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INSTITUTE OF GEOLOGICAL SCIENCES

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ASSESSMENT OF BRITISH SAND AND GRAVEL RESOURCES No. 5

The sand and gravel resources of the country around Hethersett, Norfolk

Description of 1 : 25 000 sheet TG 10

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with contributions by A.R. Clayton

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PREFACE

It has become increasingly clear in recent years that an assessment of resources of many minerals should be undertaken. This, another Report of the Mineral Assessment Unit, which was set up in May 1968 to undertake such work, is the second of three for the Norwich area. It describes and quantifies the resources of sand and gravel of 60 km^2 of country south-west of Norwich, shown on the accompanying 1:25 000 resource sheet TG 10.

This survey is concerned with assessing sand and gravel resources on a regional scale at the indicated level; the deposits are not outlined completely nor their grade established throughout. The work may be regarded as the application to large areas of methods used commercially for evaluating reserves on small sites. It may also be regarded as an extension of geological mapping by providing information about the thickness and quality of deposits.

The survey was conducted by Mr. E.F.P. Nickless, assisted by Mr. A.R. Clayton as field officer who supervised the drilling and sampling programme and helped in the preparation of data for this publication. The work is based on a geological survey at 1:10 560 carried out in 1965-70 by Dr. F.C. Cox, Mr. M.C. McKeown and Mr. E.G. Poole (East Anglia and South-East England Field Unit). Dr. Cox also helped in the geological interpretation.

Mr. J.W. Gardner, C.B.E. (Land Agent) has been responsible for negotiating access to land for drilling. The ready cooperation of land owners and tenants in this work is gratefully acknowledged. Special thanks are due to Dr. T.L. Thomas of the Royal School of Mines, London, for his advice on methods of resource calculation. Financial support for the survey was provided by the Department of the Environment.

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Summary

The geological maps of the Institute of Geological Sciences, pre-existing borehole information, and sixty-three boreholes drilled for the Mineral Assessment Unit form the basis of the assessment of sand and gravel resources in the Hethersett area, Norfolk.

All deposits in the area which might be potentially workable for sand and gravel (mineral) have been investigated geologically and a simple statistical method has been used to estimate the volume. The reliability of the volume estimates is given at the 95 per cent confidence level.

The 1:25 000 map is divided into resource blocks, each ideally containing approximately 10 km^2 of sand and gravel. For each block the mineral-bearing area, the mean thickness of overburden and mineral, and the mean grading are given and the geomorphology and geology of the deposits described.

The position of the boreholes and exposures, the geology and topography and the outlines of the blocks are shown on the accompanying map TG 10. Detailed borehole data are given.

Sommaire

Les cartes géologiques de l'Institute of Geological Sciences, les renseignements sur des trous de sonde qui existaient déjà, et trous de sonde forés pour le Mineral Assessment Unit, constituent la base de l'évaluation des ressources en sable et en gravier dans la région de Hethersett, Norfolk.

Tous les dépôts dans la région, qui présentent la possibilité d'exploitation pour le sable et le gravier (mineral), ont été étudiés de point de vue géologique, et on s'est servi d'une methode statistique simple pour en évaluer le volume (cubage). Les évaluations de volume sont tenues d'être a 95 pour cent exactes.

La carte 1:25 000 est divisée en blocs de ressources, chacun d'eux ayant idéalement environ 10 km^2 de sable et de gravier. On donne pour chaque bloc l'étendue minéralisée, l'epaisseur moyenne de recouvrement et de minéral, et la gradation moyenne. On décrit la géomorphologie et la géologie des dépôts.

La situation des trous de sonde et des affleurements, la géologie et la topographie, et la configuration des blocs sont montrées sur la carte TG 10. Des données détaillées des trous de sonde se trouvent.

Zusammenfassung

Die geologischen Karten von der Institute of Geological Sciences, die vorher existierende Information im Bezug auf Bohrlochern, auch 63 Bohrlöcher, die für das Mineral Assessment Unit gemacht waren, bilden den Grund für die Einschätzung der Sand- und Schottermittel im Hethersett Gebiet, Norfolk.

Man hat im Gebiet alle Ablagerungen, die möglich bearbeitbare für Sand und Schotter (Mineral) sind, geologisch untersucht, und man hat auch eine einfache statistische Methode (in Zusatz A beschrieben) benutzt, um das Volumen zu schätzen. Man gibt die Zuverlässigkeit der Volumenschatzungen mit 95 Prozent Vertrauensgrenzwerten.

Man teilt die 1:25 000 Karte in Mittelsblöcke, wovon jeder ungefähr 10 km^2 von Sand und Schotter einschliesst. Für jeden Bloch gibt man das mineralhaltige Gebiet, die Durchschnittsdiche von Überlastung und Mineral, und die Durchschnittsklassifizierung, und beschreibt die Geomorphologie und Geologie der Ablagerungen.

Man zeigt die Lage von den Bohrlöchern und Aufschlüssen, die Geologie und Topographie, auch die Skizzen von den Blöchen auf der Begleitkarte TG 10. Man gibt ausführliche Bohrlöcherdaten.

The sand and gravel resources of the country around Hethersett, Norfolk

Description of 1 : 25 000 resource sheet TG 10

E. F. P. Nickless,[1] BSc

Introduction

AIMS AND LIMITATIONS

National resources of many of the 'bulk' or 'industrial' minerals may seem so large that stocktaking is unnecessary, but the demand for land for all purposes and for minerals is intensifying. In contrast with other developments of land there may be little or no choice of area for the working of minerals and in the case of low-price materials such as sand and gravel transport costs will be an important factor. Whereas the economic benefit of using land for many other purposes can be assessed, hitherto little has been known of the potential value, on a regional scale, of any mineral resources which may be present. An important aim of the work is to improve the factual background against which planning policies can be decided (Archer, 1969; Thurrell, 1971).

Sand and gravel, considered together as naturally occurring aggregate, was selected as the bulk mineral demanding the most urgent attention, particularly in the south-east of England, where about half the national output is won and very few sources of alternative aggregates are available. Following a short feasibility project, initiated in 1966 by the Ministry of Land and Natural Resources, the Mineral Assessment Unit began systematic surveys on a regional scale in Essex, Suffolk, and Norfolk in May 1968. This work is being supported by the Department of the Environment (which incorporates the former Ministry of Housing and Local Government and the Ministry of Public Building and Works) and is being undertaken with the cooperation of the Sand and Gravel Association of Great Britain (SAGA). The detail is at the 'indicated' level, a term introduced in the United States in connection with the estimation of national mineral resources. The level is that 'for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geological evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.' (Anon., 1948, p.15).

The survey is therefore concerned not with the estimation of reserves (which can only be assessed in the light of particular or existing economic considerations), but rather with resources, which include deposits which are not currently exploitable but have a foreseeable use. Clearly, the social and economic criteria used to decide whether a deposit may be workable at some time in the future cannot be rigorously defined. After discussion with the industry, the following arbitrary physical criteria were adopted for this survey.

a. the deposit should average at least 3 ft (0.9 m) in thickness.
b. the ratio of overburden to sand and gravel should be no more than 3:1.
c. the proportion of fines (that is, particles passing 1/16 mm (approximately No.200 mesh B.S. sieve)) should not exceed 40 per cent.

Ground below 80 ft (24.4 m) from the surface is seldom explored, this being taken as the likely maximum working depth under most circumstances. It follows that boreholes are drilled no deeper than 60 ft (18.3 m) if they are still in overburden.

A deposit of sand and gravel that broadly fulfils the above criteria is considered to be 'potentially workable' and is assessed as 'mineral'. It is recognised that small parts such a deposit may not satisfy all the requirements.

The volume and chief characteristics of sand and gravel within defined but relatively large areas, referred to as resource blocks, are assessed. Ideally, each resource block contains roughly 10 km^2 of sand and gravel.

The consequent limitation of the use to which the results can be put must be emphasised. The assessments of quantity and composition

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apply to the resource block as a whole.

> Valid conclusions cannot be drawn about the mineral in parts of a block, except in the immediate vicinity of the actual sample points.

It follows that reserves, which are accurately demarcated areas of economically workable mineral, must be proved by the customary detailed exploration undertaken by the industry. However, the information provided about the resource blocks in an area may assist in the selection of the best targets for such commercial exploration and evaluation.

Thus the work can be regarded as the statistically controlled application to large areas of methods similar to those applied by industry to establish the existance of workable reserves on a relatively small site, and also as an extension of conventional geological mapping techniques, which delineate (with varying degrees of accuracy, depending, for example, on the presence of cover) the areal extent of deposits.

PROCEDURE

Trial and error during preliminary studies showed that for the complex and variable glacial deposits of East Anglia and Essex, an absolute minimum of five sample-points evenly distributed across the sand and gravel are needed to provide a worthwhile statistical assessment, but that, ideally, there should be no fewer than ten. Sample-points are any points for which there exists adequate information about the nature and thickness of the deposit and, apart from the holes drilled during the survey, may include exposures and other boreholes. In particular, the cooperation of sand and gravel operators has ensured that boreholes have not been drilled where reliable information was already available. Such data are held confidentially by the Institute and cannot be disclosed, although they may have been used in the calculations.

The mineral shown on each 1:25 000 sheet is divided into resource blocks. The arbitrary size selected, 10 km^2, is a compromise to meet the aims of the survey and to provide sufficient sample-points in each block. As far as possible the block boundaries are determined by geological boundaries; for example, wherever practicable glacial and river terrace gravels are separated. Otherwise division is by arbitrary lines, which may bear no relationship to the geology. The blocks are drawn provisionally before drilling begins.

A reconnaissance of the ground is carried out to establish whether there are any exposures, and inquiries are made to ascertain what borehole information is available. Borehole sites are then selected to provide an even pattern of sample-points at a density of approximately one per square kilometre. Ideally the distribution should be unbiassed with respect to the geology, to ensure that the data obtained are representative of any broad trends in the variation in thickness or grading, as this will govern spot values.

However, because broad trends are independently overlaid by smaller scale variations, characteristically random in form, it is unnecessary to adhere to a square grid pattern. Thus such factors as ease of access and the need to minimise disturbance to land and the public have been taken into account in siting the holes; at the same time it has been necessary to guard against the possibility that ease of access (that is, the positions of roads and farms) may reflect particular geological conditions, which may bias the drilling results. The built-up area of Norwich has been avoided, but otherwise in siting the boreholes and in the subsequent calculations, no account is taken of any factors, for example, roads, villages and areas of high agricultural and landscape value, which might stand in the way of sand and gravel being exploited. The estimate of total volume of sand and gravel therefore bears no simple relationship to the amount that could be extracted in practice.

Ideally the drilling machine employed should be capable of providing a continuous sample representative of all unconsolidated deposits, so that the in-situ grading can be determined, if necessary, to a depth of 100 ft (30 m) at a diameter of about 8 in (200 mm), and beneath different types of overburden. It should be reliable, quiet, mobile and relatively small (so that it can be moved to sites of difficult access) and it should be fast. Although uncased continuous flight power augers can meet these requirements in some ground, they fail below the water table in some clay-free sand and gravel when the mineral does not stay on the flights, or when the borehole caves. On the area covered by this sheet the German Wirth B1 drill (or B0 modified) was used extensively. With this machine, casing can be advanced at the same time as the hole is being drilled, thus minimising disturbance to the ground, and avoiding contamination and caving. In difficult ground a bailer can be substituted for the auger although this method suffers from the disadvantage that there is a tendency for the pumping action to draw unwanted material into the hole either from the sides or the bottom. Other machines, including conventional 'shell and augers', were also used.

A continuous series of bulk samples is taken throughout the thickness of sand and gravel. Ideally, samples are composed exclusively of the whole of the material previously occupying the space defined by the hole's ideal dimensions, as determined by the internal diameter of the casing and the thickness penetrated. A new sample is commenced whenever there is an appreciable lithological change within the sand and gravel, or for every 3 ft (0. 9 m) of depth. The samples are despatched in heavy-duty polythene bags to a laboratory for grading. Care is taken to discard, as far as possible, material which has caved, or been pumped from the bottom of a hole. The samples sent for analysis each weigh 60-100 lb (27 - 45 kg). The grading procedure is based on BS 1377: 1967. Random checks are made on the accuracy of the laboratory grading.

All data, including mean grading analysis figures calculated for the total thickness of the mineral, are entered on standard record sheets, abbreviated copies of which are reproduced in Appendix C.

Detailed records may be consulted at the appropriate offices of the Institute, upon application to the Director.

The methods used in estimating the volume of mineral and other statistics for each of the resource blocks are described in Appendix A and the results are quoted on p. 10.

THE MAP

The sand and gravel resource map is folded into the pocket at the end of this report. The base map is the Ordnance Survey 1:25 000 Outline Edition in grey, on which the topography is shown by contours in green, the geological data in black and the mineral resource information in shades of red.

Geological Data

The geological boundary lines, symbols, etc., shown are taken from the geological map of this area, which was surveyed recently at the scale of 1:10 560. This information was obtained by detailed application of field mapping techniques by the field staff in the Institute's East Anglia and South-East England Unit. Borehole data, which include the stratigraphic relations and mean particle size distribution of the sand and gravel samples collected during the assessment survey, are also shown.

The geological boundaries are regarded as the best interpretation of the information available at the time of survey. However, it is inevitable, particularly with glacial deposits (such as those included in the area of sheet TG 10) which change rapidly vertically and laterally, that local irregularities or discrepancies will be revealed by some boreholes (for example, at boreholes NW 17 and NE 61). These are taken into account in the assessment of resources (see below and Appendix A).

Mineral Resource Information

For assessment purposes the map is divided into areas of mineral and areas where sand and gravel is either not potentially workable or absent. (For definitions of 'mineral' and 'potentially workable' see p. 1).

The mineral on TG 10 is subdivided into areas where it crops out, and areas where it is present in continuous (or almost continuous) spreads beneath overburden. All of the area of exposed sand and gravel as mapped is considered as mineral, although it may include small areas where sand and gravel is not present or is not potentially workable.

The mineral may be continuous (or almost continuous) or discontinuous beneath overburden. The recognition of these categories is subjective, depending on the importance attached to the proportion of boreholes which did not find potentially workable sand and gravel and the distribution of barren boreholes within a block. The mineral is described as 'almost continuous' if it is present in 75 per cent or more of the boreholes in a resource block. The 'discontinuous' category has not been recognised on the present sheet.

Areas where bedrock crops out, where boreholes indicate absence of sand and gravel beneath cover and where sand and gravel beneath cover is interpreted to be not potentially workable, and areas not assessed are uncoloured on the Map; where appropriate the relevant criterion is noted. In such areas it has been assumed that mineral is absent in infrequent and relatively minor patches which can neither be outlined nor assessed quantitatively in the context of this survey.

The area of the exposed sand and gravel is measured from the mapped geological boundary lines. Inferred boundaries have been inserted around areas where sand and gravel beneath cover is interpreted to be not potentially workable or absent. Such boundaries (for which a distinctive symbol is used) are drawn primarily for the purpose of volume estimation. The symbol is intended to convey an approximate location within a likely zone of occurrence rather than to represent the breadth of the zone, its size being limited only by cartographic considerations. For the purpose of measuring areas the centre-line of the symbol is used.

