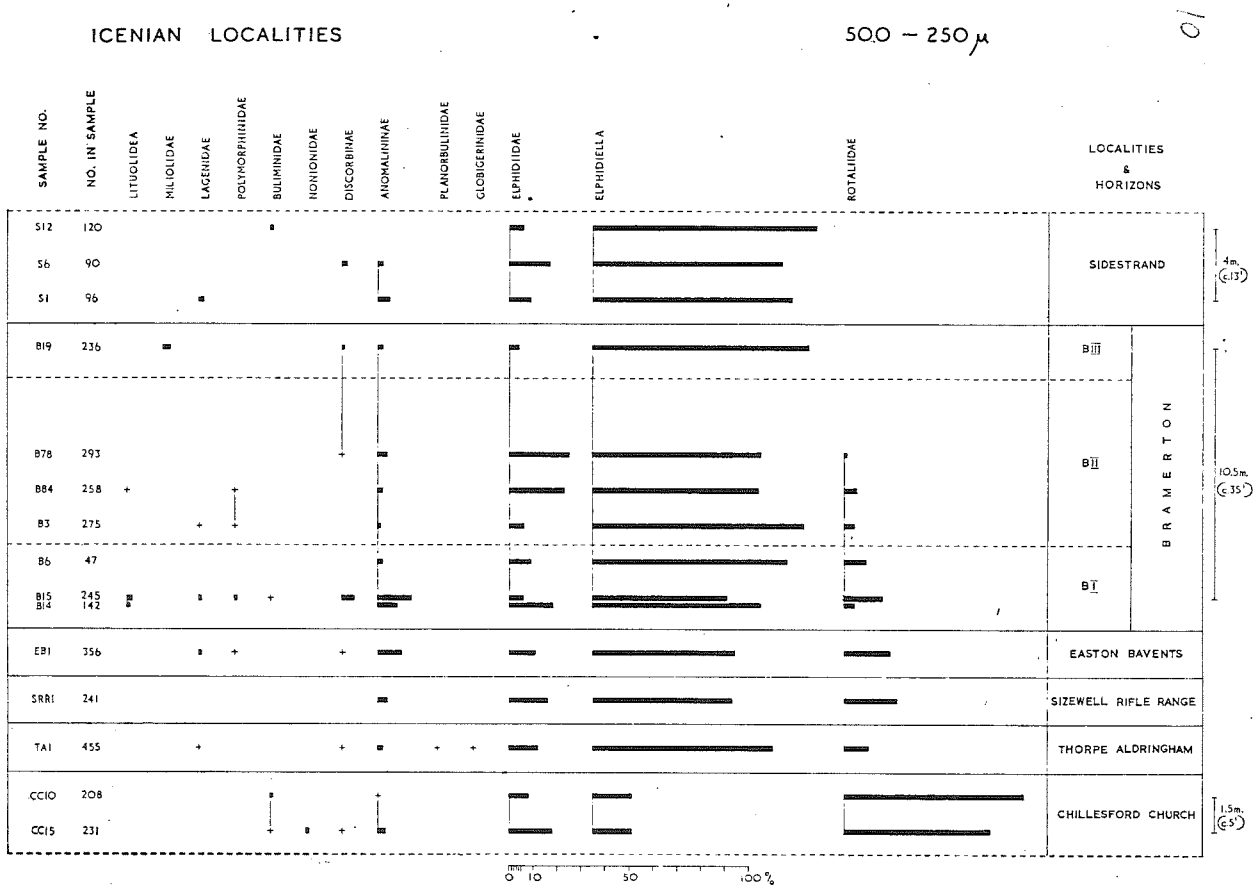
Above the Chalk erratic at Sidestrand there are several metres of grey and yellow sands, with marine shells at the base, and thin grey silt horizons in the lower part. A pollen diagram from the section indicates cold climatic conditions with open vegetation. The restricted foram fauna (Funnell, 1961) suggests cold conditions, and so does the impoverished mollusc fauna (Norton, 1967). The mollusc fauna includes *Macuna balthica* and is a typical Wybourne Crag fauna. The shelly sands and silts are probably of Baventian age. See figs. 10, 11 and 12.

(PHB)

2. First Till Homogeneous, dark brown, sandy till with rather few, small, generally rounded erratics.

Erratics (400: 100 from each of 4 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 54-65 | 57 |
| Chalk | 2-5 | 4 |
| Quartz & -ite | 10-21 | 14 |
| Exotics | 6-24 | 16 |
| Shells | 4-14 | 9 |



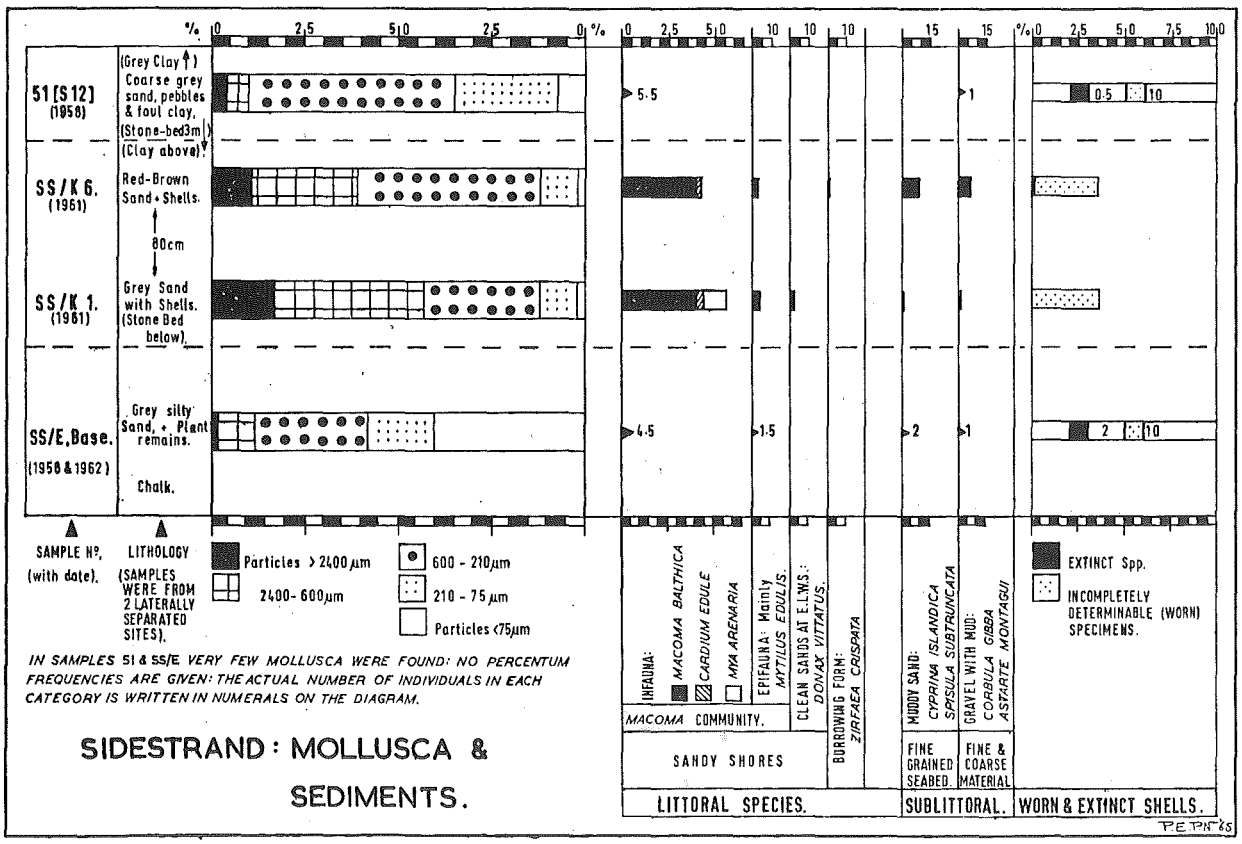

General composition of foraminiferal assemblages

FIGURE 10

## Sidestrand Mollusca

Frequencies are given as percentages (method of calculation, see p. 168) except where figures in *italics* represent the actual number of individuals seen. A dot indicates a nil result.

| | species | SS/E base | SS/K 1 | SS/K 6 | S 12 (51) |
|---|---|---|---|---|---|
| intertidal species | *Littorina littorea* | × | × | . | . |
| | *Macoma balthica* | *4·5* | 39·7 | 39·8 | *5·5* |
| | *Cardium edule* | × | 3·8 | 3·1 | . |
| | *Mya arenaria* | . | 12·8 | . | . |
| | *Hydrobia ulvae* | *1* | 1·3 | . | . |
| | *Mytilus edulis* | *0·5* | 2·6 | 3·1 | *0·5* |
| | *Donax vittatus* | × | 1·9 | . | . |
| | *Zirfea crispata* | . | . | 0·8 | . |
| subtidal species | *Cyprina islandica* | *1* | 0·6 | 1·6 | *0·5* |
| | *Spisula subtruncata* | *1* | 0·6 | 7·8 | . |
| | *Astarte montagui* | . | 0·6 | . | . |
| | *Corbula gibba* | *1* | . | 6·2 | *1* |
| incompletely determinable forms | *Astarte* sp. | . | 0·6 | . | . |
| | *Cardium* sp. | . | . | 3·1 | . |
| | *Gastropod* sp. | *2* | 2·6 | 3·1 | *2* |
| | *Lamellibranch* sp. | *2·5* | 12·8 | 13·3 | *3·5* |
| | *Mya* sp. | . | . | 0·8 | . |
| | *Pholas* sp. | . | 1·9 | . | . |
| | *Spisula* sp. | . | 0·6 | 0·8 | . |
| | *Tellinid* sp. | *2·5* | 3·2 | 10·9 | *3* |
| | *Yoldia* sp. | *3* | 10·3 | 2·3 | *1·5* |
| extinct spp. | *Macoma obliqua* | *2* | . | . | . |
| | *Nucella lapillus vulgaris* | × | . | . | . |
| | *Nucula cobboldiae* | . | × | 0·8 | *0·5* |
| | *Yoldia* cf. *oblongoides* | *0·5* | . | . | . |
| | *Tornus supranitidus* ?? | . | 1·3 | . | . |
| | individuals | 20·0 | 78·0 | 64·5 | 18·0 |
| | species | 15 | 20 | 15 | 9 |
| | % contribution of 1 individual | — | 1·28 | 1·55 | — |




Sidestrand Mollusca (ecological groups) and granulometric analysis. Four samples from three horizontally separated localities are represented

**FIGURE 11**

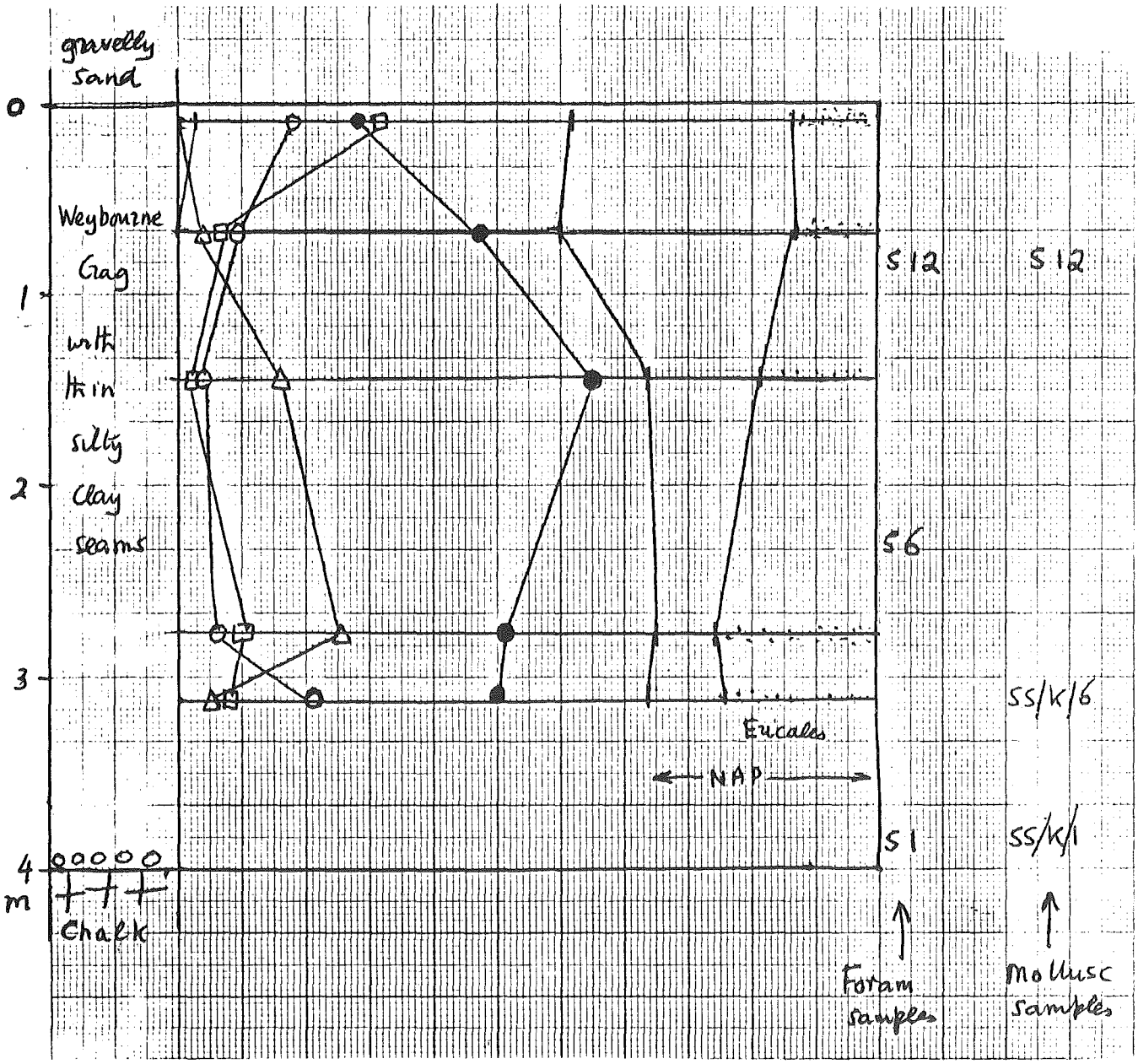

gravelly sand
0
Weybourne Crag with thin silty clay seams
1
2
3
4
m
Chalk
S12
S12
S6
SS/K/6
Eucales
NAP
S1
SS/K/1
Foram samples
Mollusc samples

FIGURE 12

Structures No folds which were undoubtedly formed at the time of the emplacement of the First Till have been found. A few rather steep, open folds which affect the top of the CFBS and the bottom part of the First Till trend 140° - 170°.

Erratic pebble lineations (50+ from each of 2 stations) when plotted show a single strong peak at 035°.

Ice movement from the NE is perhaps most likely, although the evidence is slim.

3. Intermediate Beds (?) Laminated clays with occasional lighter, silty beds overlie the First Till immediately north of Overstrand.

4. Second Till A relatively soft (because waterlogged) grey, chalky till with many chalk erratics.

Erratics (200: 100 from each of 2 stations, i. e. excluding Second Till (?) involved in the more intensely deformed parts of the section - see later)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 34-36 | 35 |
| Chalk | 54-56 | 55 |
| Quartz & -ite | 6-7 | 7 |
| Exotics | 2-4 | 3 |
| Shells | 0-1 | 1 |

Structures In the small in situ outcrop available no folds have so far been found either within or below the Second Till.

Erratic pebble lineations (50+ from each of 2 stations); each sample shows a strong, single peak at 020° (approx.). Ice movement from 290° is possible by analogy with Mundesley.

5. Mundesley Sands (?) Pale yellow, bedded and current bedded sands overlie the Second Till immediately to the north of Overstrand. Even here this bed everywhere terminates upward at a more or less sharp plane of glacial tectonic dislocation.

6. Third Till This till nowhere rests upon undeformed lower beds. It is, as at Mundesley (etc.), typically an inhomogeneous, brown, sandy till containing numerous sand rafts and laminae which highlight the presence of very numerous folds.

Erratics (500: 100 from each of 5 stations)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 75-81 | 79 |
| Chalk | 0-8 | 2 |
| Quartz & -ite | 2-15 | 11 |
| Exotics | 6-10 | 8 |
| Shells | 0-3 | 1 |

Structures Folds which are flat and relatively tight are numerous; refolding about more open, steeper folds also occurs. Both these sets plunge at low angles to NE and SW (of Mundesley N-S). No unambiguous, general direction of overturning has been deduced.

