BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/97/77

Onshore Geology Series

TECHNICAL REPORT WA/97/77

Geological notes and local details for 1:10 000 sheet TG 22 NE (Westwick)

Part of 1:50 000 sheets 147 (Aylsham) and 148 (North Walsham)

R J O Hamblin

Geographical index
UK, E England, E Anglia, Norfolk

Subject index
Geology, Quaternary, Cretaceous

Bibliographic reference
Hamblin, R J O. 1997. Geological notes and local details for 1:10 000 sheet TG 22 NE (Westwick). *British Geological Survey Technical Report* WA/97/77.

Keyworth, Nottingham. British Geological Survey 1997.

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and at Murchison House, Edinburgh, and in the BGS London Information Office in the Natural History Museum Earth Galleries. The adjacent bookshop stocks the more popular books for sale over the counter. Most BGS books and reports are listed in HMSO's Sectional List 45, and can be bought from HMSO and through HMSO agents and retailers. Maps are listed in the BGS Map Catalogue, and can be bought from Ordnance Survey agents as well as from BGS.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

The British Geological Survey is a component body of the Natural Environment Research Council.

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

CONTENTS

GEOLOGICAL NOTES AND LOCAL DETAILS FOR GEOLOGICAL SHEET TG 22 NE (WESTWICK)

INTRODUCTION

The following report is designed to be used in conjunction with 1 : 10 000 Geological Sheet TG 22 NE. Uncoloured copies of the map may be purchased from the Survey's offices at Keyworth. The district covered by the map is included in 1 : 50 000 Geological Sheets 147 (Aylsham) and 148 (North Walsham). It formed part of Old Series One-Inch sheet 68E, and was surveyed at a scale of 1 : 63 360 by H B Woodward in 1879. An accompanying memoir was published (Reid, 1882). The district was resurveyed at 1 : 10 000 scale by the present author in 1996-7, with Dr I R Basham as regional geologist.

The area lies to the north of Norwich (Figure 1). The market town of North Walsham extends onto the northern part of the sheet, and Worstead into the south-eastern corner. Apart from this the area is predominantly rural, with the small settlements of Westwick, Swanton Abbott and Skeyton in the south. In the north of the area the land rises to a plateau, with maximum altitudes of over 40m OD at Lord Anson's Wood [26 28] and North Walsham [28 29]. Small streams drain this plateau to the west, south and east, including Skeyton Beck in the north-west and Stakebridge and Westwick becks in the south. All are tributaries of the River Bure, which flows into the area known as the Norfolk Broads and ultimately drains to the sea at Great Yarmouth. In the east the ground drops away rapidly into the valley of the River Ant, a major tributary of the Bure.

In general the high plateau formed by the sands of the Corton Formation, which is very well drained, forms poor agricultural land and is traditionally grazed by sheep, hence the importance in medieval times of cloth manufacture in the village of Worstead. Nowadays much of this higher land is given over to commercial woodland and pheasant rearing. The remainder is used for arable crops but requires intensive irrigation. However, some areas of the Corton Formation outcrop, particularly at lower levels, are covered by up to rather more than a metre of cover silt, and these areas, along with the outcrop of the Crag Group, produce 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, little artificial irrigation is required despite the low rainfall in this part of the country. The alluvium and peat outcrops of the Stakebridge Beck and Westwick Beck are given over to woodland and permanent pasture, grazed by cattle, sheep and horses.

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. The non-confidential water wells and boreholes in the district are shown on Figure 2; identification numbers quoted are those of the BGS records collection, in which they are prefixed TG 22 NE. Complete logs of the non-confidential wells and boreholes can be obtained from BGS Information Services (Geological Records) at Keyworth.

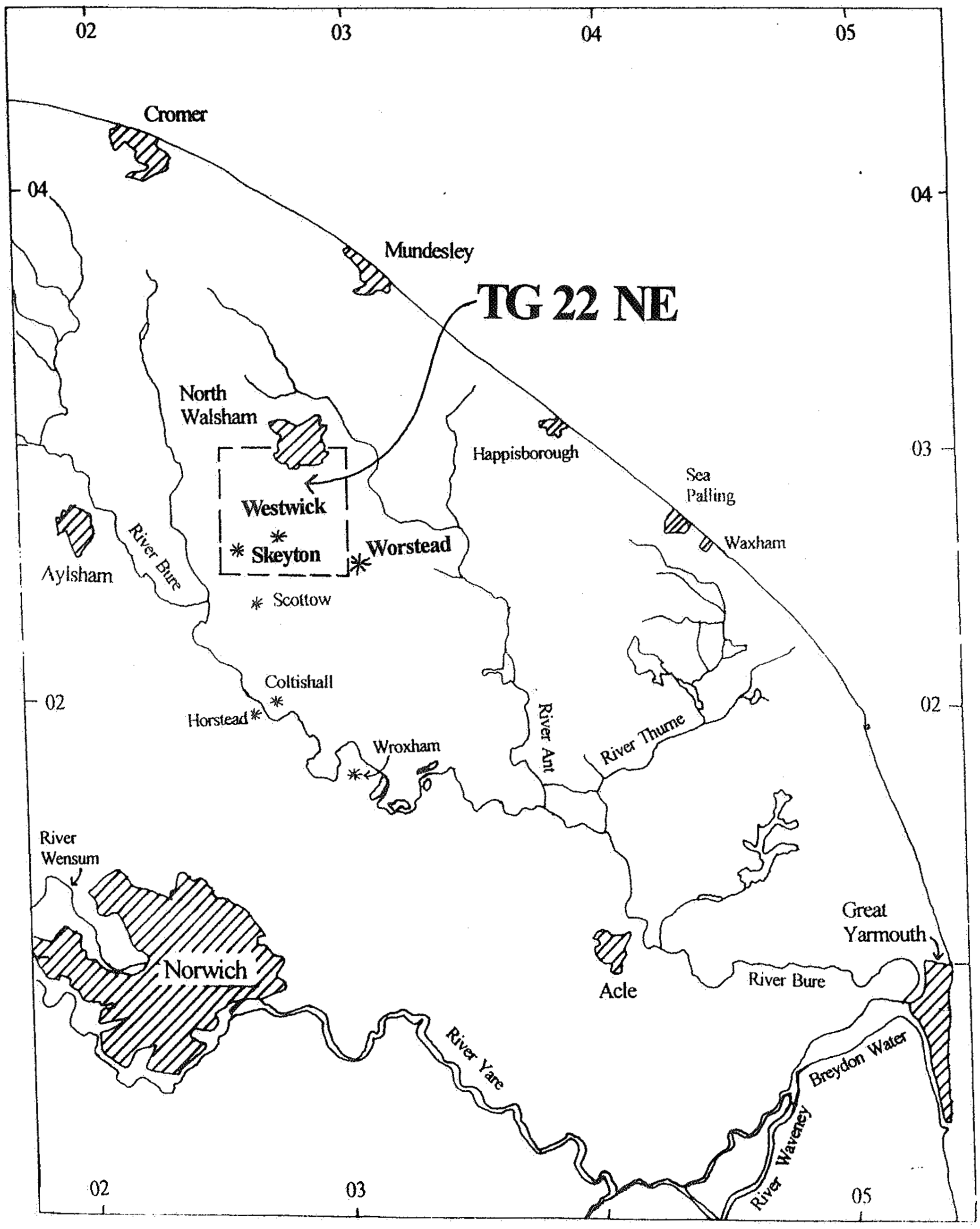

Figure 1 : Location diagram.