Description of sheet TG 10

GENERAL

Chalky Boulder Clay covers much of the area. The south-western two-fifths of the map comprises a plateau of boulder clay. The mean thickness of the till probably exceeds 60 ft (18. 3 m). Any underlying sand and gravel that may be present is, therefore, judged to be not potentially workable, as the overburden ratio is probably greater than 3:1, and no assessment has been made for this 43 km^2 of ground. The built-up area of Norwich, a further 3. 5 km^2, is also excluded. Of the remaining area, 48. 6 km^2 (approximately 90 per cent) is gravel bearing (see Table 1).

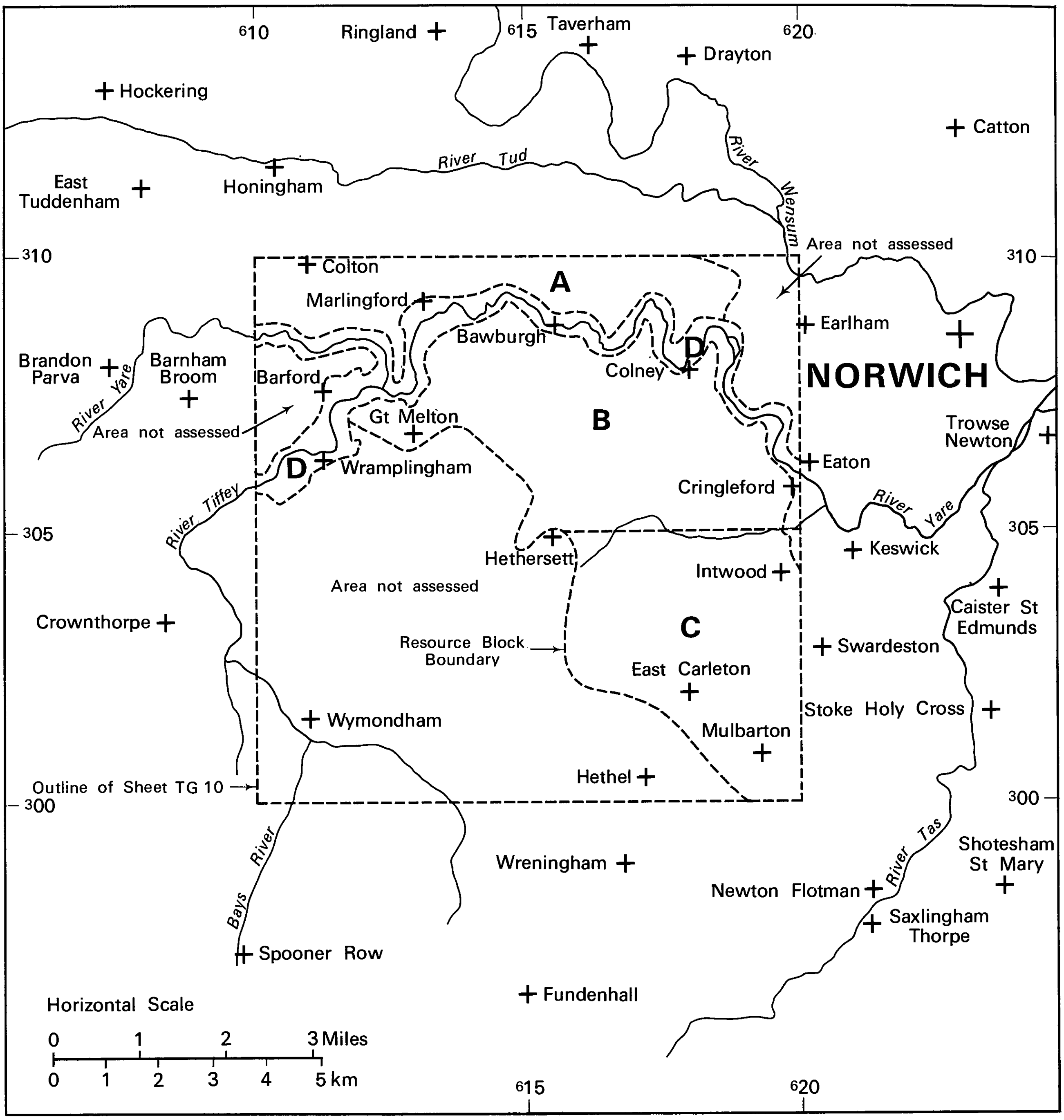


Fig. 1. Sketch map showing the location of sheet TG 10

TOPOGRAPHY

The generally featureless Chalky Boulder Clay plateau lies at about 150 ft (45 m) above O.D. In the north-east outwash sands and gravels are present at the surface. The northern part of the area has been dissected by the River Yare and its tributary the Tiffey, and has considerably varied relief. The valleys are steep-sided and narrow with small areas of peaty marsh. In the south, the area around Wymondham [115 018] [1] has been locally dissected by the upper reaches of the River Tiffey and the Bays River.

GEOLOGY

The relationship of one bed to another is in many cases complex. The following outline of the geology is intended only to assist in understanding the distribution of the sand and gravel.

The Chalk which crops out along the sides of the valley of the River Yare, forms the bedrock to the overlying, mainly unconsolidated, younger deposits.

Except where the fairly flat pre-Pleistocene surface of the Chalk is protected by Norwich Crag it has been strongly and somewhat irregularly dissected by glacial and fluvial erosion. Drift deposits, including sand and gravel, in glacially deepened channels are commonly overlain by more recent river deposits.

During Pleistocene times the sea advanced across this part of Norfolk depositing a basal residual cobble bed (The Stone Bed of older authors) and the Norwich Crag. The cobble bed, up to 1 ft (0.3 m) thick consists mostly of brown-coated, cobble-size flints, whose mean size varies from 4 to 12 in (100 to 300 mm). Occasionally bones and shells can be found in it. The Norwich Crag comprises alternations of sand, gravelly and shelly sands and thin clay seams. The clay seams are usually no more than 1 in (2 cm) thick.

Elsewhere, for example on the neighbouring sheet TG 20 (Nickless, 1971), the Norwich Crag was deposited as a continuous sheet in which there is an east-west variation in grade. However, on this sheet the Norwich Crag is present only in the north-east between Bawburgh [168 093] and Cringleford [200 067]; its original extent is unknown.

To the east, for example, at Whitlingham Pit [268 077] (Nickless, 1971), the Norwich Crag becomes increasingly gravelly towards its top; these gravelly beds have been called the Bure Valley Beds or Westleton Beds by some workers (for example, Baden-Powell and West, 1960), but in this area no such subdivision is recognisable.

The Pleistocene Period in Norfolk was punctuated by a number of glacial episodes. Several glacial advances are known; each is characterised by a sequence of boulder clays, glacial sands and gravels, outwash sands and various constructional features such as eskers and kames. During warmer periods when the ice-fronts retreated, vast spreads of outwash sand and gravel were deposited by meltwaters; these deposits represent the major sand and gravel resource of this area.

The nature and complexity of deposition during Pleistocene times varies considerably from place to place. (For a simplified explanation of the sequence of events throughout the area see Fig. 2).

The earliest indisputably glacial deposit in the region of Norwich is the Norwich Brickearth, a sandy clay, usually brown or orange-brown in colour, containing scattered pebbles of flint, quartz and quartzite. Although no Norwich Brickearth has been found on sheet TG 10, it crops out 2 miles ($3\frac{1}{2}$ km) to the north of the sheet near Drayton [183 142].

The edge of the Chalky Boulder Clay deposit runs very approximately south-eastwards from The Hangings [149 099] to Intwood [199 043]. North-east of this line Glacial Sand and Gravel crops out (Bawburgh-Cringleford area), while to the south-west it is associated with boulder clay (Marlingford-Mulbarton area). To the south-west (Wramplingham-Wymondham-Bracon Ash area) most of the ground is covered by thick boulder clay (Fig. 3). It is probable that the Chalky Boulder Clay in the Norwich area— the product of the so-called Lowestoft Ice, which advanced from the north-west or west (West and Donner, 1956) —is approximately the same age as the Norwich Brickearth, the product of the North Sea Ice (which moved from the north-east).

The Chalky Boulder Clay is a stiff bluish-grey chalky clay with pebbles, cobbles and boulders mainly of chalk, flint and quartzite. Other rock types are also present, predominantly of Jurassic and Lower Cretaceous origin, indicating that the Chalky Boulder Clay ice-sheets passed over outcrops of formations now exposed largely in western Norfolk and Lincolnshire. Various authors (for example, Baden-Powell, 1948; West and Donner, 1956) have considered that the Chalky Boulder Clay as a whole is the product of two separate glaciations, the Lowestoft and the Gipping, separated by an interglacial period, the Hoxnian. However, the existence of a Gipping glaciation has still to be confirmed (Bristow and Cox, 1973). Laminated silty clays,

1 National Grid References in this publication all lie within the 100 km square TG (63).

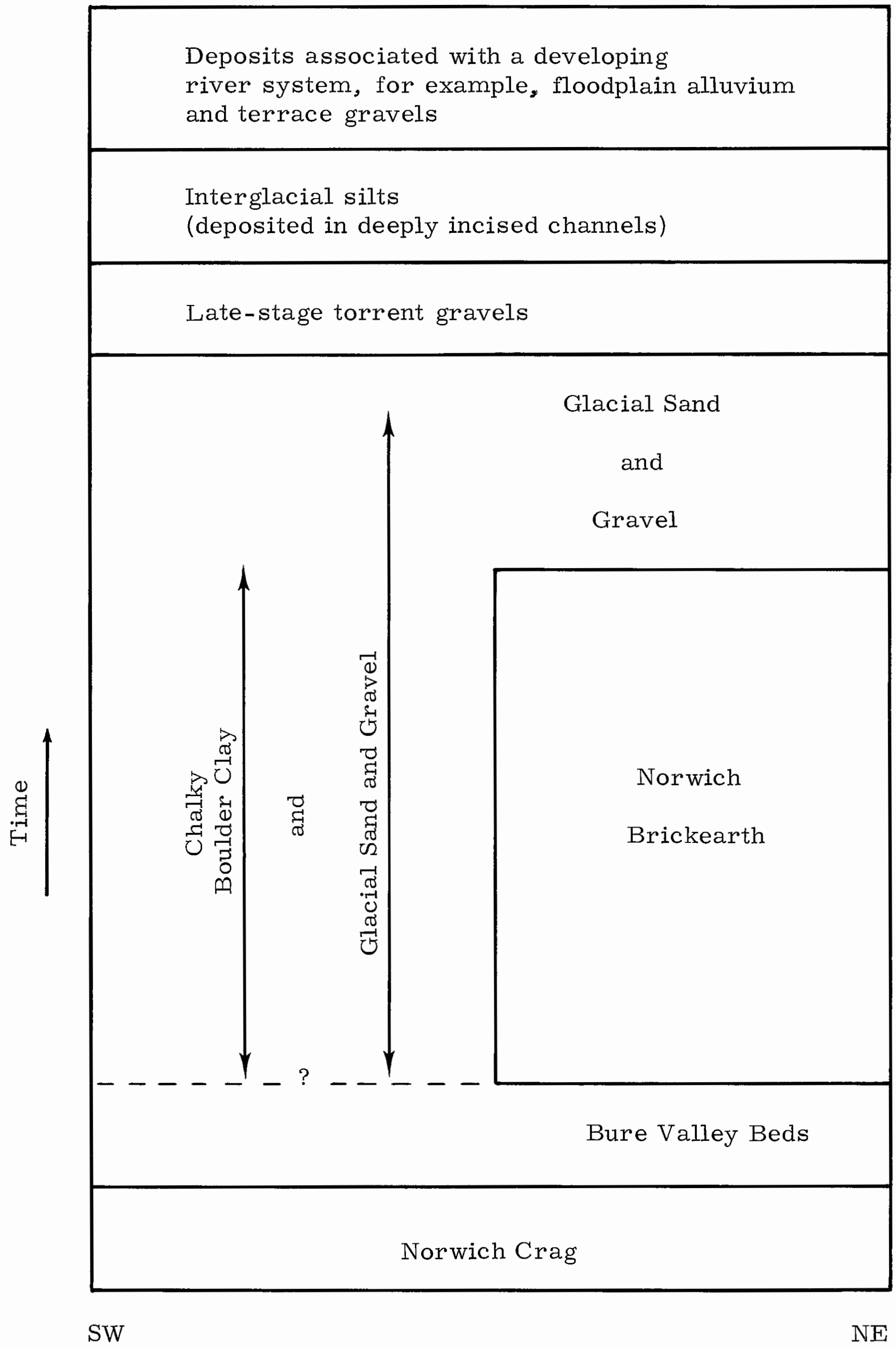
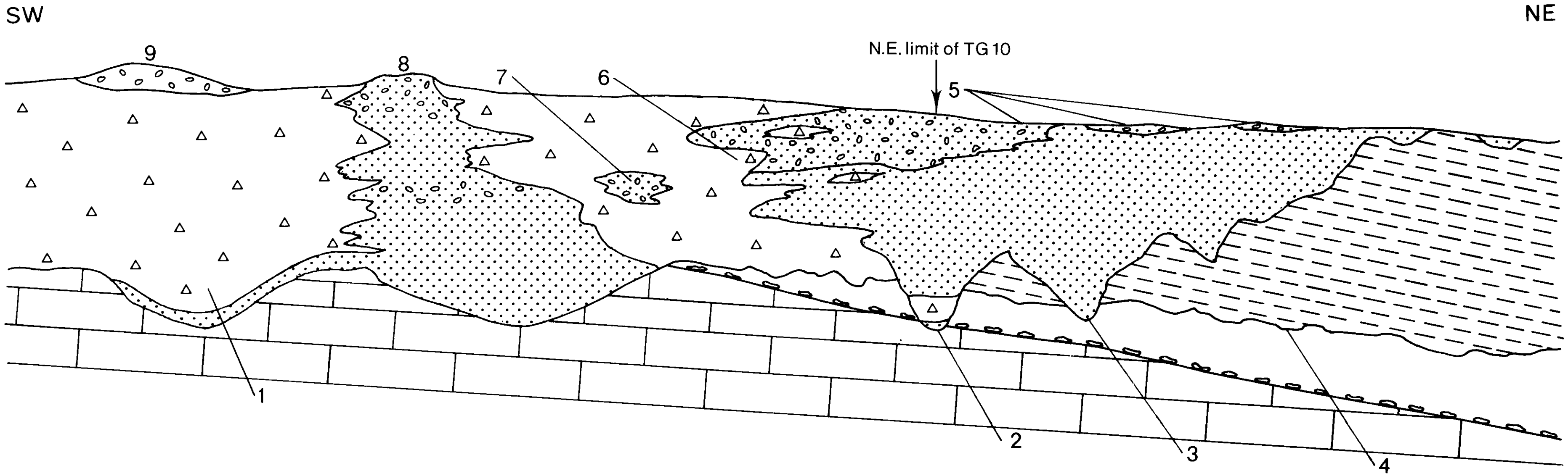


Fig. 2. Diagram to show the general relationship of Pleistocene and Recent deposits in time and place, in the Norwich area, the left side of the diagram representing the geological succession in the present sheet area



1 Deep channel beneath Chalky Boulder Clay, and infilled with glacial deposits (e.g. south-west of Wymondham).

2 Deep channel with long glacial history; shows early advance of Chalky Boulder Clay.

3 Channel formed by sandy outwash from Chalky Boulder Clay; frequently cuts out all earlier drifts.

4 Contact of Norwich Brickearth with Norwich Crag; shows evidence of slight channel developement.

5 Torrent gravels deposited at final decay stage of Chalky Boulder Clay ice.

6 Margin of Boulder Clay interdigitating with outwash deposits. (e.g. Hethersett-Little Melton area)

7 Included mass of glacial sand and gravel.

8 Gravel mound, its margins interdigitating with Chalky Boulder Clay.

9 High level torrent gravels.

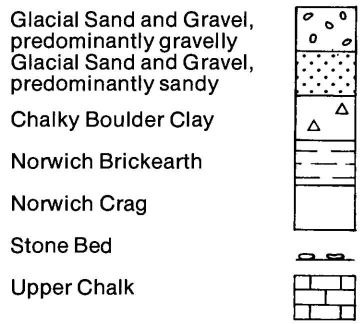


Fig. 3. Schematic section across the Chalky Boulder Clay ice front, showing the stratigraphy of the Norwich area

identified by Miss L. Phillips, Sub-department of Quaternary Research, Botany School, Cambridge, as Hoxnian in age, were found in borehole NW 2 at Barford. Here Terrace Gravel, not boulder clay, overlies the interglacial sediments in a deeply incised valley cut into Chalky Boulder Clay (Cox and Nickless, 1972).

