BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/96/5

Onshore Geology Series

TECHNICAL REPORT WA/96/5

Geological notes and local details for 1:10 000 sheet TG 32 NE (Lessingham)

Part of 1:50 000 sheet 148 (North Walsham)

R J O Hamblin

Geographical index
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Subject index
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Palaeogene, Cretaceous

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Parent Body

Natural Environment Research Council
Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU.
Telephone 01793 411500
Telex 444293 ENVRE G
Fax 01793 411501

Kingsley Dunham Centre
Keyworth, Nottingham NG12 5GG.
Telephone 0115 936 3100
Telex 378173 BGSKEY G
Fax 0115 936 3200

Murchison House, West Mains Road, Edinburgh EH9 3LA.
Telephone 0131 667 1000
Telex 727343 SEISED C
Fax 0131 668 2683

London Information Office at the Natural History Museum, Earth Galleries, Exhibition Road, South Kensington, London SW7 2DE.
Telephone 0171 589 4090
Telephone 0171 938 9056/57
Fax 0171 584 8270

19 Grange Terrace, Edinburgh EH9 2LF.
Telephone 0131 667 1000
Telex 727343 SEISED C

St Just, 30 Pennsylvania Road, Exeter EX4 6BX.
Telephone 01392 78312
Fax 01392 437505

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS.
Telephone 01232 666595
Fax 01232 662835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB.
Telephone 01491 38800
Telex 849365 HYDROL G
Fax 01491 25338

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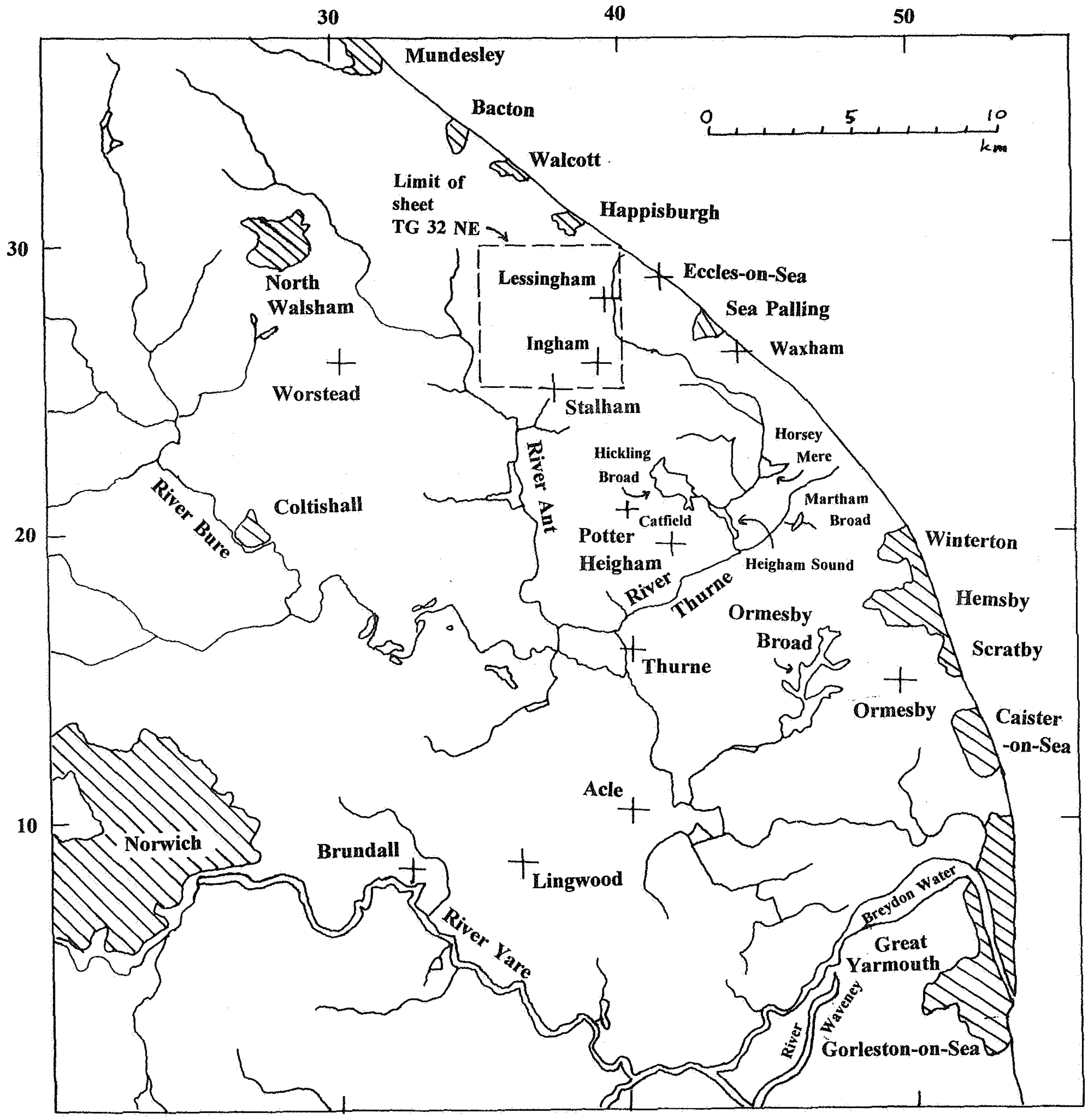

Figure 1 : Location diagram

GEOLOGICAL NOTES AND LOCAL DETAILS FOR GEOLOGICAL SHEET TG 32 NE (LESSINGHAM)

INTRODUCTION

The following report is designed to be used in conjunction with 1 : 10 000 Geological Sheet TG 32 NE. Uncoloured copies of the map may be purchased from the Survey's headquarters at Keyworth. The district covered by the map is included in 1 : 50 000 Geological Sheet 148 (North Walsham). It formed part of Old Series One-Inch sheet 68 E, and was surveyed at a scale of 1 : 63 360 by C Reid in 1877-1878. The district was resurveyed at 1 : 10 000 scale by the present author in 1995, with Dr I R Basham as regional geologist.

The area lies to the north-east of Norwich, and just touches the coast at Cart Gap which lies between Happisburgh to the north and Eccles on Sea to the east (Figure 1). The market town of Stalham lies on the southern border of the district, and the villages of Ingham and Lessingham lie within the eastern part of the district. The remainder of the district is rural, and includes parts of the parishes of Brumstead and East Ruston. No major rivers drain the district, but the River Ant passes just to the west; this flows southwards into the area known as the Norfolk Broads to join the Bure and ultimately drains to the sea at Great Yarmouth. The un-named steam which flows to the east of Lessingham rises just to the north-east of the district and continues southwards via the New Cut, Horsey Mere, Meadow Dyke, Heigham Sound and the River Thurne to join the Bure at Thurne.

The land is gently undulating, with ridges generally running east-west. The highest point in the district is Hill Sixty [368 299], presumably so-called as it is approximately sixty feet high, which actually rises to just over 20m. In contrast the land drops to below sea level along the floodplain of the un-named stream east of Lessingham, and to below 1m O.D. on the floodplain of the River Ant in the south-west.

Over most of the district the geological sheet shows Corton Formation, but this is almost universally covered by up to rather more than a metre of cover silt, which produces excellent agricultural land, neither too heavy nor too light. Large crops of wheat, barley, sugar beet and potatoes are grown, and owing to the water-retentive properties of the cover silt, most farms do not need articial irrigation despite the low rainfall in this part of the country. The floodplains of the Ant and the stream east of Lessingham are given over to permanent pasture, which is largely grazed by cattle. These floodplains lie at a very low level as a result of shrinkage of the ground owing to drainage - the peats within the Breydon Formation are particularly prone to shrinkage and oxidation on drying.

National Grid References in this report are given in square brackets; these all fall within 100-kilometre square TG. All depths and thicknesses in the report are given in metres. Borehole numbers quoted are those of the BGS record collection, in which they are prefixed TG 32 NE/ (Figure 2). Complete logs of non-confidential boreholes can be obtained from BGS Information Services (Geological Records) at Keyworth.

GEOLOGICAL SEQUENCE

Strata known to be present on sheet TG 32 NE are listed below. BGS practice in East Anglia is to classify all deposits overlying the Crag Group as Drift, and the Crag Group as the youngest deposit of the solid succession. The solid sequence shown below is interpreted from boreholes within the district.

Holocene to Recent	**Made ground**	**up to c 2.0**
	Shoreface and beach deposits	**up to c 5.0**
	Blown sand	**up to c 5.0**
	Coastal barrier deposits	**up to c 2.0**
	Breydon Formation	**up to c 12.0**
Pleistocene to Recent	**Head and Hillwash**	**up to c 2.0**
Pleistocene	**Cover silt**	**up to c 2.0**
	gravels and sands	**up to c 2.0**
	Yare Valley Formation	**up to c 2.0**
	Corton Formation	**up to c 20.0**
	Crag Group	**up to c 34.0**
unconformity		
Palaeogene	**Ormesby Clay Formation**	**up to c 20.0**
unconformity		
Upper Cretaceous	**Chalk Group**	**361.2**
unconformity		
Lower Cretaceous	**sandstones and claystones**	**109.7**
unconformity		
Jurassic	**Lias**	**85.3**
Triassic	**Haisborough Group**	**149.4**
	Bacton Group	**111.3**
Permian	**Zechstein Group**	**79.2**
	Rotliegendes Group	**73.2**
unconformity		
Carboniferous	**Dinantian limestones**	**100.6**
	Dinantian shales & sandstones	**13.7**
unconformity		
Silurian	**siltstones, shales, sandstones**	**413.3+**