Erratic pebble lineations (215: at least 50 each of 4 stations) at each station show the characteristic Third Till cross peaks. One peak trends NE (044° on average) and the other SW (145° on average; this slightly skewed cross, also shown by individual samples, is of interest) (see Mundesley account for relations of pebbles and folds).

Conclusion ice-movement from NW (or SE ?).

7. Gimingham Sands Yellow-orange sands and gravels

8. Brick Kiln Dale Gravels (Banham, 1968 p. 508). The type locality for this bed is between Overstrand and Cromer (TG233495). They are coarse flint gravels and may consist of two rather distinct beds. They are possibly the lateral equivalents of the Britons Lane gravels of Baden-Powell (1948).

Later Structures

As the result of both syn-Third Till and post-Brick Kiln Dale Gravels deformation, three sub-horizontal glacial tectonic zones were developed and can be recognised in the field (see Banham 1968 fig. 2).

The first of these is located below a plane of decollement, which throughout most of the section, lies within, or at the top of, the ? Intermediate Beds (fine, laminated clays), but which passes up through the Second Till into the ? Mundesley Sands near Overstrand. Below this tectonic plane the beds are normally undeformed, although a few large, open, steep approximately symmetrical folds of NE trend (usually) do occur where this lowest zone is thickest near Overstrand.

The second tectonic zone rests upon the plane of decollement and consists mainly of lithologies, which, during mapping, were provisionally assigned mainly to the Second Till and ? Mundesley Sands. Subsequent erratic counts (400: 100 from each of 4 stations) would seem to confirm the presence of the Second Till.

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 33-61 | 48 |
| Chalk | 17-63 | 42 |
| Quartz & -ite | 3-13 | 6 |
| Exotics | 1-9 | 4 |
| Shells | 0-4 | 1 |

(a general decrease in chalk erratics is to be expected in view of their softness and the degree of deformation suffered).

Smaller amounts of other, less chalky till which may consist in large part of First Till, can be found, especially near Overstrand.

Within this second tectonic zone these beds (i.e. First Till- ? Mundesley Sands) have been much folded and thrust. Around Kirby Hill (TG239413) the folds are very large (30m+ from crest to trough), tight isoclines, the Second Till cores of which have usually diapired up through the enclosing ? Mundesley Sands along the axial planes of the anticlines. Further south-east, folds are much flatter, tighter and disrupted by axial planar thrusts. The dominant trend of all these folds is NE-SW (although a significant minority of the same styles, and, apparently, age, trend NW-SE). Overturning to the SE is usual. (NB: the Third Till is not involved in these structures).

The third tectonic zone is limited below by the base of the Third Till and includes that bed together with the overlying Gimingham Sands and Brick Kiln Dale Gravels. These beds have been thrown into large, open, steep synclines and anticlines which appear to trend dominantly from NNE-NNW and which show a slight overturning to the E. A large thrust in the south-east limb of the syncline ("sand basin") at Kirby Hill strikes NNE and dips 40 W. These folds have markedly little effect upon the structures in the tectonic zones below. The Third Till here (as elsewhere, e.g. Mundesley and West Runton), has acted as a buffer - thinning along synclinal axes and thickening (and diapiring) along anticlinal axes.

The large chalk raft in the cliffs near Cromer is emplaced in what almost certainly is the Third Till (or so erratic pebble counts would seem to indicate).

Conclusions concerning late structures

It seems possible that the structures within the second tectonic zone (plus the few late folds which affect the first zone) were formed at the time of the emplacement of the Third Till. These folds share a NE-SW trend with those actually within the Third Till, and movement of the depositing ice from the NW seems most probable.

The third tectonic zone structures are clearly post-Brick Kiln Dale Gravels in age, however, and appear to have resulted from movements from the W. However, no post BKDG till has been found and apparently very similar structures elsewhere have been attributed to "static" perma-frost activity (e.g. Dzulynski, 1964, fig. 1).

(NBP) Fig. 13 shows details of one of the chalk rafts at Overstrand.

LOCALITY 4 EAST RUNTON

(NBP)

At East Runton, as at other points along the coast, massive chalk rafts occur within the "Contorted Drift". Figure 14 shows some of these rafts and the structures associated with them.

## DAY 3 WEST RUNTON-CROMER RIDGE-HOLT-WEYBOURNE

The day's excursion encompasses several rather different zones. Firstly, at West Runton there occurs the best section that we shall see in the Cromer Forest Bed Series, overlain by some excellent sections in the "Contorted Drift". We then travel along the line of the Cromer-Holt ridge, the outstanding topographic feature of north Norfolk, and see some of the gravels of this ridge exposed at Britons Lane Pit. Lying to the north of the ridge in the Holt area, there occurs a sandar plain complex and a series of hummocky gravel mounds, considered by some to be kames, and by others to be erosional remnants. On the coast at Weybourne, another stratified folded till sequence occurs which has been correlated (Banham) with the "Contorted Drift" of West Runton.

The main problems apart from those of genesis of the "Contorted Drift", and correlation along the coastline are of stratigraphy in an area of poor exposure where geomorphic criteria are most important.

### LOCALITY 1 WEST RUNTON

Succession (maximum thicknesses given)

5. Gravels of Beeston Hill 17m+ (Plateau Gravels ?, Britons Lane Gravels ?, Brick Kiln Dale Gravels ?)
4. Sands 15m+ (Gimingham Sands ?)
3. Contorted Drift 60 m+
2. Cromer Forest Bed Series 11m+
1. Chalk 1m+

Description of Beds

1. Chalk Exposed at low tide on the foreshore

(RGW)

2. Cromer Forest Bed Series

A rather complete succession of Cromer Forest Bed Series has been seen in this area over the past ten years (fig. 15). The sequence shows both freshwater and estuarine facies, with fossils and ice-wedge casts indicating successive temperate and cold conditions.

The area can be considered marginal to the pre-glacial estuary or coastline of the southern part of the North Sea, perhaps near the estuary of the "Rhine plus Thames", as suggested by Clement Reid. The sequence is shown in fig. 15. The Upper Freshwater Bed is the type deposit for the Cromerian stage. It overlies a "late-glacial" marl

Chalk Bluff east of Overstrand

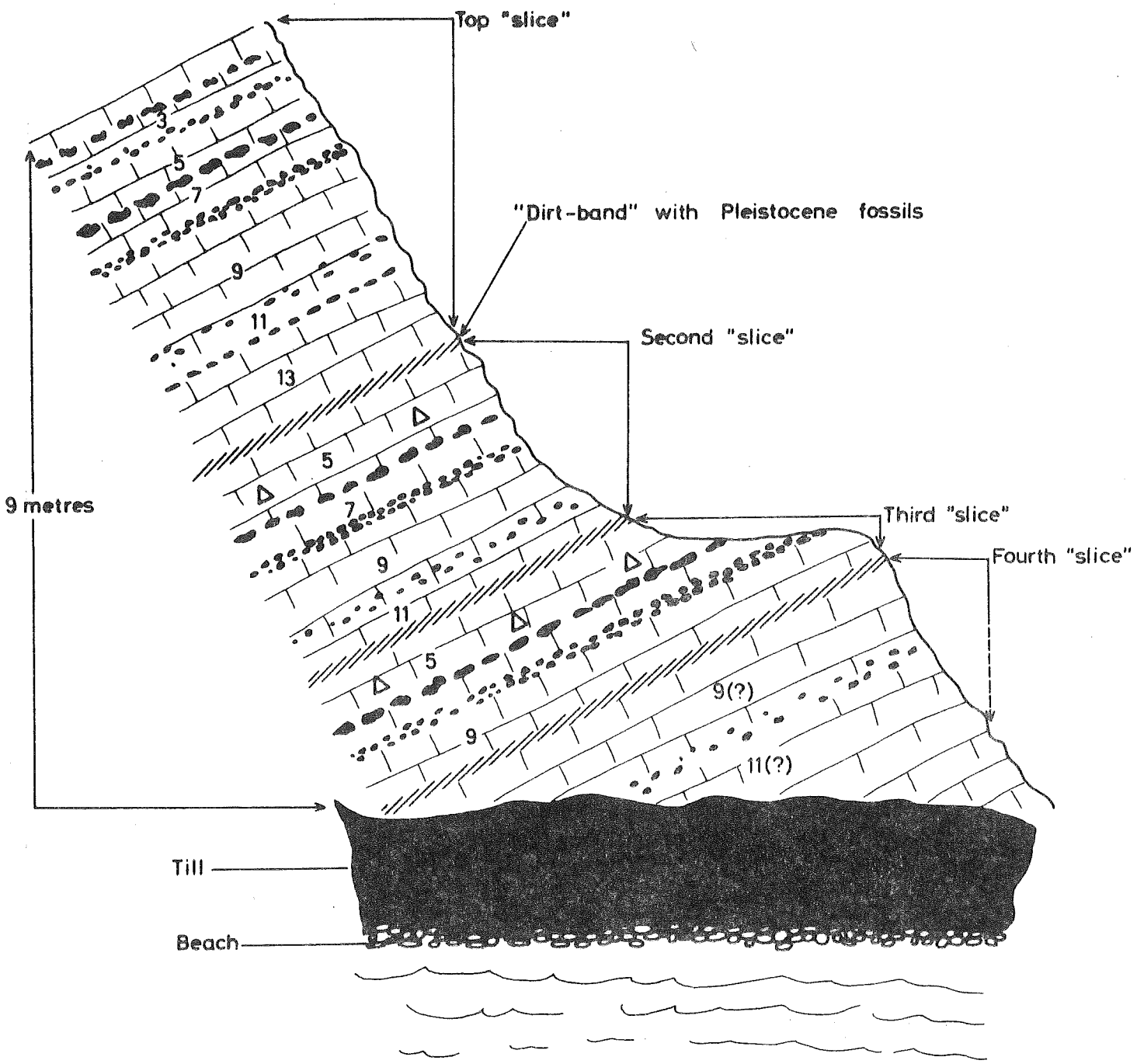



FIG. 13

# Section immediately west of East Runton

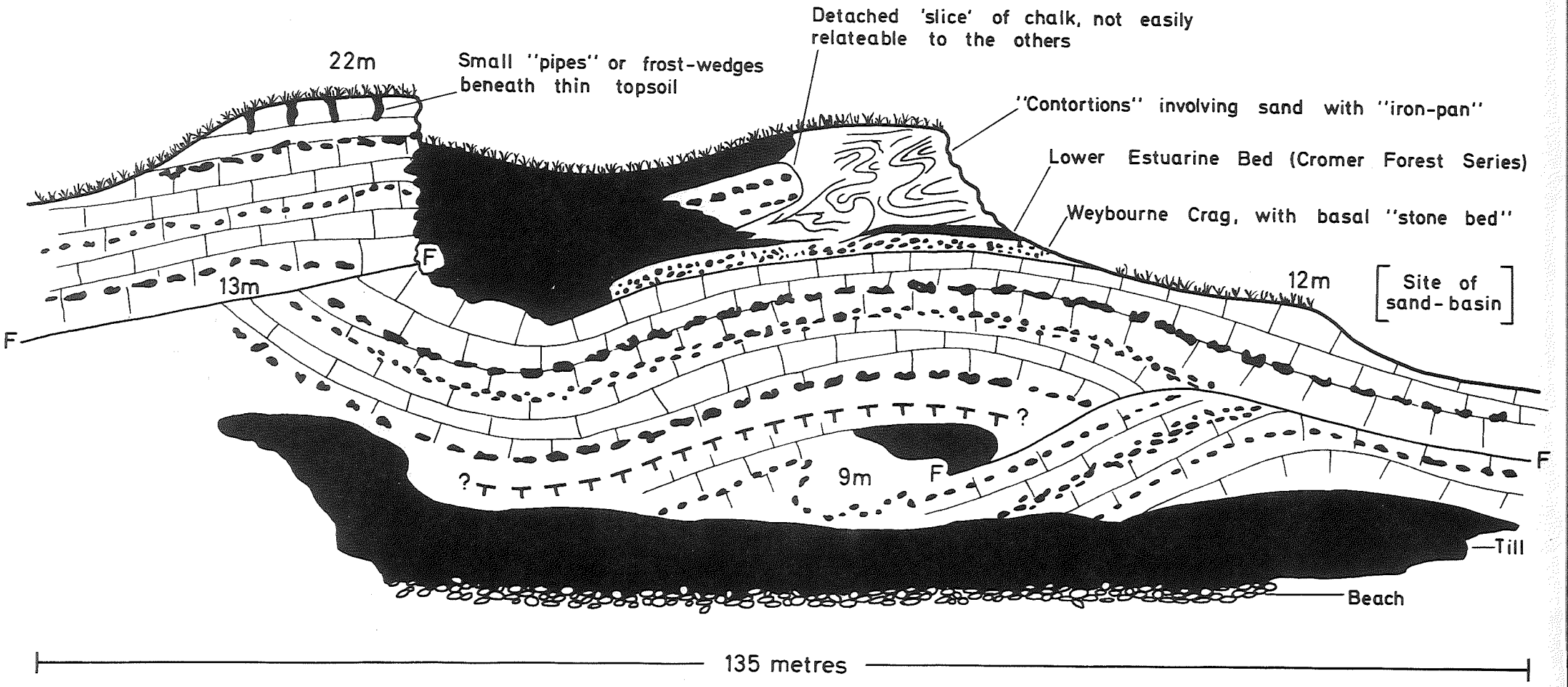
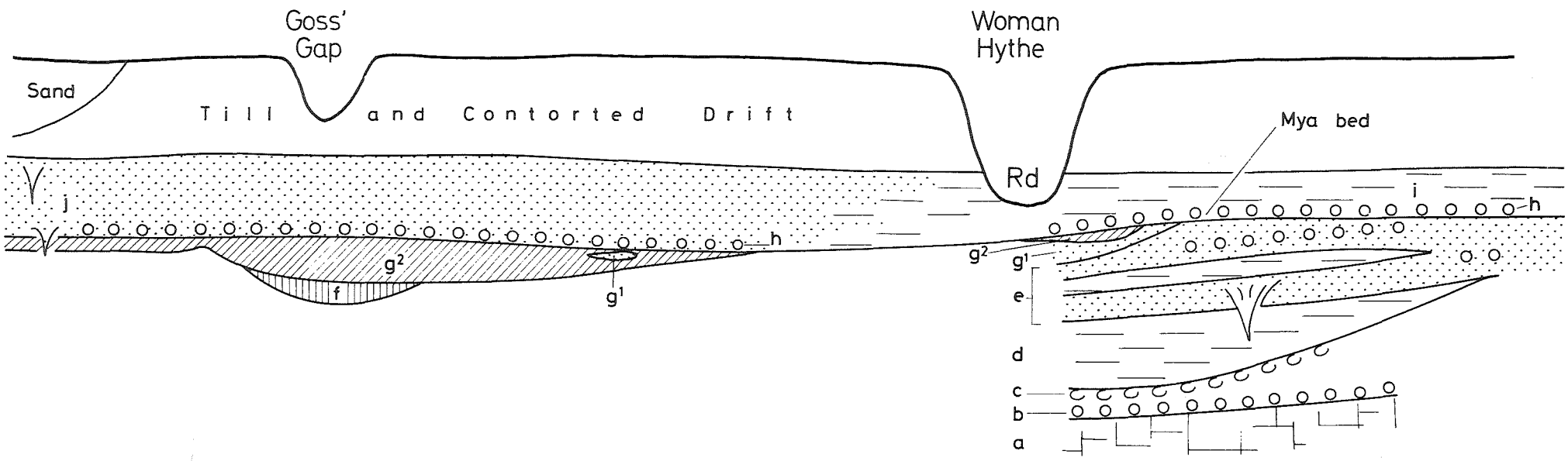



Fig. 14

# Section at West Runton Gap 1960 - 1969




| | | | |
|---|---|---|---|
| LOWESTOFTIAN | j | Yellow sands, ice-wedge casts | Regression |
| CROMERIAN | i | Estuarine silts | Transgression |
| | h | Flint gravel, with Mya | |
| | $g^2$ | Freshwater mud | |
| | $g^1$ | Freshwater sands, shelly | |
| BEESTONIAN | f | Late-glacial marls | |
| | e | Sands and gravels, thin silts, ice-wedge casts | |
| PASTONIAN | d | Estuarine silts | Regression |
| | c | Shelly sand, marine | Transgression |
| | b | Stone bed | |
| | a | Chalk | |

J.T.

Fig. 15

horizon. Several difficulties of pollen analysis are illustrated by the U. F. W. B. section. Derived lumps of late-glacial marl are present in the interglacial mud. Weathered mud at the upper interface of the U. F. W. B. contains a pollen flora heavily affected by weathering.

