THE UNIVERSITY OF HULL

The Quaternary History and Stratigraphy of North-East Yorkshire

being a Thesis submitted for the Degree of

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by

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<u>CONTENTS</u>

Summary of Thesis submitted for Ph.D. degree

by Christopher Andrew Edwards, B.Sc.,

on

The Quaternary History and Stratigraphy of North-East Yorkshire

A brief history of research during the 19th and 20th centuries is given.

The study area is delimited and sub divided into eight topographically distinct sub-areas.

Detailed descriptions and measured sections of the coastal stratigraphy between Flamborough Head and Robin Hood's Bay are given and the Lower and Upper Till Series are recognised on the basis of mechanical and pipette analyses, Munsell colour notation and field observations. These are correlated with the Skipsea and Withernsea tills of Holderness respectively.

Stone orientations at selected coastal sites are described and demonstrate local variations in ice flow due to obstruction by the pre-Quaternary basement.

A Devensian ice limit at Thornton Dale in the Vale of Pickering is recognised and shown to be contemporaneous with isolated, short-lived lacustrine conditions in the western Vale. Late Devensian and Flandrian deposits in the western Vale of Pickering are described and details of extensive augering presented. Two differing lacustrine lithologies occur; the older being composed of reworked Mesozoic clay and the younger of less consolidated silty alluvium.

A borehole traverse from Malton to Seamer reveals an outwash plain with corresponding lateral facies change associated with ice in the east and westward flowing meltwater.

Periglacial deposits are described, including pre-Hoxnian soliflucted chalk gravel beneath the Speeton Shell Bed, Wolstonian chalk gravel on the Yorkshire Wolds scarp and Devensian tundra polygons on the North Yorkshire Moors.

The chronology of ice retreat has been established by interpretation of associated geomorphological features using aerial photographs. The mode of formation and ages of the North Yorkshire Moors meltwater channels are discussed with particular reference to Newton Dale and Kirkham Priory channel.

The micro fauna and tectonic structure of the Speeton Shell Bed is described and it is considered to be an ice-rafted Hoxnian deposit.

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CHAPTER I PREVIOUS RESEARCH

Quaternary investigations in north-east Yorkshire began with the work of John Phillips in the early nineteenth century. It is beyond the scope of this work to give a detailed account of every contribution made since then but it is appropriate to refer to those whose work either brought about significant advances in contemporary Quaternary thinking or illustrated the ideas currently popular at the time of writing.

The trends of early research in the Vale of Pickering and the eastern moors are broadly similar to those of the Holderness area. Phillips (1829) described the Vale of Pickering as having 'a general covering of diluvial clay and pebbles' (1829, 1836) and mentioned the good coastal exposures of these clays between Filey and Speeton. He described the deposits of 'diluvial clay' that occur in the neighbourhood of Scarborough and in Robin Hood's Bay, paying particular attention to the far-travelled rocks within the clay. From the existence of these erratics he drew support for his theory of dispersal by powerful diluvial currents. His conclusions as regards provenance and routes by which stones reached their present area of deposition agree closely with modern glacial theory..... 'thus we trace back to Shap Fell its porphyrhytic granite, to Carrock Fell its syenite and greenstone'.....etc.

Phillips commends Buckland's earlier work on Kirkdale cave (1822). However, Buckland's was of less significance than that of Phillips as he was merely interested in the excavation of the newly discovered cave, though he did make a valuable contribution in dating the cave and its contents as 'ante diluvian'.

With the exception of Sorby (1850, 1851, 1859), north-east Yorkshire's glacial geology was neglected until Lamplugh, the amateur and the professionals Dakyns, Reid and Cameron began working in the area in the late 1870's. Sorby (1850) related the formation of Yedmandale to the scouring action of a strong current from the north. He saw this as a feasible mechanism for producing the steep headwall of the valley. About this time, the theory of a diluvial submergence was being remoulded to accommodate the action of stranded icebergs as agents for the production of contortions in the diluvial beds (Sorby 1851). Trimmer's suggestion (1851) of ice within the drift was taken a step further by Dakyns (1878) who considered that a submergence could not account for the distribution of Shap granite in north-east Yorkshire. He attributed the transport of erratics to land ice, being unable to envisage a mechanism by which floating ice could initially incorporate erratics within its mass.

Lamplugh's first paper was published in 1879, heralding the onset of thirty years rigorous investigation. He was a glacialist who probably did more in Britain than any other to seal the fate of the theory of the great submergence. Lamplugh's work tended to be of a local descriptive nature recording inland and coastal exposures as and when they were accessible. He is outstanding among Quaternary geologists as being one of the first to draw his conclusions directly from his own observations, making no attempt to fit them into pre-conceived theories. The bulk of his work was published in short observational papers mostly before the end of the nineteenth century. It is a tribute to Lamplugh that his observations have stood the test of time and can be relied upon to be an accurate record of what he saw.