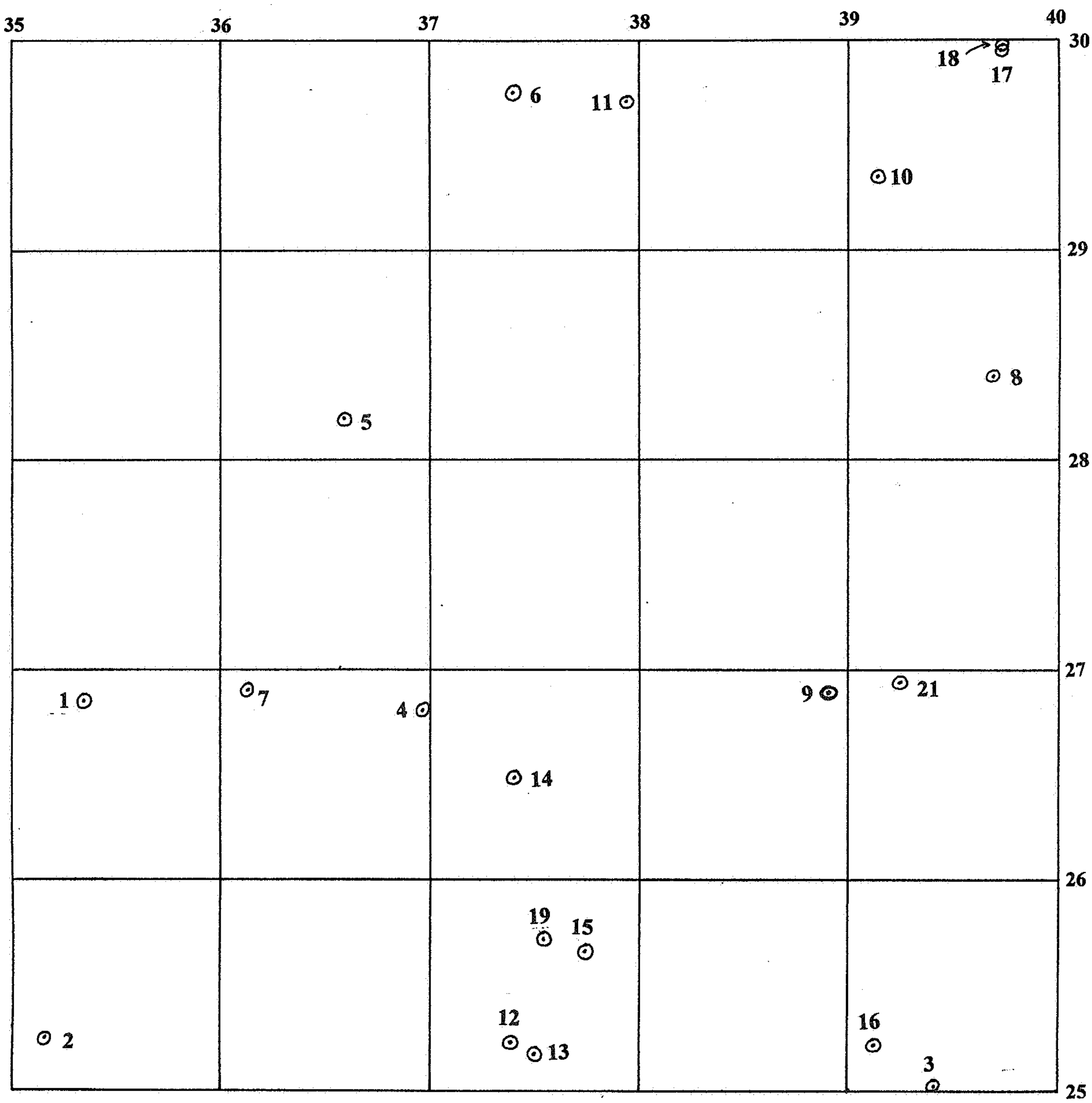

Figure 2: sites of boreholes on TG 32 NE, taken from BGS records. The number of each site is prefixed TG 32 NE/.

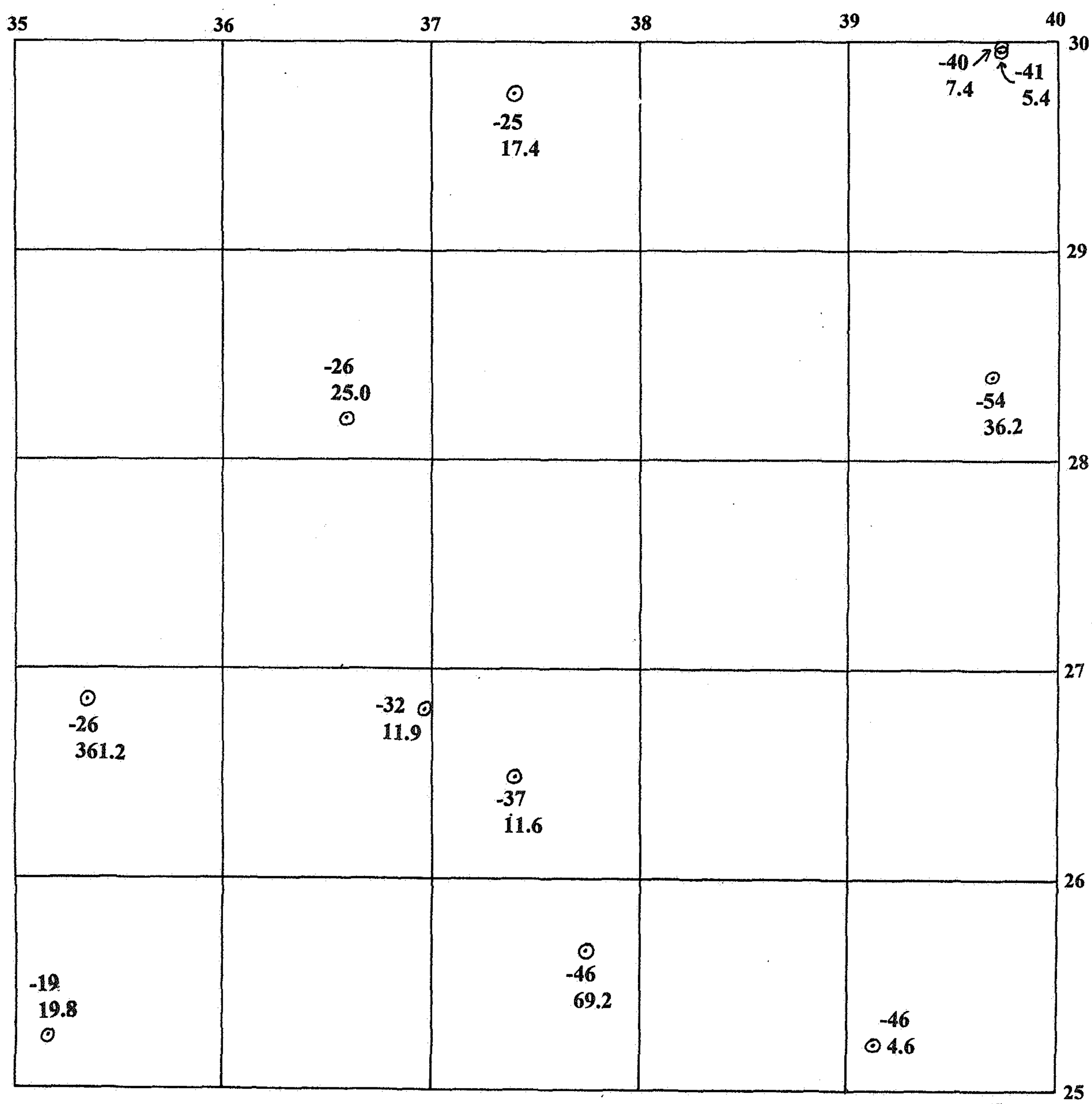

Figure 3: sites of boreholes on TG 32 NE which penetrate into the Chalk Group, showing the level of the top of the Upper Chalk relative to O.D. (upper figure) and the thickness of the Chalk penetrated (lower figure).

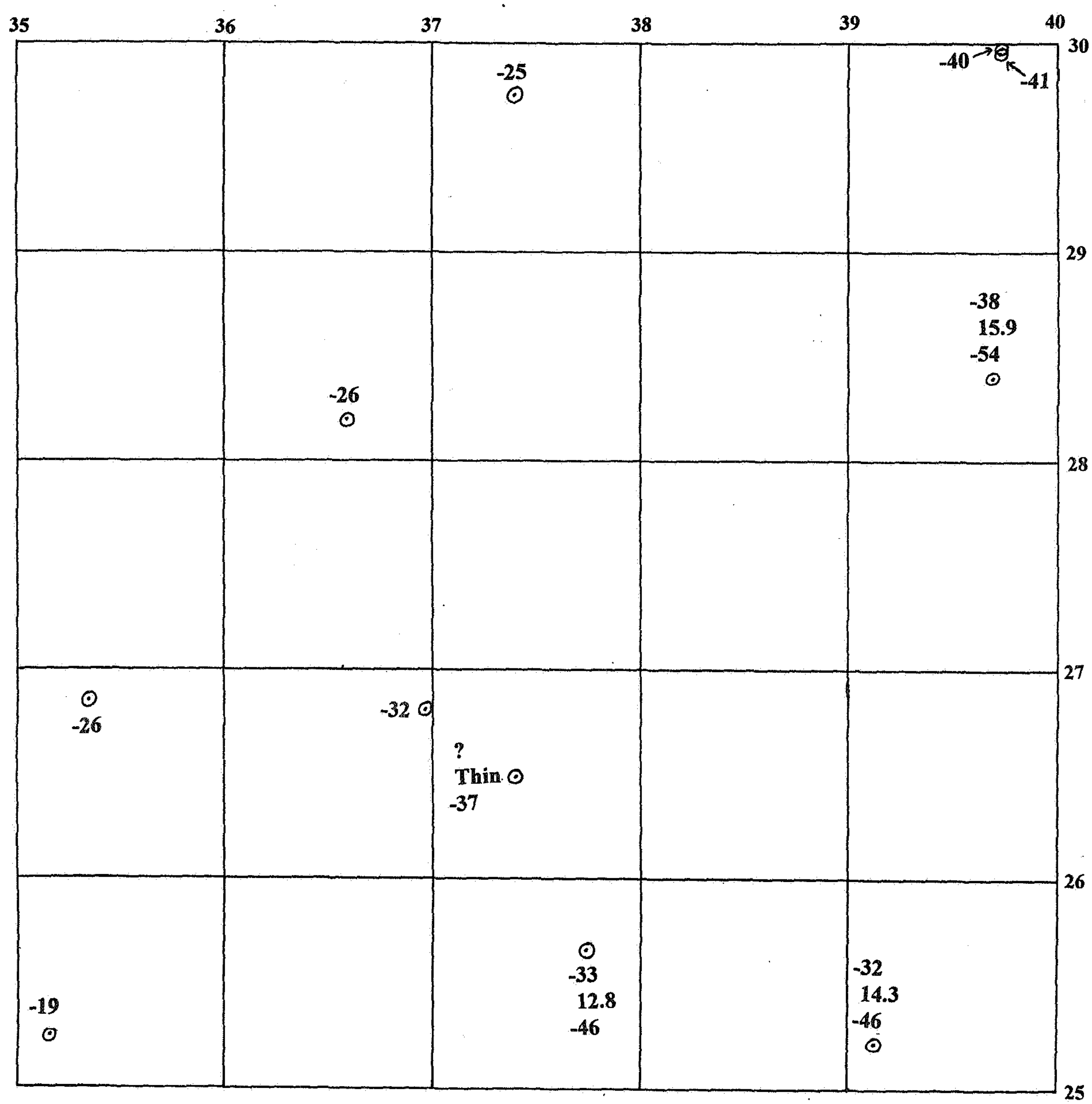

Figure 4: sites of all boreholes on TG 32 NE which penetrate the base of the Crag, showing the level of the base of the Crag relative to O.D. (uppermost or only figure), the thickness of Palaeogene (middle figure or word 'thin'), and the level of the base of the Palaeogene relative to O.D. (lowermost figure).