As the ice-sheets decayed, meltwaters carried vast quantities of clay, sand and gravel which were deposited as outwash beyond the ice margin, for example, in the area around Bawburgh, and boulder clay was dumped at or behind the ice margin in unsorted and unstratified masses. Thus at the ice margin the relationship of boulder clay to sand and gravel is complex, for example, south of the River Yare.

The last phase of sand and gravel deposition is represented by torrent gravels, formerly the Cannon-shot Gravels of Woodward (1882), which are ill-sorted, rapidly deposited gravels (see section on Wymondham area. p. 12). They consist predominantly of well-rounded flint cobbles in a sandy matrix but such exotic rock types as rhyolite, microgranite, felsite and porphyrite are also present. In places these gravels are overlain in turn by Chalky Boulder Clay which may represent a minor oscillation at the end of this glacial period although alternative explanations of multi-till sequences have been suggested, for example, by Boulton (1972).

By the end of Pleistocene times the discharging meltwaters had imposed a new drainage system (Cox and Nickless, 1972), within which a series of fluviatile deposits are still forming. Only one terrace is known. The grading characteristics of the terrace and of the gravels which lie beneath the alluvium of the present floodplains, here referred to as Sub-alluvium Gravels, are almost identical and they may represent a single phase of deposition prior to downcutting and formation of the present flood-plain. A cover of alluvium usually composed of fine sand, clay or silt up to 8 ft (2.4 m) thick forms the floodplains of the rivers. Downstream on the Yare, in the neighbourhood of Bowthorpe, [178 082] there are local developments of peat, up to 6.5 ft (2 m) thick within the Alluvium.

COMPOSITION OF THE SAND AND GRAVEL DEPOSITS

There are four potentially workable mineral horizons represented on the sheet area: Terrace Gravels; Sub-alluvium Gravels; Glacial Sand and Gravel; Norwich Crag.

The Terrace Gravels

The Terrace Gravels vary from gravel to 'very clayey' pebbly sand (Fig. 7) and have a mean grading of fines 9 per cent, sand 42 per cent, gravel 49 per cent (for definition of these terms and discussion see Appendix B). The gravel consists predominantly of coarse with some fine subangular flint pebbles. Occasionally flint cobbles occur. Minor amounts of fine subrounded ?vein quartz are also present. The sand is composed of medium to coarse subangular ?vein quartz and flint. Chalk was recorded in the gravels in boreholes NE 46 and NE 60. In borehole NW 12 the mineral is 'very clayey', and in borehole NW 15 'clayey'. On the data from eight sample points the Terrace Gravels are on average 10 ft (3.2 m) thick and are overlain by a mean thickness of 3.5 ft (1.0 m) of overburden.

The Sub-alluvium Gravels

The Sub-alluvium Gravels, proved in three boreholes, vary from gravel to sandy gravel and have a mean grading of fines 2 per cent, sand 47 per cent, gravel 51 per cent. On average they are 14 ft (4.2 m) thick, and overlain by 6.5 ft (2.0 m) of overburden. The Sub-alluvium and Terrace Gravels are very similar in composition and may belong to the same phase of deposition.

The Glacial Sand and Gravel

The Glacial Sand and Gravel consists of ill-sorted slightly clayey sands and gravels which usually contain a little chalk (less than 1 per cent by weight) in both the sand and gravel fractions. No systematic regional variation in grade has been identified; on a local scale there is rapid variation in grade both vertically and laterally.

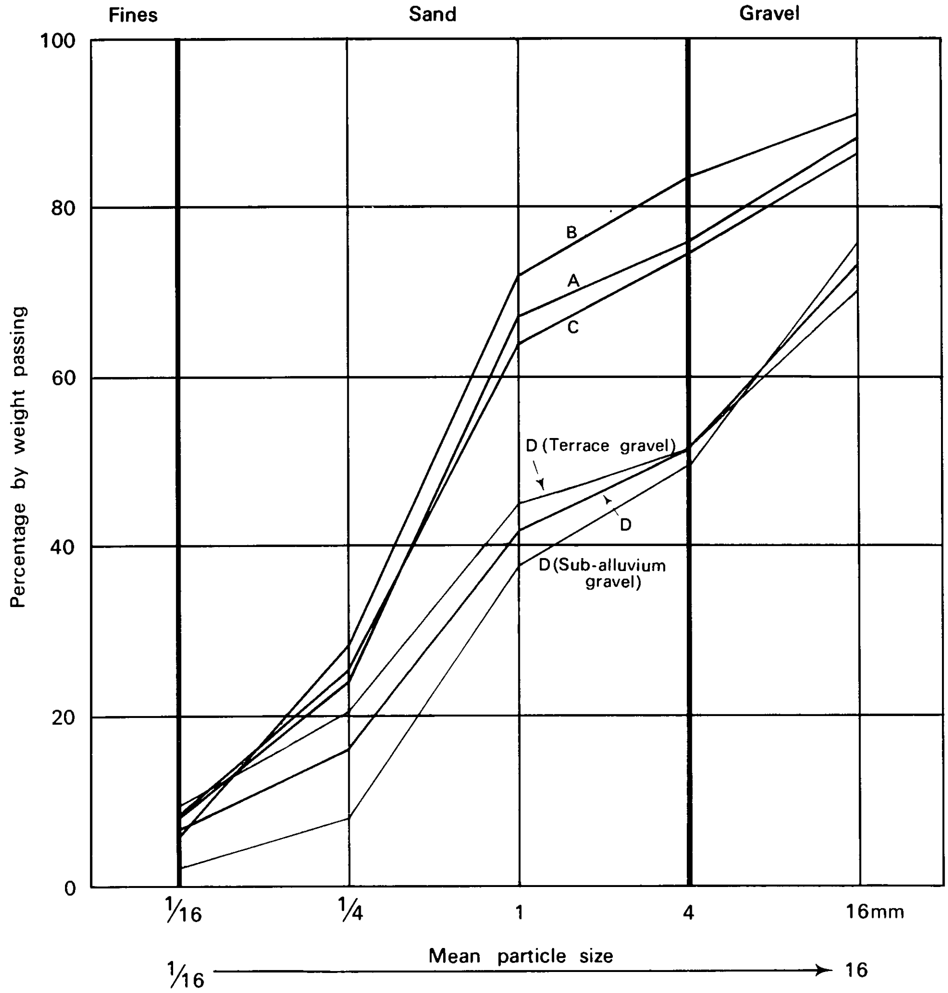
Although the sand varies from fine to coarse grained, the medium grade predominates. The sand is composed of quartz and flint and varies in degree of rounding from subangular to subrounded. Fines average 6 to 8 per cent by weight. The gravel consists predominantly of fine to coarse subangular flint pebbles with minor amounts of fine subrounded vein-quartz and quartzite.

The Norwich Crag

The Norwich Crag is very restricted in occurrence having been found in only two boreholes, 161/363a and NE 56 (see notes on resource block A). The Crag consists of alternating seams of gravelly and shelly sand with thin clay seams. The sand is usually white or orange, medium-grained and subrounded. The gravel is composed of fine-grained subangular flint with subrounded to well-rounded quartz and quartzite pebbles. The mean grading of the deposit at borehole NE 56 is fines 9 per cent, sand 87 per cent, gravel 4 per cent.

RESULTS

The statistical results are summarised in Table 1. Fuller grading particulars are shown in Fig. 4.



BLOCK	Percentage by weight passing				
	1/16mm	1/4mm	1mm	4mm	16mm
A	8	24	67	76	88
B	5	28	72	83	91
C	8	25	64	74	86
D	6	16	42	51	73
D (Sub-alluvium gravel)	2	8	38	49	76
D (Terrace gravel)	9	21	45	51	71

Fig. 4. Particle size distribution for the assessed thickness of sand and gravel in the resource blocks A to D of sheet TG 10

Table 1. Statistical assessment of sand and gravel resources of sheet TG 10.
The methods used in the assessment of resources are given in Appendix A.

BLOCK	Area		Mean thickness				Volume of sand and gravel				Mean grading per cent		
	Block	Sand and gravel	Over-burden		Sand and gravel		million m^3	million yd^3	Limits at the 95% confidence level		Fines	Sand	Gravel
	km^3	km^3	m	ft	m	ft			± %	$\pm 10^6$ m^3	-1/16 mm	-4 +1/16 mm	+4 mm
A	10.1	8.7	3.4	11.0	7.2	23.5	63	82	57	36	8	68	24
B	20.4	19.0	6.6	22.0	7.2	23.5	137	179	31	43	5	78	17
C	16.8	14.7	4.6	15.0	6.4	21.0	94	123	46	43	8	66	26
D	6.2	6.2	1.6	5.0	3.8	12.5	23	31	28	7	6	45	49
	46.5	The Wymondham district, Barford and the built up area of south-west Norwich not assessed											
Total	100.0	48.6					317	415	19	60			

Subdivisions of block D

Sub allu-vium gravel	6.2	3.8	2.0	6.5	4.2	14.0	16	21	51	8	2	47	51
Terr-ace gravel	6.2	2.4	1.0	3.5	3.1	10.0	7	10	42	3	9	42	49

Accuracy of Results

For the four resource blocks on sheet TG10, the accuracy of the results at the 95 per cent confidence level varies between 28 per cent and 57 per cent (that is, it is probable that nineteen times out of twenty the true volumes present lie within these limits). However, the true values are more likely to be nearer the figures estimated than the limits. Moreover, it is probable that in each block roughly the same percentage limits would apply for the estimate of volume of a very much smaller parcel of ground (say, 200 acres) containing similar sand and gravel deposits if the results from the same number of sample points (as provided by, say, ten boreholes) were used in the calculation. Thus, if closer limits are needed for the quotation of reserves of part of a block, it can be expected that data from more than ten sample points will be required, even if the area is quite small. This point can be illustrated by considering the whole of the potentially workable sand and gravel on sheet TG 10. The volume (317 million m^3) can be estimated to limits of ± 19 per cent at the 95 per cent confidence level, by a calculation based on the data from seventy-six sample points spread across the four resource blocks. However, it must again be emphasised that the quoted volume of sand and gravel has no simple relationship with the amount that could be extracted in practice, as no allowance has been made in the calculations for any restraints (such as existing buildings and roads) on the use of the land for mineral working.

NOTES ON RESOURCE BLOCKS A TO D

Block A

The Chalk is irregularly exposed along the northern side of the Yare valley. In the eastern part of the block, near Bowthorpe [182 090], it is overlain by Norwich Crag. Elsewhere, glacial deposits rest on the Chalk. The general distribution of the glacial deposits is discussed in the Geology section. In the west of the block, around Colton [109 098], the Chalky Boulder Clay is thought to have a mean thickness in excess of 60 ft (18.3 m). The area where sand and gravel, if present, is judged not to be potentially workable may be more or less extensive than has been outlined on the map. East of Colton and west of Marlingford [133 091] is an area where both Glacial Sand and Gravel and boulder clay occur. The large sand and gravel body at Marlingford, between [112 088] and [128 098], is almost completely surrounded by and underlain by boulder clay, which separates an upper and lower mineral horizon. There is insufficient evidence on which to base an assessment of the lower horizon. The small patches of sand and gravel at [126 089] and [126 079] are thought to be thin and to overlie boulder clay. East of Marlingford Glacial Sand and Gravel crops out; thin patches of boulder clay overlie the sand and gravel in the parish of Bawburgh, at [154 097], [176 097] and [180 098].

Because of its limited extent Norwich Crag has not been separated from Glacial Sand and Gravel for the purposes of assessment.

In block A mineral of mean thickness 23.5 (7.2 m) is overlain by cover whose mean thickness is 11 ft (3.4 m). The assessed mineral thickness varies from 5 ft (1.5 m) in borehole 161/363a to 54 ft (16.5 m) in borehole NE 56. The thickness of overburden in boreholes proving mineral varies from 1 ft (0.3 m) in borehole NW 14 to 23 ft (7.0 m) in borehole NW 6. The estimate of volume of mineral is 63 million $m^3 \pm$ 57 per cent at the 95 per cent confidence level. (All limits quoted for the volume estimates are calculated at the 95 per cent confidence level.)

There is 4 per cent of gravel in the Norwich Crag in borehole NE 56. The Glacial Sand and Gravel contains a higher proportion of gravel, 25 per cent. The mean grading for the whole block is fines 8 per cent, sand 68 per cent, gravel 24 per cent.

Block B

The Chalk, except where it is irregularly exposed along the southern side of the Yare valley, is covered by glacial deposits; Norwich Crag has not been found to the south of the river. The western margin of blocks B and C has been drawn where, on the bases of borehole information from outside the block (for example, boreholes NW 18, NW 23 and SE 1), of morphology and of geological interpretation, the thickness of overburden is believed to generally exceed 60 ft (18.3 m). Block B comprises a large area where the relationship between Chalky Boulder Clay and Glacial Sand and Gravel is complex (Fig. 3), and a small area, running very approximately north-west to south-east from Colney Hall [170 082] to Cringleford [196 056] where, apart from a few isolated occurrences of Chalk, only Glacial Sand and Gravel is exposed. In the centre of the block near Little Melton [160 067] the boulder clay either has a mean thickness in excess of 60 ft (18.3 m) or rests directly on Chalk; this area, in which sand and gravel, if present, is judged to be not potentially workable, may be more or less extensive than is shown on the map.