During the latter part of the nineteenth century, Quaternary geologists were extremely active in north-east Yorkshire. Over a period of approximately thirty years, the entire coast was closely scrutinised. Striated bed-rock surfaces were observed and noted by Stather on Filey Brigg (1897) and at Sandsend (1902). In 1896, Muff and Sheppard saw a striated surface in Robin Hood's Bay which closely agreed with the observations made by Stather. It was during this period that the bulk of the work which led to the compilation of the reports of the Yorkshire Boulder Committee was performed. Taken collectively these reports provide a fair representation of the rock types and relative proportions that are found in the coastal exposures of boulder clay. Provenance of the erratics, plus the information obtained from the few known striated surfaces made it possible to trace the path of the ice back to its origin. The boulder clay of north-east Yorkshire was generally divided into two units, separated by the "middle sands and gravel" as portrayed by Martin Simpson (1859), Curator of Whitby Museum, in his long section of the Yorkshire coast extending from Whitby to Spurn Point. In 1895 Harrison suggested that the "middle sands and gravel" were of en-glacial origin, thus contradicting the suggestion made by S.V. Wood in 1871 that a marine transgression was responsible for their deposition, and also for much of the till.

The first attempt at a large scale regional assessment of the Quaternary deposits of north-east Yorkshire was the Geological Survey sheet memoir for the area to the north and west of Malton (Fox-Strangways 1881). No correlation with the coast or Vale of York was attempted, and in fact none has since been made. The western Vale has not been re-mapped by the Geological Survey, and this volume still remains the basic Quaternary reference to the area. More recently various aspects of the post-Tertiary evolution of the Vale of Pickering have been dealt with by Versey (1938a, 1938b) and Palmer (1973). The next major contribution was again made by the Geological Survey with the publication of 'The Geology of the Country between Whitby and Scarborough' (Fox-Strangways and Barrow 1882). This included the first comprehensive account of the Quaternary deposits of the coastal region, and to this day has remained unsurpassed.

In 1902, P.F. Kendall published his classic work on glacier lakes in the Cleveland Hills. Using evidence from the newly completed survey maps plus his own field work and knowledge of Alpine glaciers, he reconstructed the glacial limits and the history of deglaciation in north-east Yorkshire. He envisaged ice in Eskdale and in the eastern Vale of Pickering as far as Wykeham, which on melting formed a series of ice-marginal lakes each overflowing into the next lower of the series by well defined 'overflow channels'. Though Kendall categorically stated the existence of marginal lakes, he admitted there was no evidence for them other than the apparently descending sequences of 'overflow channels'. From a geomorphological viewpoint Kendall's work was the most influential ever written on Yorkshire. His views remained in favour for nearly half a century and were not constructively criticised by geomorphologists until the nineteen fifties.

The period of active research experienced at the turn of the nineteenth century ended during the first decade of the twentieth century and was never truly revived. A limited revival was made during the nineteen thirties and forties, one of the more important contributions being the controversial work of Carruthers (1944). His first publication was in 1939 when he suggested that sedimentary features hitherto considered as being of fluvial origin were in fact of sub or en-glacial origin and that the entire sequence of Pleistocene deposits in coastal north-east Yorkshire were the product of one glaciation. There was considerable opposition to his views which he again provoked in 1943 and 1944. In spite of this, it is obvious now that Carruthers was the first to draw attention to the importance of sub and en-glacial processes thus providing the means to begin a constructive re-appraisal of Kendall's hypothesis.

During the last two decades Kendall's hypothesis has come increasingly under attack. Gregory (1962) for example, re-interpreted the deglaciation of a part of Eskdale and concluded that many of the geomorphic features there were due to sub-glacial processes resulting from ice stagnation and not to sub-aerial processes following active ice retreat as postulated by Kendall.

Since 1962, Quaternary research in Britain has been of a more quantitative nature than previously. In north-east England, work has been concentrated on Holderness (Catt and Penny 1966, Penny and Catt 1967), and on County Durham (Francis 1962, Smith and Francis 1967, Francis 1970). However, the intervening area of north-east Yorkshire has seen very little quantitative research, with the exception of Andrews and Smith (1970).

Boulton (1968, 1970a, b, 1972) revolutionised the approach to Quaternary stratigraphic investigations with his observations on till deposition in Spitzbergen. It is perhaps fitting at this point to pay tribute to Lamplugh (1911) who, by visiting the Sefstrom glacier in Spitzbergen, obviously realised the necessity to undertake quantitative observations in present day glacial environments in order to more accurately elucidate the processes by which Pleistocene till has been deposited.