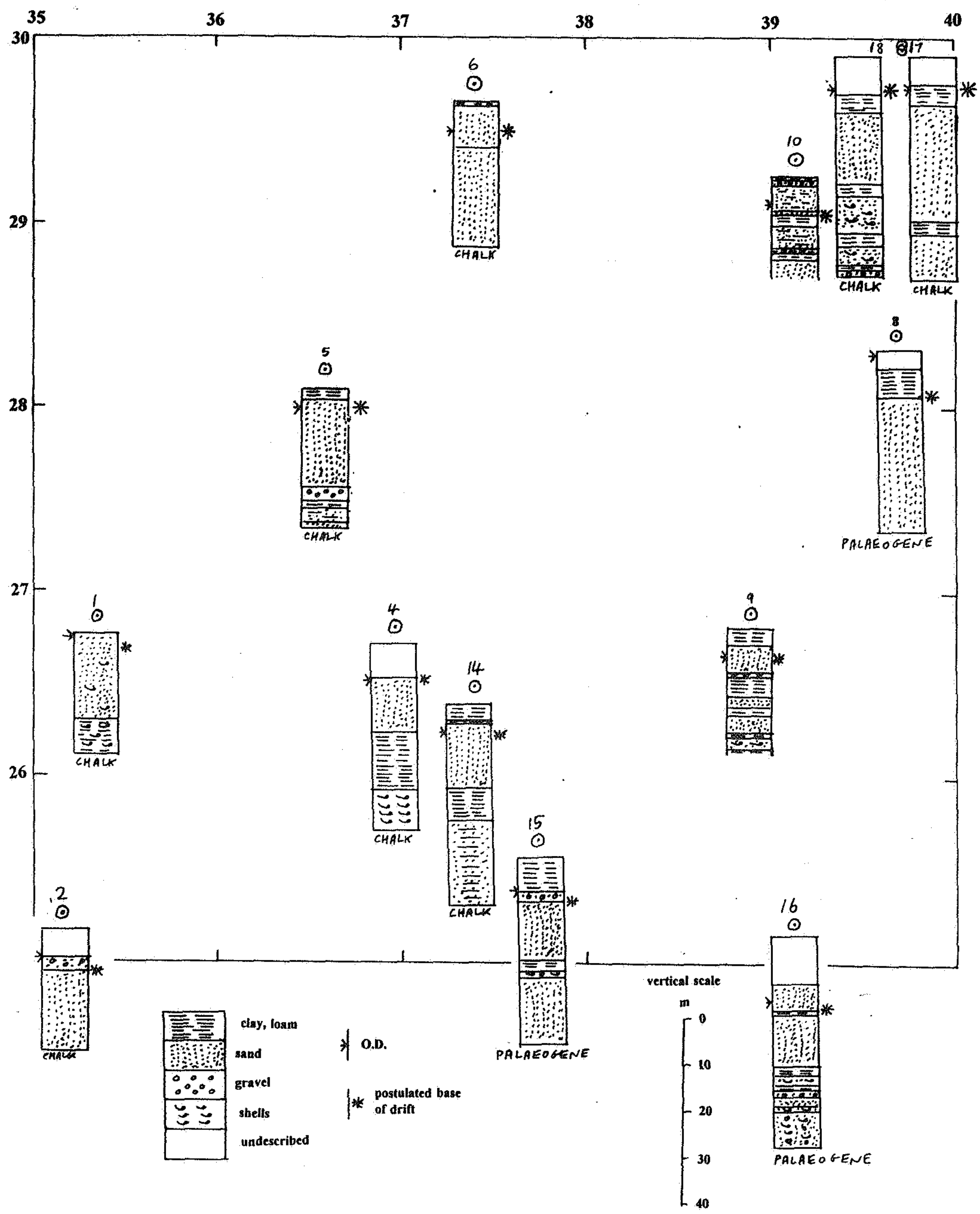

Figure 5: graphical representation of all boreholes which penetrate a significant thickness of Crag. The levels shown for the top of the Crag (asterisks) are only approximate owing to the difficulty of distinguishing weathered Crag from the overlying drift deposits. In the case of the eleven boreholes which penetrate the base of the Crag, the underlying strata are identified. Also, in TG 32 NE/14, the lowest part of the sequence depicted as Crag is believed to be Palaeogene.

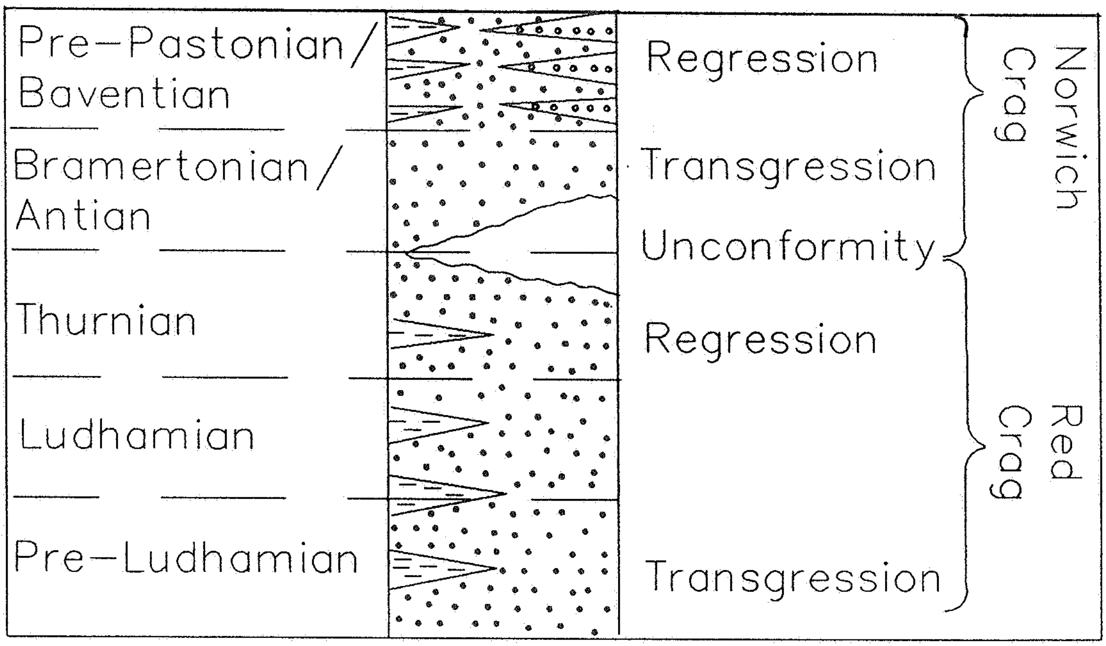

Figure 6: Generalised stratigraphy of the Red and Norwich Crag formations, after Hamblin *et al.* (1997). The sedimentology indicated is that found in eastern Suffolk, and recognises sands (dotted), gravels (small circles), and clays (dashed).

SOLID FORMATIONS

Ten wells sunk for water have penetrated through the Crag into the Upper Chalk, and an oil exploration borehole at East Ruston (TG 32 NE/1)[3530 2680] was extended down to ?Silurian.

?SILURIAN

The lowermost 413.3m of the East Ruston borehole comprised a sequence of siltstones and shales with subordinate interbedded sandstones, interpreted as a turbiditic shelf sequence of Silurian age (Abbott, in Arthurton *et al*., 1994). The siltstones and shales are pale to dark grey or black in colour, carbonaceous, micaceous and pyritic, with veins of quartz and dolomite. The sandstones are white or pale to dark grey, very fine- to medium-grained and poorly sorted, comprising angular quartz grains in a siliceous or dolomitic cement, with calcite veins and traces of pyrite.

CARBONIFEROUS - DINANTIAN

The ?Silurian in the East Ruston borehole is overlain by 13.7m of shales and sandstones which are considered to represent the base of the Carboniferous Limestone succession. The shales are pale to dark grey or black, silty and micaceous with carbonaceous specks, while the sandstones are multicoloured red, green, grey, yellow and white, very fine-grained, with angular quartz grains in a calcareous matrix.

These are overlain by 100.6m of massive dolomitic limestones, which are cream, white or pale to dark grey in colour, stained pink with haematite near the base. They have veins of calcite and traces of galena and pyrite.

PERMIAN AND TRIASSIC

The Permian and Triassic strata comprise from the bottom up, the Leman Sandstone Formation (Rotliegendes Group), Zechstein dolomite, an upper Zechstein sandstone, the Bacton Group (Bunter Shale and Bunter Sandstone formations), and the Haisborough Group. The Leman Sandstone is 73.2m thick in the East Ruston borehole. It is white or pale grey in colour, very fine- to very coarse-grained, poorly sorted, porous and friable, with pebbles of quartz and quartzite, veins of anhydrite and traces of galena and pyrite. It has a basal conglomerate with clasts of quartzite, siltstone, and red, green and lilac silty shales, in a sandy matrix, partly mineralised with pyrite and galena. At the top of the formation is a band of pale brown mudstone.

The Zechstein dolomite is 9.1m thick, white to pale tan in colour, hard and crystalline with specks of pyrite. It is overlain by 70.1m of white to pale grey or red, fine- to coarse-grained sandstone, with interstitial pyrite and thin laminae of anhydrite and brown or green claystone.

The Bunter Shale Formation is 74.7m thick and comprises red-brown and green-grey mottled silty claystones, locally micaceous, interbedded with pale green micaceous siltstones, fine- to medium-grained sandstones, and persistent anhydrite and gypsum beds. The Bunter Sandstone Formation is 36.6m thick, and comprises pale green to white or locally red sandstones, very fine- to medium-grained with anhydritic cement and interstitial pyrite. The Haisborough Group comprises 149.4m of red-brown claystones, mottled and streaked with pale green, locally silty, with wisps of fine-grained sandstone, abundant anhydrite and traces of pyrite.

JURASSIC - LIAS

In the East Ruston Borehole only 85.3m of Lias were preserved beneath the Cretaceous unconformity. Poor recoveries revealed pale to medium grey clays, locally silty or calcareous, with plant material and finely disseminated pyrite.

CRETACEOUS

The Lower Cretaceous in eastern Norfolk is sub-divided into a lower sequence of clays of Barremian to Albian age, overlain by the Carstone (Lower Greensand equivalent) and Gault (Arthurton *et al.*, 1994). In the East Ruston borehole these totalled 109.7m in thickness, but poor samples were obtained because of the looseness of the sandstones and softness of the claystones; most of the samples retrieved were cavings from the Chalk. The sandstone samples recovered comprised medium- to very coarse-grained rounded quartz, and the clays were medium to dark grey or brown in colour, silty and glauconitic, with phosphatic nodules and traces of pyrite, lignite and coal.

All three subdivisions of the Chalk Group, the Lower, Middle and Upper Chalk, are present beneath the whole of the area, totalling 361.2m in the East Ruston borehole. The thickness of Chalk penetrated in boreholes on sheet TG 32 NE is shown on Figure 3. The base of the group is believed to dip regionally to the north-east at 0.25° to 0.5° (Arthurton *et al.*, 1994). The principal lithology of the Chalk Group is soft, white, micritic, coccolith limestone, generally rather porous and poorly cemented. The Lower Chalk is less pure than the Middle and Upper Chalk and is grey in colour and flintless, with some indurated layers or 'hardgrounds', and bands of dark grey shell-detrital chalk. The Middle Chalk is flintless except for two horizons, and includes seams of marl throughout its thickness and beds of shell-detrital chalk in its lower part. The bulk of the Chalk Group however comprises the Upper Chalk, which is notably white, and rich in flint in the form of nodules or in tabular form. It contains a number of hardgrounds. The upper surface of the Upper Chalk, where it is overlain by the Crag, is commonly indurated and stained brown to a depth of a few centimetres, or else the uppermost chalk may be weathered to a depth of several metres to a soft, weak material commonly recorded in borehole logs as 'putty chalk'.

PALAEOGENE - ORMESBY CLAY

The Ormesby Borehole (TG 51 SW/7)[5145 1425] demonstrated that in eastern Norfolk the lowest Palaeogene formation is a clay, named the Ormesby Clay (Knox *et al.*, 1990; Arthurton *et al.*, 1994). This is of Thanetian age and hence equivalent to the Thanet Sands of Kent. In the Ormesby Borehole it was 27m thick. On sheet TG 32 NE the thickest record of Palaeogene is only 15.9m and hence it is reasonable to assume that only the Ormesby Clay is represented on the sheet.

At the base of the Ormesby Clay is a thin (less than 2m) bed of green glauconite-coated flint pebbles and cobbles. The remainder of the formation comprises a sequence of grey, olive-grey, pale green and reddish brown claystones, commonly silty, glauconitic or bioturbated. Several volcanic ash layers occur low in the sequence, and burrowed horizons occur between the sub-units.

The Ormesby Clay can be clearly recognised in three borehole logs. In borehole TG 32 NE/8 [3969 2840], 15.9m of strata may be ascribed to the formation, of which the upper 7.9m are described as 'black clay'. At TG 32 NE/16 [3912 2522], 14.3m of strata are described as brown, blue and green clays. At TG 32 NE/15 [3774 2566], 12.8m of strata are described as: dark green clay and shells, 4.3m; clay stone, 0.3m; grey clay, 7.3m; grey clay and flints, 0.9m. Finally, at TG 32 NE/14 [3740 2649], the Upper Chalk is overlain by 18.3m of strata described as grey sand and clay, and from comparison of the levels of the base of the Crag in adjacent boreholes, it is likely that the basal few metres are Ormesby Clay and the remainder belong to the Crag.