The relationship of the horizons named in fig. 15 tallies well with Clement Reid's description of the section, but he thought that only one temperate period was indicated. The Weybourne Crag in this area is Baventian in age in some sections where the basal stone bed contains molluscs. Elsewhere it appears to be Pastonian. Coombe Rock is seen on the Chalk surface below the stone bed. Presumably this originated in a pre-Pastonian cold period, before the marine transgression associated with the stone bed and its contained molluscs. Reid Moir described large ochreous flint implements from the stone bed opposite West Runton Gap. Are they artefacts or eoliths?

3. Contorted Drift and 4/ Gimingham Sands

Three possible explanations are offered for the structures in these beds, two by PHB, and another by GSB.

(PHB) - Contorted Drift

This "bed" occupies most of the cliff exposure in this section. It is extremely inhomogeneous. The till matrix consists of both sandy and chalky elements and contains many large sand rafts, but rather few, small, chalk rafts. During the mapping it was noted that the deposit was roughly "stratified" and a wide range of fold styles were characteristic. At the base it is a relatively homogeneous, brown, sandy till; above this, generally in the middle portions of the cliff, is a much chalkier zone, and this in turn is overlain by a thick upper zone of sandy till with many sand rafts, laminations and folds. Between the two upper zones occur frequent pods (boudin) of sands. Slater noted this zoning in the 1920s.

An hypothesis that here the Contorted Drift consists of the intensely deformed lateral extensions of the beds found further south-east appears to be borne out by the evidence of erratic pebble counts from various levels in the cliff.

Erratic pebble counts (1200: 100 from each of 12 stations); L - lower zone; M - middle zone; U - upper zone: a comparison with the figures for the First, Second and Third Tills respectively of other areas is at least suggestive.

| Lithology | L. | | M. | | U. | |
|---|---|---|---|---|---|---|
| | Range % | Av. % | Range % | Av. % | Range % | Av. % |
| Flint | 71-77 | 74 | 42-57 | 51 | 77-79 | 78 |
| Chalk | 6-15 | 9 | 20-52 | 34 | 0-2 | 1 |
| Quartz & -ite | 6-19 | 11 | 2-7 | 5 | 7-12 | 9 |
| Exotics | 3-7 | 5 | 3-18 | 8 | 9-16 | 12 |
| Shells | 0-1 | 0 | 1-3 | 2 | 0 | 0 |

Structures The approach to unformity of the trend of structures within and immediately below the Contorted Drift suggests what might be expected, that is, that later deformation has at least partly obscured and/or rotated any earlier structures. (Especially of the First and Second Tills; the upper zone, proposed Third Till equivalent, seems to be much less disturbed - cf. Overstrand-Cromer).

Two main fold sets can be recognised: flat, very tight, small folds which are refolded by much larger more open folds with steeply dipping axial planes. The early folds trend in the main between N-S and NE-SW (after removing later rotations). At the base of the Drift more open folds of this trend also involve the CFBS and are consistently overturned to the SE. Higher in the Drift the later, open folds are much more erratic both in trend and amount of plunge, (see also under "later structures"). (See also Dhonau & Dhonau, 1963).

The few small chalk rafts exposed here normally occur low in the Contorted Drift.

No erratic pebble lineations have been done recently. However, in 1955 Dr. West (personal communication) took measurements at four stations in this section. All diagrams are rather diffuse, but the strongest peak of each lies within 30° of 020°.

Conclusion The main deformation of the Contorted Drift was caused by ice-movement from the WNW (cf. Overstrand "Contorted Drift" and Third Till).

4. Sands (Gimingham Sands ?) Yellow-orange, current bedded sands preserved within late synclines (or tectonic basins).

Gravels of Beeston Hill Coarse, flint gravels preserved in the core of a complex, large, late syncline (tectonic basins).

Later Structures

Late, open, steep synclines and anticlines deform the succession above the CFBS. The lack of downward penetration of these folds is remarkable and came about, it is thought, because of the "buffer" effect of the Contorted Drift, which is thin along synclinal axes and thick (and diapired) along anticlinal axes. Many of the later, open folds of "variable" orientation within the Contorted Drift have undoubtedly formed as the result of lateral and upward till flow toward anticlinal crests.

That these "synclines and anticlines" are actually linear is debatable. The dips most often seen in an E-W section are to E and W, but N and S dips (plunges ?) do occur and the most likely conclusion, perhaps, is that they are elongated (approx. N-S) tectonic basins. That is, glacial tectonic, or alternatively, permafrost features; certainly they show no pronounced overturning.

(GSB) - Contorted Drift

Clearly defined at West Runton, and also occurring along the coast as far as Weybourne, there are a series of synclines of sand resting upon contorted and stratified tills. The stratification within the tills is formed by till bands of different composition, by chalky laminae, and sand laminae. These tills may pass into sands, silts and gravels through an interbedded zone, and sometimes contain large lenses and pods of sands and silts.

The deformational structures within this sequence have been described by P. H. Banham (above). There are three main types of fold, tight, isoclinal folds which effect only the till stratification, more open folds which equally affect tills and sands and gravels, and thirdly the sand synclines at the top of the cliff section. In these latter, the bedding in the sands at the margins of the synclines dips at angles much greater than the natural angle of rest of sands.

Such a sequence is shown in figure 16a, which illustrates one of the sand basins at West Runton. In addition to the above features, it should be noted that:

1. Overturned folds tend to be overturned in a direction away from the sand syncline.

2. The underlying Cromer Forest Bed series is relatively undisturbed.

3. The contacts between the sand synclines and till are not erosional.

4. The major folds affect the whole of the till-bearing sequence.

Origin of the till-bearing sequence

The detailed lithologies of the tills and their mode of variation are identical to those of modern tills known to be of subaqueous origin and probable of turbiditic facies. Stratification and internal folds develop during subaqueous flow away from the snout of a glacier which terminates in water (see figure 16b).

Whilst admitting that such stratified tills could theoretically develop from an in situ melt-out of an englacial load in which stratification reflects glacier foliation, there are strong practical reasons why the known subaqueous origin rather than the hypothetical englacial origin should be preferred.

The major folds and contortions

Pro-glacial streams, pouring into the sea (or a lake) beyond the margins of modern glaciers, seasonally dump considerable volumes of sediment as subaqueous sandbanks or deltas. I would suggest by analogy with these modern forms that the sand synclines at West Runton represent such sandbanks which have been dumped on top of a water soaked subaqueous till sequence, which has responded to this load by diapirism and flow away from the axis of the sandbank. The sandbank has thus sunk into the underlying till sequence and acquired oversteepened bedding at

its margins (fig. 16c-e). In addition to the major overturned folds, there are many structures indicative of loading of saturated sediments of differing mechanical properties, diapirs, mushroom and tear-drop structures etc.

It is obvious that the major contortions in these coastal sections are not a result of glacier overriding, and I would also suggest that the permafrost interpretation proposed by Banham (above) is also unlikely.

If one accepts the subaqueous origin of these tills and the associated folds, there then arises the problem of the nature of the water body in which they were deposited. A lake penned up by Channel land is an obvious possibility, but perhaps it would be more plausible to suggest regional depression of the crust under the load of a large ice cap, which might allow an arm of the sea along the ice front.

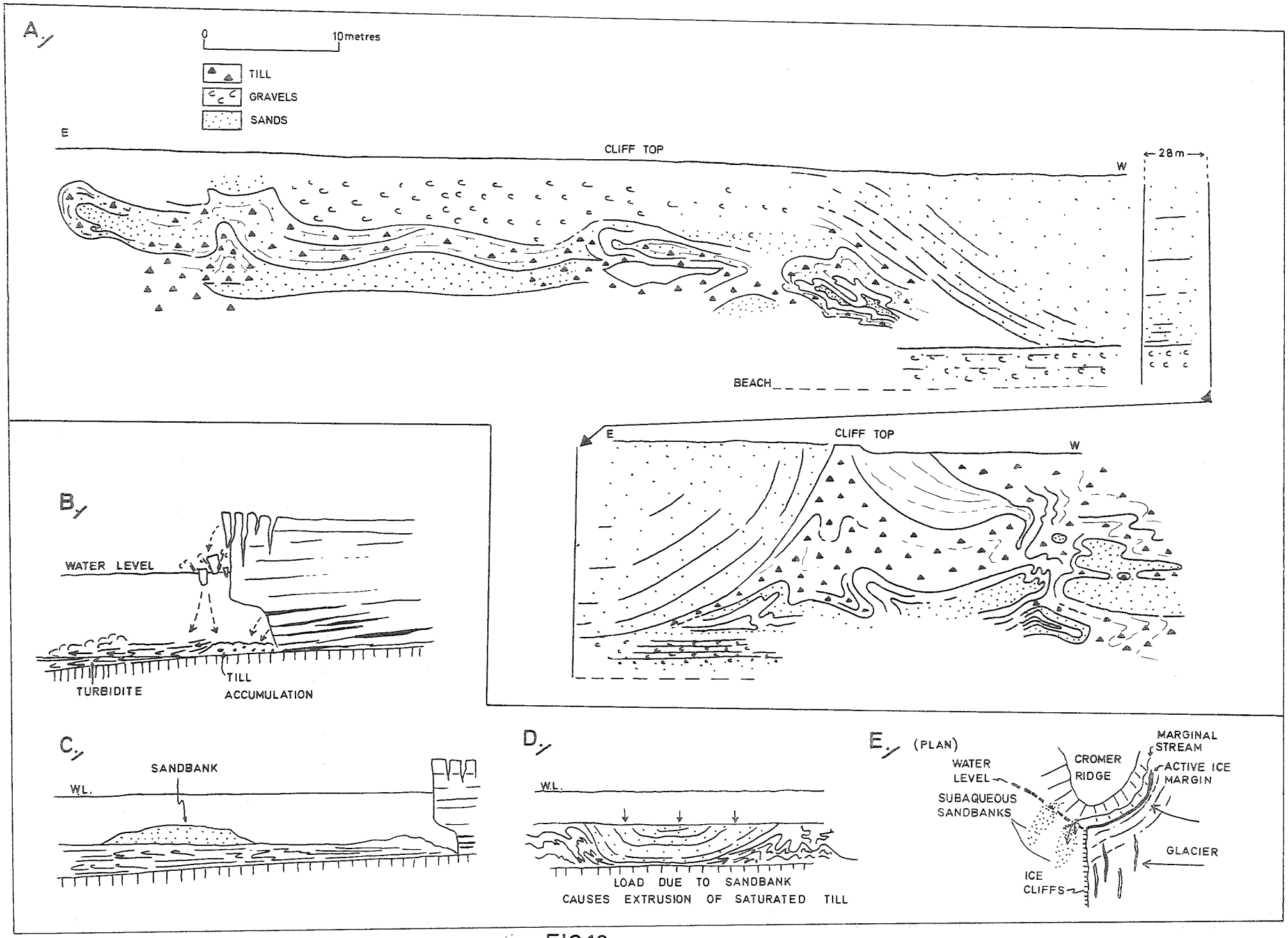

A.
0
10 metres
TILL
GRAVELS
SANDS
E
CLIFF TOP
W
28 m
BEACH
B.
WATER LEVEL
TURBIDITE
TILL
ACCUMULATION
E
CLIFF TOP
W
C.
SANDBANK
W.L.
D.
W.L.
LOAD DUE TO SANDBANK
CAUSES EXTRUSION OF SATURATED TILL
E. (PLAN)
WATER
LEVEL
SUBAQUEOUS
SANDBANKS
CROMER
RIDGE
MARGINAL
STREAM
ACTIVE ICE
MARGIN
GLACIER
ICE
CLIFFS

FIG.16

## LOCALITY 2 BRITONS LANE

A pit in gravels belonging to the Cromer Ridge complex. Faulting is common. Banham believes these to be the equivalents of the Brick Kiln Dale Gravels.

## LOCALITY 3 LANDFORMS IN THE HOLT-BLAKENEY AREA

The highland area known as the Cromer-Holt Ridge is a dominant feature in north-east Norfolk. The surface of the ridge is composed mostly of gravels but internal structure and stratigraphy are largely unknown. The Cromer Ridge does, however, intersect the shoreline between Cromer and Sidestrand where the cliffs are composed mainly of tills and glaciotectonic structures of presumed Lowestoftian age (West and Banham, 1968) by correlation with the Corton and Hoxne sequences. Thus the Cromer Ridge has been assumed to be a "push-moraine" of Lowestoftian age.

On the northern flank of the Cromer ridge, in the vicinity of Holt and Weybourne there are a series of terraced landforms, mentioned by Solomon (1932) and described by West (1957) as sandar plains. Straw (1960) agreed with this diagnosis, but interpreted the morphology of the sandar margins and of the Glaven Valley sides as the result of post-gravel dissection, involving slope retreat under spring-sapping and mass wastage. Isolated gravel mounds along the sandar margins and in the Glaven Valley were regarded as residual features. These views were reiterated in 1965 (written 1962) when Straw also presented reasons for relating the sands and gravels to the underlying chalky till, and considered that both gravels and till were deposits of the same ice sheet.

The 'erosional hypothesis' was rejected by Sparks and West (1964) who insisted that the majority of the hummocky features, and by implication their constituent slopes, were original glacifluvial and ice-contact forms.

SPARKS and WEST (figs. 17, 18, 19)

The fresh-looking landforms in this area are thought to be the product of outwash from an ice front which stood at a) Kelling Heath, with an escape south over the Briston Gap, and then b) Salthouse Heath, with drainage back into the ice. With this latter stage are correlated kame terraces and kames in the Glaven Valley. The Blakeney "esker" is really a composite feature, partly crevasse filling, as indicated by flat surfaces and angular course, partly esker. Aerial photos show clearly the parallel lineation of kames and terraces. The drainage while the Blakeney "esker" was formed appears to be to the NW.

The problem of this area is summed up by the presence of a kame, Candlestick Hill, near the base of a valley in the underlying marly drift. Were the outwash features deposited after the partial formation of this valley (but certain valleys, like those of the U. Glaven certainly post-date the outwash plain?).

STRAW

The major elements in the landscape of the area around Holt are:

1. The Cromer Ridge.

2. The Holt and Salthouse sandar.

3. The river Glaven Valley.

1. The Cromer Ridge trends west from Overstrand (TG247407) to West Beckham (TG140397), and thence south-west to Edgefield (TG097345), its crest at or a little above 300 feet O.D. The south side displays gentle slopes, with shallow dry valleys. It is broken at Briston (TG062325) by a broad gap, the floor of which is on glacifluvial gravels at c. 180 feet O.D. West of the gap is a further portion of the Ridge between Melton Constable (TG044331) and Thursford (TG986338).

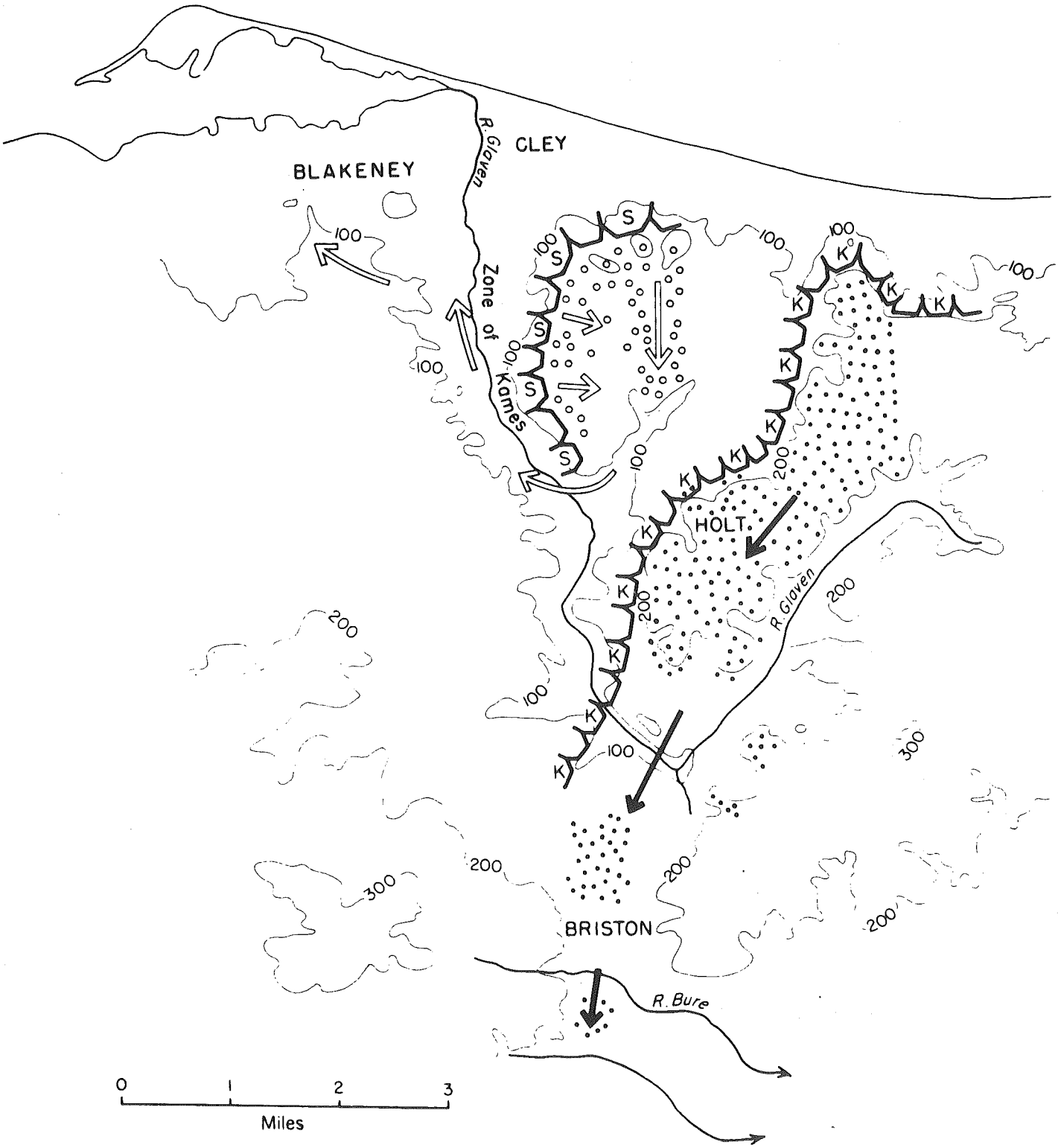
2. East of a north-south line from Morston (TG008439) to Bale (TG010368), and within the angle between the Cromer Ridge and the Coast, are large expanses of sand and rolled flint gravel which constitute two large outwash plains or sandar (fig. 20), the surfaces of which decline gently south from their higher northern and north-western margins. Other gravel spreads west of the upper Glaven are related to the Salthouse sandar (fig. 20) but small gravel features west of the lower Glaven form a complex morphologically distinct from the sandar.