In the foregoing account, the various stratigraphical classifications that have been used in north-east Yorkshire have purposely been omitted. Instead, they are presented in tabular form (Table 1). In column 1, Lamplugh's original classification is given for Filey Bay (1879) which has formed the basis of most of the more recent attempts to resolve the glacial stratigraphy of the area. He also worked in Holderness and on Flamborough Head and attempted to trace the tills of Holderness northwards into Filey Bay. In 1879 he identified the lowest

LAMPLUGH (1879) FILEY BAY	LAMPLUGH (1891) FLAMBRGH	MUFF et al (1896) ROB. H's BAY	BISAT (1940) FILEY BAY	CATT (1963) HLDRNESS	MITCHELL et al (1973) N.E. YORKS	EDWARDS (1978) N.E. YORKS
HESSLE TILL	UPPER TILL	HESSLE TILL	SANDY TILL U. PURPLE TILL	HESSLE TILL	UPPER TILL	UPPER TILL SERIES
BROWN TILL	INTER-STRATIFIED SERIES	UPPER TILL	L. PURPLE TILL	PURPLE TILL	UNNAMED TILL OF FILEY BAY	
GRAVEL		MIDDLE SANDS	SAND, SILT & GRAVEL	DRAB TILL	GRAVEL	GRAVEL
GREENISH-PURPLE TILL		LOWER TILL	GREY, SUB & STONY DRAB TILLS		LOWER TILL OF COAST	LOWER TILL SERIES
BASEMENT TILL				DIMLINGTON SILTS BASEMENT TILL	CHALK RUBBLE BASEMENT TILL	CHALK RUBBLE BASEMENT TILL
CHALK RUBBLE					SPEETON SHELL BED	CHALK RUBBLE SPEETON SHELL BED

Table I.

continuous till of Filey Bay as Lower Purple (Skipsea till of modern Holderness nomenclature) then in 1889 he referred to the Lower Purple as Basement till. The conclusion one draws from this is that from 1889 onwards, Lamplugh was mistaking Skipsea till (Holderness nomenclature) for Basement till north of Flamborough Head. This is supported by Lamplugh (1889) stating that he believed the Basement could be traced beyond Scarborough, Whitby and Saltburn with some local interruptions, which would be true for the Skipsea but not for the Basement. In 1891 he erected a separate classification for Flamborough Head (Column 2) which he related to Bridlington Bay and Filey Bay by suggesting that the Interstratified series was a thin-ice lateral equivalent of the Skipsea and Withernsea tills (Columns 4 and 5) in the two bays. In Robin Hood's Bay, Muff and Shepherd (Column 3) discovered the straight forward three tiered succession which they correlated with the upper part of Lamplugh's 1879 Filey Bay classification.

Apart from observations made by Carruthers in Filey Bay (1939), north-east Yorkshire was neglected until Bisat examined the glacial stratigraphy of Filey Bay (1940)(Column 4). He introduced the term Drab for what had previously been called Lower Boulder Clay and regarded the Hessle till as merely the upper part of the Purple till. More recently, Catt (1963), although primarily concerned with Holderness, extended his four-fold classification (Column 5) as far north as Reighton, consequently it is relevant to this present work. The most recent classification (Mitchell et al, 1973) draws attention to the problem of naming the tills in this area north of Flamborough Head, (Column 6). It is the most comprehensive of the classifications that have been applied to north-east Yorkshire in that in its complete form it combines a chronological sequence of the inland episodes of deglaciation with the earlier periods of till deposition seen in coastal sections.

Radio carbon dates, although determined from Holderness, have provided the means to determine the maximum age of the Skipsea till - 18,500 ± 400 years B.P. (1-3372), 18,240 ± 250 years B.P. (Birm.108) - and to date the establishment of late glacial conditions. These dates can be quite meaningfully extrapolated to north-east Yorkshire. Other recent work in Holderness which is also relevant to north-east Yorkshire is that of Madgett (1975). His re-interpretation of the Hessle till, supporting the views of Bisat (Column 4) has resolved a major problem in the stratigraphy of north-east Yorkshire and Holderness.

Part of the purpose of this present work is to resolve some of the problems of the glacial stratigraphy which have been highlighted by Catt (1963), Mitchell et al (1973) and Madgett (1975). A new nomenclature for the tills of north-east Yorkshire is proposed and this is correlated with the glacial sequence of Holderness, as established by Catt (1963) and Madgett (1975).

Table 1 shows the relationship between the various interpretations of the Quaternary coastal sequences in north-east Yorkshire. Column 7 is the result of this present work and shows that the tills of north-east Yorkshire have been named as the Lower and Upper till series. The Lower till series is equated with the Skipsea till of Holderness and the Upper till series with the Withernsea till. Type localities are not given as the extreme variation within the tills of north-east Yorkshire does not make the application of conventional nomenclature possible. The stratigraphical relationship between and within the coastal tills of north-east Yorkshire are described in Chapter 3.

CHAPTER II PHYSIOGRAPHICAL ELEMENTS OF THE AREA

The southern limit of the area of study follows the natural watershed along the chalk scarp from Flamborough Head to Malton. From Malton via Helmsley to Pickering the west and north-western borders of the area correspond to the break of slope between the Vale of Pickering and the higher surrounding land. Between Pickering and Robin Hood's Bay the boundary follows the western side of Newton Dale to Fen Bog, thence north-eastward along the natural watershed of the North Yorkshire Moors to the west approximately one km. north of Bay Town (Fig.1).