In an area where the Pleistocene stratigraphy is complicated, there are discrepancies between four boreholes and the geological map. Boreholes NW 17 and NE 61, according to the map sited on Glacial Sand and Gravel, in fact proved at the surface 42 ft (12.8 m) and 30 ft (9.1 m) respectively of Chalky Boulder Clay; boreholes NE 42 and NE 47, according to the map sited on Chalky boulder clay, in fact proved at the surface 12 ft (3.7 m) and 42 ft (12.8 m) respectively of mineral.

Because of the rapid vertical and lateral variation within the glacial deposits and the complex relationship of sand and gravel to Boulder Clay, it has not been possible to outline barren areas. A different statistical method for calculating the estimate of volume has been used, by which 'nil thicknesses' (from boreholes where sand and gravel was absent) are included in the calculation of the mean thickness.

The mineral, of mean thickness 23.5 ft (7.2 m), is overlain by overburden with a mean thickness of 22 ft (6.6 m). The assessed mineral thickness varies from 5 ft (1.5 m) in borehole NW 22 to 51 ft (15.5 m) in borehole NE 44. The thickness of overburden in boreholes proving mineral varies from 1 ft (0.3 m) in borehole NE 42 to 49 ft (14.9 m) in borehole 161/279. The estimate of volume of mineral is 137 million $m^3 \pm$ 31 per cent.

An unusually high percentage of sand grade material was found in boreholes NE 58 and NE 61, but no conclusions can be reached about systematic variation in the grading in the whole block which has a mean grading of fines 5 per cent, sand 78 per cent, gravel 17 per cent.

Block C

The Chalk, irregularly exposed along the sides of the tributary valleys of the Yare, forms the bedrock to the glacial deposits which occupy the remaining surface of the block. The western margin of the block has been drawn where the thickness of overburden is believed to generally exceed 60 ft (18.3 m). At Ketteringham [167 033] and Mulbarton [193 010], areas judged not to be potentially workable may be more or less extensive than those outlined on the map. In both areas water-well and assessment borehole records indicate that the Chalky Boulder Clay exceeds 60 ft (18.3 m) in thickness or rests directly on the Chalk. As in block B, an entirely statistical method has been used for assessment in view of the large inherent doubt about the position of concealed geological boundaries.

The borehole logs of SE 7 and SE 8 disagree with the geological map, according to it being sited on Glacial Sand and Gravel but in fact proving 14 ft (4.2 m) and 7 ft (2.1 m) respectively of boulder clay at the surface.

In block C mineral of mean thickness 21 ft (6.4 m) is overlain by overburden with a mean thickness of 15 ft (4.6 m). The assessed mineral thickness varies from 3 ft (0.9 m) in borehole SE 11 to more than 75 ft (22.9 m) in borehole 161/227. The thickness of overburden in boreholes proving mineral varies from 3 ft (0.9 m) in boreholes SE 6, SE 10, SE 11 and SE 15 to 35 ft (10.7 m) in borehole SE 2. The estimate of volume of mineral is 94 million $m^3 \pm 46$ per cent. The mean grading is fines 8 per cent, sand 66 per cent, gravel 26 per cent; no systematic variation can be deduced.

Block D

The limits of the block are drawn to include the Terrace and Floodplain Gravels, both potentially workable, of the Rivers Yare and Tiffey.

The terrace forms an easily recognisable feature standing about 6.5 ft (2 m) above the floodplain. The overburden, comprising mainly soil on clay, has a mean thickness of 3.5 ft (1.0 m). The mean thickness of the gravel based on eight sample points is 10 ft (3.1 m) and the volume is estimated to be 7 million $m^3 \pm 42$ per cent.

On the floodplain the thickness of overburden (consisting of alluvial clays, silts, sands and peat) is greater, with a mean of 6.5 ft (2.0 m). Locally, small areas of peat up to 6.5 ft (2.0 m) thick are present at the surface. The gravel has a mean thickness of 14 ft (4.2 m) with an estimated volume of 16 million $m^3 \pm 51$ per cent.

The grading of the Terrace and Sub-alluvium Gravels differ only slightly in the proportion of fines and it is probable that the deposits are continuous, representing a single phase of deposition. The mean grading is fines 6 per cent, sand 45 per cent, gravel 49 per cent.

The part of the Tiffey-Yare valley shown on the map, but excluding the Barnham Broom branch of the Yare, follows the course of a glacial channel cut into the Chalk. Overdeepened by sub-glacial meltwaters, it was later filled with boulder clay and sand and gravel (Cox and Nickless, 1972). The longitudinal profile is exceedingly irregular. The deepest known part on sheet TG 10 is near Barford, at borehole 161/264 [1142 0772], where the surface of the Chalk lies at -114 ft (-34.7 m) O.D. No channel has been found in the Yare valley above Barford, where Recent Alluvium lies directly on Chalk rather than on boulder clay or Glacial Sand and Gravel.

Wymondham Area

No assessment of resources has been made for the 43 km^2 of ground in the south-western part of the map. The area was excluded at the reconnaissance stage of the investigation, as existing borehole information indicated that the mean thickness of overburden generally exceeds 60 ft (18.3 m) and that the ratio of overburden to mineral is probably greater than 3:1. In the upper reaches of the Tiffey, in the vicinity of Wymondham, large patches of high level torrent gravel rest on the Chalky Boulder Clay. However, much of the gravel has been worked out and new housing and industrial development around the town has sterilised some of the remaining deposits. Locally, relatively small areas of poorly-sorted, coarse, flint gravel may be potentially workable.

LIST OF QUARRIES

In May 1971, three sand and gravel quarries were known to be in operation in the area.

Table 2. List of quarries and their locations

Location	Grid Reference	Worked Horizon
Working quarries		
The Lodge, Bawburgh	167 085	Terrace Gravel
Bowthorpe Marsh	174 088	Sub-alluvium Gravel
Norwich Hill, Ketteringham	171 031	Glacial Sand and Gravel
Abadoned quarries		
Gravel Pit Grove Plantation, Colton	121 093	Glacial Sand and Gravel
Three Cornered Plantation, Marlingford	146 095	Glacial Sand and Gravel
Near Algarsthorpe	144 089	Glacial Sand and Gravel

Near Great Melton	149 062	Glacial Sand and Gravel
Near Bowthorpe	177 085 176 083	
Wymondham	115 016 116 014	
Jubb's Farm, Wymondham	110 008	
Near Wymondham	113 007 116 007 120 008 123 007	
Norwich Hill, Ketteringham	176 032	

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Appendix A: Assessment Procedure

1. Within a resource block, a statistical assessment is made for a sampled area of mineral greater than 2 km^2 and containing a minimum of five evenly-spaced boreholes.

2. If the sampled area of mineral is between 0.25 and 2 km^2 and contains one or two suitably sited boreholes an inferred assessment is made. An inferred assessment may also be attempted for any area where the deduced mineral content is small and which consequently has not been sampled by boreholes. No specific level of accuracy is claimed for such subjective assessments.

3. No assessment is attempted for an area of mineral less than 0.25 km^2.

Statistical Assessment

4. The simple methods used in the calculations are consistent with the amount of data provided by the survey. Conventional confidence limits (that is, the tolerance on the estimate or the range within which the result falls) are calculated at the two-sided 95 per cent confidence level, that is, there is a $2\frac{1}{2}$ per cent or 1 in 40 chance that the result exceeds the stated upper limit and a corresponding $2\frac{1}{2}$ per cent chance that it is less than the stated lower limit.

5. The volume estimate (V) for the sampled mineral in a given block is the product of the two variables, the sampled areas (A) and the mean thickness ($\bar{l}$) calculated from the individual thicknesses at the sample points. The standard deviations for these variables are related such that

$$S_V = \sqrt{S_A^{\,2} + S_{\bar{l}}^{\,2}} \quad \dots\dots\dots\dots \quad (1)$$

where S_V, S_A and $S_{\bar{l}}$ are the standard deviations for volume, area and mean thickness, expressed as proportions of V, A and $\bar{l}$, respectively.

6. The above relationship may be transposed such that

$$S_V = S_{\bar{l}} \sqrt{\left[1 + \left(\frac{S_A}{S_{\bar{l}}}\right)^2\right]} \quad \dots\dots\dots\dots \quad (2)$$

From this it can be seen that as $\left(\frac{S_A}{S_{\bar{l}}}\right)$ tends to 0, S_V tends to $S_{\bar{l}}$. If, therefore, the standard deviation for area is small with respect to that for mean thickness, the standard deviation for volume approximates to that for mean thickness.

7. Given that the number of approximately evenly spaced sample points in the sampled area is n, with mineral thickness measurements $l_1, l_2, \dots l_n$, then the best estimate of mean thickness, $\bar{l}$ =

$$\frac{\sum(l_1 + l_2 \dots l_n)}{n}$$

For groups of closely spaced boreholes a discretionary weighting factor may be applied to avoid bias (see note on weighting below). The standard deviation for mean thickness, $S_{\bar{l}}$ expressed as a proportion of the mean thickness is given by

$$S_{\bar{l}} = \frac{1}{\bar{l}} \sqrt{\frac{\sum(l - \bar{l})^2}{n\,(n - 1)}}$$ where l is any value in the series l_1 to l_n.

8. The sampled area A in each resource block is coloured pink on the map. Wherever possible, calculations relate to the mineral within mapped geological boundaries (which may not necessarily correspond to the limits of a deposit). Generally, therefore, the only error in determining the area is the negligible planimetering error and S_A is 0. Where the area is not defined by a mapped boundary, that is, where the boundary is inferred (and the distinctive symbol is used), experience suggests that S_A is small relative to $S_{\bar{l}}$.

The relationship

$$\frac{S_A}{S_{\bar{l}}} \leqslant \frac{1}{3}$$ is assumed in all cases.

It follows from equation (2) that

$$S_{\bar{l}} \leqslant S_V \leqslant 1.05\, S_{\bar{l}} \quad \dots\dots\dots\dots \quad (3)$$

9. The two-sided 95 per cent confidence limits, $L_{\bar{l}}$, for the estimate of mean thickness of mineral in the sampled area, for values of n between 5 and 20, may be expressed in absolute units.

$\bar{l} \pm (t \times S_{\bar{l}} \times \bar{l})$,

or as a percentage

$\bar{l} \pm (t \times S_{\bar{l}} \times 100)$ per cent

where t is Student's t at the two-sided 95 per cent confidence level for (n - 1) degrees of freedom and is evaluated by reference to statistical tables. In applying Student's t it is assumed that the measurements are distributed normally.

10. Values of t at the two-sided 95 per cent confidence level for values of n up to 20 are set out below:

BLOCK CALCULATION

1:25 000 Sheet } Fictitious
Block

Area

Block: 11.08 km^2
Mineral: 8.32 km^2

Thickness

Overburden: 2.5 m
Mineral: 4.5 m

Volume

Overburden: 21 million m^3
Mineral: 38 million m^3

95 per cent confidence limits of the estimate of mineral volume
Percentage: ± 53 per cent
Units of volume: ± 20 million m^3

Thickness estimate (l = thickness)
Measurements in metres

Sample point	Weighting w	Overburden lo	wlo	Mineral lm	wlm	Remarks
SE 14	1	1.5	1.5	5.2	5.2	MAU Boreholes
SE 18	1	3.3	3.3	nil	-	
SE 20	1	nil	-	2.1	2.1	
SE 22	1	0.7	0.7	9.3	9.3	
SE 23	1	6.2	6.2	5.7	5.7	
SE 24	1	4.3	4.3	6.5	6.5	
SE 17	½	1.2	1.6	4.2	3.9	
123/45	½	2.0		3.6		Hydrogeol. Dept. record
1	¼	2.4	2.5(25)*	3.4	3.6(25)*	Close group of four boreholes (commercial)
2	¼	4.5		0.8		
4	¼	0.4		4.3		
5	¼	2.8		6.0		
Totals	$\sum w$ = 8	$\sum wlo$ =	20.1(25)*	$\sum wlm$ =	36.3(25)*	
Averages		$\bar{l}o$ =	2.5(16)*	$\bar{l}m$ =	4.5(41)*	

Calculation of Confidence Limits

l	$(l - \bar{l})$	$(l - \bar{l})^2$
5.2	0.7	0.49
nil	4.5	20.25
2.1	2.4	5.76
9.3	4.8	23.04
5.7	1.2	1.44
6.5	2.0	4.00
3.9	0.6	0.36
3.6	0.9	0.81
$\sum l$ = 36.3 (25)	$\sum(l - \bar{l})^2$ = 56.15	
n = 8		
$\bar{l}$ = 4.5 (41)		
≃ 4.5		

n = 8
t = 2.365

$$L_V = 1.05 \frac{t}{\bar{l}} \sqrt{\frac{\sum(l - \bar{l})^2}{n\,(n-1)}} \times 100$$

$$= 1.05 \times \frac{2.365}{4.541} \sqrt{\frac{56.15}{8 \times 7}} \times 100$$

$$= 54.77$$

$$\simeq 55\%$$

* The figures in brackets are additional decimal places used only in the calculation of confidence limits.