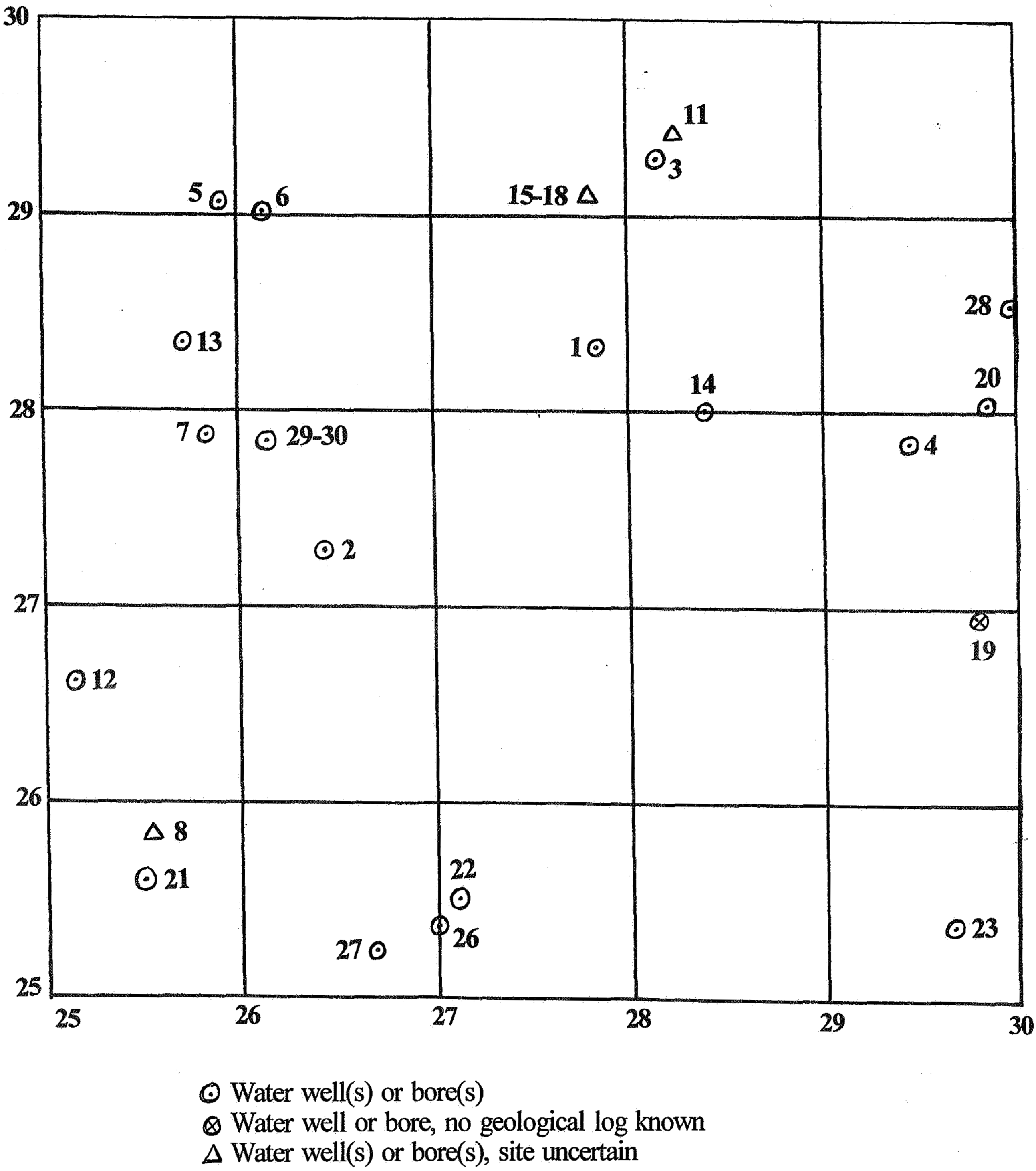

Figure 2 : Water wells and bores on Sheet TG 22 NE, taken from BGS records. The number of each site is prefixed TG 22 NE.

GEOLOGICAL SEQUENCE

Strata proved on sheet TG 22 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.

Holocene to Recent	**Made ground**	**Up to c 5.0**
	Peat	**Up to c 2.0**
	Alluvium	**Up to c 2.0**
Pleistocene to Recent	**Head**	**Up to c 2.0**
Pleistocene	**Cover silt**	**Up to c 1.5**
	gravel and sand	**Up to c 3.0**
	Yare Valley Formation	**Up to c 2.0**
	Corton Formation	**Up to c 35.0**
	Crag Group	**Up to c 25.0**
unconformity		
Upper Cretaceous	**Upper Chalk**	**96+**

SOLID FORMATIONS

CRETACEOUS AND EARLIER FORMATIONS

No strata older than the Upper Chalk have been proved by boreholes within the district, but deep boreholes in the surrounding area (Figure 3) have penetrated strata as old as Silurian. Details can be obtained from the BGS Records Collection, and are summarised in Arthurton *et al.* (1994). All three subdivisions of the Chalk Group, the Lower, Middle and Upper Chalk, are present beneath the whole of the district, although only the Upper Chalk has been proved in boreholes. The biostratigraphy, lithology and structure of the Chalk of Norfolk have been reviewed by Peake and Hancock (1961, revised and re-published 1970). The lithostratigraphy, biostratigraphy and history of research of the Chalk of Norwich were updated by Wood (1988), which is summarised in the memoir for the district (Cox *et al.*, 1989).

A map of sub-divisions of the Chalk at rockhead (Peake and Hancock, 1970) indicates that the district is largely underlain by Paramoudra Chalk, with Maastrichtian Chalk coming in at depth beneath the Crag in the east (Figure 3). Levels of the base of the Group are also given on Figure 3: these imply a level of around -450m OD beneath the present district. Since the base of the Crag here lies at around +10m OD, this implies that the thickness of the Chalk Group is about 460m. The base of the group is believed to dip regionally to the north-east at 0.25° to 0.5° (Arthurton *et al.*, 1994). On sheet TG 22 NE the Upper Chalk has been penetrated by 30 boreholes. Thicknesses of Chalk penetrated are shown on Figure 4; the maximum is 95.6m at borehole TG 22 NE/17 [278 291].

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 Trunch Borehole (Gallois and Morter, 1976) (Figure 3) was sunk to provide a standard sequence for the Upper Cretaceous of East Anglia. The full log is held in the BGS Records Collection, while the biostratigraphical zones recognised are summarised in Table 2 (after Arthurton *et al.*, 1994). Comparing this with the subdivisions used by Peake and Hancock (1970) (Figure 3), the *B. lanceolata* zone corresponds with the Maastrichtian, while the Paramoudra Chalk, Beeston Chalk, Weybourne Chalk, Eaton Chalk and Basal *mucronata* Chalk are all *B. mucronata* zone, and the *O. pilula* zone is included in Peake and Hancock's map along with the *G. quadrata* zone.

The lithologies of the main subdivisions of the Upper Chalk in the Trunch Borehole may be summarised as follows:

	Thickness
Maastrichtian Chalk: soft marly chalk with large flints; low core recovery	c 21.3
Paramoudra Chalk: massive white chalk with large tabular thalassinoid flints, generally few fossils	c 54.5
Beeston Chalk: yellow, white and grey, fossiliferous chalks with large thalassinoid flints; hardgrounds at the top and base of the unit, the latter equivalent to the Catton Sponge Bed of Norwich	c 31.1
Weybourne Chalk and Eaton Chalk: grey-white marly and hard yellowish chalks with large thalassinoid-nodular flints; very fossiliferous	c 39.4
Basal *mucronata* Chalk: grey-white chalk with more marly bands and large and small nodular flints; tough hardground marking base of zone	c 17.0
Gonioteuthis quadrata Zone: grey-white marly chalk with large nodular flints; creamy white chalk with small nodular and lensoid flints	c 63.47
Offaster pilula Zone: massive white chalk with a few tabular flints	34.25
Marsupites testudinarius and *Uintacrinus socialis* zones: white massive chalk with oyster beds; largely flintless except for occasional thin tabulars	28.84
Micraster coranguinum Zone: hard grey-white marly burrowed chalk, with small scattered nodular flints; bands of medium-sized nodular flints and *Inoceramus* shells below	84.7
Micraster cortestudinarium Zone: hard grey-white and yellowish white chalk, with stylolitic surfaces, thin marl seams, hardgrounds and medium-sized nodular and tabular flints; fossiliferous, several sponge beds	11.77
Sternotaxis planus Zone: hard white massive chalk with several major hardgrounds, marly concentrations and sponge beds stained yellow or grey; flints small and nodular or thin and tabular; conspicuous marl seam at base of Upper Chalk	30.71

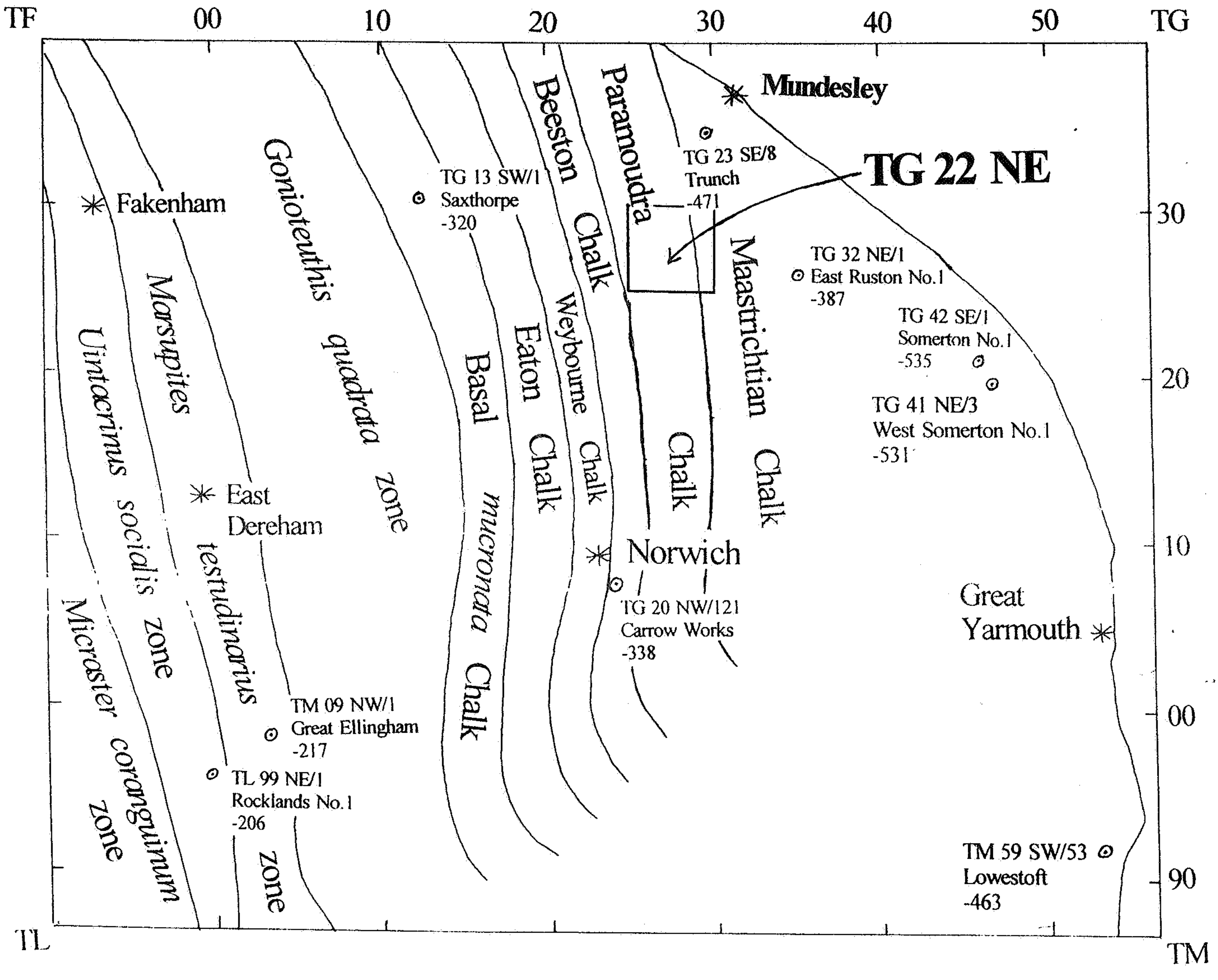

Figure 3 : Map of north-east Norfolk, showing deep boreholes. Along side each is shown its registration number in the BGS borehole records collection, its name, and the OD level of the base of the Chalk Group. The sub-divisions of the Upper Chalk at rockhead are shown, after Peake and Hancock (1970).