(1) COASTAL

Thick deposits of till exist in Filey Bay, Cayton Bay, Scarborough Bay and Robin Hood's Bay. Along the crests of the solid cliffs between these bays, much thinner deposits of till occur and these show a progressive thinning towards the north as the cliff height increases. Within the bays, the full glacial succession is frequently visible with weathered till at the surface whereas on the intervening high land the till which is present is often weathered throughout its profile.

(2) INLAND

In recent years, geomorphologists have made increasing use of aerial photographs as a means of investigating both small and large scale geomorphological features in Britain and abroad (Dimbleby, 1952., Friedman et al 1971., Svensson 1963, 1967, 1972). This is chiefly due to recent advances in aerial photographic technology which have vastly improved the definition and quality of prints that are now widely available, compared to those obtainable 15 years ago. Many of the observations made from aerial photographs in this study are by virtue of the excellent quality of prints obtainable from an extensive cover of north-east Yorkshire, flown by Meridian Air Maps in July 1969.

The value of good quality aerial photographs and stereoscope (Hilger-Watts) in an investigation such as this cannot be over emphasised. They

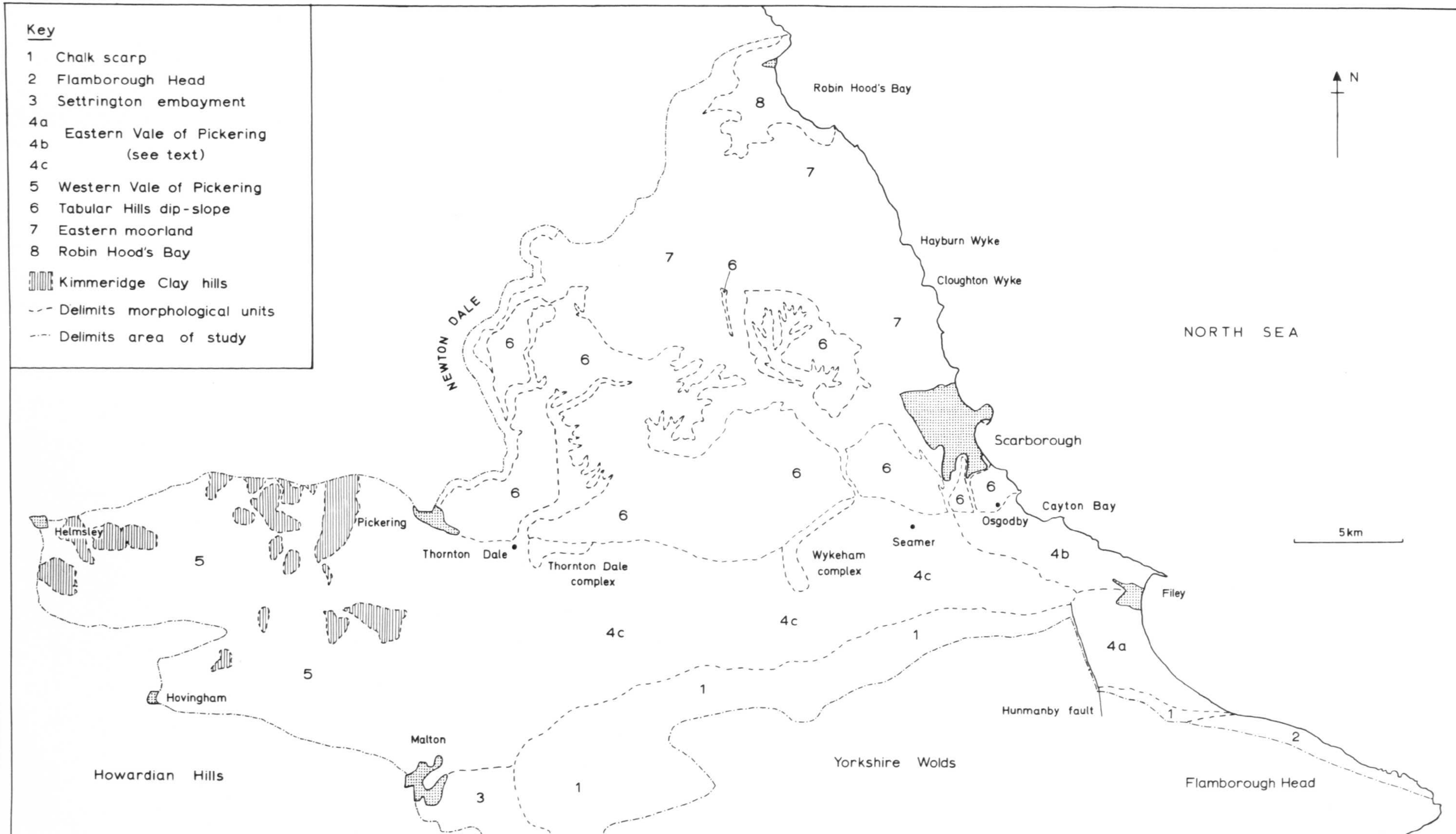


Fig.1. MAP OF N.E. YORKSHIRE TO SHOW TOPOGRAPHICAL COMPONENTS OF THE AREA OF STUDY

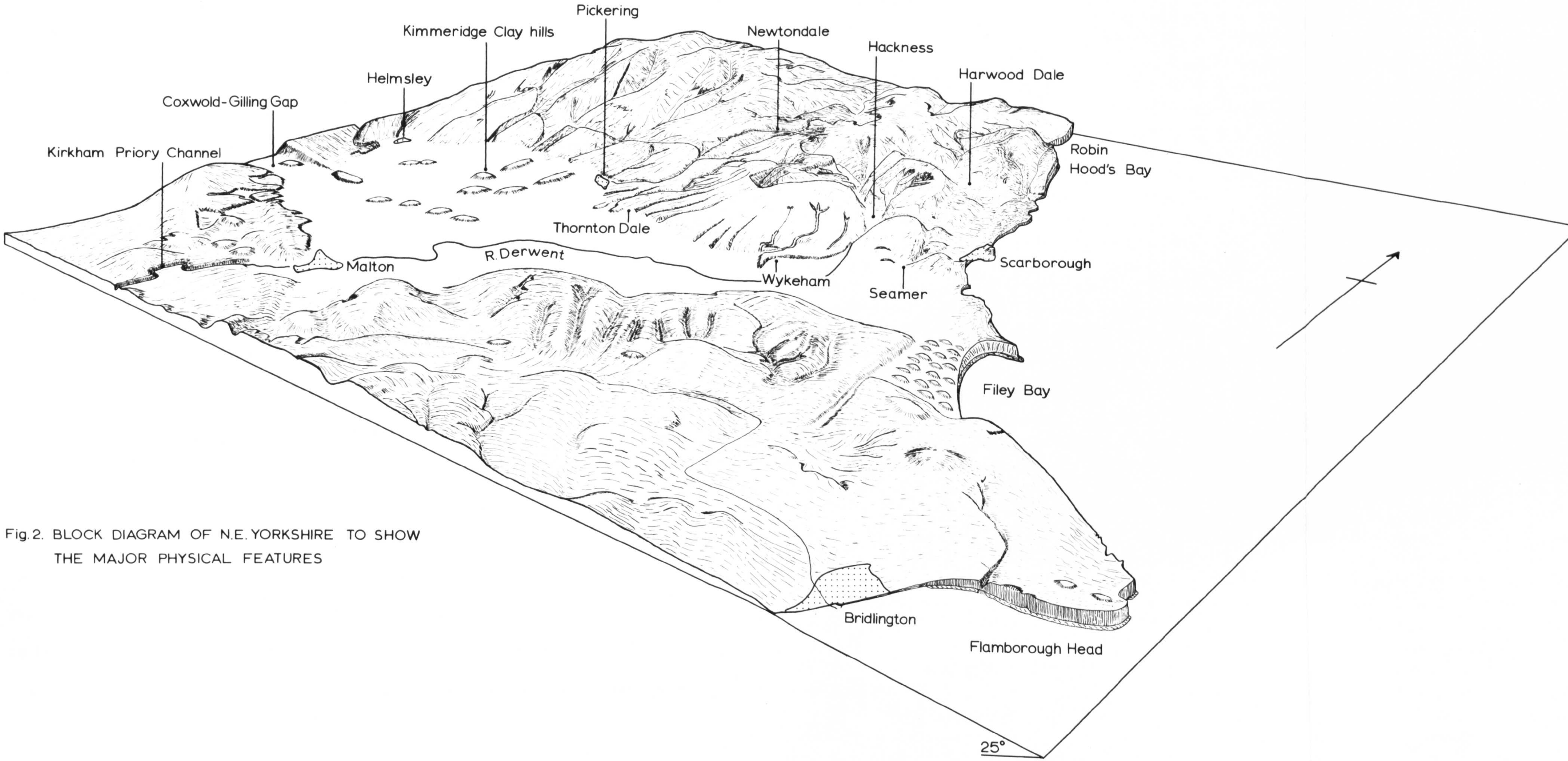


Fig. 2. BLOCK DIAGRAM OF N.E. YORKSHIRE TO SHOW THE MAJOR PHYSICAL FEATURES

have provided the means to view the area of study stereoscopically and on this basis it has been topographically sub divided into the following areas (see Fig. 1).

(A) CHALK SCARP

This is a very prominent feature stretching from Muston (TA 09 79) to Scagglethorpe (SE 83 72). The foot of the scarp is accurately delimited by the 30.5 m. contour, the summit being delimited by the crest which rises to 189.6 m. O.D. at SE 923 750. The crest averages 167.6 m. O.D. and gently declines towards the east. Gradients on the scarp are steep (12^{o} at Potter Brompton Brow). It shows no surface drainage in its upper and middle reaches, though a spring line occurs near the scarp foot where the Speeton Clay outcrops. It is cut by several large dry valleys, e.g. Sked Dale, Ganton Peak, and is traversed by numerous small dry valleys and channels, being particularly well developed below East Heslerton Brow.