QUATERNARY - CRAG GROUP

The Crag Group represents the relatively coarse-grained marginal facies of a well-developed clastic sequence present in the southern North Sea (Cameron *et al.*, 1992). The strata comprise sands and shelly sands with subordinate seams of clay and gravel. The bulk of the sediments are fine- to medium-grained well-sorted micaceous sands. In an unweathered state they are glauconitic and dark green or dark grey in colour, but near the surface they become oxidised to shades of yellow and red, with layers of iron pan developing from the decomposition of glauconite. Fossils are not common, particularly in the upper part of the sequence, possibly as a result of decalcification. Flints form the bulk of the clasts in the gravel beds, although quartz and quartzite pebbles become important in gravels towards the top of the the Crag.

In the present district, the uppermost Crag appears at outcrop discontinuously at low levels along the western margin of the sheet [351 273, 351 287, 351 295, 350 298], although overgrown disused pits [353 297, 353 298] north of Atthills Farm are assumed to have penetrated the Crag beneath the Corton Formation. However, there are currently no exposures: the outcrops are everywhere obscured by a wash of gravel. Thirteen boreholes within the district proved Crag, of which eleven penetrated the base. Figure 4 shows the O.D. levels of the base, revealing a gentle dip toward the north-east. Since the top of the Crag lies generally not far above or below O.D., these figures approximate to the thickness of the Crag, which is seen to thicken north-eastward, from about 17m in the south-west (TG 32 NE/2 [3511 2523]) to about 41m in the north-east (TG 32 NE/17 [3972 2995]). Figure 5 shows in graphical form those boreholes which penetrate a significant thickness of Crag, including the eleven which penetrate the base. The levels shown for the top of the Crag (asterisks) are only approximate owing to the difficulty of distinguishing weathered Crag from the overlying drift deposits. Also, in TG 32 NE/14 [3740 2649] the lowest part of the sequence depicted is believed to be Palaeogene: in other holes the base of the Crag resting upon Palaeogene or Upper Chalk is clearly defined.

The colours of Crag sands where noted in borehole logs are generally grey or brown. In TG 32 NE/2 [3511 2523], where 5.5m of 'brown sand' overlies 11.3m of 'green sand', an upper weathered zone is implied. In TG 32 NE/16 [3912 2522], 'red sand' overlies 'blue clay' and then 'grey sand', but it is believed that the red sand is drift, while the blue clay and grey sand are Crag. In boreholes TG 32 NE/5, 14 and 15 the highest Crag sand is described as grey, implying that it has not been oxidised, while boreholes TG 32 NE/1, 4, 8, 9, 17 and 18 do not specify the colour of the highest Crag sand.

In Suffolk the Crag commonly has a basal bed of pebbles and cobbles of glauconite-coated flint, up to 2m thick, representing a transgressive beach deposit (Hamblin, in Moorlock *et al.*, in press). However in the present district only two boreholes revealed a basal conglomerate: in TG 32 NE/18 [3972 2998] this comprised 0.9m of 'sand and shingle', whilst in TG 32 NE/16 [3912 2522] the lowermost 8.2m of Crag strata are described as 'grey sand, sea shells and stones', although it is not clear whether the 'stones' are present throughout this thickness or just near the base.

Clays, described variously as blue, grey or black, are recorded in the Crag in all but three of the boreholes, generally in the lower part of the sequence. Shells are also noted in the lower part of six of the sequences which contain clays (boreholes TG 32 NE/1, 4, 9, 15, 16, 18). Also, in six cases (boreholes TG 32 NE/5, 9, 10, 15, 16, 18) gravel or 'shingle' appears in association with clays. In eastern Suffolk a similar situation is recorded (Hamblin, in Moorlock *et al.*, in press), and interpreted as a coastal complex, with gravel bodies (the 'Westleton Beds') interpreted as shoreface deposits, and the Easton Bavents and Covehithe clays interpreted as estuarine and lagoonal. The same interpretation may be valid in the present district.

The Red and Norwich Crag formations of Suffolk have recently been described by Hamblin *et al.* (1997). They record a series of transgressions and regressions (Figure 6), and have placed the base of the Norwich Crag at the unconformity shown at the base of the Antian/Bramertonian strata. In Norfolk, it is now clear that the uppermost Crag is significantly younger than any known in Suffolk. Current Survey practice is to include all the marine and estuarine deposits infilling the Crag Basin within the Crag Group, although on this basis the Crag includes deposits of Pastonian age, which would be included in the Cromer Forest-Bed Formation by West (1980). The uppermost Crag has been shown on the 1:10 000 sheet as Norwich Crag Formation, but at the time of writing it is proposed to raise the term Wroxham Grag Formation to include these highest strata. They differ from the underlying Norwich Crag Formation in that their gravel component is characterised by a significant proportion of quartz and quartzite as well as flint.

No palaeontological work has been done on boreholes within the present sheet, but in surrounding districts detailed work has been done on boreholes at Ludham (TG 31 NE/27 [385 199]; West, 1961), Ormesby (TG 51 SW/7 [5145 1425]; Arthurton *et al.,* 1994) and Happisburgh (TG 33 SE [3834 3112]; West, 1980, p.77, 189). The terms Ludhamian, Thurnian and Antian were erected as pollen biozones at Ludham (West, 1961), and later became accepted as chronostratigraphical stages (Mitchell *et al.*, 1973). At Ludham, between -18.9 and -49.7m O.D., 30.8m of strata of Ludhamian and Thurnian age correspond to the

Red Crag Formation as defined by Hamblin *et al.* (1997). These were overlain by 24m of strata of Antian and Baventian age and younger, corresponding to the Norwich Crag Formation of Hamblin *et al.* (1977), although West did not note a lithological break at the Thurnian:Antian junction. At Ormesby, 24.7m of Pre-Ludhamian and Ludhamian strata (ie Red Crag Formation) were proved between -40.4 and -65.1m O.D., overlain by at least 31.37m of Norwich Crag Formation. Here a clear lithostratigraphical break was recorded between the formations, with no Thurnian strata being preserved.

At Happisburgh, West (1980) recorded Norwich Crag down to at least -16.5m O.D., and then further Crag strata down to the Upper Chalk surface at -27.7m O.D. Thus the Red Crag can be no more than 11.2m thick here, if it is indeed present at all. Work in Suffolk (Hamblin *et al.*, 1997) suggests that while the Red Crag is preserved in contemporaneously formed, structurally controlled basins, the Norwich Crag overlies it disconformably as a tabular sheet. On this basis, if the base of the Norwich Crag rises from -40.4m O.D. in the Ormesby borehole to -18.9m O.D. at Ludham, then Red Crag should be present in the present district, where Crag is recorded down to -41m O.D. However, it is possible to interpret the local stratigraphy in either of two ways.

The sands with clays and associated gravel bands which have been recorded in the lower part of the sequence in the present district appear to most closely resemble the strata in the upper part of the Ormesby Borehole, which are of Baventian age, as is the coastal complex of gravels and clays known in eastern Suffolk (Hamblin, in Moorlock *et al.*, in press). In this case none of the strata preserved in the present district would be Red Crag. In the Ludham borehole, a clay of Baventian age was proved at -10m O.D.: Holman (1994) traced this clay by seismic reflection surveys as far as Waxham, where it lay at -20m O.D. This again accords with the clays in the present district, which is up-dip of Waxham, being Baventian. The base of the Crag from Catfield to Waxham was found to lie at about -60m O.D., much deeper than anywhere on TG 32 NE (Figure 4). This could be explained by a deep basin extending from Ludham to Waxham, infilled with both Red and Norwich Crag formations, with the Norwich Crag (Antian and younger) transgressing northwards out of the basin onto TG 32 NE. This interpretation can readily be applied to the Happisburgh borehole. Here, West (1980, p.77, 189) recorded Norwich Crag down to at least -16.5m O.D., and then discontinuous cold floras down to -25.1m, with a ?temperate flora in the basal sands which overlay the Chalk at -27.66m O.D. If the cold floras above -16.5m and continuing down to -25.1m are all Baventian, then the basal ?temperate flora would be Antian.

However, there is an alternative scenario. In the Ludham Borehole, thick clay sequences occur from about -10m to -15m (Baventian), and from about -19m to -28m (Thurnian). Downing (1959), working from BGS borehole records before the sinking of the Ludham Borehole, identified two clay seams over wide areas of Norfolk, and if his correlations are correct then it is possible that these are the Baventian and Ludhamian clays in the Ludham Borehole, although he did not record the clay seams as overlapping - he recorded the higher clay to the south of the River Bure, and the lower to the north. However, if he is correct and if the seams correlate with Ludham, then the lower (Thurnian) seam should be present below the present district (Downing, *op. cit.* Figure 3). In the Happisburgh Borehole, West (1980) records Norwich Crag cold floras down to about -16.5m O.D., and further cold floras associated with a clay and gravel complex at around -20m, but these are separated by barren sands and gravels which West interpreted as representing a marine transgression. By correlation with Ludham, it is possible that the lower clay is Thurnian and the barren, transgressive sands and gravels, Antian/Bramertonian. If this is the case then at least some of the clay sequences at depth in boreholes on TG 32 NE will be Thurnian. The two clay sequences in the Crag of borehole TG 32 NE/16, which lies half-way between the Ludham and Happisburgh boreholes, correlate well with the two in these other two holes and would clearly be Baventian and Thurnian, while the clay seams low in TG 32 NE/17 and 18 in the north-east would be Thurnian.

Either explanation is possible in the present state of knowledge, although in view of the levels of the base of the Norwich Crag in the Ludham and Ormesby boreholes, discussed above, it seems more likely that the Red Crag is indeed present in this district. Boreholes on the west side of the district generally show single clay sequences, and it is considered likely that these are Baventian, with the Red Crag being cut out unconformably beneath the Norwich Crag. However it is alternatively possible that the Baventian has come to crop and the clays in question are Thurnian.

DRIFT DEPOSITS

It is the practice of the British Geological Survey to portray the largely marine Early Quaternary Crag formations as 'solid', and all succeeding deposits as 'drift'. In the present district the earliest drift deposits known are the Corton Formation, a glacigenic formation of Anglian age. However, it is possible that earlier, pre-Anglian drift deposits are represented at depth, or even that they appear at outcrop and have not been distinguished, although it is known that none were present in the Happisburgh Borehole to the north [3834 3112] (West, 1980).

DRIFT DEPOSITS UNDERLYING THE CORTON FORMATION

In Suffolk, three pre-Anglian drift formations are known (Hamblin and Moorlock, 1995). These are the Kesgrave Sands and Gravels, a terraced sequence of fluvial sands and gravels corresponding to the pre-Glacial River Thames, the Bytham Sands and Gravels, a similarly terraced fluvial sequence deposited by a river flowing from the West Midlands to the Lowestoft area, and the Cromer Forest-Bed Formation, a coastal complex of interbedded fluvial, estuarine and marine strata which form the downstream correlative of the Bytham Sands and Gravels. In the memoir for the Great Yarmouth district (Arthurton *et al*., 1994) these are combined as the Kesgrave Group, but that practice has not been adopted elsewhere.

The **Cromer Forest-Bed Formation** is known along the Norfolk coast north of the present district, but in the Happisburgh Borehole [3834 3112] (West, 1980), Corton Formation rested on Pastonian strata which have been included in the Crag in the present survey, so no strata accredited to the Cromer Forest-Bed Formation are present. The Formation is also known from coastal areas north and south of Lowestoft, but it is possible that these and the North Norfolk coastal outcrops represent separate estuaries, and that the Formation was never deposited in the present district. Alternatively it might be present beneath the south-east of the district, since a borehole for oil at West Somerton (TG 41 NE/2 [4736 1935]) records interbeds of lignite and peat within orange sands which would otherwise be classed as Crag. Lignite or peat are only rarely recorded in the Crag, so it is possible that this record relates to the Cromer Forest-Bed Formation.