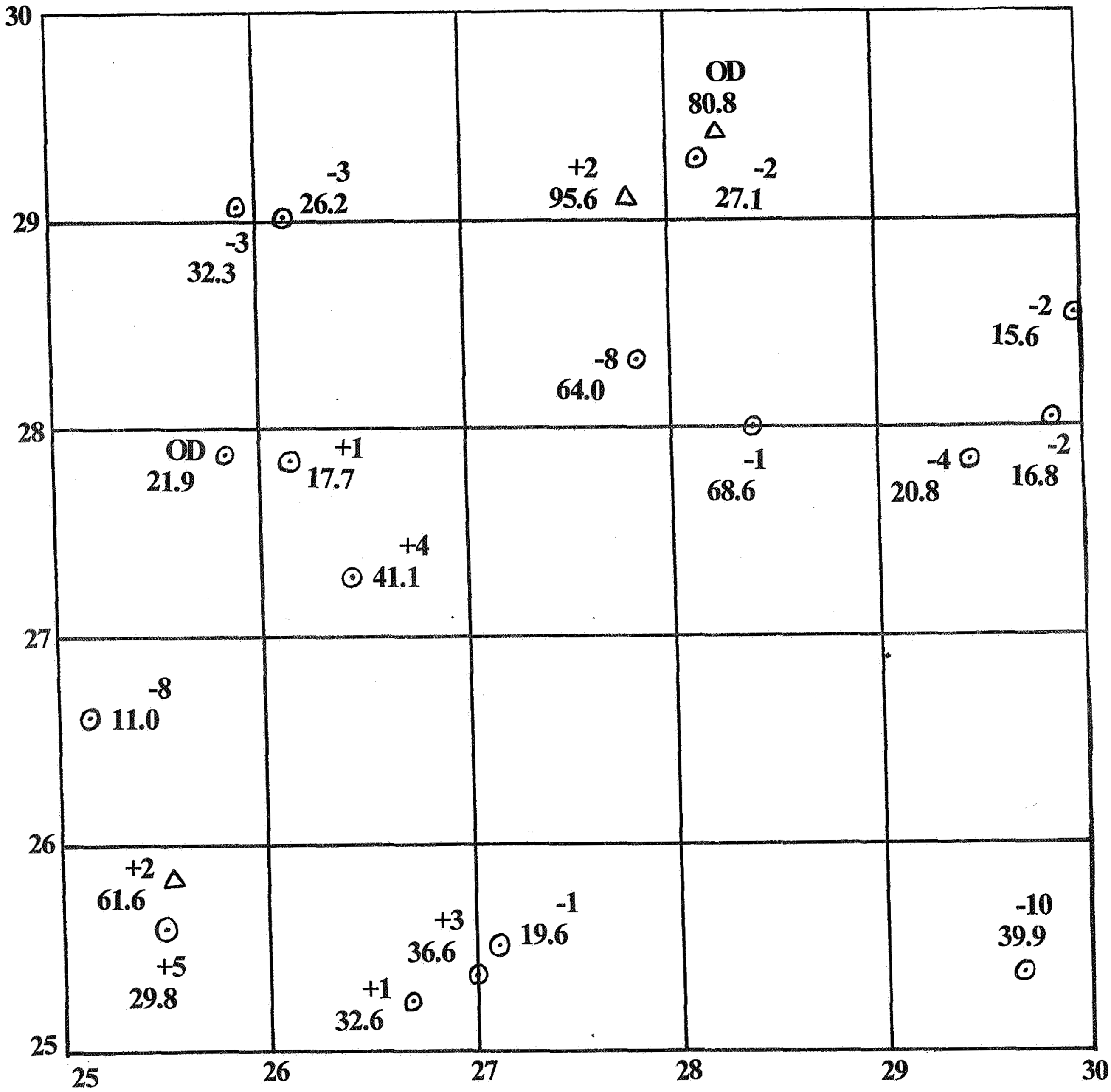

Figure 4 : Water wells penetrating the Upper Chalk. The lower figure indicates the thickness of Upper Chalk penetrated, and the upper figure the OD level of the top of the Upper Chalk.

UPPER CHALK	*Belemnella lanceolata* s.l.	
		c.61m
UPPER CHALK	*Belemnitella mucronata* s.l.	
		209.07m
UPPER CHALK	*Gonioteuthis quadrata*	
		272.50m
UPPER CHALK	*Offaster pilula*	
		306.72m
UPPER CHALK	*Marsupites testudinarius*	
		?
UPPER CHALK	*Uintacrinus socialis*	
		335.26m
UPPER CHALK	*Micraster coranguinum*	
		411.50m
UPPER CHALK	*Micraster cortestudinarium*	
		432.03m
UPPER CHALK	*Sternotaxis plana*	
		469.32m
MIDDLE CHALK	*Terebratulina lata*	
		493.97m
MIDDLE CHALK	'*Mytiloides labiatus* s.l.'*	
		500.51m
LOWER CHALK	*Metoicoceras geslinianum*	
		501.10m
LOWER CHALK	*Calycoceras guerangeri*	
		c.502m
LOWER CHALK	*Acanthoceras jukesbrownei*	
		502.32m?
LOWER CHALK	*Acanthoceras rhotomagense*	
		506.30m?
LOWER CHALK	*Mantelliceras dixoni*	
		509.80m
LOWER CHALK	*Mantelliceras mantelli*	
		512.22m

*includes an unnamed zone, the *Mytiloides* spp. Zone and the *Neocardioceras juddii* Zone

Table 2 : Biostratigraphical zones recognised in the Trunch Borehole, with depths of occurrence of zonal boundaries, after Arthurton *et al.* (1994).

THE UPPER SURFACE OF THE UPPER CHALK

Figure 4 shows the levels of the surface of the top of the Upper Chalk, in all cases overlain by the Crag Group. Allowing for the inevitable errors in borehole logging, this indicates a gently undulating surface, lowest (-10m OD) in the south-east and highest (+5 OD) in the south-west.

The upper surface of the Upper Chalk is commonly weathered to a soft, weak material sometimes known in borehole logs as 'putty chalk'. The term marl is also common in borehole logs and is also taken to imply soft chalk. In the Trunch Borehole, Gallois and Morter (1976) recorded poor core recovery in the highest 34m of the Upper Chalk, although here it was possibly glacially disturbed. In percussion-drilled water wells, the top of the Chalk may not always be accurately recorded because of this softening; sand from higher strata may fall down the hole, mixing with the soft chalk and staining it brown. In the Scottow district to the south (TG 22 SE; Hamblin, 1997a), the levels of the top of the Upper Chalk in boreholes are consistently a few metres lower than the levels mapped along the sides of the valleys of the Bure and its tributaries, suggesting a consistent error on the part of the well-sinkers, which is most likely a reflection of the weathered state of the top part of the chalk. However, borehole logs suggest that there is much less weathering of the Chalk surface on both sheets TG 22 SE and TG 22 NE than in the Belaugh district (TG 21 NE; Hamblin, 1997b), presumably because the Upper Chalk lies at a much shallower depth in the latter district. In the present district, softening of the upper surface of the Upper Chalk is indicated by 'marl' in boreholes TG 22 NE/8 [255 258], /11 [282 294] and /21 [2551 2560], 'loose chalk' in /8, 'clay and chalk' in TG 22 NE/14 [2840 2800], and 'soft chalk' in /14 and /26 [2700 2538]. Borehole TG 22 NE/1 [2785 2834] refers to 'brown sand and chalk' at the top of the Upper Chalk, implying that the sand has caved into the chalk during drilling: /18 [278 291] refers to 'dirty chalk', which may also be an artifact of percussion drilling.

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. Flints form the bulk of the clasts in the gravels, although quartz and quartzite become important in gravels in the higher part of the sequence. 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 developed from the decomposition of glauconite. Fossils are not common, and it has been suggested that the Crag has become decalcified, at least in its upper part.

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 5), and have placed the base of the Norwich Crag at the unconformity shown at the base of the Antian/Bramertonian strata. In eastern Norfolk, both the Red and Norwich Crag formations are known, with the latter transgressing the former to rest upon the Upper Chalk near Norwich (Funnell *et al.*, 1979). However, it is now clear that the uppermost Crags of Norfolk, including the so-called Weybourne Crag and Bure Valley Beds (Hamblin, 1997a, b), are significantly younger than any known in Suffolk. Current Survey practice is to include all these marine and estuarine deposits which infill the Crag Basin within the Crag Group, although on this basis the Crag Group includes deposits of Pastonian age which would be included in the Cromer Forest-Bed Formation by West (1980).