(B) FLAMBOROUGH HEAD

At Muston the chalk scarp is offset 4 km. to the south by the Hunmanby fault, from where it continues eastwards through Reighton to the coast at Speeton Cliffs (134.7 m. O.D.) thence forming Flamborough Head. The Flamborough peninsula is highest along its northern coast, the land falling gradually southward with the regional dip and being incised by the dry valley systems characteristic of the Yorkshire Wolds. The headland acted as an obstacle to ice movement and though covered in till, the most notable glacial features, with the exception of Beacon Hill, are the sand and gravel deposits heaped along the northern coast.

(C) SETTRINGTON EMBAYMENT

This is a low lying area of about 18 sq. km. to the south and east of Malton, Within the embayment, Upper Jurassic limestones emerge from beneath the chalk and rise to the west to form the Howardian Hills. There is very little solid outcrop, apart from around the periphery, as the area is quite thickly covered in post-glacial sand and gravel (Fox-Strangways, 1881).

(D) EASTERN VALE OF PICKERING

The eastern Vale is divisible into three parts :-

(i) the area immediately inland from Filey Bay

(ii) the area between Filey and Osgodby

(iii) the low lying region to the west of (i) and (ii)

(i) This embayment, produced by the Hunmanby fault offsetting the chalk scarp, is thickly covered in the till, which is exposed in coastal sections, and whose surface has been moulded into numerous drumlins; the long axis of which trend roughly parallel to the peripheral chalk scarp.

(ii) North-west of Filey, Jurassic rocks rise rapidly above O.D. and form a major part of the sea cliffs. Consequently, the till is thinner than that to the south-east. Topographically, the surface is rather monotonous, though along the south-western margin of the till exposure, the break in slope between the glacial and post-glacial deposits accurately delimits the areal extent of the till.

(iii) The area to the west of (i) and (ii) is a flat lying region composed of post-glacial and recent sediments including sand, gravel, peat, alluvium and lacustrine clay, and lies almost wholly below 30.5m.O.D. There are intermittent glacial deposits along its northern margin which include the Thornton Dale complex and the Hutton Buscel Kame terrace.

(E) WESTERN VALE OF PICKERING

Within the low lying area of the western Vale, the general description given for (D)(iii) applies with the addition of numerous small hills.

These rise to 30 m above the general level of the western Vale which is 30 - 38m O.D., though they tend to be higher in the north and west with one at Sproxton (SE 619 818) reaching 98.8m O.D. They have Mesozoic clay cores and are randomly scattered throughout the area.

(F) TABULAR HILLS

Within the area of study these extend from Newton Dale eastwards to Osgodby and are bounded on the north by the lower Calcareous Grit Scarp which runs from Saltergate to Silpho. In the west the dip slope ranges in height from approximately 30m O.D. to 290 m. O.D. at Whinney Nab (SE 865 948). To the east of Hazelhead Moor, Blakey Topping (SE 873 938) exists as an outlier of the dip slope. In its more northerly reaches, the dip slope is extensively covered by large scale ice-wedge polygons. It is deeply incised by numerous valley systems all draining south into the Vale of Pickering. Some of the valleys contain streams e.g. Thornton Dale, though the majority are dry with spring lines along the Corallian/Oxford Clay contact e.g. Sand Dale (SE 868 853). Most notable of the valleys in this area are Newton Dale and the Hole of Horcum.

East of Dalby Forest the dip slope is incised from the north-east by Trouts Dale. North of Trouts Dale it continues eastwards as far as the River Derwent, ranging in height from 213m O.D. at Hern Head (SE 907 879) to 244m O.D. in the northern part of square SE 90 91. This particular dip slope facet, whose surface is free from dissection by valleys, is covered by several extensive areas of ice-wedge polygons. South of Trouts Dale and the River Derwent, the dip slope ranges in height from 30.5m O.D. to 221m O.D. near Brompton Moor House (SE 933 888). It is regularly incised by a series of valleys, some of which contain streams, e.g. Sawdon Dale and one of which (Wy Dale) breaches the northern watershed. In the east the watershed and dip slope is breached by Forge Valley which carries the River Derwent through into the Vale of Pickering.

East of Forge Valley, the dip slope rises from the 30.5 contour in the south to over 175 m. O.D. on Seamer Moor (TA 00 89) and extends eastwards to Seamer Valley which is also a watershed breach. East of Seamer Valley, Oliver's Mount is a continuation of the dip slope which itself is separated from the most easterly of the three facets by Deep Dale. The third facet terminates in coastal cliffs at the north-western end of Cayton Bay. Of the three areas, the first mentioned has the closest network of dry valleys and below 84 m. O.D. displays a system of glacial drainage channels some of which are continuous with those on Oliver's Mount. Along the northern scarp, ice-wedge polygons are present above 137 m. O.D.