The earliest members of the **Kesgrave Sands and Gravels** have commonly been portrayed as extending northwards through eastern Suffolk and Norfolk (Rose, 1994; Arthurton *et al*., 1994). However, mapping of the Lowestoft and Saxmundham 1:50 000 geological sheets has revealed no evidence of these deposits north of Aldeburgh (Hamblin and Moorlock, 1995), and it appears unlikely that the Thames ever crossed north-eastern Suffolk or Norfolk, although it may well have flowed northward beneath what is now the North Sea east of the present district. It is thus unlikely that the Kesgrave Sands and Gravels are present in the Lessingham district.

The **Bytham Sands and Gravels** are known to follow the line of the River Waveney in the area around Bungay, and are believed to continue north-eastward to pass into the Cromer Forest-Bed Formation between Lowestoft and Yarmouth (Hopson and Bridge, 1987). It is thus unlikely that they occur beneath the present district. However a third river is believed to have existed, farther north than the Kesgrave or Bytham rivers and flowing eastward from the Pennines to pass into the Cromer Forest-Bed Formation in north Norfolk. A pebble suite implying input from this 'Northern River' is recorded in the Crag at How Hill on sheet TG 31 NE (Rose *et al.*, 1996). It is possible that after the completion of the infilling of the marine Crag basin, the mouth of this river moved eastward and fluvial deposits were formed in this area. It is thus possible that gravelly sands interpreted as Corton Formation in boreholes TG 32 NE/2 and /15 (Figure 5), and as Crag in TG 32 NE/9, might belong to such a fluvial formation. However, the small number of boreholes which record any such gravel at the correct level of the sequence could be said to argue against this.

ANGLIAN GLACIAL DEPOSITS

The Anglian glacial deposits of Norfolk are included within two formally defined formations (Arthurton *et al.* 1994), the Corton Formation below and the Lowestoft Till Formation above, although only the former is present in the Lessingham district. The formations derive from two separate ice-sheets, the North Sea Drift or 'Scandinavian Ice Sheet' which entered the area from the north or just east of north, and the 'British Eastern Ice Sheet' which entered from the west. In general it can be said that the deposits of the Corton Formation are derived from the former ice sheet, since they are characterised by a suite of Scandinavian igneous and metamorphic erratics, while the deposits of the Lowestoft Till Formation are derived from the latter ice sheet and contain erratics derived from Mesozoic outcrops to the north-west, principally the Chalk and Kimmeridge Clay. However, there is some evidence to suggest that the deposits of the Corton Formation also include detritus from the British Eastern Ice Sheet.

Where the two formations are found in contact, the Lowestoft Till Formation always overlies the Corton Formation, and it has been suggested (eg Hopson and Bridge, 1987) that the Scandinavian Ice Sheet withdrew from East Anglia before the British Eastern Ice Sheet reached the area. However, many more authors (eg Hart and Peglar, 1990; Hart and Boulton, 1991) consider that the two ice sheets co-existed, although the Scandinavian Ice Sheet must have retreated from the area before the British Eastern Ice Sheet reached its eastern limit. A possible explanation is that the Anglian in reality represents two glaciations, as suggested by Sumbler (1995) on the basis of work in the South Midlands. The main Anglian glaciation is generally ascribed to Oxygen Isotope Stage 12 (Bowen *et al.*, 1986), principally because deep-sea data show this to be one of the coldest stages of the Mid-Pleistocene, and on this basis it is accepted that the Corton Formation dates from Stage 12. However, the type site of the Hoxnian, at Hoxne, has been shown by amino acid geochronology to date from (warm) Stage 9 (Bowen *et al.*, 1989), and hence it is likely that, at least in western Suffolk, the Lowestoft Till Formation dates from (cold) Stage 10. If the Lowestoft Till Formation represents a single till sheet then the same age must apply in Norfolk, but this has not been proved, and in particular no (warm) Stage 11 deposits have ever been found underlying the Lowestoft Till Formation, even where it overlies the Corton Formation. The possibility thus arises that the British Eastern Ice Sheet advanced into east Anglia during both stages 12 and 10, with the Scandinavian Ice Sheet only reaching the area in Stage 12.

Corton Formation

The formation comprises diamicts (tills), sands and sandy gravels, and subsidiary lacustrine clays, and is believed to comprise both waterlain and terrestrial sediments (Lunkka, 1988; 1994). Eyles *et al*., (1989) noted that the close association of the tills and sands indicate allied depositional environments, and considered that the tills were the products of 'rain-out' of fine-grained suspension and coarse debris from floating ice. They concluded that the water-lain deposits are marine, but Lunkka (1994) considered that they were formed in a large lake. It is now widely believed that the Dover Strait was cut by the overflow of a pro-glacial lake during the Anglian (Gibbard, 1988; Hamblin *et al*., 1992), and it is suggested that a part of the Corton Formation was formed within this lake, held up between the Chalk ridge of the Dover Strait to the south and the 'Scandinavian Ice Sheet' to the north. However, as far as the tills are concerned, in cliff sections between Happisburgh and Cromer, Lunkka (1994) attributes three tills or diamicton members to 'lodgement' till with a fourth described as waterlain in an extensive glacial lake.

The stratotype is at Corton in the Great Yarmouth district (Arthurton *et al*., 1994). Here a basal till, the Corton Till, is overlain by fine-grained chalky sands, the Corton Sands. The Corton Till comprises very silty sandy clay or clayey sand, commonly laminated, with a scatter of pebbles. This is brownish grey to yellowish brown in colour and firm to stiff when fresh, but in surface outcrops it is commonly decalcified and weathers rapidly to a soft and friable condition because of its high sand content. At least a part of the till is believed to be water-lain, formed by the 'rain-out' of material from a floating ice-sheet (Eyles *et al*., 1989). However, the basal part of a till exposed at the base of the Corton Formation in a temporary section at How Hill [377 199], assumed to be laterally equivalent to the Corton Till, lacked laminations and appeared to have been formed sub-aerially (Rose *et al*., 1996).

Mechanical analysis of till from an area around Lowestoft (Bridge and Hopson, 1985; Hopson, 1991) showed the <2mm fraction to be extremely uniform and to comprise 22.0% clay, 23.6% silt and 54.4% fine- and medium-grained sand, while pebbles and coarse sand (>4mm) accounted for only 4.7% by weight and included a high percentage of coarse sand-grade chalk. Pebbles were mostly flints, with subordinate vein quartz, quartzite, chalk and shell fragments (from the Crag), and a sparse suite of rhomb porphyries, non-porphyritic lavas, mica schists, gneisses and granitoids believed to be of Scandinavian origin (Boswell, 1916). The 4mm to 8mm size range comprised 54% flint, 24% vein quartz, 8% quartzite, 3% sandstone and 2% each of limestone, ironstone and igneous/metamorphic rocks.

The Corton Sands comprise greyish or yellowish brown well sorted fine- to medium-grained sands, locally clayey, formed from sub-angular to sub-rounded quartz with subsidiary sand-grade flint, quartzite and disseminated chalk grains, calcite prisms and some mica flakes. Thin layers of silt, clay or pebbly diamicton occur, but pebble-grade material accounts for only 0.3% of the deposit (Hopson and Bridge, 1987), occuring as stringers of fine-grained gravel with angular and rounded flint, vein quartz, quartzite, chalk and traces of Scandinavian porphyry, granitoids and metamorphics. Sedimentary structures recorded in coast sections demonstrate that the sands are waterlain, and it is suggested that they were deposited in the ice-dammed lake, ahead of the ice-sheet from which the till was deposited. After the till had been formed, the ice-sheet retreated northward to leave open water within which the sand was deposited. Further, the high degree of sorting and roundness of the sand grains, which gives them a smoother 'feel' than the Crag sands, implies that at least a proportion of the material has an aeolian history, presumably being blown into the body of water in which the strata were forming.

Hopson and Bridge (1987), working in the Waveney Valley, identified a clastic unit of the Corton Formation below the Corton Till, which they termed the Leet Hill Sands and Gravels. At Scratby they also identified a second Corton Formation till above the Corton Sand, overlain by further sands and then a third till, although it is possible that this third till may be a part of the Lowestoft Till Formation. In the area around Potter Heigham (Hamblin, 1997), the Corton Formation comprises a discontinuous basal sand and gravel unit (which equates with the Leet Hill Sands and Gravels), overlain by the Corton Till, the Corton Sands, and a further till. The gravels within the basal unit of the formation are dominated by sub-angular to angular black-hearted white-patinated flints in a matrix of fine- to coarse-grained sand. Other pebbles include quartz and quartzite, sandstones and igneous rocks.

The presence of Lowestoft Till Formation at low levels in the valley of the River Thurne on sheet TG 41 NW (Hamblin, 1997) demonstrates that the cutting of this valley dates from the Anglian. At How Hill, on sheet TG 31 NE, sandy gravels with a heavy mineral signature indicating Corton Formation occur at a very low level in the valley of the River Ant, lower than the Crag at outcrop on the adjacent hillside (Hallsworth, 1994). This suggests that the valleys of the Ant and Thurne date from the final deglaciation stage of the Corton Formation, prior to deposition of the Lowestoft Till Formation, and that the gravelly wash covering the lower flanks of the valley sides date from this same period. Similar gravels are found low on valley sides in the present district, and are presumed to date from the same period, hence they are considered to be the latest member of the Corton Formation. However these gravels are too thin to show on the map.

The Corton Formation strata have locally been subject to glacial tectonics, or pushing by the 'Scandinavian Ice-sheet'. In general it can be said that the southern half of the district has been subjected to a degree of glacial tectonics, while the northern half has not. The effect of the deformation, coupled with the ubiquitous presence of cover silt overlying the Corton Formation, and the gravel wash overlying the junction between the Corton Formation and the Crag, makes the mapping of the Corton Formation difficult. In the southern half of the district, where glacial tectonics have occurred, augering is the only mapping technique applicable, and the mapped boundaries should be assumed to be accurate to only 100m or so. In the northern half of the district, where the undisturbed bodies of sand and till are largely horizontal, feature mapping can also be practised, and the boundaries are more precise. Also, in auger holes it is commonly not possible to distinguish lacustrine clays from tills, or between sands and gravels, hence on the map the formation is divided into Corton Formation (arenaceous deposits) and Corton Formation (argillaceous deposits).

The Corton Formation was once present throughout the whole of the present district, but it has been eroded from the restricted areas where Crag is now present at outcrop, and from beneath most of the area of outcrop of the Breydon Formation, eg in boreholes TG 32 NE/1

[3530 2680] and /8 [3969 2840] where the Breydon Formation rests upon Crag. However, sub-division of the Corton Formation is not clear, partly because of the obscuring effect of the ubiquitous sheet of cover silt which masks the formation at surface, and partly because of the glacial tectonics. Certainly there are at least two tills present, of which the lower is assumed to be the Corton Till. However the identity of every individual till outcrop is not certain, in contrast to the situation at Potter Heigham (Hamblin, 1997) farther south. The tills are separated by sands, but augering implies that these contain a significant proportion of coarse sand and gravel as well as the typical fine-grained sand of the Corton Sands. The lower till is believed to be underlain by further sands of the Corton Formation, which appear to include coarse sands and gravels and also fine sands of Corton Sand type, but the borehole records indicate that these sands are neither very thick nor very gravelly.