The uppermost Crag in the present district belongs to the Bure Valley Beds, although borehole and surface mapping evidence implies that they are less gravelly than in the type area of the Bure Valley around Wroxham. The Bure Valley Beds have been shown on the 1:10 000 scale maps as Norwich Crag Formation, but at the time of writing it is proposed to raise the term Wroxham Crag Formation to include the Bure Valley Beds, the Weybourne Crag, and certain other similar deposits of Pastonian and Pre-Pastonian age. The Wroxham Crag differs from the underlying Norwich Crag in that its gravel component is characterised by a significant proportion of quartz and quartzite as well as flints. The Wroxham Crag is known to overstep the Norwich Crag, resting directly upon the Upper Chalk in the Belaugh district (TG 21 NE, Hamblin 1997b). It is possible that the Norwich Crag is also present at depth in the Westwick district, while the Red Crag is assumed to be absent.

The sands of the Crag Group are fine- to medium-grained, well-sorted and micaceous. In an unweathered state they are glauconitic and dark green or dark grey in colour, but near the surface they normally become oxidised to shades of yellow and red, with layers of iron pan developed from the decomposition of glauconite. Both grey, green and brown sands are mentioned in borehole logs, indicating that unweathered glauconitic strata are preserved at depth. Fossils are not common, especially in the upper part of the sequence, possibly as a result of decalcification, but shelly sands are common lower in the sequence; shells are recorded in boreholes TG 22 NE/2 to 4, 15, 17, 18, 26 and 28 to 30.

Gravels are an important constituent of the local Crag: only boreholes TG 22 NE/2, 5 to 8, 12 and 28 to 30 record complete sequences with no mention of gravel at all, either as gravel, shingle, flints or stone. The thickest gravel bed mentioned in a borehole is 7.6m thick, at the base of the Crag in borehole TG 22 NE/22 [2711 2552]. The gravel is dominated by flint clasts, and these may be up to 20cm long. The flints are generally of high sphericity, well rounded and chatter marked, particularly the smaller ones, but in the Belaugh district (TG 21 NE, Hamblin 1997b) a distinction was noted between pits in which massive beds of very high sphericity flints are believed to indicate beachface aggradation [2662 1680, 2872 1724], and a pit [2696 1700] with less massive, more sandy beds of gravel, with flints of lower sphericity, which is believed to indicate offshore, possibly sub-littoral sedimentation. However it is generally considered that the flints are second-cycle, derived from pre-existing Palaeocene outcrops to the west (Moorlock *et al.*, in press), so if the distinction noted here is correct, then the very high degree of rounding of the beachface-facies flints must be an effect of the Quaternary re-working. Quartz and quartzite are also important constituents of the gravels in the Wroxham Crag, but not in the Norwich Crag.

The Crag commonly has a basal bed of pebbles and cobbles of glauconite-coated flint, representing a transgressive beach deposit (Hamblin, in Moorlock *et al.*, in press). This is generally referred to as the Stone Bed. It is present at the only pit at which the unconformity was observed during the present survey, in the Belaugh district [2657 1675] (Hamblin, 1997b). The flints there are up to 20 cm long, with black cortices and white patinas, with their horns broken off by abrasion, in a matrix of coarse-grained orange-brown sand. In the present district, boreholes TG 22 NE/1, 3, 4, 11, 15, 17, 18, 21, 22, 23, and 27 specifically mention gravel at the base, in the form of gravel, shingle, flints or stones.

Clays, generally grey or buff in colour, are common in the Crag, interbedded with the sands and gravels. They are recorded (as 'clay' or 'marl') at all levels in the sequence in the present district, variously grey, yellow, brown and blue in colour, and in all boreholes recording complete sequences of Crag except TG 22 NE/4, 7, 11, 20, 21, 27, 29 and 30. In eastern Suffolk a similar aggradation of sands, gravels and clays 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 apply in the present district.

The levels of the base and top of the Crag Group, as logged at outcrop and in 30 boreholes which penetrated to the Upper Chalk, are shown on figure 6. As explained above, levels for the base are likely to be accurate to a metre or so. They vary from OD -10m in the south-east to OD +5m in the south-west. At outcrop the boundary at the top of the Crag Group is commonly difficult to fix by augering because of a wash of gravel from the overlying Corton Formation, and there is rarely a clear change of slope at the boundary: it ranges from around +13 to +18m OD in the south of the district. In boreholes this boundary is even more difficult to fix, since both the Crag and the Corton Formation are characterised by sands, gravels and clays. It is known with reasonable confidence at +11m OD in borehole TG 22 NE/26 near the outcrop, and at +10/13m OD in TG 22 NE/11 and /15-18 in North Walsham, and it is assumed to adopt a roughly planar surface from here to its outcrop. On this basis, it is possible to place the base with rather less confidence at boundaries recorded in boreholes

TG 22 NE/1, 3, 4, 7, 12, 14, 20 and 28. However, at TG 22 NE/5, 6 and 13 it appears to lie within a thick clay unit, and within thick sand and gravel units in 2, 23, 29 and 30. The greatest figure for the thickness of the Crag which can be given with confidence is thus 12.4m at borehole TG 22 NE/15, and a figure of c 12m has been adopted for the 1 : 10 000 scale map. However, if the estimates for the level of the top of the group in other boreholes are correct, then the greatest thickness is 23m in TG 22 NE/12 in the west.

Local details

Around Hall Farm [255 252], gravels, sands and sandy clays were augered in the fields, and a pit [254 251] may have been worked for either gravel or clay. Borehole TG 22 NE/21 [2551 2560] records sand and stone from 4.3m to 9.8m depth, beneath a brick-lined well, but borehole TG 22 NE/8 [255 258] records yellow clay to 2.1m then brown and grey fine-grained sand resting upon the Upper Chalk at 11.6m depth.

East of Cramp Lane [258 255], the Wroxham Crag crops out over a broad flat area. Pale grey and brown clays, grey medium-grained sands and orange fine-grained sands were augered, but much of the area could not be penetrated with the auger owing to a wash of gravel. The farmer reports the fields here as heavy and difficult to work, and the uneven area either side of the filter beds [265 251] may be abandoned clay workings, but where children have dug 'dens' hereabouts [263 251] sand is revealed. Borehole TG 22 NE/27 [2670 2525] recorded sand and shingle layers to 11.6m depth, beneath an existing well 3.0m deep. North of here, orange sandy soil in the fields proved on augering to be very gravelly.

East of Westwick Beck, the outcrop is largely covered with gravel to the north of Aylsham Road, but south of the road, orange and grey clays and orange coarse sands were augered, and orange sand was revealed in a badger sett [2683 2529]. Several small pits [2730 2574, 2689 2545, 2703 2544, 2746 2515] may have been worked for gravel or clay. In the east of the Crag outcrop, augering distinguished fine- to coarse-grained orange sands of the Crag from the overlying fine-grained pale yellow sands of the Corton Formation.

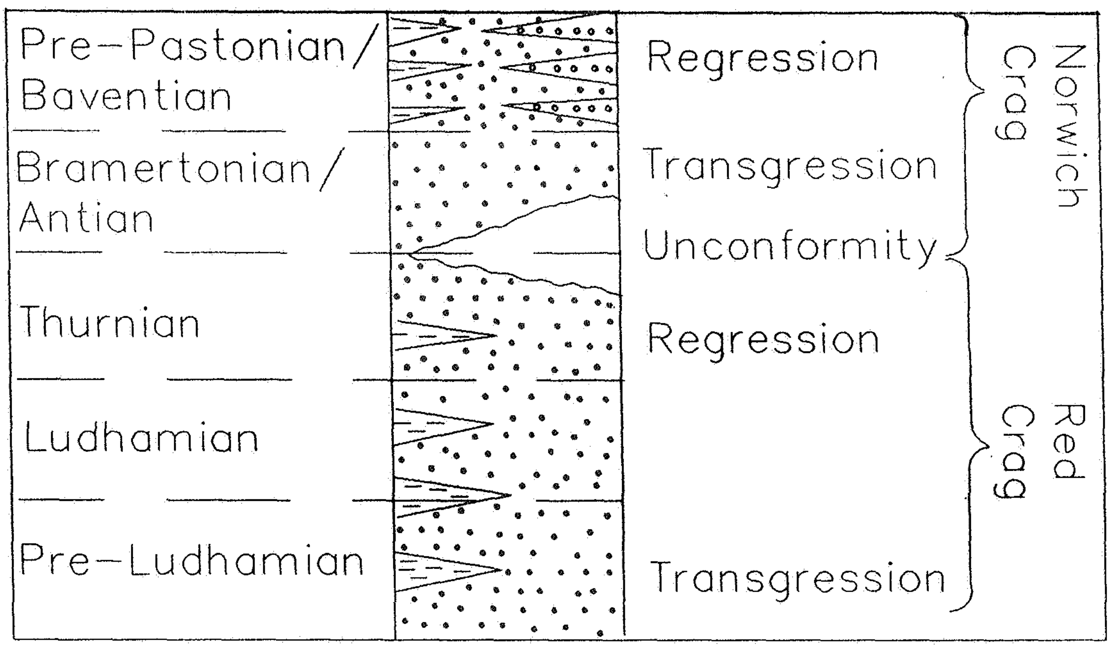

Figure 5 : Generalised stratigraphy of the Red and Norwich Crags, after Hamblin *et al.* (1997). The sedimentology indicated is that found in eastern Suffolk, and recognises sands (dotted), 'Westleton Beds' gravels (small circles), and clays (dashed).