North-east of the River Derwent the Hackness-Suffield dip slope area ranges in height from about 152 m. O.D. around Suffield Ings Farm (SE 982 893) to over 221 m. O.D. in the north-west (SE 94 94). The area is intensely dissected by Low Dales Beck and Cross Dales Beck and their respective tributaries. At the head of the northern and eastern scarp slopes, ice-wedge polygons have been reported. They also occur on Lang Dale Rigg, an outlier of this surface, which exists to the west of Lang Dale.

(G) EASTERN MOORLAND - NORTH OF LOWER CALCAREOUS GRIT SCARP

West of Jugger Howe Beck and Biller Howe Dale a large tract of monotonous peat covered moorland rises to over 297 m. O.D. at Stony Leas (SE 887 992). East of the two dales an extremely complex area of glacial drainage channels exists, stretching from Low Moor (NZ 91 03) in the north to Cloughton (TA 00 94) in the south. They trend approximately north-south and drained southwards into Harwood Dale. The highest point (265 m. O.D.) is in the north at NZ 970 012. The remainder of the area does not rise much above 213 m. O.D. and is frequently lower. Till is not extensively distributed in the region of the channels, though it is more widespread to the south of Cloughton, being thickest beneath Scarborough.

(H) ROBIN HOOD'S BAY

This forms a distinctive topographical unit being basically half of a dissected dome, so that the bay itself is entirely surrounded by high land. Below the 152.4 m. contour, till is quite extensive becoming thicker with decreasing height, forming a relatively level plain below 61 m. O.D. Post-glacial drainage systems have become deeply incised within the plain e.g. Mill Beck. In the coastal sections, the entire glacial succession, which rests on Liassic Shale, is exposed.

Fig. 2 shows the major physical features of north-east Yorkshire and gives a three dimensional view of the topographical components outlined in Fig.1. Key features and places are labelled; other details may be recognised by referring to Fig.1.

CHAPTER III - COASTAL STRATIGRAPHY

(1) INTRODUCTION

Glacial deposits occur almost continuously along the north-east Yorkshire coast from Flamborough Head to Robin Hood's Bay. In the lowland areas, e.g. Filey Bay, Robin Hood's Bay, occasional complete in-situ exposures show the full Devensian sequence. Where accessible these have been accurately measured by means of a Paulin aneroid and tape, and are figured in the text. Much of the coastal exposure is obscured by vegetation and slipped masses of till making correlation between measured sections difficult. However, this problem has been partially overcome by recording exposures which are occasionally revealed beneath the slipped masses and these too are figured in the text. For the same reason, long sections of the cliffs are not presented, with the exception of parts of Filey Bay when they are used to illustrate the complex lateral variations that occur within the till over short distances.

The following description of the coastal stratigraphic succession is based on observations carried out between January 1974 and October 1976. It is not a definitive account, but has proved to be sufficient to form the basis for a moderately detailed sub division of the coastal tills of north-east Yorkshire. The entire coastal outcrop is very mobile and in order to elucidate the stratigraphy it is necessary to repeatedly re-visit the coast, walking the entire length many times over, especially after periods of bad weather, in order to observe the ever-changing cliffs and record the short-lived exposures. Many of the exposures have been accurately measured though this has not always been possible due either to inaccessibility or to the danger of approaching them especially in the wet winter months when the cliffs are particularly unstable.

(2) TECHNIQUES

In this chapter, a qualitative description of each exposure, based on field notes, is accompanied by details of (A) Munsell colour, (B) Mechanical analysis, (C) Pipette analysis. Each locality is individually presented in a systematic fashion.

(A) MUNSELL COLOUR

Small representative samples were allowed to air-dry in the laboratory for several days. The samples were then moistened with water until the rapid uptake of water by the dry sample ceased. The moist Munsell colour was noted at this point. By this method, it has been possible to measure the moist Munsell colours under reasonably consistent moisture conditions, which is not always possible in the field. All Munsell colours throughout this work refer to samples treated in this way.

(B) MECHANICAL ANALYSIS

Mechanical analysis have frequently been used for correlating and distinguishing between tills (e.g. Krumbein 1933, Shepps 1953). In East Yorkshire, Bisat (1948) used crude mechanical analysis to measure the sand and silt content of the till. More extensive observations were made by Catt (1963) and more recently by Madgett (1975). North of Flamborough Head, no systematic investigations of the particle size distribution of the tills have been previously performed.

(i) SAMPLING

Fresh representative bag-samples of till were collected in the field. However, due to the extreme range of particle sizes within the tills, the samples are not considered to be wholly representative of the coarse end of the particle size scale. They are considered to be representative of the content of the till finer than very coarse sand (B.S. 12 mesh sieve).

(ii) METHOD

About 150 grams of till were oven-dried at 105^{o}C for 24 hours and then allowed to equate with room temperature in a desiccator. The sample was then weighed to 0.01 grams and placed in a plastic container with excess water and gently rotated on a tumbler until the clay was dispersed. The suspension was then wet-sieved through a B.S. 240 mesh sieve, the material retained on the sieve being dried thoroughly in a 105°C oven. It was then allowed to cool and dry-sieved through the following sieve sizes on a ro-tap shaker for 15 minutes :-

B,S. Mesh Sieve No.	Microns	Phi Intervals
8	2000	-1
12	1500	
16	1003	0
22	750	
30	500	+1
44	375	
60	251	+2
85	178	
120	124	+3
170	89	
240	76	+4

Each sieve fraction was weighed, the total being subtracted from the original dry sample weight to give the weight of silt and clay lost through the B.S. 240 mesh sieve. The resulting data illustrate the differing particle size properties of the tills best when displayed as distribution curves . These are figured in the text.