Fig. 5. Example of resource block assessment: statement and calculation

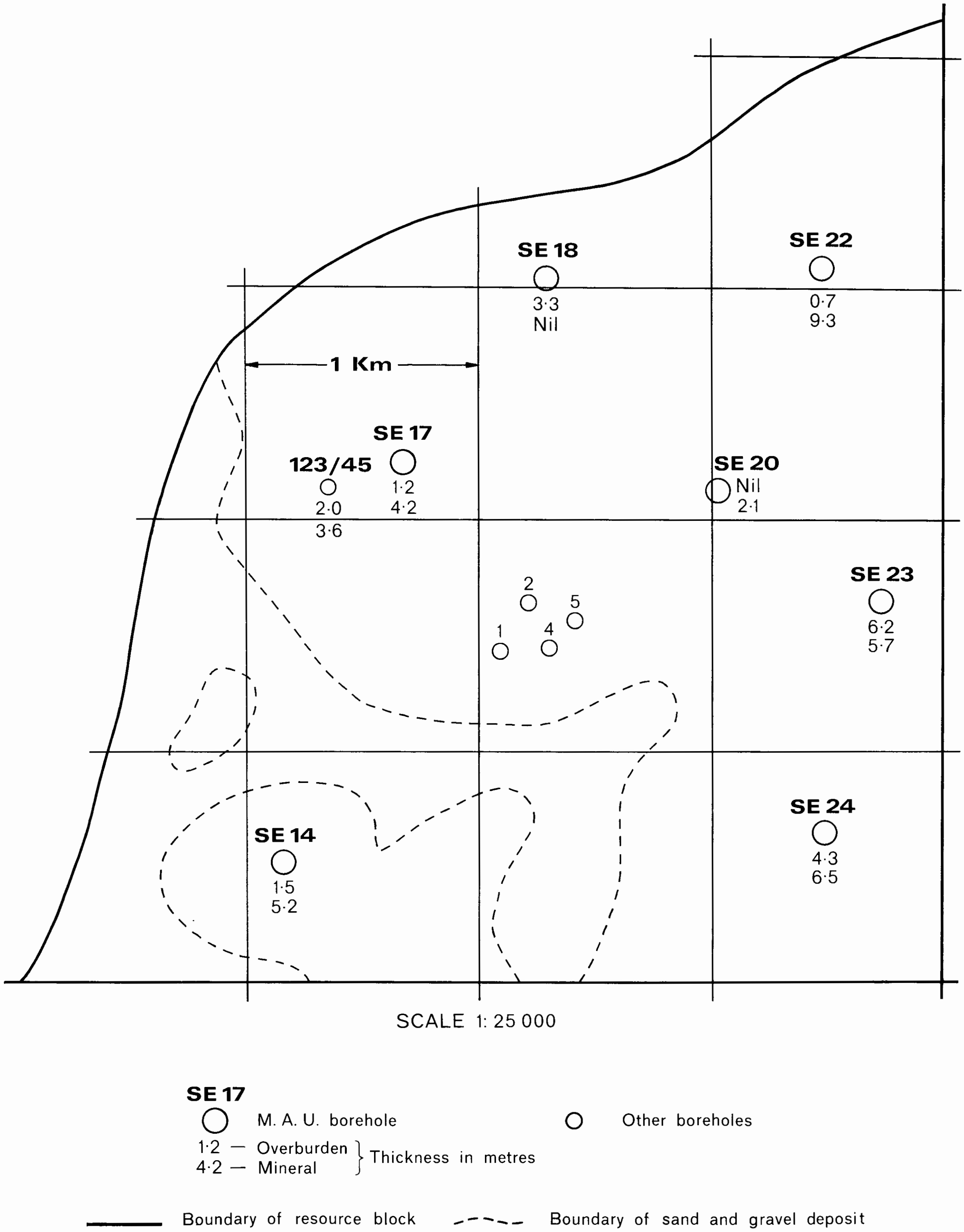


Fig. 6. Example of resource block assessment: map of a fictitious block

n	t	n	t
1	∞	11	2.228
2	12.706	12	2.201
3	4.303	13	2.179
4	3.182	14	2.160
5	2.776	15	2.145
6	2.571	16	2.131
7	2.447	17	2.120
8	2.365	18	2.110
9	2.306	19	2.101
10	2.262	20	2.093

(From Table 12, Biometrika Tables for Statisticians, Volume 1, Second Ed. Cambridge University Press, 1962).

The value of t, 1.96, when n is infinity is used when n is greater than 20.

11. In calculating the two-sided 95 per cent confidence limits for volume, L_V, the following inequality corresponding to (3) is applied:

$$L_{\bar{l}} \leqslant L_V \leqslant 1.05 \; L_{\bar{l}}$$

12. In summary, for values of n between 5 and 20, L_V is calculated as

$$\frac{1.05 \times t}{\bar{l}} \times \sqrt{\frac{\sum(l - \bar{l})^2}{n\ (n - 1)}} \times 100 \text{ per cent}$$

and when n is greater than 20, as

$$\frac{1.05 \times 1.96}{\bar{l}} \times \sqrt{\frac{\sum(l - \bar{l})^2}{n\ (n - 1)}} \times 100 \text{ per cent}$$

13. An illustration of the procedures outlined above is given in Figs. 5 and 6, where a volume estimate with confidence limits at the 95 per cent level of confidence is derived from fictitious data.

Inferred Assessments

14. If the sampled area of mineral in a resource block is between 0.25 km^2 and 2 km^2 an assessment is inferred based on geological and topographical information usually supported by the data from one or two suitably sited boreholes. The volume of mineral is calculated as the product of the sampled area, chosen from interpretation of field data as in the statistical assessment, and the judged average mineral thickness. Confidence limits are not calculated.

15. In some cases in addition to the sampled area of mineral a resource block includes an area left uncoloured on the map, generally based on interpretation of mapping and sample data. On occasions some mineral may be present in such areas and an assessment is made on the basis of the average mineral thickness deduced from exposures and any other evidence available.

Note on Weighting

16. The thickness of a deposit at any point in a sampled area may be governed solely by the position of the point in relation to a broad trend. However, most sand and gravel deposits in addition exhibit a random pattern of local, and sometimes considerable, variation in thickness.

17. Thus, in estimating mean thickness of sand and gravel from a number of data points in a sampled area only the use of simple weighting factors is justified, and the distribution of data points need be only approximately regular. In practice, equal weighting can often be applied to thicknesses at all data points within the sampled area. If, however, there is a distinctly unequal distribution of points, the thicknesses must be weighted to avoid the bias this creates. Weighting factors are determined by first dividing the sampled area into broad zones, to each of which a value roughly proportional to its area is assigned. This value is then shared between the data points within the zone.

Appendix B: Classification and Description of Sand and Gravel

The terminology commonly used by geologists when describing sedimentary rocks (Wentworth, 1922) is not entirely satisfactory for the purposes of this Report. For example, Wentworth proposed that a deposit should be described as a 'gravelly sand' when the proportion of sand is greater than that of gravel which must exceed 10 per cent, fines and oversize materials (that is, with diameter greater than 64 mm) being less than 10 per cent. Because deposits containing more than 10 per cent fines (material less than 1/16 mm) are not embraced by this system a modified binary classification based on Willman (1942) has been adopted.

For the purposes of assessing resources of sand and gravel a classification should take account of economically important characteristics of the deposit, in particular the absolute content of fines and the ratio of sand to gravel.

When the fines content exceeds 40 per cent the material is considered to be not potentially workable and falls outside the definition of mineral. Deposits which contain 40 per cent fines or less are classified primarily on the ratio of sand to gravel and qualified in the light of the fines content, as follows: less than 10 per cent fines—no qualification; 10 per cent or more, but less than 20 per cent fines—'clayey'; 20 to 40 per cent fines—'very clayey'.

The term 'clay' (as written, with single quote marks), is used to describe all material passing 1/16 mm. Thus it has no mineralogical significance and includes particles falling within the size limits of silt. Wherever the term clay does not appear in single quotation marks the normal meaning applies.

The ratio of sand to gravel defines the boundaries between Sand, Pebbly Sand, Sandy Gravel and Gravel (at 19:1, 3:1 and 1:1).

Thus it is possible to classify the mineral into one of twelve descriptive categories (see Fig. 7). The procedure is as follows.

1. Classify according to ratio of sand to gravel.
2. Describe fines.

For example, a deposit grading: gravel, 11 per cent; sand, 70 per cent; fines, 19 per cent is classified as 'clayey' pebbly sand. This short description is included in the borehole log (see Note 10, p.22).

Many differing proposals exist for the classification of the grain size of sediments (Atterberg, 1905; Udden, 1914; Wentworth, 1922; Wentworth, 1935; Allen, 1936; Twenhofel, 1937; Lane and others, 1947). As Archer (1970a, b) has emphasised, there is a pressing need for a simple metric scale acceptable to both scientific and engineering interests, for which the class limit sizes correspond closely with certain marked changes in the natural properties of mineral particles. For example, there is an important change in the degree of cohesion between particles at about the 1/16 mm size, which approximates to the generally accepted boundary between silt and sand. In this and other respects the system shown in Table 3, used in this report, is satisfactory. It is based on Udden's geometric scale and a simplified form of Wentworth's terminology.

The fairly wide intervals in the scale are consistent with the general level of accuracy of the quantitative assessments of the resource blocks. Three sizes of sand are recognised, fine (−¼ + 1/16 mm), medium (−1 + ¼ mm) and coarse (−4 +1 mm). The boundary at 16 mm distinguishes a range of finer gravel (−16 + 4 mm), often characterised by abundance of worn tough pebbles of vein quartz, from coarser ranges often of notably different average composition. The boundary at 64 mm distinguishes pebbles from cobbles. The term 'gravel' is used loosely to denote both pebble-sized and cobble-sized material.

The size distribution of borehole samples is determined by sieve analysis, and is presented by the laboratory as logarithmic cumulative curves (see, for example, British Standard 1377:1967). In this report the grading is tabulated on the borehole record sheets (Appendix C), the intercepts corresponding with the simple geometric scale 1/16 mm, ¼ mm, 1 mm, 4 mm, 16 mm, and so on as required. Original sample grading curves are available for reference at the appropriate office of the Institute.

Each bulk sample is described, subjectively, by a geologist at the borehole site. Being based on visual examination, the description of the grading is inexact, the accuracy depending on the experience of the observer. The descriptions recorded are modified, as necessary, when the laboratory results become available for inclusion in Appendix C.

The relative proportions of the rock types present in the gravel fraction are indicated by use of the words 'and' or 'with'. For example, 'flint and quartz' indicates very approximate equal proportions with neither constituent accounting for less than about 25 per cent of the whole; 'flint with quartz' indicates that flint is dominant and quartz, the accessory rock type, comprises 5 to 25 per cent of the whole. Where the accessory material accounts for less than 5 per cent of the whole, but is still readily apparent, the phrase 'with some' has been used. Rare constituents are referred to as 'trace'.

The terms used in the field to describe the degree of rounding of particles—which is concerned with the sharpness of the edges and corners of a clastic fragment and not the shape—(after Pettijohn, 1957) are as follows.

Angular: showing little or no evidence of wear; sharp edges and corners.

Subangular: showing definite effects of wear. Fragments still have their original form but edges and corners begin to be rounded off.

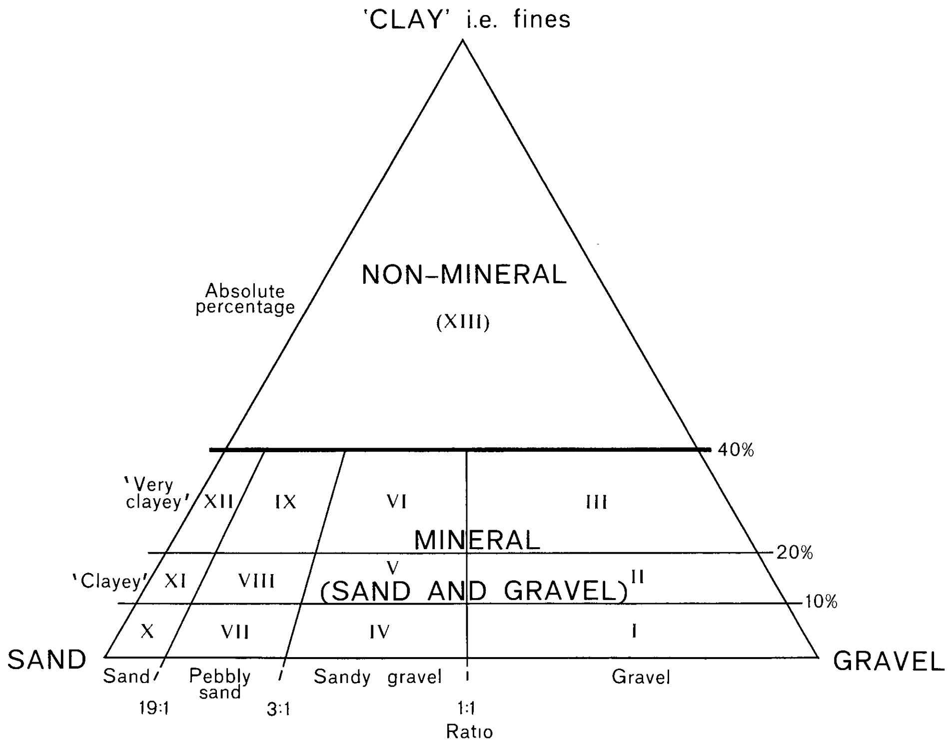
Subrounded: showing considerable wear. The edges and corners are rounded off to smooth curves. Original grain shape is still distinct.

Rounded: original faces almost completely destroyed, but some comparatively flat surfaces may still remain. All original edges and corners have been smoothed off to rather broad curves. Original shape is still apparent.

Well-rounded: no original faces, edges or corners left. The entire surface consists of broad curves; flat areas are absent. The original shape is suggested by the present form of the grain.

Table 3. Classification of Gravel, Sand and Fines

Size limits	Grain size description	Qualification	Primary classification
	Cobble		Gravel
64 mm			
16 mm	Pebble	Coarse Fine	
4 mm			
	Sand	Coarse	Sand
1 mm			
		Medium	
¼ mm			
		Fine	
1/16 mm			
	Fines (silt and clay)		Fines



I	Gravel	MINERAL
II	'Clayey' gravel	
III	'Very clayey' gravel	
IV	Sandy gravel	
V	'Clayey' sandy gravel	
VI	'Very clayey' sandy gravel	
VII	Pebbly sand	
VIII	'Clayey' pebbly sand	
IX	'Very clayey' pebbly sand	
X	Sand	
XI	'Clayey' sand	
XII	'Very clayey' sand	
(XIII)	NON-MINERAL	

Fig. 7. Diagram to show the descriptive categories used in the classification of sand and gravel

Appendix C: Borehole Records

EXPLANATION

Annotated Example of a Borehole Record

TG 10 SE 15[1] 1963 0472[2] North-east of Intwood Hall[3]

Surface level (+ 19.9 m) 65 ft[4]	[7] Overburden (0.9 m) 3 ft
Water not struck[5]	Mineral (4.9 m) 16 ft
Wirth B O, 8 inch diam.,[6]	Waste (3.7 m) 12 ft
January 1970	Bedrock (1.2 m +) 4 ft +[8]

		Thickness (m)	Thickness ft	Depth[11] (m)	Depth ft
	Soil	(0.9)	3	(0.9)	3
[9] Glacial Sand and Gravel	[10]'Clayey' sandy gravel 'Very clayey' at base. Predominantly hard chalk fragments from 10 to 15 ft. Gravel: fine and coarse, subangular flint, with fine subrounded quartz. Sand: medium with coarse and fine, subangular flint. Brown.	(4.9)	16	(5.8)	19
Chalky Boulder Clay	Grey chalky clay with traces of gravel.	(3.7)	12	(9.5)	31
Upper Chalk	Clayey chalk sand and chalk gravel.	(0.3)	1	(9.8)	32
	Chalk	(0.9 +)	3 +	(10.7)	35

	%	mm	%
[15] Gravel	31	+ 64	0
		− 64 + 16	15
		− 16 + 4	16
Sand	56	− 4 + 1	13
		− 1 + ¼	30
		− ¼ + $\frac{1}{16}$	13
Fines	13	− $\frac{1}{16}$	13

Depth below surface (ft)	Percentage Fines	Sand	Gravel[15]
[12]3 − 66	11	57	32
6 − 77	10	72	18
7 − 10	13	57	30
10 − 15	(13	57	30)[14]
15 − 18	9	51	40
18 − 19	32	51	17

The numbered paragraphs below correspond with the annotations given on the specimen record above.