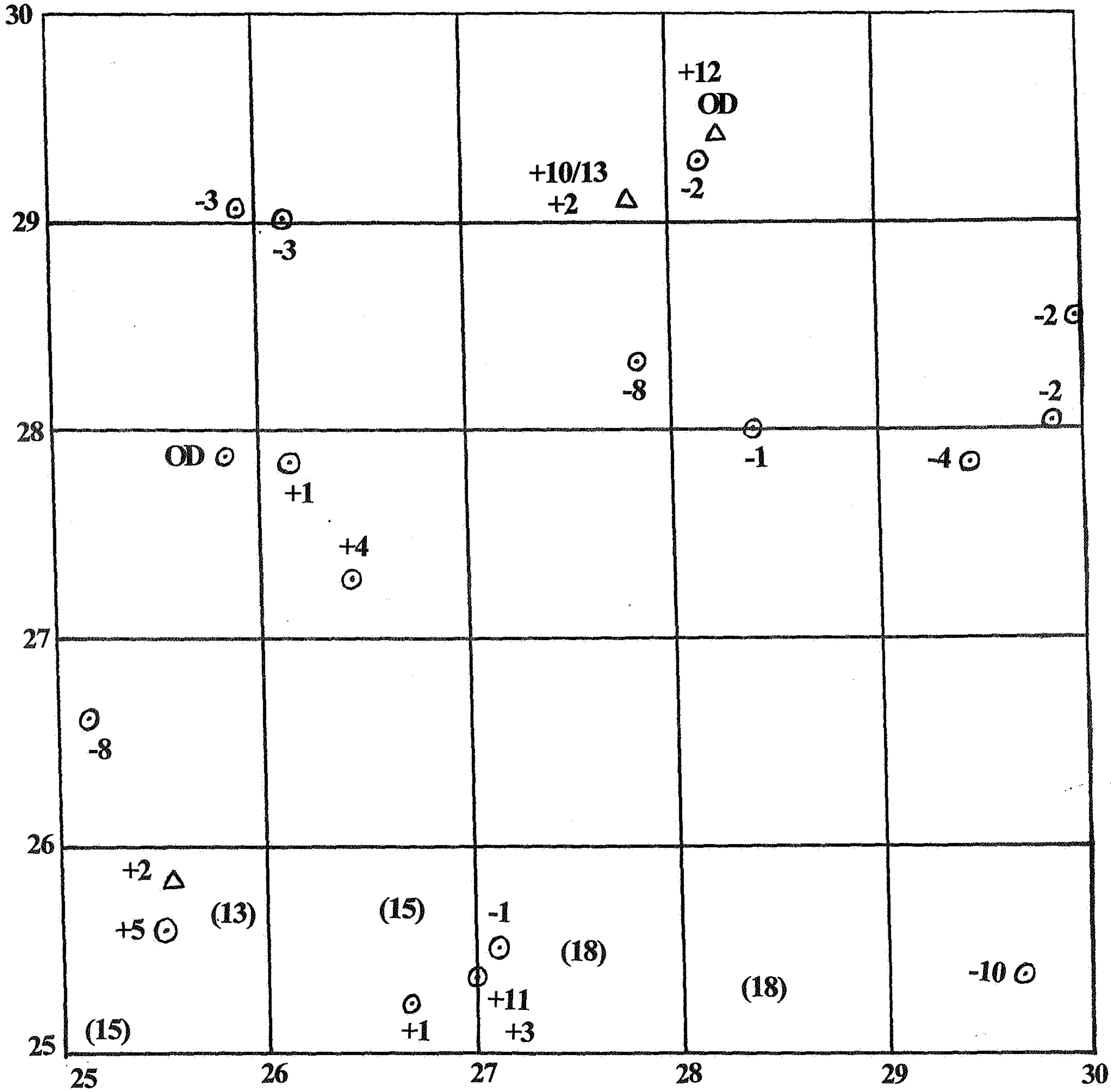

Figure 6. Levels for the base and top of the Crag Group. Where only a single figure is given, in brackets, this is the level of the top as mapped at outcrop. Where only a single figure is given and this is not in brackets, this is the level of the base in a borehole where the top is not recorded.

DRIFT DEPOSITS

It is the practice of the British Geological Survey to portray the largely marine Early Quaternary deposits of the Crag Group as solid, and all succeeding deposits as 'drift'. In the present district the earliest drift deposits known to be exposed at surface 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 from the overlying Corton Formation.

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 now 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. Either way it is unlikely to be present the Westwick district.

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 Scottow 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). Sands and gravels with a pebble content resembling the Bytham Sands and Gravels are known at Flordon, south of Norwich (Rose, Allen *et al.* 1996), but there is no evidence that they occur within 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, Gulamali *et* *al.*, 1996).

Although it is considered unlikely by the present author that the Kesgrave Sands and Gravels *sensu stricto* occur in Norfolk (Hamblin and Moorlock, 1995, 1996, Hamblin *et al.*, 1996), sands and gravels with a pebble content implying derivation from the proto-Thames are common in the area (Green and McGregor, 1996). However most of these deposits are marine and hence form a part of the Crag Group. The Crag at How Hill contains proto-Thames as well as Pennine material. Where fluvial deposits with a proto-Thames pebble signature occur, for instance at Caistor St. Edmund south of Norwich (Postma and Hodgson, 1987) and at Mayton Wood Pit on sheet TG 22 SW ('Coltishall' in Rose, Allen *et al.*, 1996), they overlie Crag with a similar pebble content, and could have been derived by re-working of that.

It is thus likely that after the completion of the infilling of the marine Crag basin, the mouth of the 'Northern River' moved eastward and fluvial deposits were formed in the present district. These would be expected to contain clasts derived from the Pennines via the 'Northern River', and also proto-Thames material derived from reworking of the youngest Crag. It is thus possible that gravelly sands interpreted as Corton Formation or as Crag during the current survey might belong to such a fluvial formation. Since they are fluvial rather than marine they would be expected to have less well rounded flints than in the Crag, so in field mapping they could be mistaken on the ground for Corton Formation. However, the thickness of such a formation is not likely to be more than a few metres.

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 Scottow 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 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 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), 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 Corton Formation is present throughout most of the district, everywhere overlying the Crag Group. Mapping indicates that the base of the formation lies at around OD +13/18m where it overlies the Crag at outcrop in the south, and at +10/13m in boreholes TG 22 NE/11 and /15-18 in North Walsham, while, as discussed above under the Crag Group, estimates can be made of the level of its base in other boreholes (Figure 6). On this basis, the formation is thickest, about 31m, beneath North Walsham.

The formation comprises tills (diamicts), sands and sandy gravels, and subsidiary lacustrine clays, and it is believed to comprise both waterlain and terrestrial sediments (Lunkka, 1988; 1994). Eyles *et al.* (1989) noted that the close association of tills and sands indicates 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 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 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.

The stratotype of the formation 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. It 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, Gulamali *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 was formed, the ice-sheet retreated northwards 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 (Lowestoft district), 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 part of the Lowestoft Till Formation. In the area around Potter Heigham (Hamblin, 1997c), the Corton Formation comprised a discontinuous basal sand and gravel unit (which would equate 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.

Mapping of the Corton Formation is hindered by the overlying cover silt, which often has a basal bed of gravel which is impenetrable to an auger, so while it has proved possible to broadly separate areas of clay deposits (mostly till), and arenaceous deposits (Corton Sands, sands and gravels) it is likely that further pods and patches of till occur within the arenaceous deposits, and vice versa. Around the margins of the district two thin, discontinuous tills crop out, and it is possible that these are the local representatives of the two Corton tills, but since they are both thin and are only around 5m apart vertically, it is more likely that they represent two leaves of the lowest Corton Till; certainly they combine into a single till in at least one area [29 26]. The lower till forms the base of the Corton Formation at Skeyton [25 25], but elsewhere it is more commonly underlain by further arenaceous strata comprising both fine-grained Corton Sand and coarse-grained sands and gravels. A similar mixture of fine- and coarse-grained sands occur between the tills and immediately above the upper till in the south of the district and at lower levels in the east and west of the district, but on the higher ground which forms most of the centre and north of the district, medium- to coarse-grained rather gravelly sands form a thick *sandur* of outwash material.

Corton Formation - Details

North-west of Skeyton Beck, both fine-grained and medium- to coarse-grained sands have been widely augered. Two patches of till have been mapped at around 27m OD [255 296, 251 293]; the northern one is believed to continue northwards onto sheet TG 23 SE and may connect with that at Tungate Farm [270 299], while a pond [2515 2877] at Lodge Farm may indicate a further patch at a slightly lower level. All four patches would be of the higher of the two discontinuous tills known in the district. East of Skeyton Brook, Bryant's Heath has been extensively quarried for sand. This is orange, medium- to coarse-grained, and moderately gravelly, with angular flint pebbles. Similar sands have been augered as far east as the outskirts of North Walsham, with patches of till [270 299, 268 293] within the sands at about +33m OD.