Corton Formation - Details

The bulk of the clastic sequence in the north-west of the district is believed to belong to the Corton Formation, since many of the auger holes proved fine-grained sand of Corton Sand type, and from the low level of the strata (OD <7), and by correlation with TG 32 NW to the west, it underlies the Corton Till. Coarse-grained sands and gravels were also augered, but these are believed to belong to the gravelly wash which mantles the lower part of the valley sides and post-dates the remainder of the Corton Formation.

The Corton Till overlies these basal sands to the south and east, and also occurs as an outlier [357 299] at the northern limit of the map. The till can be traced as a continuous sheet as far as [367 267] Brunstead and [392 274] Chapel Loke. Large excavations [352 279, 358 285, 362 287] were presumably worked for brick clays; one of these [358 285] is reported to become waterlogged in wet weather, implying that this pit, 2m deep, does not extend to the base of the till, while another [352 279] reportedly remains dry, suggesting that this pit, 5m deep, extends to the base of the till and that the underlying sands are free-draining. Smaller pits, generally water-filled and commonly adjacent to farms or field boundaries, are common, and were most likely excavated as watering holes for cattle. Borehole TG 32 NE/5 [3659 2819] records 2.4m of 'brick earth' overlying 1.3m of black sand and 17.6m of grey sand: the base of the Corton Formation may be postulated to lie at the base of the black sand. Borehole TG 32 NE/7 [3613 2690] records 0.75m of 'soil and loam' resting on 'fine whitish sand'. A further large excavation for brick-clay survives beside Brunstead House Farm [372 275], and smaller pits along The Avenue [368 267] at Brunstead Hall.

Corton Sand at least 7m thick overlies till over a large area around High Hill [354 274]. However, sands and gravels around Bristows Farm [376 268] underlie the till, and vary widely from fine-grained Corton Sand lithology to coarse-grained sand and gravels. Along High Hill Road [351 273] the till appears to have died out and the over- and underlying sands and gravels cannot be separated. An inlier of sand and gravel lies within the adjacent outcrop of the Breydon Formation [3515 2682].

Corton Sand overlies the Corton Till from [363 283] south of St.Mary's Church to [368 299] Hill Sixty and thence eastwards to [393 299] near the coast. Auger holes mostly proved the typical fine-grained yellow sand, although some proved coarser, gravelly sand, particularly east of Grub Street [374 298]. At Hill Sixty the Corton Sand must be more than 10m thick, since fine-grained sands were augered from the top of the hill at over 20m O.D., down to below the +10m contour to the south and east. Borehole TG 32 NE/6 [3740 2976], situated at the top of the till, records only 0.9m of 'loam' resting on 9.2m of 'silver sand' then 21.3m of 'brown sand'. The latter is clearly Crag, but the 'silver sand' may include weathered Crag as well as Corton Formation.

The patch of sand at Short Lane [369 291 to 375 293] is largely fine-grained and of Corton Sand type, and since it does not topographically stand above the surrounding till it is probably an 'inlier' of the sand underlying the till, its appearance confirming the thinness of the till hereabouts. Another patch of sand and gravel [361 280 to 366 274] is probably a similar 'window'; the sands here are coarser and more gravelly than those at Short Lane. However, three patches of Corton Sand farther east [380 292, 380 287, 378 284] form low hills standing above the till plane and presumably overlie the till. One includes an abandoned sand pit [3800 2926]. A further large patch of sands and gravels overlying the till stretches north and south of Lessingham [391 289 to 392 275]. This is dominated by fine-grained Corton Sand but includes coarser, gravelly sands. At Grange Farm [3922 2780] a shallow pit (dug for burying a dead pig) revealed grey flat-bedded coarse-grained sand with stringers of gravel.

Coarse- to fine-grained sands and gravels underlie the till sheet in the valleys around Lessingham. Coarse-grained sands and gravels crop out west of the Star public house [388 284 to 387 279], and a mixture of coarse-grained sands and gravels and fine- to medium-grained sands from Fern House [3887 2785] past Ivy House [3929 2742] and Grange Farm [393 278] to Briar Cottage [3873 2920]. The farmer at Fern House has collected boulders up to 30cm across of 'puddingstone' and volcanic rocks from this horizon. Further sands and gravels crop out in the valley at Whimpwell Green [386 294, 385 295 to 383 299] but these appear to connect with the Corton Sand which overlies the till westward along the northern margin of the district, so apparently the till sheet has died out north-eastward.

East of the head-filled valley at Whimpwell Green, a till sheet can be traced from [392 292] south of Mill Farm to the coast at Cart Gap [398 299], where till was augered in the cliffs below the blown sand. Boreholes TG 32 NE/17 and 18 were sunk from the bottoms of un-logged wells respectively 6.1m and 7.9m deep, below which they record clays to depths of 10.7m and 11.9m. In TG 32 NE/17 this clay is referred to as 'brick earth', which implies till, but by correlation with the Happisburgh Borehole, just beyond the northern boundary of the sheet, the greater part of these clays is likely to be Crag. The till crops out over a wide area south of Cart Gap, overlying sands and gravels, and also crops out [394 299 to 392 292] along the slope east of Mill Farm, but does not appear to extend farther west. It is probably at the same horizon as the till sheet which crops out south-west of Whimpwell Green, but may never have been connected to it. Borehole TG 32 NE/10 [3914 2934], which would penetrate this till if it were continuous, records sand and shingle to 0.9m, sand and clay to 7.3m, white sand to 7.6m, then yellow clay to 10.4m: the yellow clay is probably Crag as in /17 and /18, and the base of the Corton Formation may lie immediately above. Till at the northern limit of the district [390 299] connects with that which extends to Cart Gap, but two further patches of till [389 297, 391 295] lie at a higher level and may be part of a higher till sheet.

Along the eastern edge of the district, two separate tills crop out, and these may be correlated with the two postulated above. The lower extends from Hempstead Heath [399 276] to [398 290] west of Seaside Lane. In the south this is around 2m thick and lies between 4m and 6m O.D., while it declines northwards to 1m thick at around 4m O.D. The upper till, at Church Farm [399 283], lies only a metre or so above the lower. The two tills are separated by uniform yellow fine-grained sand. Since they lie so close together it is possible that they join northward and westward to correlate with the single till sheet known north of Brumstead, since at Hill Sixty [368 299] this lowest till is overlain by Corton Sand more than 10m thick.

A large area of fine-grained sands extending from near the Croft [368 284] to Happisburgh Common [376 286] and Brumstead Road [375 272] lies at much the same topographic level as the till sheet either side; its uniform 'Corton Sand' lithology suggests that it should overlie the till, but it is continuous with sands and gravels at a lower level west of Orchard Farm [377 273]. It is possible that here the till sheet has died out, or alternatively the conjunction of the 'Corton Sand' and the gravelly coarse-grained sands may result from glacial tectonics, which appear to become important in the southern half of the district. The till extending south from Moat Farm [385 283] is overlain to the west by Corton Sand, although this is in continuity with gravelly sands at a lower level to the south [384 275]. Also the Corton Sand appears to be overlain to the west by a further till [381 281 to 380 274], although this till is apparently in continuity, via Manor Farm [378 282], with the till extending south from Moat Farm. It is not clear whether this a case of one till splitting, or whether two tills have been brought into contact by glacial tectonics.

An outlier of till at New Hall [389 269] apparently rests upon Corton Sand, within a large area characterised by fine- to coarse-grained sands and gravels. However the till [387 271] near Stonebridge Farm takes the form of a ridge rather than a plateau, which may mean that it is dipping as a result of glacial tectonics.

South of grid northing [270] the tills everywhere appear as discrete patches, surrounded by sands and gravelly sands, at varying heights and apparently dipping in various directions. This is believed to result from mild glacial tectonics, with compression from the north tilting and shearing the sheet(s) of till, and is in contrast with the northern part of the district where a near-horizontal sheet of till can be traced over long distances. In this situation it is difficult to assess whether one or two original till sheets were involved.

The patch of till [365 266] west of Brumstead Church dips southward and westward, from about 9m to about 4m. The large area of till extending from near Stepping Stone Lane [365 256] almost to Ingham [383 260] rises from below 5m [371 264] west of Oldbarn Farm to 8m in the east and south. The Corton Sand around Oldbarn Farm apparently overlies this till, since borehole TG 32 NE/14 [3740 2649] recorded brown clay to 3.4m depth, brown clay and sand to 4.0m, then grey sand, believed to include both Corton Formation and Crag, to 18.3m. The till patches along Wayford Road [355 254, 364 253] are less tilted, but augering demostrates that they are separate from one another and from that mentioned above; the till [360 250] south of the sewage works lies at a lower level, below 5m O.D. North of West End Farm [365 251] there are several large disused brick-clay pits, all around 2m deep. The sands separating these various patches of till are generally fine-grained, of the Corton Sand type, although they must be mostly or wholly lower in the sequence that the lowest Corton Formation till.

The extent of till in the town of Stalham is unknown and most of the built-up area is shown on the map as Corton Formation undifferentiated. Borehole TG 32 NE/19 [3754 2572] recorded clay to 7.3m depth, resting on sand and gravel, while TG 32 NE/15 [3774 2566] recorded red loam, brown clay and reddish brown clay to 7.3m resting on yellow sand and shingle. This implies that although the till sheet appears to dip to the north-west, the sand augered to the south-east of these holes cannot pass below it at a shallow angle. Borehole TG 32 NE/12 [3733 2522] within Stalham recorded 3m of 'brick-earth' on sand, clay and gravel, while TG 32 NE/13 [3747 2520] recorded brown clay to 1.5m depth overlying coarse-grained sand and shingle.

The large patch of till extending eastward from [383 256] west of Ingham, and the smaller patch at Greenacres [386 255], have been extensively worked for brick-making at the brickworks operated at Brick Yard Farm [386 258] until the start of the Second World War, when it was closed because of the difficulty of conforming with blackout regulations. The till patch around Bluebell Wood [396 262], which also includes two small brick-clay pits, is flat-lying and at a lower level than the Ingham patch. The two patches are separated by a steep slope of Corton Sand and it appears that the Bluebell Wood patch passes beneath the Ingham patch. Borehole TG 32 NE/3 [3940 2502], at the south end of the Ingham till patch, records silty sands to 4.7m depth, sandy silty clay with fine gravel to 6.6m, then more sands and gravels; it is possible that the clay layer is the Bluebell Wood till sheet. Small patches of till at Harveys Farm [397 256] and [387 264] north of Ingham are also at a low level and may correlate with that at Bluebell Wood.

WOLSTONIAN AND DEVENSIAN DRIFT DEPOSITS

During the Wolstonian/Saalian and Devensian/Weichselian glacial episodes, southern England was subject to periglacial conditions, and sea levels in the North Sea dropped sharply as up to 5% of the global water budget was locked up in the form of ice. During these periods remarkably little erosion occurred in the present district: the bulk of the erosion of the Corton Formation must have occurred during the waning of the Scandinavian ice sheet in the Anglian stage, since in adjacent districts the Lowestoft Till Formation occurs at low levels in river valleys. Hence later erosion must be very largely restricted to overdeepening of the river valleys.

Three deposits were formed during these periods: the Yare Valley Formation, cover silt and head. The **Yare Valley Formation** (Arthurton *et al.,* 1994) occurs beneath the Breydon Formation in the valley of the River Ant in the west of the district, and possibly beneath Breydon Formation tributaries elsewhere in the district. It comprises fine- to coarse-grained gravels, mostly of flint, with variable amounts of fine- to coarse-grained sand, some silt, shell fragments and chalk cobbles. Their thickness in the present district is unknown, but they are up to 11m thick near Great Yarmouth and are generally considered to be of late Devensian and/or early Holocene age. Similar gravels may have formed during the Wolstonian and also late in the Anglian, but these would probably have been subsequently eroded away and replaced by the Devensian gravels.