1. Borehole Registration Number.
Each Mineral Assessment Unit (MAU) borehole is identified by a Registration Number. This consists of two statements.

1) The number of the 1 : 25 000 sheet on which the borehole lies, for example, TG 10.
2) The quarter of the 1 : 25 000 sheet on which the borehole lies and its number in a series for that quarter, for example, SE 15.

Thus the full Registration Number is TG 10 SE 15. Usually this is abbreviated to SE 15 in the text.

2. The National Grid Reference.
All National Grid References in this publication lie within the 100 km square TG unless otherwise stated. Grid references are given to eight figures, accurate to within 10 m, for borehole locations. (In the text, six-figure grid references are used for more approximate locations, for example, for farms).

3. Location.
The borehole location is generally referred to the nearest named locality on the 1 : 25 000 base map.

4. Surface Level.
The surface level at the borehole site is given in metres and feet above Ordnance Datum. All measurements were made in feet; approximate conversions to metres are given in brackets.

5. Groundwater Conditions.
Three kinds of entry are made: either, the level at which groundwater was encountered is given in metres and feet above Ordnance Datum; or, where no groundwater was encountered, this is stated; or, where there is no record of the groundwater conditions, this is stated.

6. Type of Drill and Date of Drilling.
Two types of drilling machine have been used in this survey; a Shell and Auger rig and a Wirth (a cased power auger). The type of machine, the external diameter of the casing used, and the month and year of completion of the borehole are stated.

7. Overburden, Mineral, Waste and Bedrock.
Mineral is sand and gravel which, as part of a deposit, falls within the arbitrary definition of potentially workable material (see p.1).
Bedrock is the formation, rock type, country rock or rock-head, below which potentially workable sand and gravel will not be found. In the Norwich area the bedrock is Chalk.
Waste is any material other than bedrock or mineral. Where waste occurs between the surface and a mineral horizon it is classified as overburden.
Thicknesses are given in metres and feet.

8. The plus sign (+) indicates that the base of the deposit was not reached during drilling.

The borehole log
9. Geological Classification.
A geological classification of the strata encountered in drilling is given whenever possible. (For an explanation of the terms used see p.5).

10. Lithological Description.
When sand and gravel is recorded, a general description based on the mean grading characteristics is followed by more detailed particulars. (For explanation of conventions see Appendix B). A description of other rock types is based on visual field examination.

11. Depth.
The figures relate to depths from surface to base of the strata recorded on the log.

Grading information
12. Sampling.
A continuous series of bulk samples is taken throughout the thickness of sand and gravel. A new sample is commenced whenever there is an appreciable lithological change within the sand and gravel, or for every 3 ft of depth.

13. Grading Results.
The limits are as follows: gravel, +4 mm; sand, -4+1/16 mm; fines, -1/16 mm.

14. Exceptionally the results of the grading of a sample are not available but an attempt has been made to give grading information by comparing the grading and field descriptions of adjacent samples with the sample in question. Such estimates are shown in brackets.

15. Mean Grading.
The mean grading for the mineral thickness is the mean of the individual sample gradings, but where the thicknesses of mineral represented by the samples are not constant each grading result is first weighted by its relative thickness.
The results are given for the three main classes, gravel, sand and fines, and for the smaller ranges within these classes.
Since fully representative sampling of sand and gravel is difficult to achieve, particularly where groundwater levels are high, there may be differences between the gradings determined during the survey and the corresponding in-situ grading of the deposit. Comparison with exposures suggests that the proportion of sand in the samples collected from boreholes may be somewhat higher. Conversely the results suggest that the proportion of fines and of +16 mm material may be lower.

Note on metrication
1) All measurements were made in feet. Approximate metric conversions appear in brackets.
2) Metric conversions of measurements of the depth and thickness of beds have been rounded off to the nearest 0.1 m, because quotation to two places of decimals would imply a higher order of accuracy than could be justified by the original figures. To eliminate any discrepancy appearing after metrication between depth as recorded and depth as obtained by summing thicknesses, adjustment has been made where necessary to one or more of the thickness figures. However, the recorded mineral thickness is not adjusted.

LIST OF ASSESSMENT BOREHOLES

Borehole No. by sheet quadrant	Grid References (all fall in 100 km square TG)		Borehole No. by sheet quadrant	Grid References (all fall in 100 km square TG)	
TG 10 NW			TG 10 SE		
3	1070	0946	1	1549	0461
4	1086	0842	2	1603	0389
5	1068	0614	3	1669	0479
6	1156	0958	4	1671	0415
7	1170	0891	5	1669	0318
8	1131	0805	6	1683	0246
9	1120	0666	7	1750	0442
10	1257	0944	8	1764	0348
11	1254	0852	9	1772	0250
12	1217	0748	10	1869	0430
13	1248	0691	11	1842	0356
14	1356	0944	12	1851	0263
15	1306	0885	13	1834	0175
16	1375	0819	14	1865	0102
17	1395	0728	15	1963	0472
18	1343	0649	16	1956	0403
19	1431	0972	17	1947	0317
20	1414	0895	18	1957	0233
21	1449	0873	19	1933	0158
22	1459	0689	20	1945	0069
23	1471	0568			
TG 10 NE					
40	1558	0965			
41	1526	0842			
42	1562	0741			
43	1531	0657			
44	1539	0568			
45	1655	0943			
46	1601	0874			
47	1652	0768			
48	1655	0659			
49	1644	0581			
50	1758	0970			
51	1721	0916			
52	1785	0833			
53	1757	0721			
54	1777	0683			
55	1748	0547			
56	1854	0935			
57	1864	0819			
58	1838	0649			
59	1851	0560			
60	1949	0663			
61	1947	0568			

THE RECORDS

TG 10 NW 3 — 1070 0946 — Sprangle Plantation, Colton

Surface level (+45.4 m) + 149 ft
Water struck at (+39.9 m) + 131 ft
Shell and auger, 8 inch diam.,
December 1969

Waste (20.4 m) 67 ft
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
Chalky Boulder Clay	Pale grey chalky clay with occasional pebbles.	(6.1)	20	(6.1)	20
	Blue to grey chalky clay with occasional pebbles and a silty and sandy clay band from 30 to 32 ft (9.1 to 9.8 m).	(7.9)	26	(14.0)	46
Glacial Sand and Gravel	Sand. Chalky in parts.	(1.5)	5	(15.6)	51
	Gravel: fine, subangular to subrounded flint, with traces of quartz.				
	Sand: medium with fine, subangular, mainly flint. Traces of carbonaceous orange clay.				
Chalky Boulder Clay	Brown sandy clay with traces of chalk and flint pebbles.	(1.2)	4	(16.8)	55
	Dark green-grey silt with sand and chalk laminations.	(2.4)	8	(19.2)	63
Glacial Sand and Gravel	Gravel.	(1.2)	4	(20.4)	67
	Gravel: coarse with fine subangular to subrounded black flint, with fine quartz and quartzite and traces of subrounded flint cobbles.				
	Sand: coarse with a little medium subangular to subrounded quartz and flint; some chalk. Light grey.				
Upper Chalk	Chalk	(0.9 +)	3 +	(21.3)	70

	%	mm			%
Gravel	2	+ 64		:	0
		− 64	+ 16	:	0
		− 16	+ 4	:	2
Sand	90	− 4	+ 1	:	6
		− 1	+ ¼	:	61
		− ¼	+ $^1/_{16}$	:	23
Fines	8	− $^1/_{16}$		:	8

Depth below surface (ft)	Percentage Fines	Sand	Gravel
46 − 49	9	88	3
49 − 51	6	93	1

TG 10 NW 4 1086 0842 Yare Valley, North of Barford

Surface level (+ 18.6 m) + 61 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (3.0 m) 10 ft;
Mineral (2.8 m) 9 ft;
Waste (7.5 m) 25 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
Alluvium	Soil and peaty clay.	(3.0)	10	(3.0)	10
Sub-alluvium Gravel	Gravel. Shelly at base. Gravel mainly at top of the deposit. Gravel: fine to coarse sub-angular black flint with traces of fine chalk. Sand: medium and coarse mainly flint with traces of chalk. Grades down into fine and medium shelly sand which becomes dominant near the base of the deposit. Grey to brown.	(2.8)	9	(5.8)	19
	Shelly and peaty sand with traces of gravel.	(2.7)	9	(8.5)	28
Chalky Boulder Clay	Grey chalky clay with traces of sand and gravel.	(1.8)	6	(10.3)	34
Glacial Sand and Gravel	'Clayey' pebbly sand. Chalky. Gravel: fine to coarse sub-angular flint. Sand: fine and medium, sub-angular.	(1.8)	6	(12.1)	40
Chalky Boulder Clay	Grey chalky clay with a trace of sand and gravel.	(1.2)	4	(13.3)	44
Upper Chalk	Chalk.	(0.9 +)	3 +	(14.2)	47

	%	mm	%
Gravel	55	+ 64	0
		− 64 + 16	27
		− 16 + 4	28
Sand	43	− 4 + 1	10
		− 1 + ¼	26
		− ¼ + 1/16	7
Fines	2	− 1/16	2

Depth below surface (ft)	Percentage Fines	Sand	Gravel
10 – 13	1	24	75
13 – 16	1	27	72
16 – 19	4	79	17

TG 10 NW 5   1068 0614   Wramplingham Hall, Wramplingham

Surface level (+ 23.5 m) + 77 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (0.3 m) 1 ft;
Mineral (3.5 m) 11.5 ft;
Waste (13.3 m) 43.5 ft;
Mineral (7.3 m+) 24 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
	Soil.	(0.3)	1	(0.3)	1
Terrace Gravel (a)	Gravel. Clayey in top 3 ft (0.9 m). Chalky at base. Gravel: fine to coarse subangular flint with fine white flint. Sand: medium with fine and coarse, subangular, medium and fine predominant at the top of the deposit. Brown, light brown and grey.	(3.5)	11.5	(3.8)	12.5
Chalky Boulder Clay	Grey chalky clay with a chalky sand and gravel seam from 44 to 46 ft (13.4 to 14.0 m).	(13.3)	43.5	(17.1)	56
Glacial Sand and Gravel (b)	Pebbly sand. Clayey in parts. Some chalk. Gravel: fine with coarse, mainly subangular flint. Sand: medium with fine and traces of coarse, mainly subangular. Grey.	(7.3 +)	24+	(24.4)	80

		%	mm	%
(a)	Gravel	48	+ 64	0
			− 64 + 16	32
			− 16 + 4	16
	Sand	46	− 4 + 1	5
			− 1 + ¼	29
			− ¼ + 1/16	12
	Fines	6	− 1/16	6

Depth below surface (ft)	Fines	Sand	Gravel
1 − 4	13	78	9
4 − 7	4	34	62
7 − 10	2	25	73
10 − 12.5	4	49	47

		%	mm	%
(b)	Gravel	8	+ 64	0
			− 64 + 16	2
			− 16 + 4	6
	Sand	83	− 4 + 1	7
			− 1 + ¼	45
			− ¼ + 1/16	31
	Fines	9	− 1/16	9

Depth below surface (ft)	Fines	Sand	Gravel
56 − 59	7	79	14
59 − 62	7	82	11
62 − 65	10	86	4
65 − 68	9	76	15
68 − 71	11	81	8
71 − 74	6	92	2
74 − 77	8	85	7
77 − 80	14	83	3

TG 10 NW 6 1156 0958 East of Colton

Surface level (+ 48.8 m) + 160 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (7.0 m) 23 ft;
Mineral (6.4 m) 21 ft;
Waste (7.6 m) 25 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
Chalky Boulder Clay	Soil and brown chalky clay.	(6.1)	20	(6.1)	20
	'Very clayey' sand with gravel.	(0.9)	3	(7.0)	23
Glacial Sand and Gravel	Gravel. Chalky in parts.	(6.4)	21	(13.4)	44
	Gravel: fine to coarse subangular flint, with traces of fine subrounded quartz and quartzite, with only a little coarse gravel near the base of the deposit.				
	Sand: medium and coarse, subangular. Brown.				
Chalky Boulder Clay	Brown chalky clay.	(1.8)	6	(15.2)	50
	'Very clayey' sand with traces of gravel.	(0.9)	3	(16.1)	53
	Brown chalky clay.	(4.9)	16	(21.0)	69
Upper Chalk	Chalk.	(0.9+)	3+	(21.9)	72

	%	mm	%
Gravel	50	+ 64	0
		− 64 + 16	20
		− 16 + 4	30
Sand	47	− 4 + 1	17
		− 1 + ¼	24
		− ¼ + 1/16	6
Fines	3	− 1/16	3

Depth below surface (ft)	Percentage Fines	Sand	Gravel
23 − 26	1	36	63
26 − 29	3	36	61
29 − 32	3	46	51
32 − 35	4	41	55
35 − 38	4	50	46
38 − 41	4	54	42
41 − 44	2	66	32

TG 10 NW 7 1170 0891 South-east of Colton

Surface level (+ 42.6 m) + 140 ft
Water struck at (+27.7 m) +91 ft
Wirth B O, 8 inch diam.,
January 1970

Overburden (1.2 m) 4 ft;
Mineral (7.3 m) 24 ft;
Waste (2.7 m) 9 ft;
Mineral (2.7 m) 9 ft;
Waste (4.3 m) 14 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	ft	Depth (m)	ft
	Soil.	(1.2)	4	(1.2)	4
Glacial Sand (a) and Gravel	Gravel. 'Clayey' near base. Gravel: coarse with fine subangular with subrounded flint, with fine subrounded quartz. Sand: medium with coarse and fine, subangular with some subrounded, mainly flint and quartz. Brown	(7.3)	24	(8.5)	28
Chalky Boulder Clay	Dark brown clay with traces of chalk and occasional sandy layers.	(2.7)	9	(11.2)	37
Glacial Sand (b) and Gravel	Sand. Sand: medium with fine and traces of coarse, subangular. Light brown.	(2.7)	9	(13.9)	46
Chalky Boulder Clay	Dark brown slightly sandy clay with traces of chalk and gravel.	(3.4)	11	(17.3)	57
Glacial Sand	'Clayey' sand. Sand: fine and medium with traces of coarse, subangular, with occasional hard chalk pebbles. Brown.	(0.9)	3	(18.2)	60
	Very clayey sand.	(0.9)	3	(19.1)	63
Upper Chalk	Chalk.	(0.9 +)	3 +	(20.0)	66

		%	mm			%
(a)	Gravel	58	+ 64		:	0
			− 64	+ 16	:	40
			− 16	+ 4	:	18
	Sand	37	− 4	+ 1	:	11
			− 1	+ ¼	:	21
			− ¼	+ 1/16	:	5
	Fines	5	− 1/16		:	5

Depth below surface (ft)	Percentage Fines	Sand	Gravel
4 − 7	2	70	28
7 − 10	2	28	70
10 − 13	1	29	70
13 − 16	0	28	72
16 − 19	8	42	50
19 − 22	0	25	75
22 − 25	10	34	56
25 − 28	13	40	47