Boreholes TG 22 NE/5 and 6 [2592 2908, 2614 2903] record sand to 10.7m depth, resting on thick clays which are believed to include both the Corton Formation lower till and the highest Crag. Southwards and eastwards from here, uniform medium- to coarse-grained slightly gravelly sands crop out over a large area, at levels from over +40m OD down to the Skeyton Brook in the west at +15m OD, with fine-grained Corton Sand only rarely augered [2515 2766, 2538 2768, 2646 2779]. These sands yield very dry, poor arable soils, and large areas of woodland extend from Oak Hill [254 288] to Dairy Farm [280 268]. Borehole TG 22 NE/7 [2584 2789] penetrated yellow sand to 7.6m, sandy clay to 12.8m, and brown sand to 20.7m; the clay is relatively thick and may represent both the local tills joined together. Boreholes /29-30 [2616 2786] nearby record only grey and brown sand in the Corton Formation. A pit [2740 2757] beside Perch Lake, dug to bury burned tree stumps, revealed the following section:

Head; gravelly sand...	0.5m
Corton Formation; sand, buff, medium-grained, well bedded, current bedding dipping due NE, few pebbly stringers...	1.0m+

South of North Walsham, the fields to the west of Norwich Road are covered with a gravel wash, but brown medium-grained sand was augered locally and was seen at a badger sett [2759 2818] adjacent to an infilled sand pit [2762 2824]. Boreholes TG 22 NE/15-18 [278 291] record sands and gravels down to 15.2-17.4m, till to 22.9-27.7m, sand to 28.9-30.5m, till to 30.6-32.2m, then more sand and gravel down to 33.7m in /17, although the lower till rests directly on Crag in /15 and /18. Borehole /1 [2785 2834] records sand and gravel to 18.3m then "mixed sand clay stone" to 24.4m: this may include two tills. Between the Norwich Road, the railway and the woods at Postle's Corner [283 275], the land forms a flat plateau. Mostly medium-grained sand was augered, with locally coarse-grained sand or gravel, which may be wash. Fine-grained sand was only augered in the south [2863 2778, 2877 2779]. Augering around Piper's Pit [2828 2828] failed to reveal any clays, so possibly this large pond was dug for watering cattle and has been puddled. Borehole TG 22 NE/11 [282 294] records sand and gravel to 18.0m, sandy clay to 22.3m then brown sand to 29.0m,

/3 [2816 2931] records sand and gravel to 22.9m then clay to 28.3m, and /14 [2840 2800] records sands and gravels to 22.9m then "soft brown clay and stone" to 24.4m, so in all cases only one till is present.

East of the railway, augering the plateau north-west of Field Lane revealed gravels and medium-grained sands. East of North Walsham the ground slopes steeply down to the east, and both fine- and medium-grained sands were augered on the slopes. There are several abandoned sand pits [292 299, 293 295, 295 297, 297 299]. Between Field Lane and the new Yarmouth Road the Corton Formation outcrop slopes very steeply down to the east. More fine- than medium-grained sands were augered, although a wash of gravel obscures these above Holgate Poultry Farm [300 286]. Four large disused sand pits are known: the one [290 287] near Cangate Lodge has been planted and turned into a caravan site, two [294 290, 295 279] have been completely infilled and that [295 288] south of Hagg Farm has been largely so. The following section was seen in the south-west face of this pit [2946 2873]:

> Sand, buff with orange beds, medium-grained; mainly flat bedded, some gentle cross-bedding; scattered pebbles, mainly flint, up to 4 cm in length, in discrete beds... c 4.0m

A thin bed of till runs from [295 290] near Hagg Farm to [298 295] beyond Happisburgh Road, at around +20m OD, but augering demonstrated that it does not extend farther. Borehole TG 22 NE/4 [2945 2786] records sand and gravel to 17.7m depth, +18m OD, then grey sand with clay to 27.4m: it is possible that the till is included in the latter unit. Boreholes TG 22 NE/20 and /28 [2985 2804, 2998 2855] record loam, sand and shingle to depths of 8.3m and 5.5m, +9m and +8m OD: these start below the level of the till on the hillside, and do not indicate a lower till. Between the new Yarmouth Road and the railway, medum-grained sands were augered on the plateau, and fine-grained sands below the rim [2960 2780, 299 276].

In the south-west of the district, mainly medium-grained sands were proved on the plateau west of Malthouse Common [271 271] and north of Youngman's Lane [264 261], with scattered instances of gravel and fine-grained sand. There are a number of abandoned sand pits, both concentrated at Swanton Hill Common [262 266, 265 267] and scattered elsewhere [257 272, 258 272, 260 272, 268 273, 262 268]. The slopes to the east, south and south-west include thick beds of fine-grained as well as medium-grained sand, but the slopes to the west past Skeyton Corner [253 274] and High View [252 266] are formed of uniform medium-grained sand, very loose and subject to strong wind deflation on this exposed, west-facing slope. Two seams of till were detected, a lower one [250 274] at +15m OD near Nixon Farm, and a higher one at +23m to +26m [250 267, 250 263 to 260 260]. Augering failed to reveal any till around the pond [2550 2720] at +28m OD at Manor Farm, so possibly this was dug as a duck pond and has been puddled. Borehole /12 [2516 2663] records brown clay (the upper till) to 4.6m then sand to 10.7m, +15 OD. Below this is "blue clay" which is most likely Crag, but it is posssible that it includes the lower till at the local base of the Corton Formation. Borehole TG 22 NE/2 [2644 2730] records sand and gravel to 9.1m, brown clay to 22.9m, then grey sand: the thick clay may represent both tills combined. No till is present on the slopes east of Swanton Abbott, between Swanton Hill Common and Long Common

Lane, but a till occurs at the base of the formation [256 257 to 251 250] at Skeyton, which correlates with that at Nixon Farm. A small outlier of the lowermost Corton Formation gravelly sand occurs [269 254] straddling Aylsham Road; borehole TG 22 NE/26 [2700 2538] records "sand and clay" to 1.2m depth, although the soils indicate gravel.

In the south-east quarter of the district, medium-graind sands dominate north of Westwick House [286 263] and fine-grained sands to the south. There is very little gravel wash over the slopes even though patches of sand and gravel of uncertain age and origin are mapped [276 260, 277 258, 284 256]. The following section was measured in an abandoned sand pit [2954 2746] beside Bunn's Hill Wood:

> Sand, buff, some darker orange staining; fine- to coarse-grained, mostly medium-grained; pebbly stringers, pebbles to 8cm long mostly shattered angular flint also quartz and quartzite; horizontal, well bedded, mostly planar bedded, some shallow and steep angled cross-bedding dipping to the south-west... c 5.0

Below this pit, a thin till crops out at about +20m OD on the hillside [300 274 to 300 266]: this can probably be correlated with that which crops out at a similar height farther north. A lower till [297 269] crops out at Bunn's Farm. Extending eastwards from Westwick Park, two thin leaves of till [288 262, 284 260], which are both underlain and overlain by fine-grained sands, merge into a single till [292 261 to 298 261]; this may correlate with the two immediately to the north. A single till, underlain and overlain by fine-grained sands, crops out either side of the hill south of Westwick Park [292 257 to 286 250, 285 250 to 282 255]. To the south-east, a lower till crops out [295 250 to 298 252] at the frozen food factory, but borehole TG 22 NE/23 [2966 2539] does not record this, only sands and gravels to 10.7m depth (these will include Crag as well as Corton Formation). Farther west, a till [282 253 to 276 255] locally forms the base of the formation [277 251], and two smaller seams of till farther north [274 260, 276 261 to 276 267] may be correlated with it, but two smaller patches beside the Norwich Road [280 259, 278 260] lie at a rather higher level.

GRAVEL AND SAND OF UNCERTAIN AGE AND ORIGIN

This deposit is characterised by sandy gravels dominated by angular shattered flints up to about 20 cm long, with minor rounded flint, quartz, quartzite and sandstone, in a matrix of coarse-grained sand. It occurs on hilltops, invariably overlying gravelly sands high in the Corton Formation. Five patches occur in the north-east quarter of the district [293 292, 292 286, 293 288, 294 288, 295 286], at between +30m and +40m OD, and three patches in the south-east [276 260, 277 258, 284 256] at levels of +26m to +32m OD.

Since the deposit occurs only at high levels, unrelated to the post-glacial drainage, it is unlikely that it represents deposition later than Anglian, but it is not clear whether it belongs to the Corton Formation or the Lowestoft Till Formation. The high content of relatively large, shattered flints would suggest the latter, since high concentrations of large flints are uncommon high in the Corton Formation, but this cannot be satisfactorily demonstrated since no undoubted Lowestoft Till Formation is known in the immediate vicinity. Alternatively the deposit may have been formed by winnowing of the Corton Formation, with concentration of the larger flints by removal of the finer constituents.

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 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.

Four deposits were formed during these periods: the Yare Valley Formation, cover silt, gravelly head, and head. The **Yare Valley Formation** (Arthurton *et al.*, 1994) occurs in the valleys of the River Bure and some of its tributaries. 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. It is up to 11m thick near Great Yarmouth, and is generally considered to be of late Devensian and/or early Holocene age. Similar gravels are likely to have been formed late in the Anglian, as the North Sea Ice Sheet waned and the post-glacial drainage system was initiated, but these would most probably have been eroded and reworked during Wolstonian and Devensian periods of low sea level, so the surviving deposits are assumed to be Devensian.

Boreholes beside the River Bure in Horstead, at the northern end of sheet TG 21 NE, revealed up to 10.5m of angular flint gravel, fine- to coarse-grained sands and silts. In the present district, the Yare Valley Formation has not been proved by boreholes, but it may be assumed to be present beneath the peat and alluvium of Skeyton Beck, Stakebridge Beck and Westwick Beck, up to about 2.0m thick.