3. The Glaven River displays a curious course originating a few miles east of Holt (TG 079388), and flowing south-west to Hunworth (TG068353) and thence north to the coast. It receives left-hand tributaries near Hunworth, and a single right-hand affluent, parallel to the upper Glaven, at Letheringsett (TG060389). The valley floor lies on Chalk below Hunworth, but the valley sides throughout are largely developed on glacial drifts.

Stratigraphy The complete stratigraphy cannot be seen at any one site. The youngest deposits are the outwash and other glacifluvial gravels, which almost everywhere rest on a light-coloured till of high chalk content (presently exposed in an old marl pit south-west of Holt, (TG079379). In the Glaven Valley this till rests either directly on Chalk or on an intervening deposit of chalky gravel. Near Edgefield and to the north-east, the chalky till passes on to Cromer Ridge materials. Early descriptions indicate that the till is contorted with these materials and, as it appeared therefore to be a component of the 'Contorted Drift' it was regarded as contemporaneous with the Ridge materials. It has been argued however that the till was emplaced later than the Ridge materials (Straw, 1965), and it can be noted that the till lies northward of the Ridge crest, except south of the Briston gap where it occurs widely in the Foulsham - Reepham (TG100229) Area.

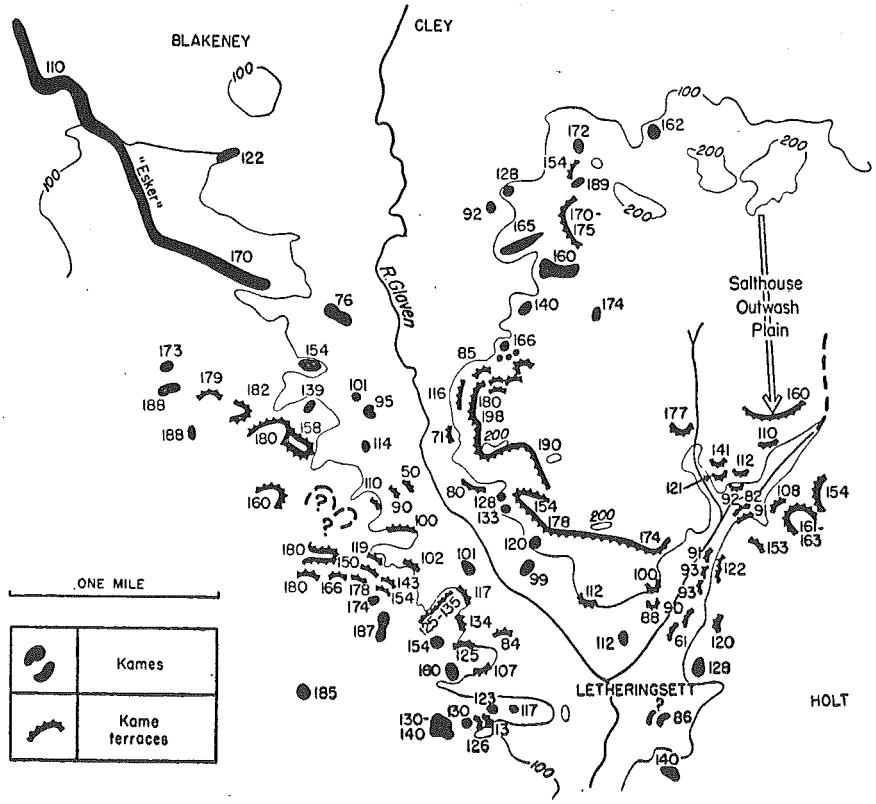
The 'erosional' interpretation of the Glaven valley features is supported by the following considerations:

1. Much of the gully and ravine development along the north side of the Cromer Ridge between Upper Sheringham (TG144419) and Cromer is probably of Weichselian date, and similar erosion is to be expected in comparable localities.

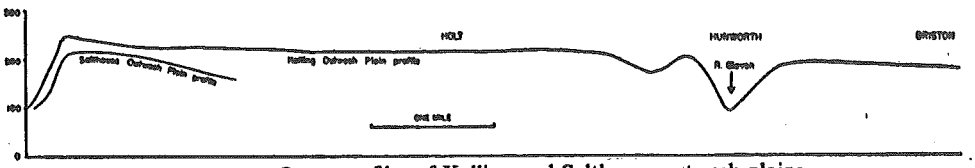



| | | | |
|---|---|---|---|
| K | Kelling ice front, outwash plain and flow direction | S | Salthouse ice front, outwash plain and flow direction |

FIGURE 17

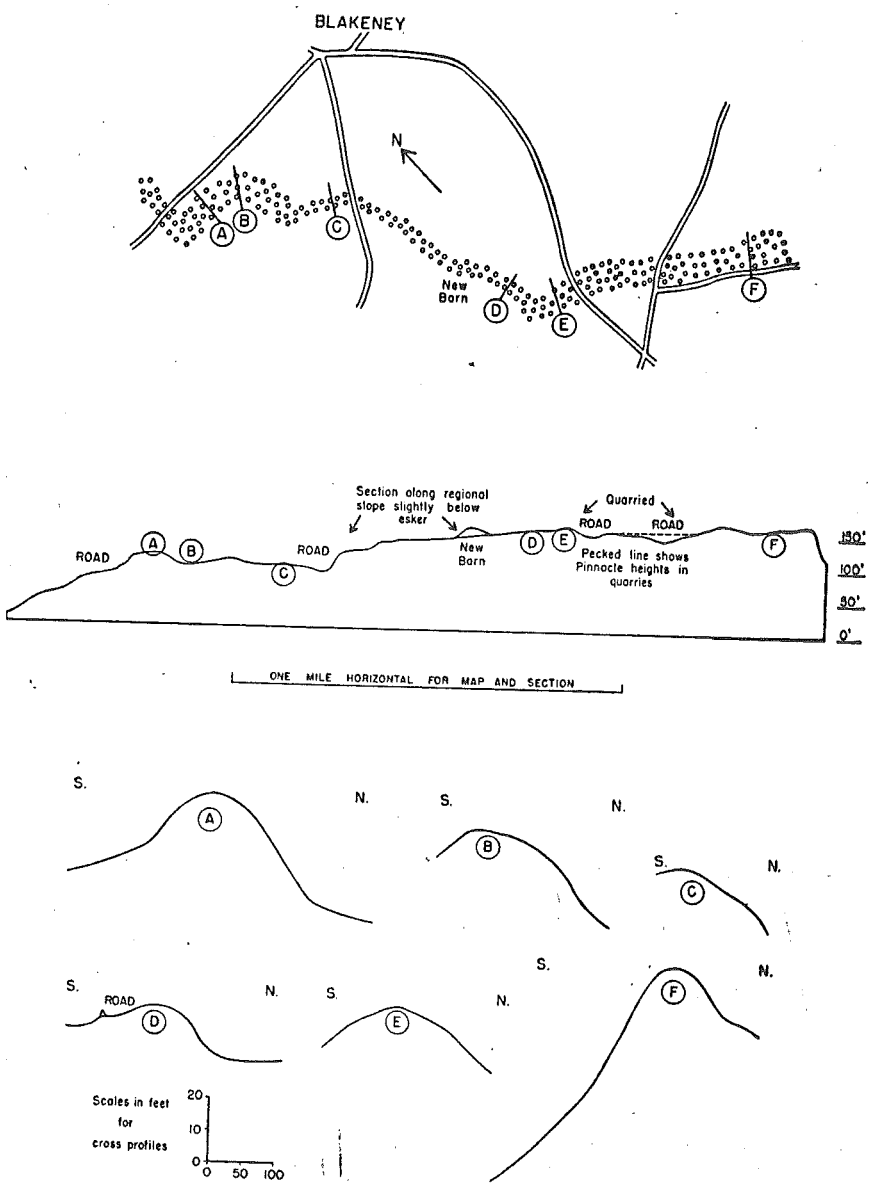



—'Esker', kames and kame terraces of the lower Glaven valley showing their heights O.D.




**–Long profiles of Kelling and Salthouse outwash plains.**

**FIGURE 18**




—Plan, long and cross profiles of the Blakeney 'esker'. The Blakeney side of the 'esker' is treated as the north in the cross profiles.

**FIGURE 19**

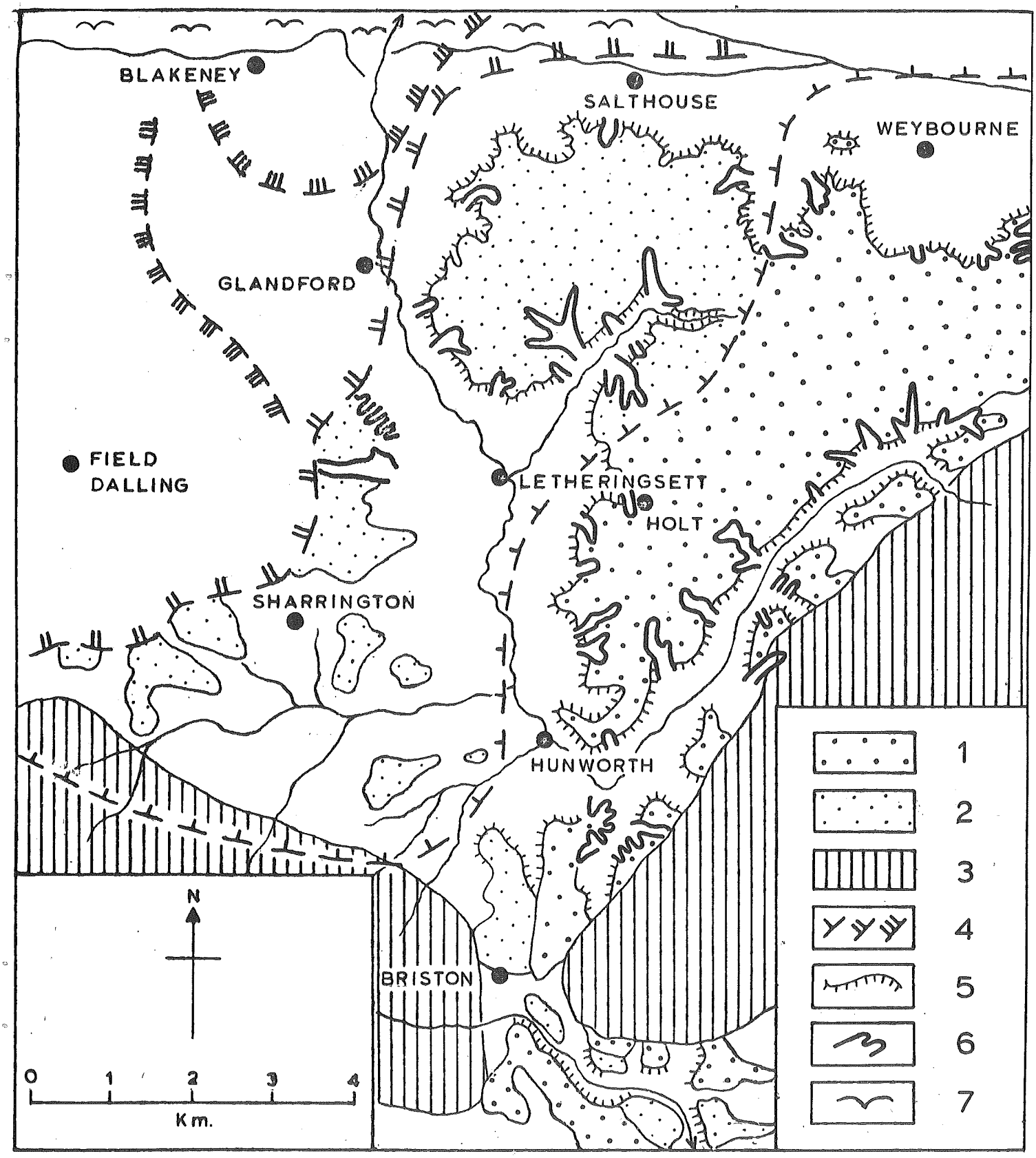



FIGURE 20 - Glacial geomorphology of the area around Holt. 1 - Holt sandur. 2 - Salthouse sandur. 3 - Morphological extent of the Cromer Ridge. 4 - Various ice margin positions. 5 - Bluffs on sands and gravels. 6 - Gullies and ravines. 7 - Marshland.

2. The Upper Glaven Valley above Hunworth, with its ramifying spring and seepage-fed tributaries, is manifestly incised into the chalky till through the sandar gravel.

3. The Salthouse sandar was probably continuous across the present Glaven Valley with the gravel spreads around and north of Sharrington (TG032370) (fig. 20), which accumulated in front of ice occupying the Field Dalling (TG007390) area to the north-west. The sandar is therefore more fragmentary than has previously been considered.

4. Sub-till gravels occur in places, and erosion along their outcrop could give rise to the low kame-like residuals of gravel that remain on Chalk near Glandford and Letheringsett. It can be observed that these gravel mounds without exception occur on the ends of small spurs cut out of Chalk or chalky till.

## The Gravel Features South of Blakeney

Several small but interesting gravel features persist west of the lower Glaven, and include the Blakeney Downs ridge, a number of low gravel mounds east of Langham around Bilsey Hill (TG022416) and a scatter of other features. The Downs ridge has attracted most attention, and has frequently been described as an esker, more recently as a crevasse-infilling (Sparks and West, 1964). Conversely, its origin as an ice-marginal feature has been suggested (Straw, 1960) though it was stated that its present form was the result of subsequent erosion. In terms of genesis these latter views are not diametrically opposed. Following aggradation of the Salthouse sandar, the Saale ice seems to have decayed with two portions, one occupying the Field Dalling area, the other covering the Blakeney-Cley area. The zone of separation of these two positions lay along what is now the broad interfluve west of Glandford (fig. 20), so that the low gravel hills which trend south-east from Bilsey Hill, and the Downs ridge may well consist of materials deposited initially in ice-contact situations as crevasse-kames. It is maintained however, that the present form of the features is not that which originally prevailed, and that the present slopes and slope angles have not survived unmodified since late-Saalian times. The till surface is furrowed by dry valleys, and the gravels once again occupy spur and interfluve crest positions. Whilst all the gravel features haveprobably been reduced in area the larger mounds retain steeper slopes because their 'reservoir' of ground water (especially after heavy rain and snowmelt) still permits some basal sapping, whereas the smaller mounds, flattened by solifluction, do not emit enough marginal seepage to regain steeper bounding slopes. All the gravels seen in exposure, including the Downs gravels, exhibit cryoturbation to depths of up to 2m., and mass wastage and modification of slopes under Weichsel periglaciation would have been unavoidable.