Cover silt is the term given to a drape of silt and sand which masks most of the outcrops shown as Corton Formation in the district. Silt is the main component, with subordinate fine- to medium-grained sand, giving a bimodal distribution (Catt *et al.*, 1971; Perrin *et al.*, 1974). These authors consider the deposit to be aeolian in origin, possibly modified by frost-heaving and biological mixing. It is considered to be Devensian in age, formed during the last ten thousand years which preceded the Flandrian marine transgression, and derived by aeolian transport from Devensian outwash sediments in northern England. In the present district the cover silt is not shown on the map, since it is almost ubiquitously developed over the Corton Formation outcrop. It is up to at least 1.4m thick, but most commonly 0.4-0.7m, and tends to be thickest where it collects within concave slopes.

At the base of the cover silt, where it rests upon till or gravelly sands of the Corton Formation, there is a layer a few centimetres thick of hard-packed gravel. This is commonly impenetrable by hand auger, and makes mapping the underlying Corton Formation difficult. It is believed to be a deflationary product of the underlying units, the fines having been winnowed out by the wind to leave hard-packed gravel. There is commonly no such gravel where the cover silt rests upon gravel-free sands of the Corton Formation.

Head comprises poorly sorted and poorly stratified clayey sands and sandy clays derived from the glacial deposits by mass movement on sloping ground. The processes involved include hillwash and soil creep as well as solifluction. The head is assumed to be largely late Devensian in age in view of the periglacial conditions then prevailing, but some may survive from the Wolstonian or even late Anglian, and some hillwash and soil creep may date from the Holocene. Remarkably little head is seen in East Anglia considering the intensity of the periglacial climate to which the area has been subjected during the last three glaciations, and in the present district head is restricted to small strips and patches in the tributary valleys of the Breydon Formation.

GRAVEL AND SAND OF UNKNOWN AGE AND ORIGIN

Four patches of gravel and sand of unknown age and origin occur, two at Ingham [392 259, 390 251] and two in the north-west of the district [366 284, 372 294]. Augering reveals these to comprise very weathered, angular gravel, mostly shattered flint, in a matrix of coarse-grained sand. They are believed to be not much more than a metre thick. It is unlikely that the gravels are a part of the Lowestoft Till Formation since they do not contain large fresh flints. The gravel content of these deposits resembles that of the Corton Formation and it may be that it is a winnowed product of that formation, equivalent to the basal gravel bed of the 'cover silt'.

BREYDON FORMATION

Breydon Formation (Arthurton *et al.*, 1994) is the name given to the Holocene estuarine sequence which forms the marshland occupying the floodplains of the various rivers which make up the Waveney/Yare/Bure catchment. The Formation as defined by Arthurton *et al.* is a 'fossil' formation formed under estuarine to marine conditions, and is not intended to include any fluvial deposits formed so far inland as to be out of estuarine influence, or deposits formed in recent times after the sea had been artificially excluded from the area and the marshland drained. The components of the Breydon Formation in the Great Yarmouth district comprise an impersistent basal peat, the Lower Clay, the persistent Middle Peat, the Upper Clay and the marginal Upper Peat. In the present district, which is remote from the sea, it is doubtful whether all these elements are present, or even whether the standard stratigraphy applies at all.

Two boreholes penetrating the Breydon Formation are known in the district. TG 32 NE/1 [3530 2680] in the valley of the River Ant does not distinguish it from the sands of the underlying Crag. Borehole TG 32 NE/8 [3969 2840] is undescribed down to 3.7m, then records 'land and sea mud' to 10.1m, on 'blowing sand (very fine)' which may be assumed to be Crag. The figure of 10.1m may be approaching the maximum thickness of the Breydon Formation in the district.

In the lower reaches of the Bure catchment, the Upper Clay and Upper Peat are both exposed at the surface. The former takes the form of a broad band either side of the rivers, while the latter occurs discontinuously along the shoreward margins of the marshland and in tributary valleys. This is because the centre of the floodplain was more prone to marine inundation than the margins, allowing vegetation to grow in the less saline marginal areas and tributaries and leading to peat growth. The exposed Upper Peat and Upper Clay are thus of approximately the same age. However, the Upper Clay does not extend upstream at surface as far as the present district, where the Upper Peat covers the whole of the floors of the valleys of both the River Ant and the Lessingham stream.

In the present district, clays occur upstream of peat in tributary valleys of the two major streams. These cannot be directly correlated with the Upper or Lower clays, but may be equivalent to both in age. The clays are considered to be of estuarine rather than alluvial origin from a consideration of the area and shape of the clay bodies: alluvial clays would have longer, thinner outcrops following clearly defined river channels. The presence of clay rather than peat may be because the Breydon Formation in these situations is so far upstream as to be too high, relative to the normal water table, for peat to have survived without oxidation.

COASTAL BARRIER DEPOSITS

A small area of coastal barrier deposits has been mapped in the north-east of the district [399 298], beside Cart Gap; this is continuous with a much larger area on sheet TG 42 NW to the east. The deposits are a mixture of fine-grained sand derived from earlier (pre-1880) blown sand, and gravelly, coarser-grained sand washed over from the beach during storms. The result is a relatively low-lying but uneven area of land.

BLOWN SAND

Blown sand occurs as a belt of dunes towards the landward side of the shoreface and beach deposits [397 299 to 399 298]. These dunes are continuous from TG 42 NW to the east and TG 33 SE to the north. The dunes comprise well sorted fine-grained sand, and are stabilised by a thick growth of marram grass. They are believed to overlie the coastal barrier deposits.

SHOREFACE AND BEACH DEPOSITS

Only a short length of relatively narrow beach appears in the present district [399 299]. The composition of this beach varies according to the effects of winter storms, but always comprises a mix of sands and gravels derived from the Quaternary deposits forming the local cliffs. Long-shore drift is from the north, so the beach deposits reflect the strata exposed in the cliffs in that direction, which are dominated by Corton Formation, with subordinate Crag Group and Upper Chalk. Thus the major components are fine- to coarse-grained sands and flint gravels derived from the Corton Formation, sands and rounded flints from the Crag, and fresh, unrounded flints from the Chalk.

MADE GROUND, WORKED GROUND AND LANDSCAPED GROUND

Most of the worked ground in the district comprises workings for brick clays within the Corton Till, some of which have been backfilled by farmers [eg 378 263, 391 261]. That south-west of Mill Farm [390 250] has been backfilled with domestic refuse by the local authority. Other such back-filled pits may have been missed during the current survey. There are two disused pits sunk into Crag [353 298, 353 297] adjacent to Fox Hill Farm, and these may have worked both gravel and brick clay. Smaller pits, particularly those at a low level near or within the Breydon Formation [eg 3535 2629, 3542 2577], will have been excavated as wildfowl decoys or for watering cattle. Many of the latter are too small to show on the map. Several moats will have served as defences for farm houses in medieval times [370 264, 383 290, 384 283].

The only made ground is the sea defence at Cart Gap [3975 3000 to 4000 2982]. Landscaped ground has been mapped at the sewage works [358 252] and at the site of a proposed sports complex [367 260].

ECONOMIC GEOLOGY

Industrial minerals

There is currently no mineral extraction in the district, although, in the past, clay, sand and gravel have been extracted from the Corton Formation and Crag. Peat has probably been extracted from the Breydon Formation although no former workings were noted during the current survey. Gravels in the Corton Formation and Grag would prove too sandy and too poorly sorted to be of economic value today. The gravels of the Yare Valley Formation have not been explored but would probably be too thin, and have too thick an overburden, to be economic.

Water supply

The Crag and the sand and gravel units of the Corton Formation are minor aquifers, with water flow through pores between the sand grains. The Crag is in hydraulic continuity with the basal sand and gravel unit of the Corton. The tills in the Corton Formation are aquacludes. The Chalk is a major aquifer, with all flow through fissures rather than intergranular. The Crag and Chalk are in hydraulic continuity except in the east of the district where the Palaeogene strata intervene.

Twenty bores for water are known within the district, TG 32 NE/2 to 21. Of these, 10 penetrated the Chalk, to depths of 45.7m to 121.9m. These revealed rest water levels of -4 to +8m O.D., and water consumptions quoted vary between 500 and 3000 gallons (2273-13,638 litres) per day. A 3-day pumping test at TG 32 NE/2 yielded 2300 gallons (10,456 litres) per hour for 3 days, with a depression of 13.7m and recovery in 1 minute and 10 seconds. Test pumping of TG 32 NE/15 produced 2650 gallons (12,047 litres) per hour with a depression of 47.5m. Water from the Chalk is hard, and some wells reported it to be ferruginous. Ten wells were restricted to the Crag or overlying drift deposits. These revealed rest water levels of +1m to +5m O.D., and water consumption quoted varied from 300 to 2000 gallons (1364-9092 litres) per day. Test pumping of TG 32 NE/10 yielded 600 gallons (2728 litres) per hour for one day, and of TG 32 NE/20, 2000 gallons (9092 litres) per hour for 8 hours.

REFERENCES

Arthurton, R S, Booth, S J, Morigi, A N, Abbott, M A W, and Wood, C J. 1994. Geology of the country around Great Yarmouth. *Memoir of the British Geological Survey,* Sheet 162 (England and Wales).

Boswell, P G H. 1916. The petrology of the North Sea Drift and Upper Glacial Brickearths in East Anglia. *Proceedings of the Geologists' Association,* 27, 79-98.

Bowen, D Q, Hughes, S, Sykes, G A, and Miller, G H. 1989. Land-sea correlations in the Pleistocene based on isoleucine epimerization in non-marine molluscs. *Nature*, 340, 49-51.

-----, Rose, J, and McCabe, A M. 1986. Correlation of Quaternary glaciations in England, Ireland, Scotland and Wales. *Quaternary Science Reviews,* 5, 299-340.

Bridge, D McC, and Hopson, P M. 1985. Fine gravel, heavy mineral and grain size analyses of mid-Pleistocene deposits in the lower Waveney valley, East Anglia. *Modern Geology,* 9, 129-144.

Cameron, T D J, Crosby, A, Balson, P S, Jeffery, DH, Lott, G K, Bulat, J, and Harrison, D J. 1992. *United Kingdom offshore regional report: the geology of the southern North Sea* (London: HMSO for British Geological Survey).

Catt, J A, Corbett, W M, Hodge, C A H, Madgett, P A, Tatler, W, and Weir, A H. 1971. Loess in the soils of North Norfolk. *Journal of Soil Science*, 22, 444-452.

Downing, R A. 1959. A note on the Crag of Norfolk. *Geological Magazine,* 96, 81-86.

Eyles, N, Eyles, C H, and McCabe, A M. 1989. Sedimentation in an ice-contact subaqueous setting: the mid-Pleistocene 'North Sea Drifts' of Norfolk, UK. *Quaternary Science Reviews,* 8, 57-74.

Gibbard, P L. 1988. The history of the great northwest European rivers during the past three million years. *Philosophical Transactions of the Royal Society of London, Series B,* 318, 559-602.

Hallsworth, C R. 1994. Variations in the heavy minerals of the Plio-Pleistocene sediments in East Anglia: the implications for provenance. *British Geological Survey Technical Report*, WH/94/88/R.

Hamblin, R J O. 1997. Geological notes and local details for 1:10 000 sheet TG 41 NW (Potter Heigham). *British Geological Survey Technical Report*, WA/95/12.

-----, Crosby, A, Balson, P S, Jones, S M, Chadwick, R A, Penn, I M, and Arthur, M J. 1992. *United Kingdom offshore regional report: the geology of the English Channel.* (London: HMSO for British Geological Survey).

-----, and Moorlock, B S P. 1995. The Kesgrave and Bytham Sands and Gravels of Eastern Suffolk. *Quaternary Newsletter,* 77, 17-31.