Cover silt is the term given to a drape of silt and sand which locally masks the outcrop of the Corton Formation. 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. It may be up to around 1.5m 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 and gravelly sands and sandy clays derived from earlier Quaternary 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 sufficiently thick to show on the map is restricted to small strips and patches up to about 2.0m thick in the stream valleys. A strip of head up to 150m wide is ubiquitous at the base of the valley of the Skeyton Beck and its tributaries in the north-west of the district. Strips up to 300m wide occur at Skeyton [25 25] and along Stakebridge Beck east of its junction with Westwick Beck [267 251]; the latter extends eastwards as a much thinner strip which continues across the watershed to Worstead on sheet TG 32 NW. Rather less head occurs as discontinuous patches along the valley of Westwick Beck [269 255 to 274 280].

ALLUVIUM AND PEAT

Alluvium comprises soft laminated silty clays and clayey silts, deposited by streams during the Holocene. It is strongly developed in the valley of Westwick Beck [267 253 to 273 271], and is also recorded in the valleys of Stakebridge Beck [258 250] and Skeyton Beck [250 279 to 252 286]. It is believed to range up to 2.0m thick in the present district.

Peat is widespread only in the valley of Stakebridge Beck [258 251 to 267 252], up to about 2m thick.

The peat and alluvium of the present district are not included in the Breydon Formation (Arthurton *et al.*, 1994) since that formation is defined as 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. It is unlikely that marine influences persisted this far upstream.

MADE GROUND AND WORKED GROUND

There is little made ground in the district. This is largely restricted to railway and road embankments, the dams of ornamental lakes, and the infill of disused sand pits east and south-east of North Walsham. There may be further, unknown areas of infilled ground (wholly back-filled worked ground) which are not shown on the map. Two areas of landfill south of the new Yarmouth Road [292 280, 293 279] do not infill old pits and may be at least in part constructed from sand excavated from the farm yard lorry park [291 283] at Carlton Farm. The big disused sand pit [295 279] at Sandhill Farm has been infilled with domestic refuse. It is not clear whether the similar domestic refuse landfill site [294 290] at Hagg Farm is infilling an old sand pit or a natural valley, or both.

There are a few small disused pits within the Crag. They may have worked any combination of gravel, clay and sand. The sands of the Corton Formation have been widely worked. Pits on common land at Bryant's Heath [258 293] and Swanton Hill Common [265 267] will have had a long history of working, none have been infilled but all are now overgrown. A number of large pits east and south-east of North Walsham are of more recent origin, but again all are now abandoned: one [290 287] is now a caravan park and many have been used for the disposal of domestic refuse. Other smaller sand pits are scattered throughout the outcrop, generally at lower levels to the west, south and east of the main North Walsham plateau. Some of the disused pits shown within the outcrop of arenaceous Corton Formation may have been within small 'pods' of till, eg flow tills. There are no undoubted brick clay pits within the mapped outcrop of the Corton Formation tills, possibly because all the bodies of till are thin and interbedded with sands and gravels. All the holes within the till outcrops are small and were probably dug as ponds for watering cattle. Two ponds within the mapped outcrop of arenaceous Corton Formation [282 282, 254 272] have presumably been puddled, as duckponds or as ponds for watering cattle. There are no peat workings or 'Broads' known in the district, but some small ponds within the peat or alluvium were probably dug as wildfowl decoys.

ECONOMIC GEOLOGY

Industrial minerals

At present mineral extraction activity within the district is restricted to minimal sand extraction by farmers for there own use, although in the past, large quantities of sand, and probably some brick clay and gravel, have been won from the Crag and Corton Formation. Further extraction of sand from the Corton Formation is possible. Gravels within the Crag are of high quality, comprising largely flint, quartz and quartzite, but they are much thinner in the present district than in the Bure Valley to the south and future workings would appear unlikely. Further gravels occur both in the Corton Formation and in the Yare Valley Formation: the former are too sandy and possibly too poorly sorted to be of economic value, while the latter have not been explored but would possibly be too thin and too difficult to extract to be economic.

Water supply

The Crag, the sand and gravel units of the Corton Formation, and any intervening pre-Anglian drift deposits 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 Formation, and with any intervening pre-Anglian drift deposits. The tills in the Corton Formation are thin, sandy and discontinuous, and would not be effective aquicludes. The Upper Chalk is a major aquifer, with all flow through fissures rather than intergranular, and the Crag and Upper Chalk are in hydraulic continuity.

Within the district, 30 bores for water are known, TG 22 NE/1 to 30, and depths quoted range from 30.5m to 137.1m. All of these penetrated the Upper Chalk, but detailed logs for some are not known. Where logs are available, the depth of penetration into the Upper Chalk is shown in Figure 4. Wells revealed rest water levels of +8m to +27m OD. Water consumptions quoted vary widely: a 4-hour pumping test at TG 22 NE/5 at 1400 gallons (6364 litres) per hour yielded a depression of 6m, with recovery in 75 minutes, while TG 22 NE/23-24 have yielded 250 000 gallons (1 136 491 l) per day maximum. Water from the Upper Chalk is hard, and some well logs reported it to be ferruginous.

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, D H, 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 the 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.

Cox, F C, Gallois, R W, and Wood, C J. 1989. Geology of the country around Norwich. *Memoir of the British Geological Survey*, Sheet 161 (England and Wales).

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.

Funnell, B M, Norton, P E P, and West, R G. 1979. The Crag at Bramerton, near Norwich, Norfolk. *Philosophical Transactions of the Royal Society of London, Series B,* 287, 489-534.

Gallois, R W, and Morter, A A. 1976. Trunch Borehole, Mundesley (132) Sheet. *In*: IGS Boreholes 1975. *Report of the Institute of Geological Sciences,* No.76/10.

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.

Green, C P, and McGregor, D F M. 1996. The Kesgrave and Bytham Sands and Gravels of Eastern Suffolk: a lithostratigraphical comment. *Quaternary Newsletter,* 79, 3-7.

Hamblin, R J O. 1997a. Geological notes and local details for 1 : 10 000 sheet TG 22 SE (Scottow). *British Geological Survey Technical Report* WA/97/25.

----- 1997b. Geological notes and local details for 1 : 10 000 sheet TG 21 NE (Belaugh). *British Geological Survey Technical Report* WA/97/24.

----- 1997c. 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 the British Geological Survey).

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

----- and -----. 1996. The Kesgrave and Bytham Sands and Gravels of East Anglia. A reply to J. Rose, P. Allen, C.P. Green, R.W. Hey, S.G. Lewis, J.M. Sinclair, and C.A. Whiteman. *Quaternary Newsletter*, 79, 26-34.

-----, -----, Booth, S J, Jeffery, D H, and Morigi, A N. 1997. The Red and Norwich Crag Formations in eastern Suffolk. *Proceedings of the Geologists' Association,* 108, 11-23.

-----, ------, and Rose, J. 1996. The Kesgrave and Bytham Sands and Gravels of Eastern Suffolk; reply to a lithostratigraphical comment by C.P. Green and D.F.M. McGregor. *Quaternary Newsletter*, 79, 8-9.

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.

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.

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.

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).

Peake, N B, and Hancock, J M. 1961. The Upper Cretaceous of Norfolk. *Transactions of the Norfolk and Norwich Naturalists' Society*, 19, 293-339. Reprinted with addenda in 1970: 293-339J in: *The Geology of Norfolk*. Larwood, G P, and Funnell, B M (editors). London and Ashford: Geological Society of Norfolk.

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.

Postma, G, and Hodgson, G E. 1987. Caistor St.Edmund Pit (TG 240 04). 131-139 in: *Pliocene-Middle Pleistocene of East Anglia. Field Guide*. Gibbard, P L, and Zalasiewicz, J A (editors). Cambridge: Quaternary Research Association.

Reid, C. 1882. The geology of the country around Cromer. *Memoir of the Geological Survey, England and Wales.*

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

-----, Allen, P, Green, C P, Hey, R W, Lewis, S G, Sinclair, J M, and Whiteman, C A. 1996. The Kesgrave and Bytham Sands and Gravels of East Anglia. *Quaternary Newsletter*, 79, 10-25.

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

Wood, C J. 1988. The stratigraphy of the Chalk of Norwich. *Bulletin of the Geological Society of Norfolk*, 38, 3-120.

APPENDIX - ABBRIEVIATED LOGS OF SELECTED BOREHOLES HELD BY BGS TO SEPTEMBER 1997

Confidential boreholes are omitted, also boreholes for which no geological logs are held. 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 22 NE.