## Chronology

Both Spark and West, and Straw, agree that the main part of the Cromer Ridge is of Lowestoftian age. The sandar plains around Holt and the hummocky topography in the Glaven valley are thought to be of Gipping age because their erratic content is very different from that of the Hunstanton till (Weichselian), and they lie at a greater

height than the nearest Hunstanton deposits at Morston. The chalky till underlying the sandar and gravel mounds is thought by Straw also to be of Gipping age, for the following reasons:

1. There are distinct similarities between the till and the gravels in terms of far-travelled erratics, heavy minerals, types of flints, and in the high fine sand content of both the chalky till around Holt and the Holt sandar materials.

2. There is interdigitation of the till and gravels in a number of localities.

3. The bulk of the gravels rest on till, implying that no dissection of the till occurred before deposition of the gravel (this argument has been advanced in another contribution in this Handbook in relation to the chalky till and the Wensum Gravels).

4. Both till and gravel margins are influenced by the form of the Cromer Ridge, which is regarded as a pre-existing feature.

5. The till across the whole of north Norfolk is dissected by valleys that, except for the Glaven, contain only Weichselian glacial deposits at their lower ends. The valleys are considered to be Ipswichian interglacial developments.

6. Comparison with east Lincolnshire, where a similar chalky till (generally accepted as of Gipping age) remaining in the central Chalk Wolds is dissected by valleys containing Weichselian tills, indicates very similar circumstances of glaciation and geomorphological development.

Straw has also suggested the following detailed chronology for the landscape around the Glaven valley:

1. Building of the Cromer Ridge around the lobate front of the North Sea (Elster) ice, with melt-waters breaking south to initiate the Briston gap.

2. Interglacial modification of the Ridge morphology and possible removal of North Sea Drift from the area north of the Ridge by a proto-Glaven and other streams.

3. Advance of North Sea (Saale) ice to the Cromer Ridge and through the Briston gap, widening it towards its present dimensions.

4. Intermittent recession of the ice-front to the north-west, permitting first the progradation of the Holt sandar, and initiation of the upper Glaven on the sandar surface as a melt stream draining through the gap. These events were contemporaneous with deposition of the Telegraph Hill - Aylsham gravels to the south.

5. Accumulation of the Salthouse sandar after further recession, water still draining to the south, depositing gravels along the Bure (terrace

surface now up to 10m above flood-plain). Probably contemporaneous with the Wensum Gravels stage. Ice beginning to to differentiate into a lower Glaven lobe and a Field Dalling lobe.

6. Deposition of sands and gravels around Bilsey Hill and Blakeney Downs within the widening crevasse zone between and marginal to the separating lobes of stagnant ice.

7. Gradual integration of the River Glaven by ground-water sapping, and excavation of its valley during the Ipswichian interglacial.

Erosion encouraged by the disposition of thick permeable sands and gravels on relatively impermeable marly till, and steepish gradients down to the present coast. More rapid extension of tributaries in the Sharrington area of thinner gravels. Basal sapping of the northern margins of the Holt and Salthouse sandar, the resultant slope retreat exposing a stripped and degraded surface of till crossed by numerous streams heading in deeply branched ravines, e.g. at and west of Upper Sheringham, and south of Weybourne and Kelling. The gravel spurs between the ravine systems were progressively dissected into residual mounds by the development of lateral ravines on the spur flanks, e.g. west of Upper Sheringham (Oak Wood, TG134426), south-east of Weybourne (Round Hills, TG123421), and Muckleburgh Hill (TG101429).

8. Intense periglaciation during the Weichselian, with continued slope modification and gully development under niveo-fluvial and soliflual processes. Degradation of the Bilsey Hill and other gravel features by solifluction. Further deepening of the Glaven Valley, and continued erosion of sub-till gravels to produce low-lying residual mounds south of Glandford.

9. Renewed seepage and local sapping of slopes in the Flandrian, involving 'steepening-up' of some gravel slopes. Wooded gravel mounds later sharpened a little by development of a 'ploughing notch' around the base.

## LOCALITY 4 CLIFFS AT WEYBOURNE

(PHB)

Succession (max. thicknesses given)

4. Sands 5m+ (Gimingham Sands?)

3. Contorted Drift 13m+ (Marly Drift of NE Norfolk (?) of Baden-Powell 1948)

2. Cromer Forest Bed Series ("Weybourne Crag") 5m

1. Chalk 6m+

Description of the Beds

1. Chalk see Peake and Hancock (1961)

2. Cromer Forest Bed Series

3. Contorted Drift Lithologically very inhomogeneous, with more chalk than further south-east. Sand rafts (sometimes shelly - see Markham in Banham, 1964) and chalk rafts are common.

Erratics (200: 100 from each of 2 stations low in the cliff)

| Lithology | Range % | Average % |
|---|---|---|
| Flint | 46-55 | 51 |
| Chalk | 37-46 | 42 |
| Quartz & -ite | 4-5 | 5 |
| Exotics | 3-4 | 4 |
| Shells | 0 | 0 |

The high chalk content is fairly general; it is especially high where the Contorted Drift directly overlies chalk and/or in the vicinity of chalk rafts. The similarity of these figures to those from the Second Till from elsewhere (to south-east) is probably at least largely incidental, although a much deformed Second Till may be present here as is conjectured between Sheringham and West Runton.

Structures The following structural sequence has been published (Banham, 1964; Banham & Ranson, 1965):-

1. Development of domes and basins in the upper 6m+ of the solid Chalk; these may be elongated N-S (see under later structures, however).

2. Emplacement of the Contorted Drift with much rafting, brecciation and incorporation of the CFBS and Chalk, together with the development of flat, tight folds within and immediately below the Contorted Drift. These folds plunge at low angles to both NW and SE (125 approx.) and are overturned predominantly to the NE. At the same time the long axes of erratic pebbles became lineated NE-SW (approx. 035°; 350 measurements, at least 50 from each of 3 stations).

3. Folding (as a result of melting slumping?) of the upper 6m of the Contorted Drift, especially, into open, steep folds of variable axial plunge (possibly, however, the largest group trends E-W).

Conclusions Ice-movement from SW (215°); no evidence found for earlier ice-movements.

4. Sands (Gimingham Sands ? ? ) Since 1964 a "sand basin" (syncline or tectonic basin) containing these Sands has appeared in the section as the result of cliff recession.

Later Structures

It is notable that the tectonic basin which post-dates the Sands (4) is co-axial planar with a tectonic basin which affects both the

Contorted Drift and Chalk below, thus throwing some doubt on the earlier interpretation of this latter and others like it as supratenuous folds over pre-Contorted Drift-ice folds of the Chalk. Post-Sands deformation (permafrost activity?) of the whole succession now seems to be a likely alternative possibility.

Chronology

The age of the glacigenic sequence of Weybourne is a matter of contention. Straw feels that the till is of Gipping age, similar to the chalky till which lies beneath the hummocky features of the Glaven Valley. Banham however considers that the till is correlable with the "Contorted Drift" of the West-Runton area, and therefore of Lowestoftian age. In this latter view, if the Gipping advance was responsible for the Holt sandar plains just to the south, it appears to have left no deposits in the Weybourne cliffs.

DAY 4 (Optional) THE NORWICH AREA

(AS)

Morning excursion

This concentrates on the area to the north-west of the city. We shall traverse Telegraph Hill-Aylsham gravel tract, and take the opportunity of examining the Wensum valley between Lenwade and Costessey, and the deposits exposed near Ringland (TG134140).

Norwich (B. 1149) - Horsford - Felthorpe - Attlebridge -

Telegraph Hill-Aylsham gravel tract, Bure tributaries, drainage contrasts.

Attlebridge - Lenwade - Ringland -

Wensum Gravel features, lower terraces, valley meanders.

Ringland - Costessey - Norwich -

Exposure of sands and gravels, at Costessey No. 1 Pit of Pointer Aggregates, Ltd. (TG150120) (fig. 23).

General Description

This is presented as a background relevant to the morning excursion and should be regarded as a basis for discussion.

The Wensum river system drains the whole of central Norfolk, and whilst many features of the stream pattern within the basin merit attention, comparison with adjacent drainage systems, particularly that of the Bure, is also profitable in terms of elucidating various glacial and deglacial events in the area.

North-west of Norwich, the Wensum river meanders freely over its floodplain, but the valley itself sweeps in broader curves, which are well developed between Norwich and Attlebridge (TG130169), and further upstream between Lenwade (TG100182) and Worthing (TF997199). The spurs on the inner sides of the 'valley meanders' are frequently flattened and carry deposits of well-rolled flint gravels at heights of between 70 and 100 feet (22-31 m) above the present floodplain. The gravel deposits have been traced along the main valley and several tributary valleys into the headstreams, and in some cases even beyond, as near Rougham (TF831204) and Lexham (TF843171). These Wensum Gravels are interpreted as a composite train of outwash materials deposited by glacial meltwaters originating from decaying ice in west and north Norfolk.

Throughout the Wensum basin, these gravels lie almost exclusively on a light-coloured, very chalky till (Marly Drift - Boswell, 1935; Straw, 1965). Apart from geological considerations

at least three geomorphological considerations indicate that gravels and till should be regarded as a closely related series of deposits associated with the advance and retreat of a single ice-sheet, no period of inter-glacial dimensions intervening between their deposition.

1. Very little weathering or dissection of the till seems to have taken place prior to deposition of the gravels.

2. The convergent gravel trains conform faithfully to broad swells and hollows in the till surface (many of which are a reflection of the underlying Chalk surface) which suggests that the meltwater streams found their way across the initial, newly-uncovered till surface.

3. It seems unlikely that one glaciation should be represented solely by till deposition, and another later one, only by gravel deposition.

Points bearing on the age of the gravel/till complex.

1. In west Norfolk, valleys draining to the Fens have been deepened below the base of the till and contain drifts of only periglacial or fluvial origin.

2. In north-west Norfolk, similar valleys draining to the North Sea are partially obstructed by glacial deposits that display a weakly constructional surface and are generally accepted as of Weichselian age.

3. The landforms and drainage pattern of central, north and west Norfolk display no evidence of a glaciation between the Weichsel phase and deposition of the chalky till and Wensum Gravels.

It is suggested therefore, that the till/gravel complex was laid down during the glaciation which preceded the Weichsel, i.e. the Saale (Penultimate; Gipping), and that the phase of valley-deepening may be ascribed largely to late-Saalian and to Ipswichian times. It is noted that previous workers consider the chalky till to be older than Saalian, i.e. deposited during the Lowestoft (Elster) Glaciation (Baden-Powell, 1948; West & Donner, 1956).

Possible easterly extent of the Saale ice

1. The chalky till (Marly Drift) extends east towards Weybourne along the north coastal zone, and in central Norfolk at least as far east as Heydon (TG114275), Cawston (TG135238) and Weston Longville (TG113158), but not east of the River Bure.

2. Its failure to surmount the Cromer Ridge, and its absence from east Norfolk suggests that the Saale ice did not extend into this area, and a provisional limit to this ice advance has been proposed previously (Straw, 1965).

3. Sand and gravel deposits between Telegraph Hill (TG116134) eight miles (13 km) west-north-west of Norwich, and Heydon and Aylsham (TG193270) can be interpreted as coalesced outwash materials related to an ice margin that ran approximately from Hindolveston (TG036294) to Heydon, Cawston, Attlebridge, and Honingham (TG103117). The gravels form a broad ridge,

the surface of which declines gently east and south-east from high areas near Telegraph Hill, Felthorpe (TG165177), Cawston and Heydon. This ridge is transected by the Wensum valley and the Wensum Gravel train between Attlebridge and Taverham (TG160138) fig. 21.

4. This gravel ridge forms the divide between the Bure system and the left-hand Wensum tributaries above Attlebridge. As such it separates two sharply contrasting patterns of drainage, at two levels of consideration (fig. 22).

a) the short right-hand Bure tributaries course north-east, east and south-east across the gravel tract, in the direction of its general surface gradients, whilst westward, Reepham and Swannington Becks display curious curving courses, running generally south on till.

b) the Bure and its major left-hand tributaries (Scarrow Beck, Gunton Beck, R. Ant) form a family of streams, draining south and south-south-east, that contrast with the overall east or east-south-easterly flow of the Wensum, Tud and Yare.

5. The Telegraph Hill-Aylsham gravel tract is not regarded as marking the maximum easterly extent of the Saale ice, for the chalky till appears to pass some way eastward beneath the gravels. Rather it is considered to represent a stabilisation of the ice margin after deglaciation had commenced and while thinning of the ice-sheet was in progress.

(FCC)

Afternoon excursion

This concentrates on the area to the south and south-east of the city. Fig. 26 shows a geological map of the area around Norwich.

Stratigraphy

Coarse gravel
Cross bedded sands
Chalky Boulder Clay
Cross bedded sand and gravel
Norwich Brickearth
Norwich Crag (including Bure Valley gravels)

General In the vicinity of the city the Norwich Crag rests on a slightly undulating Chalk surface, which falls gently eastwards. As can be seen from the map accompanying this account, its outcrop is restricted, due to the incursions of the later glacial deposits. In general the sediment becomes coarser from east to west as the former shore line is approached. The section at Whitlingham (fig. 24) contains thin clays and shelly sands but in Norwich itself at Catton Grove the Crag sequence is represented by a well rounded sandy gravel.

The Bure Valley gravel which occupies the top of the Crag sequence occurs at Whitlingham and at Eaton on the western side of Norwich. This gravel has a particularly widespread occurrence and may indicate a distinct melt water phase from ice sheets situated farther to the north and west.

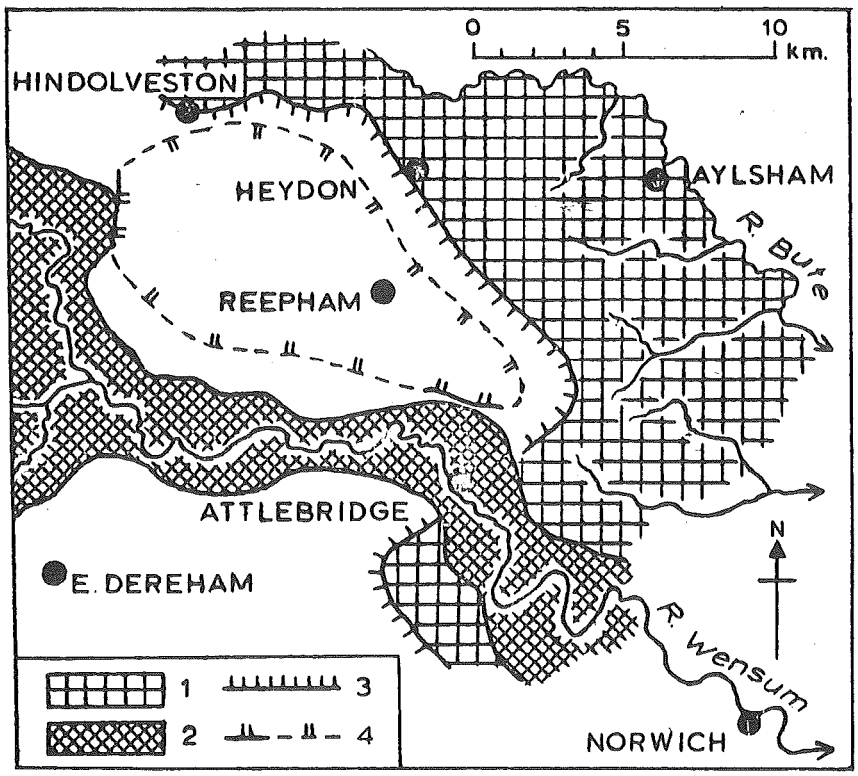



FIGURE 21 - Some glacial features north-west of Norwich.
1. Telegraph Hill-Aylsham sands and gravels.
2. Wensum Gravels outwash train.
3. Postulated ice margin at the Telegraph Hill stage.
4. Postulated residual ice at the Wensum Gravels stage.