-----, -----, Booth, S J, Jeffery, D H, and Morigi, A N. 1977. The Red and Norwich Crag formations in eastern Suffolk. *Proceedings of the Geologists' Association,* 108, 11-23.

Hart, J K, and Boulton, G S. 1991. The glacial drifts of northeastern Norfolk. In: *Glacial deposits in Great Britain and Ireland.* Ehlers, J, Gibbard, P L, and Rose, J (editors). (Rotterdam: Balkema).

----- and Peglar, S M. 1990. Further evidence for the timing of the Middle Pleistocene Glaciation in Britain. *Proceedings of the Geologists' Association,* 101, 187-196.

Holman, I P. 1994. Controls on saline intrusion in the Crag Aquifer of North-East Norfolk. Unpublished PhD Thesis, University of East Anglia.

Hopson, P M. 1991. Geology of the Beccles and Burgh St.Peter district. *British Geological Survey Technical Report,* WA/91/53.

-----, and Bridge, D McC. 1987. Middle Pleistocene stratigraphy in the lower Waveney valley, East Anglia. *Proceedings of the Geologists' Association,* 98, 171-185.

Knox, R W O'B, Morigi, A N, Ali, J R, Hailwood, E A, and Hallam, J R. 1990. Early Palaeogene stratigraphy of a cored borehole at Hales, Norfolk. *Proceedings of the Geologists' Association,* 101, 145-151.

Lunkka, J P. 1988. Sedimentation and deformation of the North Sea Drift Formation in the Happisburgh area, North Norfolk. 109-122 in: *Glaciotectonics: Forms and Processes.* CROOT, D (editor). (Rotterdam, Balkema).

----- 1994. Sedimentation and lithostratigraphy of the North Sea Drift and Lowestoft Till formations in the coastal cliffs of northeast Norfolk, England. *Journal of Quaternary Science,* 9, 209-233.

Mitchell, G F, Penny, L F, Shotton, F W, and West, R G. 1973. A correlation of Quaternary deposits in the British Isles. *Geological Society of London, Special Report,* No4.

Moorlock, B S P, Hamblin, R J O, Booth, S J, and Morigi, A N. *In press.* Geology of the country around Lowestoft and Saxmundham. *Memoir of the British Geological Survey*, sheets 176 and 191 (England and Wales).

Perrin, R M S, Davies, H, and Fysch, M D. 1974. Distribution of late Pleistocene aeolian deposits in eastern and southern England. *Nature,* 248, 320-324.

Rose, J. 1994. Major river systems of central and southern Britain during the Early and Middle Pleistocene. *Terra Nova,* 6, 435-443.

-----, Gulamali, N, Moorlock, B S P, Hamblin, R J O, Jeffrey D H, Anderson, E, and Lee J A. 1996. Pre-glacial Quaternary sediments, How Hill near Ludham, Norfolk, England. *Bulletin of the Geological Society of Norfolk*, 42, 3-28.

Sumbler, M G. 1995. The terraces of the rivers Thame and Thames and their bearing on the chronology of glaciations in central and eastern England. *Proceedings of the Geologists' Association,* 106, 93-106.

West, R G. 1961. Vegetational history of the Early Pleistocene of the Royal Society borehole at Ludham, Norfolk. *Philosophical Transactions of the Royal Society, Series B*, 155, 437-453.

----- 1980. *The pre-glacial Pleistocene of the Norfolk and Suffolk coasts.* (Cambridge: University Press).

APPENDIX:ABBREVIATED LOGS OF ALL NON-CONFIDENTIAL BOREHOLES HELD BY BGS TO JANUARY 1996

The stratigraphic classification given is the author's interpretation of the drillers' log; the quality of data is such that this must be treated with caution. Copies of the original logs may be obtained from the Survey's offices at Keyworth; the site numbers given here are prefixed TG 32 NE.

	Depth (m)	O.D. Level (m)
1. East Ruston No1 [3530 2680] SL + 6.1		
(no record)	to 3.0	+ 3
Breydon Formation, Crag Group		
Sand, loose, unconsolidated, broken shell debris	to 24.4	- 18
Clay, pale grey, silty, calcareous, glauconitic; shell debris	to 32.0	- 26
Chalk Group to ?Silurian		
(see log in NGRC)	to 1528.8	- 1523
2. Wayford Bridge, Stalham [3511 2523] SL c + 7		
(existing well)	to 6.09	+ 1
?Corton Formation, Crag Group		
Sand and stones	to 9.14	- 2
Brown sand	to 14.63	- 8
Green sand	to 25.90	- 19
Upper Chalk		
Chalk	to 45.72	- 39
3. Mill Farm, Ingham [3940 2502] c + 9		
Corton Formation		
Sands, silty	to 4.70	+ 4
Clay, sandy silty, grey brown, with fine gravel	to 6.60	+ 2
Sands, grey-brown, fine- to coarse grained, little gravel and sandy clay	to 10.50	-1
Crag Group		
Sand, fine- to coarse-grained, orange-brown, little fine gravel	to 21.70	- 13
4. The Hall, Brumstead [3697 2681] SL + 8		
(Existing well)	to 7.3	+ 1
?Corton Formation, Crag Group		
Sand (running)	to 18.9	-11
Clay, blue	to 31.4	- 23
\`Shell'	to 40.2	- 32
Upper Chalk		
Chalk, soft	to 52.1	- 44

5. Church Farm, East Ruston [3659 2819] SL + 4

Corton Formation, Crag Group		
"Brick earth"	to 2.4	+ 2
Sand, black	to 3.7	O.D.
Sand, grey	to 21.3	- 17
Shingle	to 24.4	
Clay loam	to 25.9	
Sand, grey, and loam	to 29.0	
Sand, grey	to 29.9	-26
Upper Chalk		
Chalk	to 54.9	- 51

6. Hall Farm, Happisburgh [3740 2976] SL c + 6.5

Corton Formation, Crag Group		
Topsoil, loam	to 0.9	+ 5
Sand, silver	to 10.1	- 4
Sand, brown	to 31.4	- 25
Upper Chalk		
Chalk	to 48.8	- 42

7. Brumstead [3613 2690] SL + 4.6

Corton Formation		
Soil and loam	to 0.8	+ 4
Sand, fine-grained, whitish	to 2.3	+ 2

8. Manor Farm, Hempstead [3969 2840] SL c + 1

Breydon Formation		
(undescribed)	to 3.7	- 3
`Land and sea mud'	to 10.1	- 9
Crag Group		
Sand, blowing, very fine-grained	to 39.3	- 38
Ormesby Clay Formation		
Clay, black	to 47.2	
(undescribed)	to 55.2	- 54
Upper Chalk		
Chalk, soft, with flints; chalk, very soft	to 62.5	
Chalk, with flints	to 91.4	- 90

9. New Hall, Ingham [3889 2690] SL c + 6

Corton Formation, Crag Group		
Clay, loamy	to 3.4	+3
Blowing sand	to 9.4	-3
Ballast (gravel)	to 9.8	
Clay, loamy	to 14.3	
Sand, grey	to 16.8	
Clay, loamy	to 18.6	

Sand, grey	to 22.3	
Clay, pale blue	to 23.2	
Sand, grey, with shells	to 25.9	
Clay, blue	to 26.7	- 21

10. Mill Farm, Happisburgh [3914 2934] SL c + 6

Corton Formation, Crag Group		
Loam	to 0.3	
Sand and shingle	to 0.9	+ 5
Sand and clay	to 7.3	
Sand, white	to 7.6	
Clay, yellow	to 10.4	- 4
Clay, grey, and sand	to 15.5	
Stone and clay	to 15.8	
Clay, grey	to 17.7	
Sand, grey	to 21.3	- 15

12. School, Stalham [3733 2522] SL c + 6

Corton Formation, Crag Group		
'Brick-earth'	to 3.0	+ 3
Sand, clay and gravel	to 6.1	O.D.
Sand, clean	to 7.0	- 1

13. School, Stalham [3747 2520] SL + 5

Corton Formation, Crag Group		
Soil; clay, brown	to 1.5	+ 3.5
Sand, coarse, and shingle	to 3.5	+ 1.5
Sand, fine, and shingle (blowing)	to 4.3	+ 0.5

14. Old Barn Farm, Brumstead [3740 2649] SL c + 6

Corton Formation, Crag Group		
Clay, brown	to 3.4	+ 3
Clay, brown, and sand	to 4.0	+ 2
Sand, grey	to 18.3	- 12
Clay, grey	to 25.0	- 19
Crag Group and Ormesby Clay Formation		
Sand, grey, and clay	to 43.3	- 37
Upper Chalk		
Chalk	to 54.9	-49

15. Ingham Road, Stalham [3774 2566] SL + 7

Corton Formation, Crag Group		
Soil; loam, red; clay, brown; clay, reddish brown	to 7.3	O.D.
Sand and shingle, yellow	to 9.4	- 2
Sand, grey, running; sand, greyish green, running	to 21.9	
Clay, grey	to 24.4	

Shells and flints; sand, grey, running	to 39.9	- 33
Ormesby Clay Formation		
Clay, dark green, and shells	to 44.2	
Clay stone	to 44.5	
Clay, grey; clay, grey, and flints	to 52.7	- 46
Upper Chalk		
Chalk	to 121.9	- 115

16. **Mill Road, Ingham** [3912 2522] SL c + 14

Corton Formation, Crag Group		
(undescribed)	to 10.7	
Sand, yellow, and shingle; sand, red	to 16.2	- 2
Clay, blue	to 16.8	
Sand, grey; sand, grey/brown; sand, yellow; sand, grey	to 28.0	
Clay, blue	to 29.6	
Sand, grey, and sea shells	to 32.0	
Clay, blue	to 32.9	
Sand, grey, with small stones & sea shells	to 45.7	- 32
Ormesby Clay Formation		
Clay, brown/blue, green, blue	to 60.0	- 46
Upper Chalk		
Chalk with slight sand	to 64.6	- 51

17. **Mr. Taylor's Bungalow, Cart Gap, Happisburgh** [3972 2995] SL c + 7

(Well)	to 6.1	+ 1
?Corton Formation, Crag Group		
'Brick earth'	to 10.7	- 4
Sand	to 35.4	- 28
Clay, black	to 38.4	- 31
Sand, black	to 48.2	- 41
Upper Chalk		
Chalk	to 53.6	- 47

18. **Mr. Mace's Bungalow, Cart Gap, Happisburgh** [3972 2998] SL c + 7

(Well)	to 7.9	- 1
?Corton Formation, Crag Group		
Clay	to 11.9	- 5
Sand	to 27.4	
Clay, blue	to 30.2	
Sand and shells	to 38.1	
Clay, blue	to 41.1	
Sand and shells	to 44.8	
Clay, blue	to 46.3	
Sand and shingle	to 47.2	- 40
Upper Chalk		
Chalk	to 54.6	- 48

19. Camp Field Road, Stalham [3754 2572] SL + 7

Corton Formation, Crag Group		
'(Boulder) Clay'	to 7.3	O.D.
Sand & gravel	to 7.6	- 1

20. Mill Farm, Ingham [3939 2504] SL c + 8

(Existing well)	to 8.2	O.D.
?Corton Formation, Crag Group		
Sand and stones	to 10.7	- 3
Sand, sharp	to 14.3	- 6

21. North End Farm, Ingham [3925 2695] SL c + 4

Hardcore	to 1.52	+ 2
Corton Formation, Crag Group		
Sand and gravel, orange	to 7.62	- 4
Clay, grey, sandy; boulder clay, grey	to 15.24	- 11
Sand and stone, grey, some clay	to 25.91	- 22
Sand, grey, and shells	to 36.58	- 33