		%		mm			%
(b)	Gravel	0	+	64		:	0
			−	64	+ 16	:	0
			−	16	+ 4	:	0
	Sand	99	−	4	+ 1	:	8
			−	1	+ ¼	:	65
			−	¼	+ $^{1}/_{16}$	:	26
	Fines	1	−	$^{1}/_{16}$		:	1

Depth below surface (ft)	Percentage Fines	Sand	Gravel
37 – 40	0	99	1
40 – 43	2	98	0
43 – 46	0	100	0

TG 10 NW 8 1131 0805 North of Barford

Surface level (+ 29.3 m) + 96 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (6.7 m) 22 ft;
Mineral (2.7 m) 9 ft;
Waste (14.9 m +) 49 ft +

		Thickness (m)	ft	Depth (m)	ft
Chalky Boulder Clay	Soil and light brown chalky clay.	(1.5)	5	(1.5)	5
	Brown clay with grey bands	(5.2)	17	(6.7)	22
Glacial Sand and Gravel	'Very clayey' gravel. With hard chalk.	(2.7)	9	(9.4)	31
	Gravel: fine to coarse subangular flint with fine and medium chalk.				
	Sand: medium with fine, subangular, with medium chalk. Brown.				
Chalky Boulder Clay	Dark grey chalky clay, with clayey sand and gravel from 42 to 45 ft (12.8 to 13.7 m).	(15.0 +)	49 +	(24.4)	80

	%		mm			%
Gravel	42	+	64		:	0
		−	64	+ 16	:	15
		−	16	+ 4	:	27
Sand	34	−	4	+ 1	:	5
		−	1	+ ¼	:	15
		−	¼	+ $^{1}/_{16}$	:	14
Fines	24	−	$^{1}/_{16}$		:	24

Depth below surface (ft)	Percentage Fines	Sand	Gravel
22 – 25	37	31	32
25 – 28	14	39	47
28 – 31	22	31	47

TG 10 NW 9 | 1120 0666 | Near Riversdale, Wramplingham

Surface level (+ 20.6 m) + 68 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (1.2 m) 4 ft;
Mineral (23.2 m +) 76 ft +

		Thickness (m)	ft	Depth (m)	ft
	Soil and brown clay.	(1.2)	4	(1.2)	4
Terrace Gravel (a)	Gravel. 'Clayey' in upper 3 ft (0.9 m). Sand dominant in upper 6 ft (1.8 m) of the deposit. Gravel: fine and coarse subangular flint, with traces of sub-rounded flint cobbles. Sand: medium with fine and coarse, subangular. Brown.	(4.6)	15	(5.8)	19
Glacial Sand and Gravel (b)	'Clayey' sand. Gravel mainly in upper 12 ft (3.7 m). Traces of chalk towards base. Gravel: fine subangular flint, with fine sub-rounded quartz. Sand: medium with fine, sub-angular. Brown and grey.	(18.6 +)	61 +	(24.4)	80

		%	mm	%
(a)	Gravel	48	+ 64	0
			− 64 + 16	27
			− 16 + 4	21
	Sand	46	− 4 + 1	8
			− 1 + ¼	24
			− ¼ + 1/16	14
	Fines	6	− 1/16	6
(b)	Gravel	1	+ 64	0
			− 64 + 16	0
			− 16 + 4	1
	Sand	85	− 4 + 1	3
			− 1 + ¼	43
			− ¼ + 1/16	39
	Fines	14	− 1/16	14

Depth below surface (ft)	Percentage Fines	Sand	Gravel
4 − 7	16	66	18
7 − 10	6	72	22
10 − 13	2	28	70
13 − 16	3	19	78
16 − 19	4	46	50
19 − 22	13	85	2
22 − 25	5	88	7
25 − 28	4	93	3
28 − 31	15	81	4
31 − 34	13	87	0
34 − 37	13	86	1
37 − 40	23	76	1
40 − 43	9	90	1
43 − 46	13	83	4
46 − 49	23	76	1
49 − 52	20	79	1
52 − 55	15	84	1
55 − 58	14	86	0
58 − 61	14	85	1
61 − 64	26	74	0
64 − 67	17	83	0
67 − 70	12	87	1
70 − 73	19	81	0
73 − 76	12	87	1
76 − 80	8	91	1

TG 10 NW 10 1257 0944 North-west of Marlingford

Surface level (+ 37.6 m) + 123 ft
Groundwater conditions not recorded
Wirth B O, 8 inch diam.,
January 1970

Overburden (0.6 m) 2 ft;
Mineral (3.7 m) 12 ft;
Waste (1.8 m) 6 ft;
Mineral (4.9 m) 16 ft;
Waste (3.6 m) 12 ft;
Bedrock (0.9 m+) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
	Soil.	(0.6)	2	(0.6)	2
Glacial Sand and Gravel (a)	Sandy gravel. Clayey in parts. Gravel: fine to coarse subangular to subrounded flint with fine subrounded quartz and occasional flint cobbles near the base. Sand: medium with coarse and traces of fine, subrounded with some subangular, mainly flint and quartz, clayey. Brown.	(3.7)	12	(4.3)	14
Chalky Boulder Clay	Brown clay with chalk and flint pebbles.	(1.8)	6	(6.1)	20
Glacial Sand and Gravel (b)	Sand. Clayey gravel concentrated between 29 to 30 ft (8.3 to 9.1 m). Gravel: fine with a little coarse, with traces of cobble, mainly subangular flint. Sand: medium with fine and coarse, subangular, mainly quartz. Yellow to orange brown.	(4.9)	16	(11.0)	36
Chalky Boulder Clay	Light brown silty clay, slightly sandy in places, with sandy seam from 46 to 48 ft (14.0 to 14.6 m), becoming more clayey with depth.	(3.6)	12	(14.6)	48
Upper Chalk	Chalk.	(0.9 +)	3+	(15.5)	51

		%	mm	%
(a)	Gravel	39	+ 64	0
			− 64 + 16	20
			− 16 + 4	19
	Sand	51	− 4 + 1	16
			− 1 + ¼	30
			− ¼ + 1/16	5
	Fines	10	− 1/16	10

Depth below surface (ft)	Percentage Fines	Sand	Gravel
2 – 5	7	41	52
5 – 8	14	63	23
8 – 11	9	43	48
11 – 14	10	55	35

		%		mm			%
(b)	Gravel	2	+ 64			:	0
			− 64	+	16	:	0
			− 16	+	4	:	2
	Sand	96	− 4	+	1	:	10
			− 1	+	¼	:	67
			− ¼	+	1/16	:	19
	Fines	2	− 1/16			:	2

Depth below surface (ft)	Percentage		
	Fines	Sand	Gravel
20 – 23	1	99	0
23 – 26	0	100	0
26 – 29	0	95	5
29 – 30	20	70	10
30 – 33	2	97	1
33 – 36	2	98	0

TG 10 NW 11   1254 0852   South of Hall Farm, Marlingford

Surface level (+ 24.5 m) + 80 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (0.6 m) 2 ft;
Mineral (1.8 m) 6 ft;
Waste (12.8 m) 42 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
	Soil.	(0.6)	2	(0.6)	2
Glacial Sand (a) and Gravel	'Very clayey' pebbly sand. Gravel: coarse with some fine, mainly subangular flint. Sand: fine and medium, subangular. Brown.	(1.8)	6	(2.4)	8
Chalky Boulder Clay	Brown chalky clay with silty clay seams from 11 to 20 ft (3.4 to 6.1 m)	(5.5)	18	(7.9)	26
	Grey chalky clay with silt and sand seam from 29 to 35 ft (8.8 to 10.7 m).	(4.0)	13	(11.9)	39
Glacial Sand (b) and Gravel	Pebbly sand. Some hard chalk. Gravel: predominantly fine subangular flint. Sand: medium with fine and coarse, subangular. Grey.	(1.2)	4	(13.1)	43
Chalky Boulder Clay	Dark grey silty clay with traces of chalk and pebbles.	(2.1)	7	(15.2)	50
Upper Chalk	Chalk.	(0.9 +)	3 +	(16.1)	53

		%	mm	%
(a)	Gravel	9	+ 64	0
			− 64 + 16	6
			− 16 + 4	3
	Sand	57	− 4 + 1	4
			− 1 + ¼	27
			− ¼ + 1/16	26
	Fines	34	− 1/16	34
(b)	Gravel	16	+ 64	0
			− 64 + 16	3
			− 16 + 4	13
	Sand	74	− 4 + 1	9
			− 1 + ¼	50
			− ¼ + 1/16	15
	Fines	10	− 1/16	10

Depth below surface (ft)	Percentage Fines	Sand	Gravel
2 – 5	28	62	10
5 – 8	40	51	9
39 – 43	10	74	16

TG 10 NW 12 1217 0748 Yare Valley, East of Barford

Surface level (+ 20.9 m) + 69 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (0.6 m) 2 ft;
Mineral (2.7 m) 9 ft;
Bedrock (1.8 m +) 6 ft +

		Thickness (m)	ft	Depth (m)	ft
	Soil.	(0.6)	2	(0.6)	2
Terrace Gravel	'Very clayey' pebbly sand. Chalky in the lower 3 ft (0.9 m). Gravel: fine to coarse, subangular brown and white flint. Sand: medium and fine, subangular. Brown.	(2.7)	9	(3.3)	11
Upper Chalk	Chalk.	(1.8 +)	6 +	(5.1)	17

	%	mm		%
Gravel	20	+ 64		: 0
		− 64	+ 16	: 10
		− 16	+ 4	: 10
Sand	51	− 4	+ 1	: 5
		− 1	+ ¼	: 26
		− ¼	+ 1/16	: 20
Fines	29	− 1/16		: 29

Depth below surface (ft)	Percentage Fines	Sand	Gravel
2 − 5	14	54	32
5 − 8	43	47	10
8 − 11	30	53	17

TG 10 NW 13 1248 0691 Coleseed Plantation, Great Melton

Surface level (+ 40.6 m) + 133 ft
Water not struck
Wirth B 1, 8 inch diam.,
December 1969

Overburden (4.9 m) 16 ft;
Mineral (7.3 m) 24 ft;
Waste (7.9 m) 26 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	ft	Depth (m)	ft
Chalky Boulder Clay	Soil and brown clay with traces of sand and gravel and occasional chalk pebbles.	(4.9)	16	(4.9)	16
Glacial Sand and Gravel	Pebbly sand. Clayey in places.	(7.3)	24	(12.2)	40
	Gravel: course with fine subangular and some subrounded flint, with traces of fine subrounded quartz.				
	Sand: medium with fine and traces of coarse, subangular. Brown.				
Chalky Boulder Clay	Light brown clay with traces of chalky sand and gravel.	(2.1)	7	(14.3)	47
	Light brown chalky clay.	(5.8)	19	(20.1)	66
Upper Chalk	Chalk.	(0.9 +)	3 +	(21.0)	69

	%	mm		%
Gravel	19	+ 64		: 0
		− 64	+ 16	: 12
		− 16	+ 4	: 7
Sand	74	− 4	+ 1	: 9
		− 1	+ ¼	: 41
		− ¼	+ $^1/_{16}$	: 24
Fines	7	− $^1/_{16}$		: 7

Depth below surface (ft)	Percentage Fines	Sand	Gravel
16 − 19	16	72	12
19 − 22	2	68	30
22 − 25	5	39	56
25 − 28	9	71	20
28 − 31	2	64	34
31 − 34	15	85	0
34 − 37	2	98	0
37 − 40	2	98	0

TG 10 NW 14 1356 0944 Cobb's Grove Plantation, Marlingford

Surface level (+ 37.9 m) + 124 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (0.3 m) 1 ft;
Mineral (4.9 m) 16 ft;
Waste (10.3 m) 34ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
	Soil.	(0.3)	1	(0.3)	1
Glacial Sand and Gravel	Sandy gravel. Gravel: fine to coarse subangular flint, with traces of fine subrounded quartz. Sand: medium with coarse, mainly subangular flint. Brown.	(4.9)	16	(5.2)	17
Chalky Boulder Clay	Slightly sandy brown clay with traces of gravel.	(6.4)	21	(11.6)	38
	Light brown chalky clay.	(0.9)	3	(12.5)	41
	Sandy brown clay with traces of gravel.	(3.0)	10	(15.5)	51
Upper Chalk	Chalk.	(0.9 +)	3+	(16.4)	54

	%	mm	%
Gravel	44	+ 64	0
		− 64 + 16	23
		− 16 + 4	21
Sand	53	− 4 + 1	14
		− 1 + ¼	33
		− ¼ + $^{1}/_{16}$	6
Fines	3	− $^{1}/_{16}$	3

Depth below surface (ft)	Percentage Fines	Sand	Gravel
1 − 4	6	42	52
4 − 7	2	46	52
7 − 10	6	70	24
10 − 13	0	70	30
13 − 17	1	42	57

TG 10 NW 15 | 1306 0885 | Marlingford

Surface level (+15.5 m) +51 ft
Groundwater conditions not recorded
Shell and auger, 8 inch diam.,
December 1969

Overburden (0.6 m) 2 ft;
Mineral (0.9 m) 3 ft;
Waste (9.1 m) 30 ft;
Mineral (13.8 m +) 45 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
	Soil.	(0.6)	2	(0.6)	2
Terrace Gravel (a)	'Very clayey' pebbly sand. Gravel: predominantly fine subangular flint. Sand: fine and medium subangular. Brown.	(0.9)	3	(1.5)	5
	Brown and grey clay with silty bands.	(0.9)	3	(2.4)	8
	Gravel. Gravel: fine and coarse, subangular flint. Sand: medium, subangular. Gray.	(0.9)	3	(3.3)	11
Chalky Boulder Clay	Grey silt and fine grey sand with a chalky layer from 17 to 23 ft (5.2 to 7.0 m).	(7.3)	24	(10.6)	35
Glacial Sand and Gravel (b)	'Clayey' pebbly sand. Silty between 35 and 44 ft (10.6 and 13.4 m). Fragments of hard chalk in most parts. Clayey between 59 and 77 ft (18.0 and 20.4 m). Gravel: fine with coarse subangular flint. Sand: medium with fine and coarse, subangular, grey.	(13.8 +)	45 +	(24.4)	80

		%	mm	%
(a)	Gravel	10	+ 64	0
			− 64 + 16	2
			− 16 + 4	8
	Sand	65	− 4 + 1	4
			− 1 + ¼	30
			− ¼ + $^1/_{16}$	31
	Fines	25	− $^1/_{16}$	25
(b)	Gravel	18	+ 64	0
			− 64 + 16	8
			− 16 + 4	10
	Sand	68	− 4 + 1	11
			− 1 + ¼	33
			− ¼ + $^1/_{16}$	24

Depth below surface (ft)	Percentage Fines	Sand	Gravel
2 – 5	25	65	10
35 – 38	33	66	1
38 – 41	23	73	4
41 – 44	12	80	8
44 – 47	4	70	26
47 – 50	3	79	18
50 – 53	3	80	17
53 – 56	2	56	42