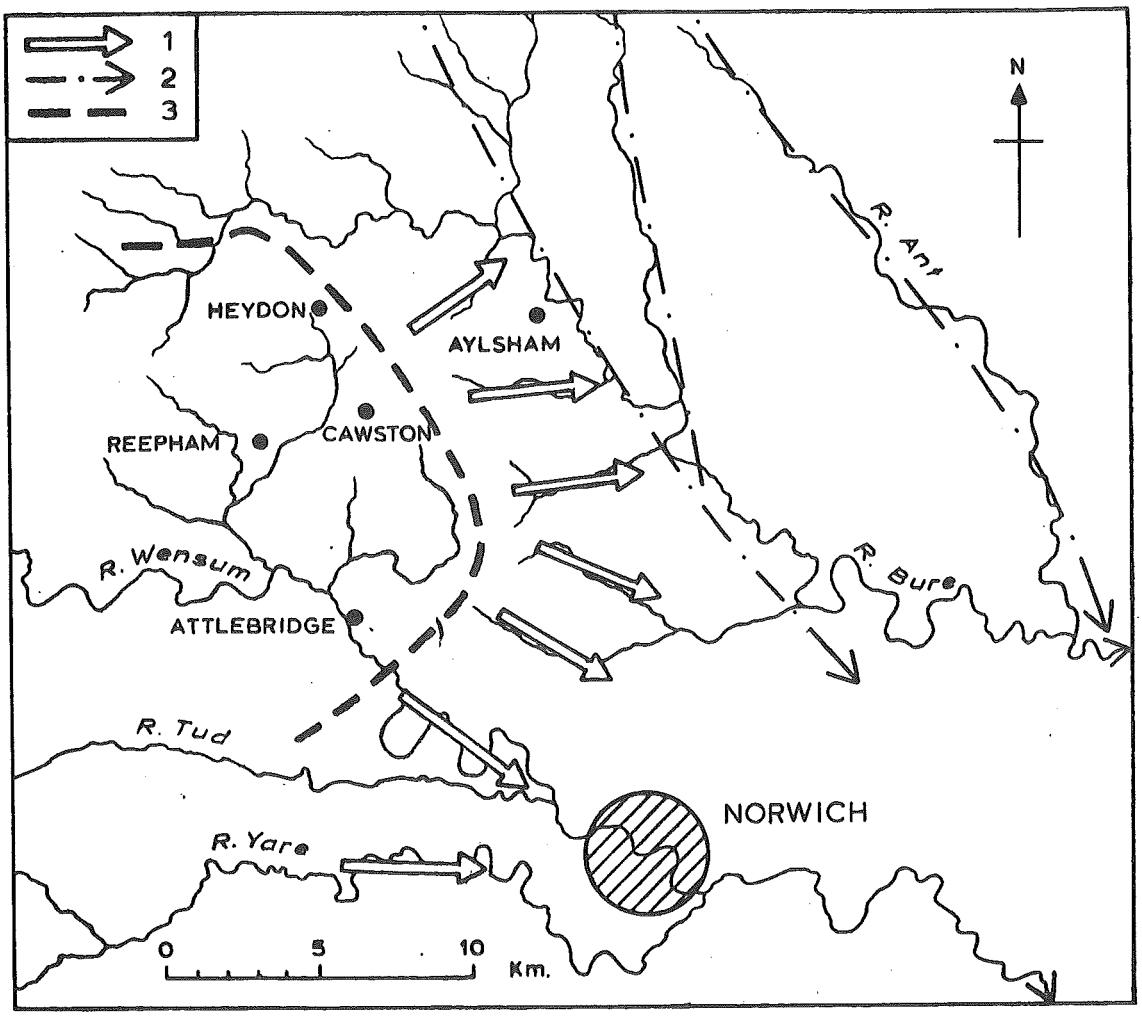



FIGURE 22 - Drainage features north and west of Norwich.
1. Possible outwash streams at the Telegraph Hill stage.
2. Pre-Saale drainage lines.
3. Divide between parts of the Wensum and Bure systems on Telegraph Hill-Aylsham gravels.

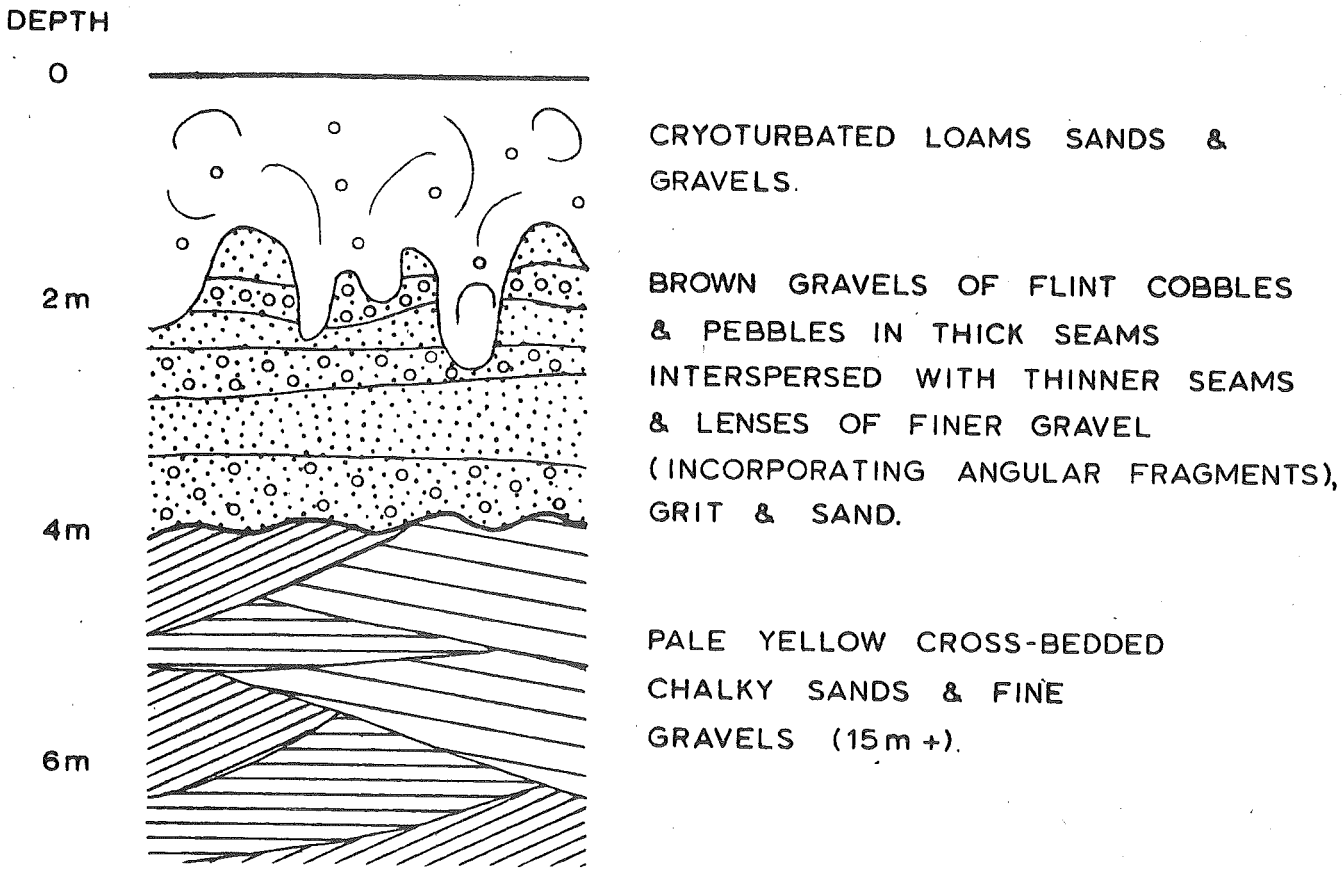



FIGURE 23 - Sketch section of deposits in Costessey No. 1 Pit of Pointer Aggregates, Ltd.

The Norwich Brickearth is no longer well exposed in the Norwich area and for this reason will not be visited on this excursion. It does not occur south of the Yare or Wensum valleys, and it is doubtful whether it ever did cross these limits. In the areas of Catton and Hellesdon it is a laminated, very sandy clay. It shows evidence of current bedding and contains some small flints. As the brickearth is traversed north-eastwards erratics became increasingly common: they include chalk, igneous and metamorphic rocks. Current bedding is absent, and the clay, although still very sandy with occasional distinct pockets of sand, is structureless. It is therefore thought probable that the ice that deposited the Norwich Brickearth was melting into a small lake in the Norwich region. The Chalky Boulder Clay that followed was transported from the north-west. The ice that had deposited the Norwich Brickearth had become inactive, but still presented a barrier to the Chalky Boulder Clay ice. For this reason the Chalky Boulder Clay forms and arcuate margin to the city; the ice halted against the Norwich Brickearth and was forced to pass south of Norwich to the coast. This has resulted in the development of a thick outwash zone to the west of Norwich, and in the superficial folding of the Chalk in the Yare valley, together with the over-deepening of this valley.

The outwash zone contains two elements: torrent gravels and the crossbedded sands that underlie them. The relationship of these beds is shown in fig. 25, a diagrammatic section of all the beds exposed in the area. The sand and gravel washed out from the Chalky Boulder Clay ice sheet has cut deep into the Chalk to remove much of the Crag and also some of the Norwich Brickearth.

The rivers that converge upon Norwich have had a long history which dates back from the Pleistocene. Glacial gravel associated with the valleys does not pass beneath the boulder clay and it is thought that these streams became established with the arrival of the Chalky Boulder Clay ice. The valleys of the Yare and Tass have been greatly over-deepened by Meltwater, but the Wensum in the vicinity of Norwich does not contain a similar buried channel.

## LOCALITY 1 WHITLINGHAM

This pit is cut in the river cliff of the Yare to the east of Norwich.

Succession

| | |
|---|---|
| Norwich Crag | 3. Quartz/quartzite rich gravels and sands |
| | 2. Alternating clays and ripple drifted sands |
| | 1. Shelly sand and stone bed |

The stone bed has been noted in the past for yielding mammal bones and the so-called rostro-carinate flints. Bones are not commonly found at this locality, although in earlier days many specimens used to be unearthed by quarry men. The rostro-carinate flints were thought to be early implements, but this interpretation is no longer generally held. The shelly fossils are lamellibranchs and gastropods. The lamellibranchs are chiefly thin shelled varieties. Although many are fragmentary, intact specimens may be found. Gastropods often show signs of having been rolled

but tend to be whole.

The alternate clays and sands above exhibit many fine sedimentary structures. Clays vary from thin partings within the sand to seams several inches thick.

The quartz/quartzite rich gravels also contain much flint and occasional igneous and metamorphic pebbles. These are equivalent to the so-called Bure Valley Beds and have been recognised at several localities in the Norwich area, the most westerly being at Eaton. From the sketch map (fig. 26) it can be seen that Crag Deposits have been recorded as far west as Drayton. It is thought that the Crag sea did not originally extend far beyond the outcrops shown on this map for the sediments are seen to become thinner and coarser as they are traced westwards.

LOCALITY 2 PORINGLAND

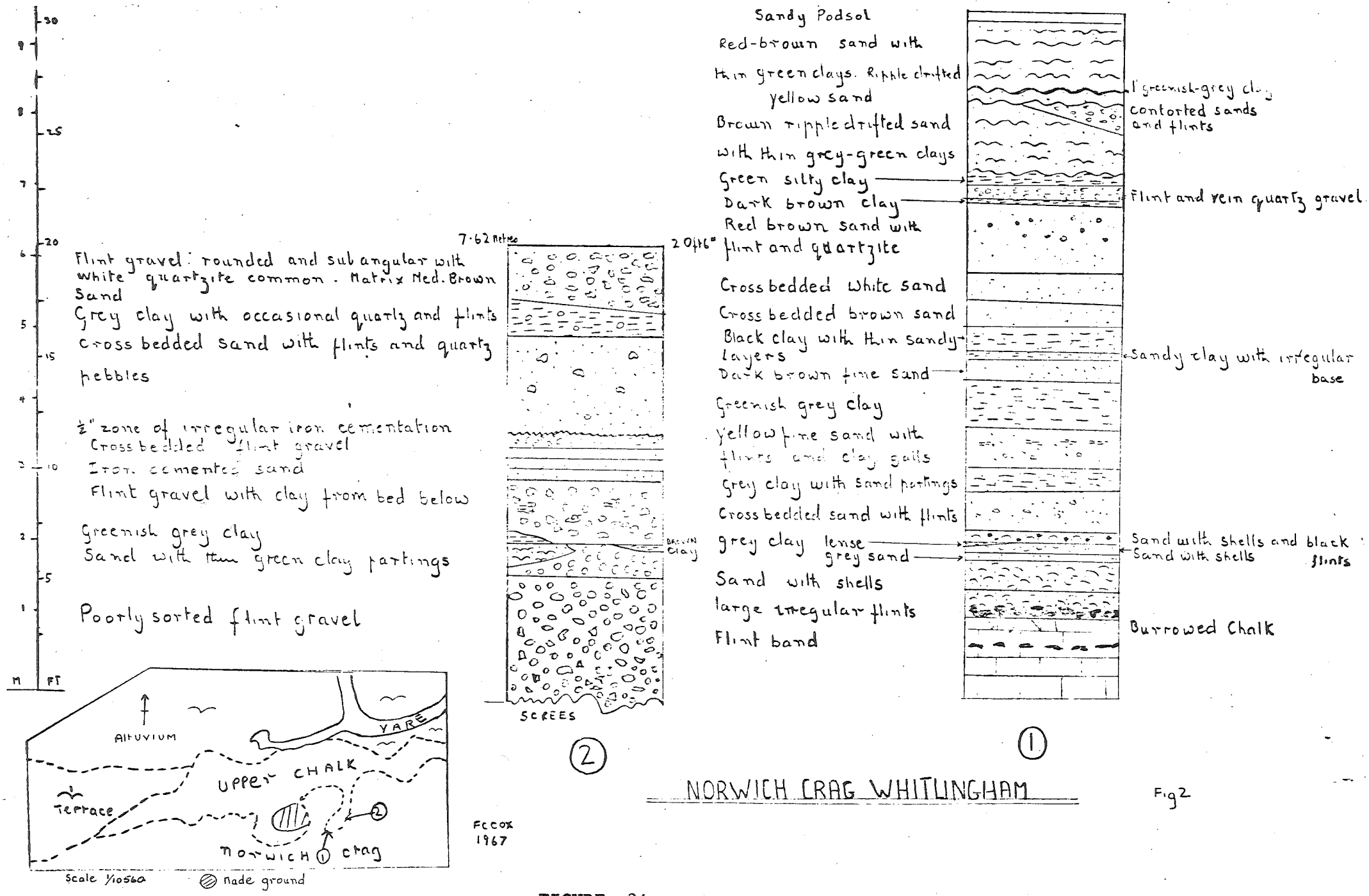
This section is in cross-bedded sands which underly the main chalky till of the area. The sands occupy a channel trending NW-SE. They contain many small structures and have been deformed by ice movements. The chalky till is also exposed at this site and is contorted by later permafrost.

LOCALITY 3 FLORDON

A great variety of lithologies are here seen beneath a highly cryoturbated chalky till. A gravel in this section is well sorted and rounded; it may represent the top of the Crag sequence. Grey clays are also present. Reference to other sections in the area, however, indicates that such evidence is not conclusive, for at Caistor St. Edmunds similar gravels overlie an earlier cryoturbated deposit.

LOCALITY 4 KESWICK

This quarry in Upper Chalk has been cut into deeply weathered chalk at the edge of the Yare Valley buried channel. Chalky Boulder Clay is seen festooned into the highly disturbed and folded Chalk.