	Depth (m)	O.D. Level (m)
1. Tollgate Farm, North Walsham [2785 2834]. OD c +35.		
Top soil	0.6	
Corton Formation, Crag Group		
Sand	9.1	+26
Gravel	9.4	+26
Sand stone	18.3	+17
Mixed sand clay stone	24.4	+11
(possible base of Corton Formation)		
Yellow sand	33.5	+1
Mixed sand clay stone	42.7	-8
Upper Chalk		
Brown sand chalk	44.2	-9
Gravel	44.5	-10
Mixed hard chalk, softer chalk	106.7	-72
2. Brake Farm, Swanton Abbott [2644 2730]. OD c +39.		
Top soil	0.3	
Corton Formation, Crag Group		
Loam	0.9	+38
Brown Sand	5.5	+33
Sand & stones	9.1	+30
Brown clay	22.9	+16
Grey sand	29.9	+9
Grey sand & clay	32.9	+6
Grey sand & shells	35.1	+4
Upper Chalk		
Chalk	76.2	-37

3. E.B. LeGrice (Roses) Ltd, North Walsham [2816 2931]. OD c +40

Corton Formation, Crag Group		
Loam	0.9	+39
Sand and stones	14.6	+25
Brown sand	22.9	+17
Brown clay	28.3	+12
(possible base of Corton Formation)		
Grey sand	30.8	+9
Grey clay	33.8	+6
Greensand	38.7	+1
Sea shells	39.0	+1
Grey sand and stones	41.5	-2
Upper Chalk		
Chalk	68.6	-29

4. Sandy Hill, Worstead [2945 2786]. OD c +36

Topsoil	0.3	
Corton Formation, Crag Group		
Sand and stones	0.6	+35
Sand	5.5	+31
Sand and stones	8.2	+28
Sand	17.7	+18
Grey sand with clay	27.4	+9
(possible base of Corton Formation)		
Grey sand and stones	32.3	+4
Grey sand	38.4	-2
Sand and shells	39.3	-3
Stones	40.2	-4
Upper Chalk		
Chalk; Chalk, hard, with flints	61.0	-25

5. Heath Farm, Skeyton Road [2592 2908]. OD c +23

Top soil	0.3	
Corton Formation, Crag Group		
Sand	10.7	+12
Clay	16.8	+6
Sand	25.6	-3
Upper Chalk		
Chalk	57.9	-35

6. Bridge Farm House, Skeyton Road [2614 2903]. OD c +26

Top soil	0.6	
Corton Formation, Crag Group		
Sand	10.7	+15
Clay	18.9	+7
Sand	28.7	-3
Upper Chalk		
Chalk	54.9	-29

7. Skeyton [2584 2789]. OD c +36

Top soil	0.3	
Corton Formation, Crag Group		
Yellow sand	7.6	+28
Sandy clay	12.8	+23
Brown sand	20.7	+15
(possible base of Corton Formation)		
Grey sand	29.3	+7
Dark grey sand	36.0	OD
Upper Chalk		
Chalk with flints	57.9	-22

8. Swanton Abbott [255 258]. OD c +14

Topsoil	0.3	
Crag Group		
Yellow clay	2.1	+12
Brown fine-grained sand	8.8	+5
Grey fine-grained sand	11.6	+2
Upper Chalk		
Marl	15.5	-2
Large flints/chalk	18.0	-4
Loose chalk	32.0	-18
Chalk/flints	73.2	-59

11. Norfolk Canneries Ltd, North Walsham [282 294]. OD +41

Corton Formation		
Sand and gravel	14.0	+27
Sand	18.0	+23
Sandy clay	22.3	+19
Brown sand	29.0	+12
Crag Group		
Running sand	29.6	+11
Sand and gravel	41.1	OD
Upper Chalk		
Marl and flints	42.4	-1
Chalk and flints	121.9	-81

12. Beech Farm, Skeyton [2516 2663]. OD c +26

Corton Formation, Crag Group		
Brown clay	4.6	+21
Sand	10.7	+15
(possible base of Corton Formation)		
Blue clay	19.8	+6
Black sand	33.5	-8
Upper Chalk		
Chalk	44.5	-19

13. North Walsham Wood House [2572 2836]. OD c +29

Corton Formation, Crag Group		
Sand; dug well to 6.7m	12.2	+17
"hard grey gault"	18.3	+11
Not seen	Not known	
Upper Chalk		
Not seen	c 53.3	c -24

14. Heath Farm, North Walsham [2840 2800]. OD c +37

Top soil	0.3	
Corton Formation, Crag Group		
Clay, sand and gravel	3.0	+34
Coarse-grained green sand	9.1	+28
Fine-grained yellow sand	22.9	+14
Soft brown clay & sand	24.4	+13
(possible base of Corton Formation)		
Soft grey clay & stone	25.9	+11
Hard grey clay & stone	27.4	+10
Grey sand & gravel	29.0	+8
Soft grey clay & sand	38.1	-1
Upper Chalk		
Clay & chalk	39.6	-3
Soft chalk & flints	106.7	-70

15. North Walsham Water Works [278 291]. OD +43.6

Soil	0.3	
Corton Formation		
Rich reddish yellow gravel and sand	2.0	+42
Flint gravel, flints up to 51cm long	2.4	+41
Pale buff very fine-grained sand	9.1	+35
Reddish brown sand	10.7	+33
Buff sand	11.6	+32
Fine-grained gravel sand	11.7	+32
Pale buff very fine-grained sand	14.6	+29
Pale yellow loamy sand	15.7	+28
Reddish brown loam	21.8	+22

Bluish compact hard stiff loamy clay, impervious to water	22.7	+21
Yellowish loam with thin bands of iron stone	22.9	+21
Yellow loamy sand	24.4	+19
Dark grey very compact sand; dark brownish grey sand	29.4	+14
Dark bluish grey stiff compact loamy clay with small stones	30.6	+13
Crag Group		
Rounded grey flints, 2-5 cm in diameter	32.5	+11
Grey blowing sand	37.3	+6
Pale grey stiff compact marl, impervious to water	37.5	+6
Grey running sand, with fragments of shells above 39.5m depth	42.7	+1
Large flints	43.0	OD
Upper Chalk		
Chalk	76.2	-33

17. North Walsham Water Works [278 291] OD +43.6

Soil	0.6	
Corton Formation		
Loamy sand	1.5	+42
Flint gravel with red sand	3.7	+40
Very fine-grained pale buff sand, water bearing below 12.8m	17.4	+26
Light clay, with a mixture of red loam and fine-grained sand	27.1	+17
Blue clay, stiff and compact	27.7	+16
Fine-grained grey sand and loam	28.9	+15
Dark grey clay, with small flint fragments	29.7	+14
Small rounded flints	32.0	+12
Grey stiff clay	32.2	+11
Fine-grained grey sand with flint fragments	33.7	+10
Crag Group		
Fine-grained grey sand, water-bearing	39.0	+5
Very fine-grained grey sand with shell fragments	39.6	+4
Close-grained stiff grey clay with fine-grained sand	41.1	+3
Large flints	41.5	+2
Upper Chalk		
Chalk	137.1	-84

18. North Walsham Water Works [278 291]. OD c +43

Soil	0.5	
Corton Formation		
Red sand	2.7	+40
Pale red sand & flint gravel	4.6	+38
Buff sand & flint gravel	6.7	+37
Brown sand & a little shingle	7.3	+36
Pale brown coarse-grained sand & shingle	8.8	+34
Buff coarse-grained sand	10.1	+33
Fine-grained brown sand	15.2	+28
Reddish brown sandy clay	17.1	+26

Hard bluish stiff compact clay	22.6	+20
Yellow loam	23.8	+19
Yellow loamy sand	26.2	+17
Fine-grained grey sand, very compact	30.5	+12
Dark blue-grey stiff compact loamy clay with small stones	31.7	+11
Crag Group		
Grey flints	33.5	+9
Grey sand & shell fragments	37.2	+6
Peat	37.5	+6
Grey sand	39.6	+3
Grey marl	39.9	+3
Grey sand	42.3	+1
Flints	42.4	+1
Upper Chalk		
Dirty chalk & flints, water	48.8	-6
White chalk & flint	121.9	-79

20. Hill Farm, Worstead [2985 2804]. OD +17.7

Top soil	0.6	
Corton Formation, Crag Group		
Loam	5.2	+13
Sand	8.3	+9
(possible base of Corton Formation)		
Shingle	9.8	+8
Black sand	19.8	-2
Upper Chalk		
Chalk	36.6	-19

21. Swanton Abbott Hall [2551 2560]. OD +14.3

Brick shaft	4.3	+10
Crag Group		
Sand and stone	9.8	+5
Upper Chalk		
Marl	22.3	-8
Chalk	39.6	-25

22. Brook Farm, Westwick [2711 2552]. OD +14.6

Top soil	0.3	
Crag Group		
Brown sand	4.0	+11
Brown clay	4.6	+10
Brown sand	7.9	+7
Shingle	15.5	-1
Upper Chalk		
Chalk	35.1	-21

23. Westwick Frosted Products Factory [2966 2539]. OD +15.5		
Corton Formation, Crag Group		
Pale yellow sand	0.4	+15
Buff sand	2.2	+13
Coarse gravel and sand	10.7	+5
Dark reddish brown loam, slightly mottled	12.3	+3
Dark grey very compact sand	12.5	+3
Dark blue clay with small stones, impervious	22.3	-7
Grey flints	23.5	-8
Grey running sand	25.1	-10
Flints	25.3	-10
Upper Chalk		
Chalk	65.2	-50
26. Tile Cottage, Swanton Abbott [2700 2538]. OD +12.5		
Black soil	0.6	+12
Corton Formation		
Sand and clay	1.2	+11
Crag Group		
Yellow sand; also shingle below 4.4	4.9	+8
Shingle	5.8	+7
'Marle'	6.1	+6
Blue clay	7.0	+6
Grey sand and sea shells	9.1	+3
Upper Chalk		
Very soft chalk to 32.9; hard chalk	45.7	-33
27. The Jolly Farmers Public House [2670 2525]. OD +12.1		
Existing well	3.0	+9
Crag Group		
Sand and shingle layers	11.6	+1
Upper Chalk		
Chalk with flints	44.2	-32
28. Holgate Farm, North Walsham [2998 2855]. OD + c13		
Top soil	0.9	+12
Corton Formation, Crag Group		
Sand and shingle	5.5	+8
(possible base of Corton Formation)		
Blue clay	6.4	+7
Running sand and shells	14.9	-2
Upper Chalk		
Chalk & flints	30.5	-18

29,30. Skeyton Road, North Walsham [2616 2786]. OD c +41

Corton Formation, Crag Group		
Brown sand	22.9	+18
Grey sand,; below 34.1, with stones	37.8	+3
Grey sand with sea shells	40.2	+1
Upper Chalk		
Chalk	57.9	-7