	%		mm		%
Fines	14	–	$^1/_{16}$	:	14

Depth below surface (ft)	Percentage Fines	Sand	Gravel
56 – 59	7	70	23
59 – 62	15	83	2
62 – 65	12	76	12
65 – 68	34	64	2
68 – 71	33	65	2
71 – 74	14	52	34
74 – 77	12	68	20
77 – 80	5	43	52

TG 10 NW 16 1375 0819 South of Chapel Farm, Marlingford

Surface level (+ 31.7 m) + 105 ft
Water not struck
Wirth B 1, 8 inch diam.,
December 1969

Overburden (0.6 m) 2 ft;
Mineral (14.9 m) 49 ft;
Waste (8.8 m +), 29 ft +

		Thickness (m)	ft	Depth (m)	ft
	Soil.	(0.6)	2	(0.6)	2
Glacial Sand and Gravel	Pebbly sand. Some hard chalk. Clayey in upper 3 ft (0.9 m). Gravel: fine with coarse subangular; traces of subrounded flint; some subrounded quartz. Sand: medium with coarse and fine, subangular, flint. Brown.	(14.9)	49	(15.5)	51
Chalky Boulder Clay	Light brown chalky clay.	(5.5)	18	(21.0)	69
	Grey chalky clay.	(3.4 +)	11+	(24.4)	80

	%		mm			:	%
Gravel	17	+	64			:	0
		–	64	+	16	:	7
		–	16	+	4	:	10
Sand	80	–	4	+	1	:	16
		–	1	+	¼	:	54
		–	¼	+	$^1/_{16}$	:	10
Fines	3	–	$^1/_{16}$			:	3

Depth below surface (ft)	Percentage Fines	Sand	Gravel
2 – 5	18	60	22
5 – 8	6	58	36
8 – 11	2	83	15
11 – 14	0	81	19
14 – 17	3	69	28
17 – 20	1	99	0
20 – 23	9	48	43
23 – 26	0	77	23
26 – 29	1	98	1
29 – 32	0	85	15
32 – 35	2	96	2
35 – 38	1	84	15
38 – 41	0	85	15
41 – 44	1	91	8
44 – 47	2	98	0
47 – 51	1	71	28

TG 10 NW 17 1395 0728 High House Farm, Great Melton

Surface level (+ 34.0 m) +112 ft
Water not struck
Wirth B 1, 8 inch diam.,
December 1969

Waste (12.8 m) 42 ft;
Bedrock (0.9 m +) 3 ft +

		Thickness (m)	ft	Depth (m)	ft
Chalky Boulder Clay	Soil and slightly sandy brown clay.	(4.6)	15	(4.6)	15
	Grey clay with traces of chalk	(1.8)	6	(6.4)	21
	Slightly sandy brown clay.	(6.4)	21	(12.8)	42
Upper Chalk	Chalk.	(0.9 +)	3 +	(13.7)	45

TG 10 NW 18 1343 0649 Melton Hall, Great Melton

Surface level (+ 39.5 m) + 130 ft
Water not struck
Wirth B 1, 8 inch diam.,
December 1969

Waste (18.3 m +) 60 ft +

		Thickness (m)	ft	Depth (m)	ft
Chalky Boulder Clay	Soil and brown clay with traces of flint and chalk pebbles.	(16.2)	53	(16.2)	53
	Brown chalky clay	(2.1 +)	7 +	(18.3)	60

TG 10 NW 19 1431 0972 Three Cornered Plantation, Marlingford

Surface level (+ 41.2 m) + 135 ft
Water not struck
Wirth B 1, 8 inch diam.,
December 1969

Overburden (5.5 m) 18 ft;
Mineral (14.9 m) 49 ft;
Waste (4.0 m +) 13 ft +

		Thickness (m)	Thickness ft	Depth (m)	Depth ft
Chalky Boulder Clay	Soil and brown stoney and chalky clay.	(5.5)	18	(5.5)	18
Glacial Sand and Gravel	Pebbly sand. Gravel mainly between 21 and 36 ft (6.4 and 10.4 m) Clayey in parts. Gravel: fine to coarse subangular with subrounded flint, with traces of fine subrounded quartz. Sand: medium with fine and coarse, subangular, mainly flint with traces of chalk. Brown.	(14.9)	49	(20.4)	67
? Norwich Crag	Light brown silty clay.	(4.0 +)	13 +	(24.4)	80

	%	mm	%
Gravel	9	+ 64	0
		− 64 + 16	4
		− 16 + 4	5
Sand	86	− 4 + 1	10
		− 1 + ¼	58
		− ¼ + 1/16	18
Fines	5	− 1/16 +	5

Depth below surface (ft)	Percentage Fines	Sand	Gravel
18 – 21	1	99	0
21 – 24	11	77	12
24 – 27	1	73	26
27 – 30	1	73	26
30 – 33	1	99	0
33 – 36	1	81	18
36 – 39	2	94	4
39 – 42	12	76	12
42 – 45	1	97	2
45 – 48	12	87	1
48 – 51	2	98	0
51 – 54	1	97	2
54 – 57	1	94	5
57 – 60	13	78	9
60 – 63	11	75	14
63 – 67	15	77	8

INSTITUTE OF GEOLOGICAL SCIENCES

MINERAL ASSESSMENT UNIT

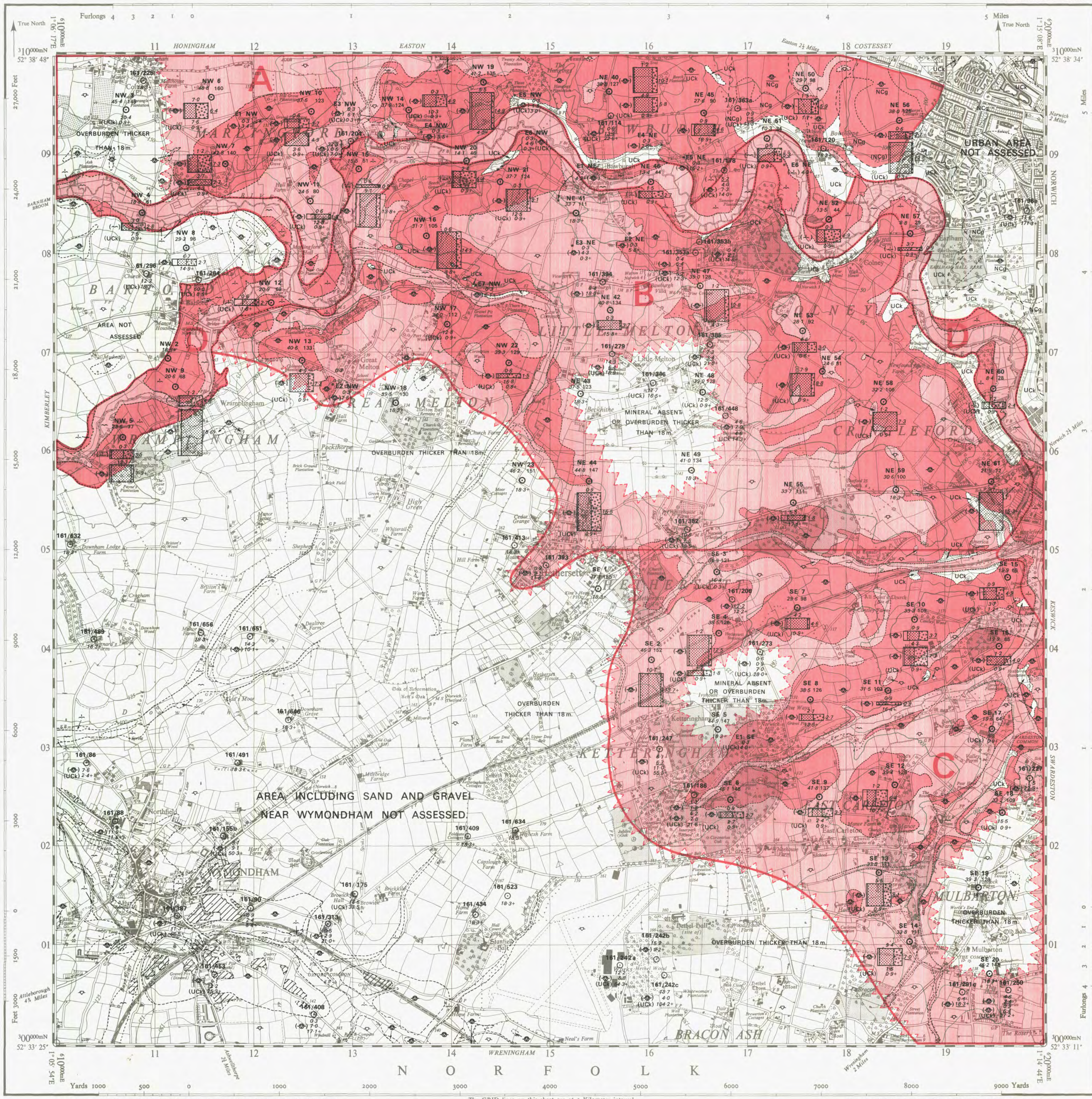
THE SAND & GRAVEL RESOURCES OF SHEET TG10 (HETHERSETT, NORFOLK)

Scale 1:25 000 or about 2½ Inches to 1 Mile

ORDNANCE SURVEY
SHEET TG10
PROVISIONAL EDITION

This map should be read in conjunction with the accompanying Report which contains details of the assessment of resources.

5



The representation on this map of a Road, Track, or Footpath, is no evidence of the existence of a right of way.

The GRID lines on this sheet are at 1 Kilometre interval.
Heights are in feet above Mean Sea Level at Newlyn.

1 square inch on this map represents 99·639 acres on the ground.

Compiled from 6'' sheets last revised 1905-26.
Other partial systematic revision 1938-53 has been incorporated.
Major roads revised 1970.

Made and published by the Director General of the Ordnance Survey, Southampton. Reprinted with minor changes.

Geological lines from a six-inch survey in 1965-1970 by F. C. Cox, M. C. McKeown and E. G. Poole. S. C. A. Holmes, District Geologist. Included in One-Inch Geological Sheet 161.

Sand and Gravel Survey by E. F. P. Nickless and A. R. Clayton between 1969 and 1970. R. G. Thurrell, Head, Mineral Assessment Unit.

*1:25 000 Sand and Gravel Resource Sheet published 1972.
Sir Kingsley Dunham, D.Sc., F.R.S., Director, Institute of Geological Sciences, incorporating the Geological Survey of Great Britain, the Museum of Practical Geology and Overseas Geological Surveys.*

2050/72

Data quoted for an individual borehole refer strictly to that site, from which reliable conclusions cannot be drawn about the thickness and grading elsewhere in the deposit, particularly in material as variable as sand and gravel. However, estimates of the volume and mean grading of the mineral as a whole in each Resource Block are given in the Report.

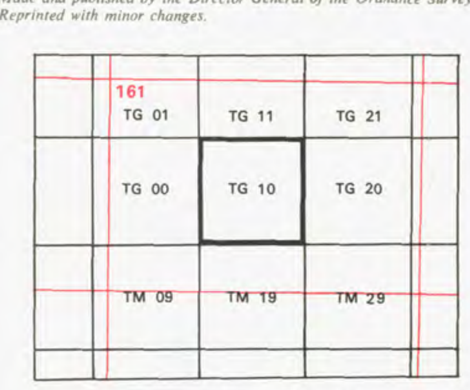


Diagram showing the relation of the National Grid 1:25 000 sheets with the One-Inch Geological Sheet 161.

EXPLANATION OF SYMBOLS AND ABBREVIATIONS

DRIFT

A-11 **Alluvium**- fine sands, clay and peat, often overlying sand and gravel.

1T-3 **1st Terrace River Gravels**- slightly clayey, medium flint gravels, chalk free.

Bc-4 **Boulder Clay**- stiff blue clay with pebbles of chalk and flint.

GS-2 **Glacial Sand and Gravel**- generally clean, ill-sorted sands and gravels with some chalk.

RECENT AND PLEISTOCENE

SOLID

NC-2 NCg **Norwich Crag**- sands and gravels with thin beds of clay. Sands occasionally shelly especially near base.

UCk **Upper Chalk**- white, soft limestone containing black nodular flints with white patina.

CRET-ACEOUS

MG-2 **Made Ground.**

WO-5 **Worked out areas**-mainly of sand and gravel.

BOUNDARY LINES

Geological boundary, Drift.

Geological boundary, Drift, delimiting area of gravel within sand and gravel outcrop.

Geological boundary, Solid. Broken line denotes uncertainty.

Inferred boundary between categories of deposits recognized.

Resource Block boundary.

BOREHOLE DATA

SITE LOCATIONS

Mineral Assessment Unit (M.A.U.) Boreholes.

Other Boreholes.

M.A.U. BOREHOLES

Borehole Registration Number. SE 10
33·3 109 — Surface level in metres and feet above O.D. (Newlyn).
Borehole Site.
0·9 — Overburden.
Grading Diagram. 3·7 — Mineral (sand and gravel).
4·3 — Waste.
Geological Classification. 7·3 — Mineral (sand and gravel).
(UCk) 0·9+ — Bedrock.

Note:
1. Figures underlined denote thicknesses used in the assessment of resources.
2. The + sign indicates that the base of the deposit was not reached.
3. The figures in *italics* are conversions to metres of measurements recorded in feet.
4. The Geological Classification is given only for mineral and bedrock.

Borehole Registration Number

Each M.A.U. borehole is indentified by a Registration Number, eg. SE 10. The letters refer to the quarter sheet and the figures to the I.G.S. serial number for that quarter. The unique designation for borehole SE 10 is TG 10 SE 10.

Grading Diagrams

Each grading diagram shows the mean particle size distribution of a distinct deposit of mineral.

Sand (+1/16–4mm)
Fines (−1/16mm) **Gravel** (+4mm)

The height of the diagram is proportional to the mineral thickness.

The widths of the divisions show the proportions of **Fines Sand** and **Gravel.**

OTHER BOREHOLES

The layout of information is the same as for M.A.U. boreholes, although data available may not be as comprehensive. They are registered in the same series, except for records in the Hydrogeological Department: for example, **161/227** signifies Hydrogeological Department record 227 on New Series One-Inch Geological Sheet 161.

EXPOSURE RECORDS

Information from the inspection of exposures is shown in the same way as for boreholes, but they are located by an asterisk, thus *. Reference number and details of thickness are shown.

CATEGORIES OF DEPOSITS

Exposed sand and gravel, as mapped. CAT-E3

Continuous or almost continuous spreads of mineral beneath overburden. CAT-C1

Sand and gravel either not potentially workable (see Report) or absent. CAT-A2

Where appropriate on other sheets, a fourth category, 'Discontinuous spreads of sand and gravel beneath overburden' is recognized.

RESOURCE BLOCKS

For the purpose of assessment the mineral-bearing land is divided into Resource Blocks (see Report). Each is designated by a letter.

Detailed records may be consulted on application to the Director, at the appropriate offices of the Institute of Geological Sciences.

Made and printed for the Institute of Geological Sciences by the Director General of the Ordnance Survey, Southampton.