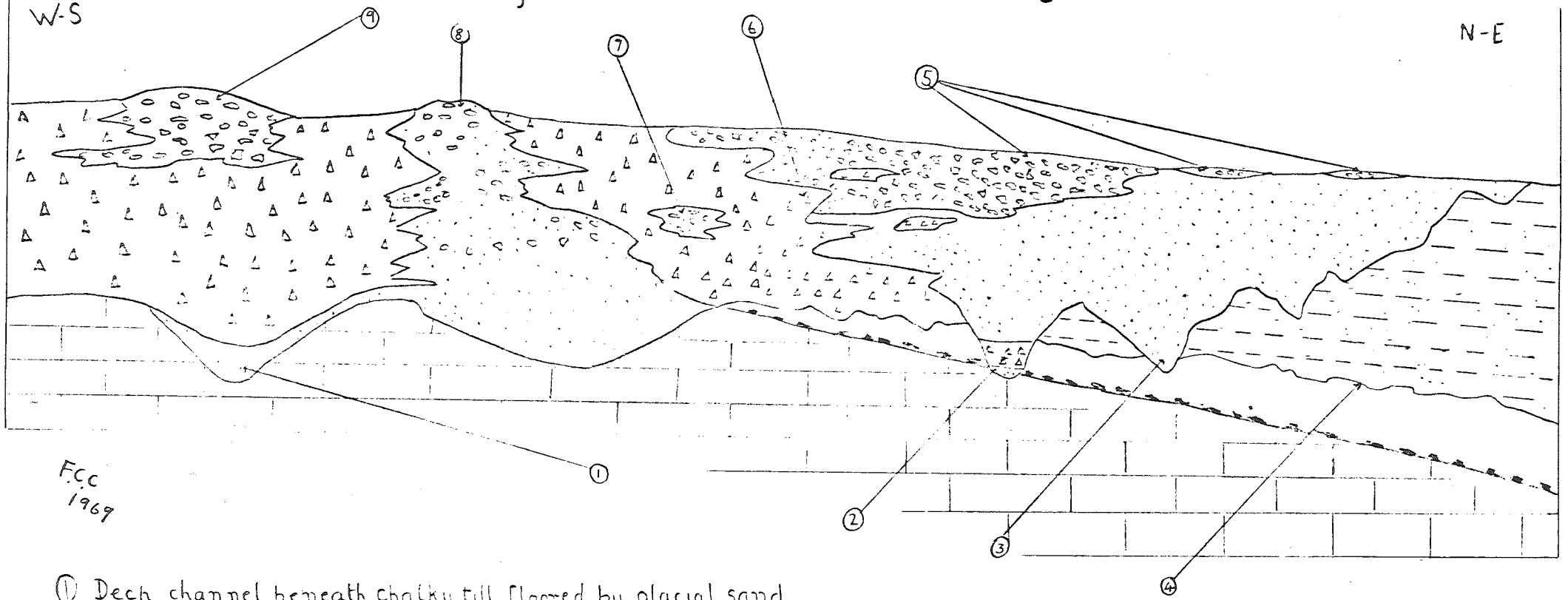



NORWICH CRAG WHITLINGHAM

Fig 2

FIGURE 24

# Generalized Section Across the Chalky Boulder Clay Ice Front




1. Deep channel beneath chalky till floored by glacial sand
2. Deep channel with long glacial history, shows early advance of chalky till
3. Channel formed by sandy outwash from chalky till
4. Contact of Norwich Brickearth with Norwich Crag shows evidence of channelling
5. Probably contemporaneous with 9 Torrent gravels deposited at final decay of till
6. Margin of chalky till interdigitates with outwash deposits
7. Included mass of glacial sand and gravel
8. Gravel mound with margins interdigitating with chalky till
9. High level torrent gravel

Glacial Gravel
Glacial Sand
Chalky Boulder Clay
Norwich Brickearth
Norwich Crag
Stone Bed
Upper Chalk

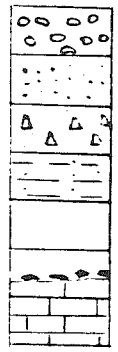
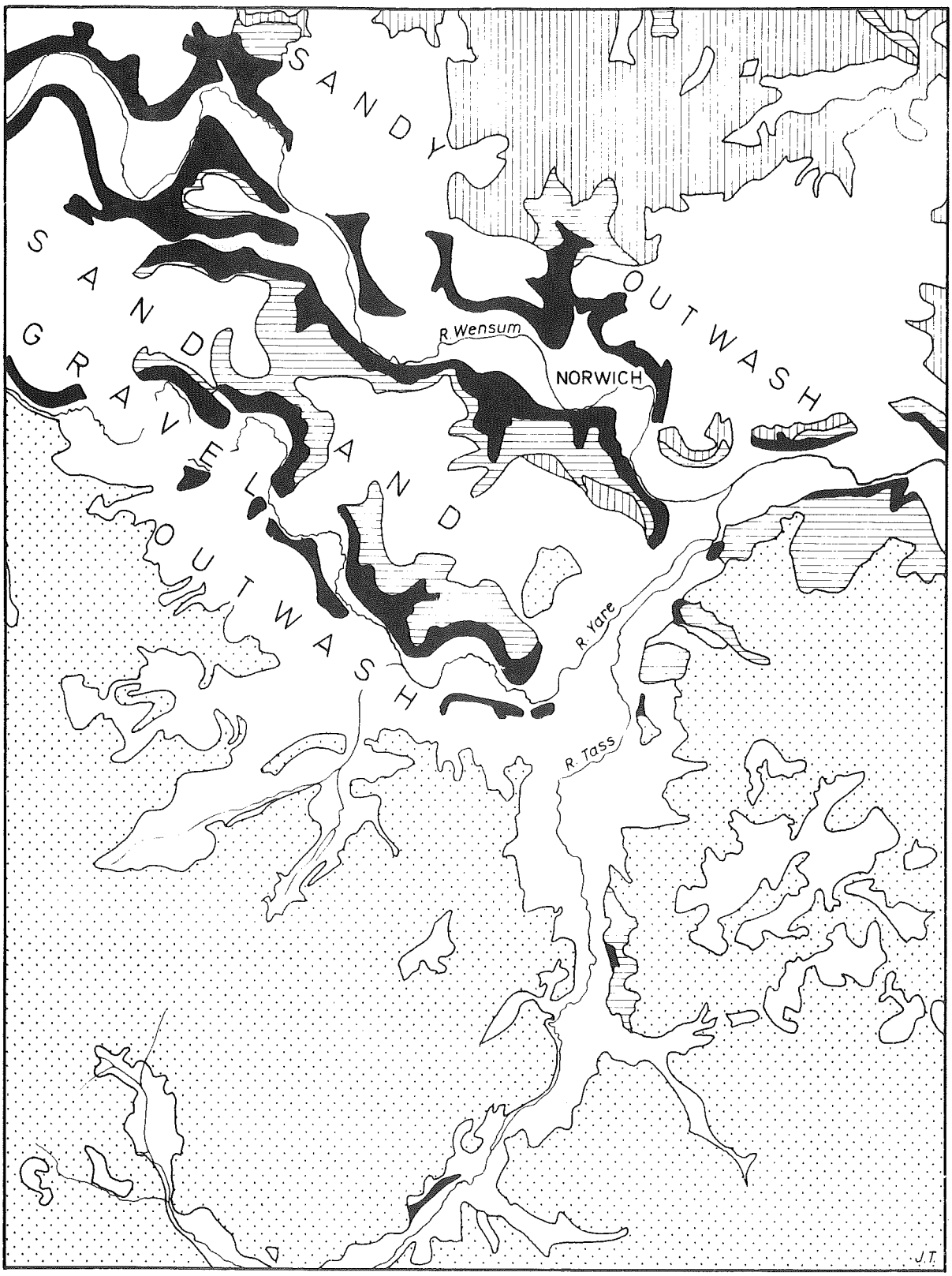


Fig 1

**FIGURE 25**

# The Geology of the Norwich Area




Chalky Boulder Clay

Norwich Brickearth

Norwich Crag

Upper Chalk

Glacial sand and gravel, terrace gravel and alluvium - unshaded

0 1 2 3 Ml.

0 1 2 3 Km.

*Compiled from unpublished I.G.S. maps, by permission of the Director I.G.S.*

Fig. 26

## APPENDIX

Alan Straw and Peter Banham have offered the following tentative regional syntheses of the glacial geology of Norfolk.

1. P.H. Banham

a) The most important general result of work carried on over the last few years, is that erratic content of tills is remarkably constant, although till matrix has yet to be analysed. The only noteworthy variation within any one till is for enrichment of chalk to the north-west within the Contorted Drift.

Regional correlations have been made on the basis of the observed constancy of erratic composition within any one till.

Figure 27 shows the petrology of till erratics.

F - flint, C - chalk, Q - quartz and quartzite, X - exotics, S - shells

H, O, St, etc. - locality symbols as in fig. 29, with the exception that samples from Mundesley-Bacton (M-B) are plotted as solid circles (dots). Each plot represents at least 100 erratics.

Diagram 1 - First Till erratics; 2 - Second Till; 3 - Third Till; 4(+5) - Fourth Till (and Fifth Till(Corton)); 6 (CD) - Contorted Drift at West Runton-Sheringham; L, M, U - lower, middle and upper parts. Note similarities to Tills 1, 2 and 3, respectively (W - Contorted Drift ("marly Drift") between Sheringham and West Runton); 7 (CD) - Contorted Drift at Overstrand-Cromer, and Sidestrand - S: note similarity to Till 2.

On the basis of Figure 27, several generalisations are possible:

1. That the erratic proportions of theFirst and Third Tills are rather similar (at least in F/C/QXS diagrams).

2. That the two main chalky tills (2 and 4, i.e.) have very different flint:chalk ratios.

3. That the Lower and Upper Brown Tills of Scratby correlate very well with the First and Third Tills of NE Norfolk, respectively.

4. That the Chalky Till of Scratby is very similar to the Lowestoft Till (4) of Corton.

5. That the Brown (bottom) Till at Corton has erratic proportions which correlate well with those of the First Till (and with the Lower Brown Till of Scratby).

The additional diagrams (fig. 27, 6 and 7) illustrate that (a) several till samples from the Contorted Drift at Overstrand-Cromer are very similar to the Second Till in erratic content, and (b) that there is a normal stratigraphy within the Contorted Drift at West Runton-Sheringham (see relevant section for a discussion).

b) Structures within the tills, such as folds and pebble lineations have been used to determine ice movement directions.

The observations are summarised in figure 28.

Locality symbols are as in fig. 29.

Full line marked F - fold trend; short dashes indicate the direction of overturning. Broken line marked P - erratic pebble lineation. Arrow - inferred ice movement direction.

d - deformed ( and obscrued) by later structures
nd - not determined
nf - not found

Vertical black bar - lateral limit of till (and late structures)

From the observations summarised in figure 28, the following conclusions are drawn:

1. The First (Cromer) Till ice came from the NE

2. the Second (Chalky) Till ice came from the NW

3. the Third Till ice came from W-NW

4. the Fourth (Lowestoft) Till ice came from the SW (West & Donner 1956)

5. the Fifth (New) Till ice came from the W

6. early, intense Contorted Drift structures below the Third Till generally indicate movement from the NW and may thus have been formed by the over-riding Third Till ice.

7. later, much more open, major structures may possibly have resulted from E-W pressures; a static permafrost origin is also possible.

8. the published explanation of the Weybourne Contorted Drift folds (Banham & Ranson, 1965) is anomalous; further work may show the need for its revision.

9. till and sub-till folds are of much more value as ice movement indicators than erratic pebble lineations.

c) Stratigraphic correlations within the region-

Figure 29 gives a correlation scheme for the coastal sections from Corton to Weybourne. The main conclusions are as follows:

1. Generally, older beds occur to the north, with younger

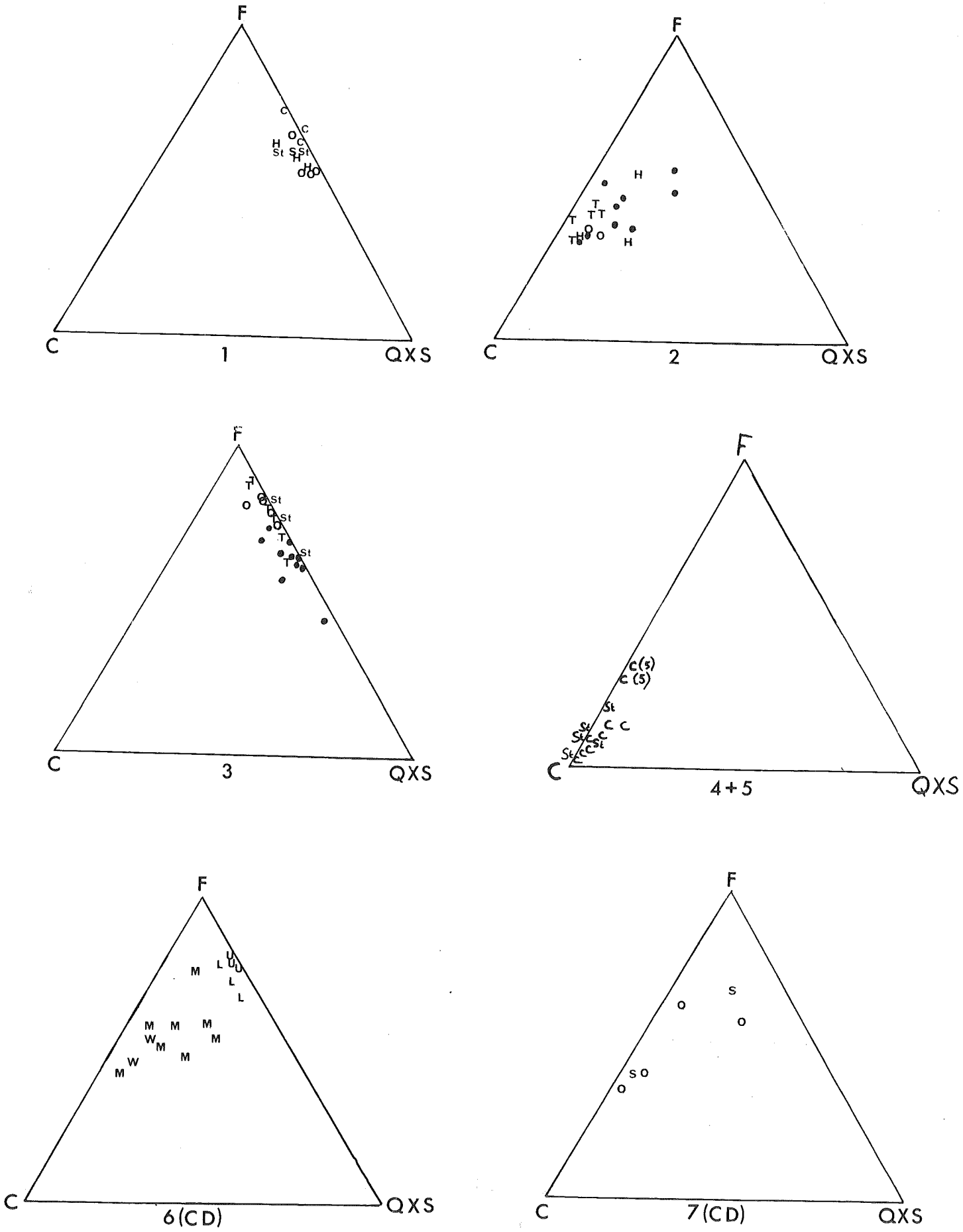
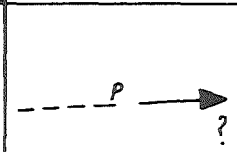
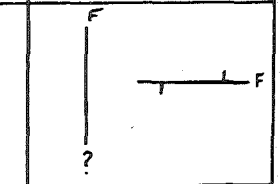
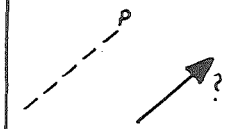
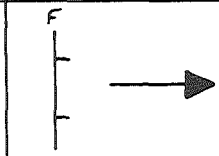
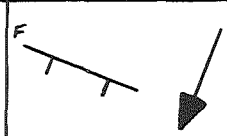
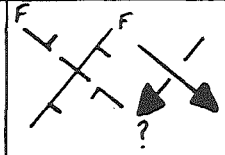
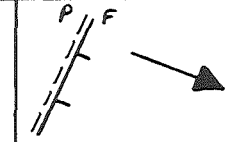
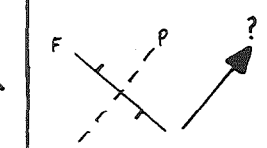
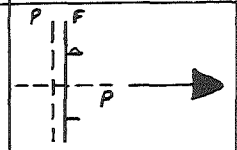
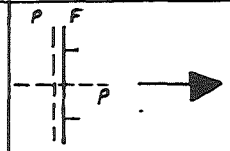
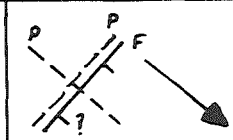
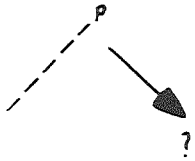
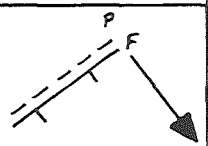
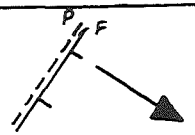
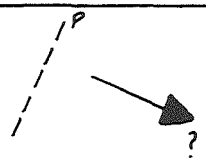
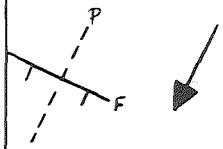
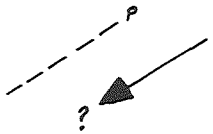
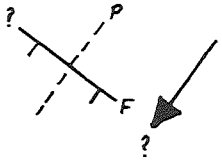



Fig. 27

Fig. 28

| Till \ Locality | C | St | H | | M-B | M-T | O-C | WR-S | W |
|---|---|---|---|---|---|---|---|---|---|
| 5 |  | nf | nf | Later Structures |  |  |  |  |  |
| 4 (Lowestoft) |  | nd | nf | |  |  |  |  |  |
| 3 | nf | nd | nd | |  |  |  | d | d |
| 2 | nf | nf |  | |  |  |  | d | d |
| 1 ("Cromer") |  | nd |  | | nf | nf |  | d | d |

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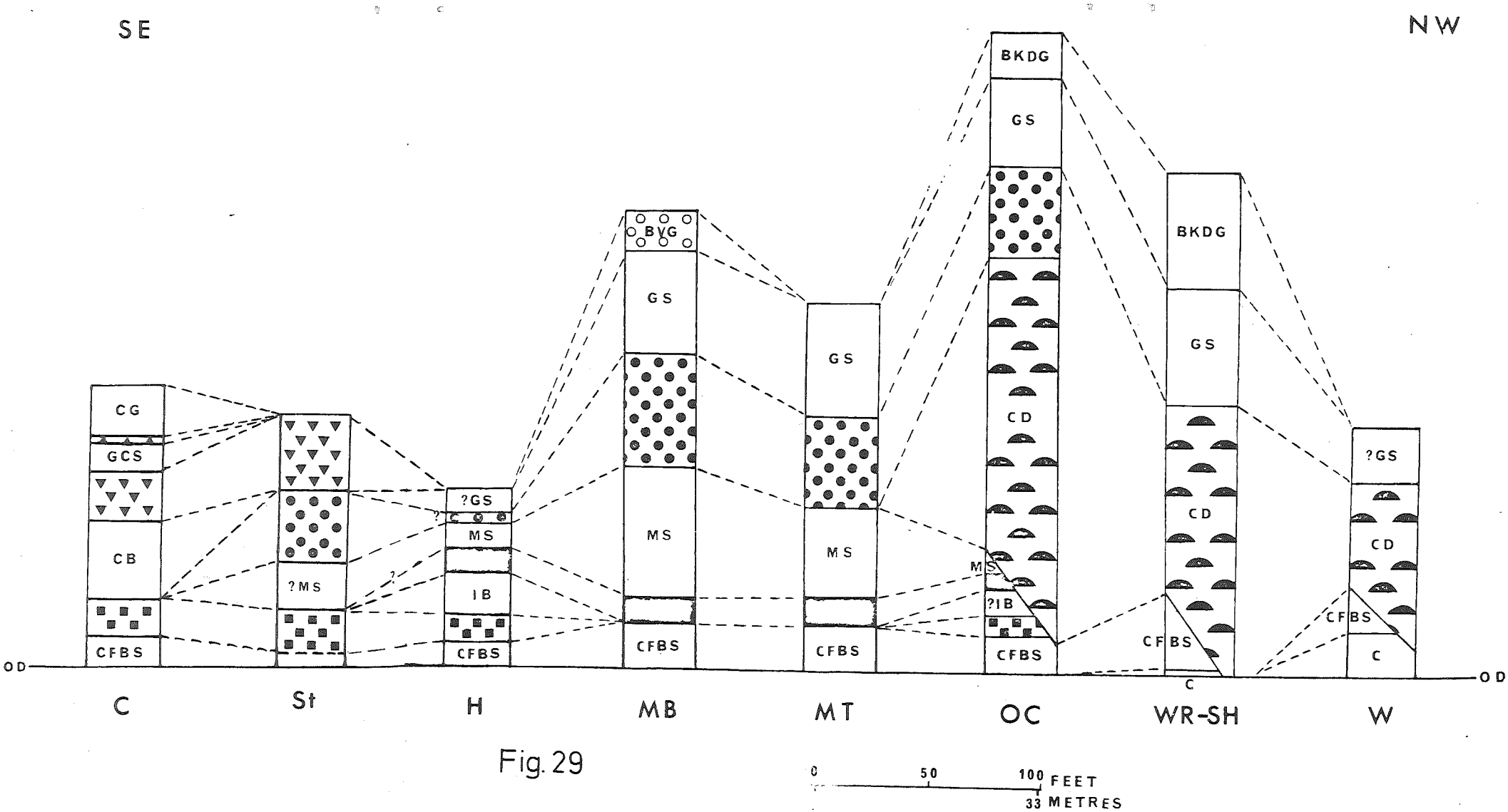



Fig. 29

Key to Geology: black squares - First Till; plain black - Second Till; black circular dots - Third Till; black triangles - 'Fourth Till' (Lowestoft Till); black crosses - 'Fifth Till'. BKDG - Brick Kiln Dale Gravels; C - Chalk; CB - Corton Beds; CD - Contorted Drift; CFBS - Cromer Forest Bed Series; CG - 'Corton Gravels'; GCS - 'Grey clays & sands - new beds'; GS - Gimingham Sands; IB - Intermediate Beds; MS - Mundesley Sands; OD - Ordnance Datum.

Key to Locations: C - Corton; H - Happisburgh; MB - Mundesley-Bacton; MT - Mundesley-Trimingham; OC - Overstrand-Cromer; St - Scratby; W - Weybourne; WR-SH - Weybourne-Sheringham.

beds to the south, the First Till occurring in both areas, together, possibly, with the Corton Beds (equivalent to Gimingham Sands ? i.e.). This view is in good accord with those of the early mappers - Wood & Wood, 1866; Harmer & Wood, 1872; Reid, 1882; Woodward, 1885; Blake, 1890; Harmer, 1909, 1928, e.g.; Boswell, 1914, 1916, 1923. More recently, Baden-Powell & Reid Moir, 1942; Baden-Powell, 1948, and Ranson, 1968, have supported the correlation of the Corton Beds and what, probably, are here called the Gimingham Sands.

2. Also, as in these early works, it is here suggested that the Lowestoft (Fourth, Great (Eastern) Chalky Boulder Clay) does not extend north into NE Norfolk as has been claimed by e.g. Boswell 1931 (equivalent to "Cromer Till" i.e.); Solomon, 1932; Baden-Powell, 1948, and West & Donner, 1956. The maps of the northern margin (N. of Scratby on the coast) by Wood (jr) 1880, and Harmer, 1904, are here confirmed (see also Straw, 1965). (i.e. not as previously suggested in a preliminary, tentative way in Banham, 1968).

3. The Contorted Drift of the NW part of NE Norfolk has been shown to be, at least in large part, the stratigraphical equivalent of the "uncontorted drift" of SE, NE Norfolk (cf Reid, 1882; Woodward, 1885; Boswell, 1916; Slater unpublished, 1930 approx.).

4. Moreover, the "Marly Drift" of the Cromer-Weybourne section, at least, is a facies of the Contorted Drift (cf Reid, 1882; Woodward, 1885, etc.) and owes its chalkiness (a) to the presence of the deformed Second Till, and (b) to incorporation of basement chalk (including rafts) during the major, (syn-Third Till ?) period of deformation.

5. No evidence for an interglacial stage has been found so far within this area (see, however, Baden-Powell in West, 1961) and all beds are thus provisionally assigned to the Lowestoftian Glacial Stage (West, 1968; Anglian of Shotton & West, 1969), with the possible exception of the (Plateau) "Corton Gravels" (Baden-Powell, 1950). The possibly Ipswichian (West, 1961) deposits of the Mundesley River Bed (now unexposed) are to receive further attention in the near future.

Provisional, local stratigraphy for the coastal sections only:

| Stage | | Formation |
|---|---|---|
| Gipping or later | 14. | Valley Gravels (NEN) ? |
| Gipping ? ? | 13. | "Corton Gravels" (C) |
| Lowestoftian ("Anglian") | 12. | Upper Chalky Till of (C) ("Fifth Till") |
| | 11. | Grey clays and sands (C; "New Beds") |
| | 10. | Lower Chalky Till of (C; S; Lowestoft Till; "Fourth Till") |
| | 9. | Brick Kiln Dale Gravels (NEN) "Plateau Gravels"?, "Briton's Lane Gravels" ? (?e.g. may be same age as 10). |
| | 8. | Corton Beds (C;S?) ≡ ? Gimingham Sands (NEN) |
| | 7. | Third Till (sandy) (NEN; S) |

| | | |
|---|---|---|
| Lowestoftian ("Anglian") | 6. | Mundesley Sands (NEN ; S?) |
| | 5. | Second Till (Chalky) NEN) |
| | 4. | Intermediate Beds (NEN) |
| | 3. | First Till (silty) NEN;S; C)("Cromer Till") |
| Cromerian etc. | 2. | Cromer Forest Bed Series |
| | 1. | Chalk (Upper) |

NEN: NE Norfolk

S: Scratby

C: Corton

2. A. Straw

A suggested sequence of glacial and deglacial events in northern East Anglia

1. ELSTER GLACIATION

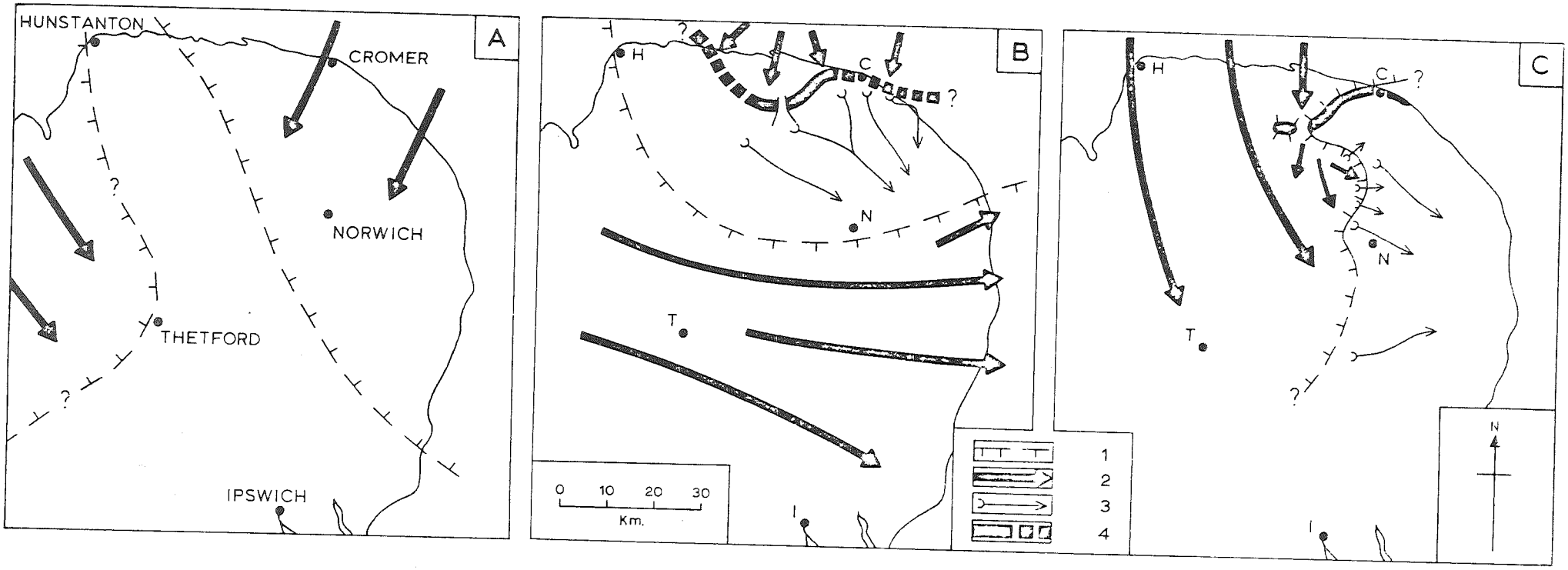
A. Advance of ice-sheet from the north and north-north-east into east Norfolk and possibly north-east Suffolk (fig.1a) over Crag deposits, probably preceded by floating ice and probably impounding water in the southern North Sea area.

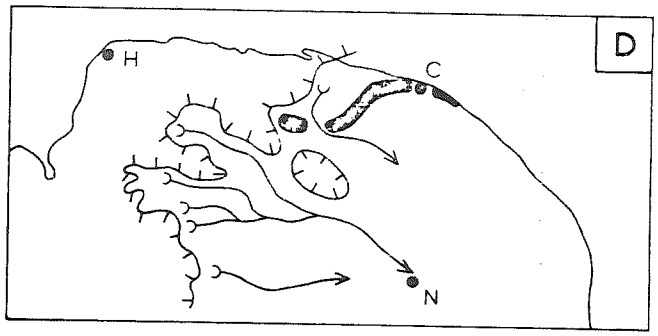
Dark grey tills emplaced in north-east Norfolk, and Norwich Brickearth to south-west as a glacio-marine or glacio-lacustrine deposit.

Advance of ice from the north-west into the Fen region and possibly the Brecklands (fig. 30a). North-west Norfolk (Docking-Fakenham-Swaffham area) probably remained ice free during this period, presumably because the North Sea ice was not strong enough to ride far up the Chalk dipslope, and the inland ice either did not reach the Cretaceous scarp or could not cross it.

B. Withdrawal of North Sea ice-front to north, and accumulation of Corton Beds.

C. Readvance of North Sea ice into north Norfolk (fig. 30b). Constructing the Cromer Ridge as a complex push moraine, with repeated shearing in the marginal zone, involving the grey tills, outwash gravels, Cromer Forest Bed Series, Crags, and Chalk. Lobate form of ice-front apparent from curves of Cromer Ridge (fig. 30b), so thrusts possible from a number of directions. Meltwater drainage established to south of Ridge, and outwash at Briton's Lane and probably at Briston.



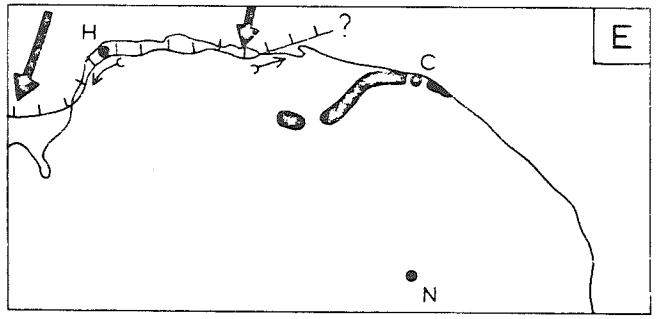




FIGURE 30. - Suggested episodes in the glacial history of northern East Anglia.
1. - Postulated ice margin positions.
2. - General directions of ice movement.
3. - Lines of meltwater movement.
4. - Cromer Ridge moraine.

Continued or renewed advance, or readvance, of inland ice over Brecklands region, taking advantage of the Thetford-Diss depression (occupied in pre-Elster time by Great Ouse river?) to reach the Norwich and Ipswich areas and pass beyond the present coast south of Scratby (fig. 30b). Deposition of a 'chalky-Jurassic' till over the Corton Beds and Norwich Brickearth.

D. Withdrawal of North Sea ice from North Norfolk.

Recession of inland ice, probable excavation of deep subglacial valleys in Yarmouth-Lowestoft area, and eventual establishment of River Waveney, and perhaps the lower Yare and east Suffolk rivers as meltwater streams.

2. HOXNIAN INTERGLACIAL

Weathering of drifts, and some incision by rivers in their upper and middle courses.

3. SAALE GLACIATION

A. Advance of ice from north and north-north-west. Pressed against Cromer Ridge, and passed round western end over the Fakenham area into central Norfolk. Small lobe through the Briston gap into the Reepham area (fig. 30 c). Probably the first ice to cover north-west Norfolk, but it did not pass east of Norwich or Diss, so that the Bure drainage system, established in late Elster time, was not disrupted. Deposition of a light-coloured chalky (generally 'non-Jurassic') till (Marly Drift) over north and central Norfolk. Movement of ice along Lower Cretaceous strike in west Norfolk, carrying sandy material into the Brecklands area, but producing a tract of mixed chalky and Jurassic tills in the Bawsey-Nar valley area. Some contortion of chalky drifts with Cromer Ridge deposits and production of secondary structures.

B. Stagnation of ice over Norfolk, with progressive decay and thinning. Progradation of Telegraph Hill-Aylsham gravels and Holt sandar, with meltwaters utilising the Bure valley. Outwash also down the Waveney.

After a critical amount of thinning had taken place, rapid disappearance of most of the ice cover from central Norfolk. Deposition of the Wensum Gravel train and Salthouse sandar by meltwaters from ice in north and west Norfolk, and initiation of much of Wensum drainage system (fig. 30d). Incision by streams, and commencement of drift dissection as ice cleared lower ground.

4. IPSWICHIAN INTERGLACIAL

Weathering of drifts, and further incision by majority of rivers. Deepening of Wensum valley, and valleys of north and west Norfolk below bases of the Wensum Gravels, Holt-Salthouse gravels and chalky till into the Chalk.

Erosion of sea cliff along the north Norfolk coast, and bluffing of Lower Cretaceous rocks in West Norfolk, probably in latter part of the period.

## 5. WEICHSEL GLACIATION

Advance by northern ice to the north Norfolk coast (fig. 30 e), and emplacement of brown Hunstanton till. Development of meltwater channels, Hunstanton Park esker, and diversion of lower Stiffkey river.

Widespread periglaciation over East Anglia. Cryoturbation to c. 2m, solifluction, nivation, and formation of patterned ground.

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