(iii) RESULTS

Visual observations in the field, coupled with Munsell colour evidence suggest that there is a two-tier till succession in north-east Yorkshire, within which various textural and lithological variations occur. This view is further supported by the results of mechanical analysis. When data are plotted as a cumulative frequency curve, the Lower and Upper Tills are broadly similar. Due to within-till variation, the two curves frequently overlap each other hence it is not possible to distinguish between Upper and Lower Tills on the form of the curve alone. Further difficulties arise regarding the starting point of each curve which is entirely dependent on the weight of material held on the B.S. 8 mesh sieve. Consequently, distribution curves have been used to distinguish between the Upper and Lower Tills. The lower Till Series invariably shows a decrease in the very fine sand fraction over the fine sand fraction. However, where an increase is shown, the curves show that this is modal displacement to the right and that the B.S. 170 mesh sieve contents always exceed the B.S. 240 mesh sieve contents. It is this mode within the fine/very fine sand fraction that has led earlier workers, e.g. Bisat (1948) to describe the Lower Till Series (Holderness, Skipsea) as a sandy till.

The Upper Till Series has a mode which occurs in the clay/silt fraction, further to the right than the Lower Till Series. This is in accord with visual observations which reveal the Upper Till Series to be soft and plastic, suggesting a high clay content in the matrix. Consequently the curves for the Upper Till Series reveal an increase in weight in the very fine sand fraction over the fine sand fraction.

(C) <u>PIPETTE ANALYSIS</u>

(i) <u>METHOD</u>

Pipette analyses are best performed with about 15 grams of clay dispersed in 1 litre of water. In order to achieve this, about 25 grams of till was oven-dried at 105°C for 24 hours, then allowed to cool in a desiccator and weighed to 0.0001 grams. It was then dispersed on a rotary tumbler and wet-sieved through a B.S. 240 mesh sieve; the sand and gravel retained on the sieve was dried and weighed. The sum of this was subtracted from the original sample weight to find the weight of silt and clay which had passed through the sieve. The clay and silt suspension was then treated with TSPP and placed on a rotary tumbler for 24 hours and then allowed to stand overnight to ensure complete dispersion. It was then carefully washed into a measuring cylinder, de-ionised water being added to make the volume up to precisely 1 litre. The temperature of the suspension was noted (sampling being temperature dependent) and it was then thoroughly stirred to ensure complete random dispersal of all the particles and then allowed to stand without disturbance whilst sampling was in progress. Samples were carefully extracted by means of a 25 cm^3 pipette from a depth of 200 mm (with the exception of 9 phi which was sampled at 80 mm) at time intervals corresponding to whole phi intervals in the range 4 - 9 phi, according to the water temperature. The sedimentation times are based on Stoke's Law and for a given particle size, decrease with increasing temperature. The fractions removed were carefully washed into beakers and oven-dried for 24 hours at 105^{o}C, allowed to cool in a desiccator and then accurately weighed. The beakers were then washed and dried and re-weighed, simple subtraction giving the weight of material removed in each pipette withdrawal. The weight of these 25 cm^3 fractions was then multiplied by 40 to determine the weight of each size fraction dispersed in 1 litre of water and hence in the original sample. The figures were individually adjusted for the amount of TSPP added. Each withdrawal of the pipette measures the weight of material still in suspension above the sample level, hence the initial withdrawal should give the total weight of clay and silt in the suspension as this is measuring the weight of material finer than the B.S. 240 mesh sieve which corresponds to 4 phi. The discrepancy between the weighed and calculated values of dispersed material was in the order of 4% which is within the limits of experimental error.

(ii) RESULTS

Cumulative frequence curves constructed from the data obtained during this study have proved to be not particularly instructive or useful for correlation purposes. Curves for the Upper and Lower Till Series overlap to such an extent that it is not possible to determine a particular till from its particle size curve. However, the data is most useful when expressed as $\frac{\%\ \text{Sand}}{\%\ \text{Sand} + \%\ \text{Silt}}$ (S Ratio)

The percentage of sand is calculated from the weight of material held on the B.S. 240 mesh sieve during disaggregation of the original sample. Where this included material coarser than very coarse sand, this material was removed and the weights adjusted accordingly. The percentage of silt is the percentage of coarse silt calculated as a percentage of the total silt and clay. This is a modification of the technique used by Madgett (1975) which, north of Flamborough Head, does not yield the consistent results that he obtained in Holderness. However, using % coarse silt (4 - 6 phi). Madgett's technique is applicable to north-east Yorkshire and can be used as a reliable method for distinguishing between the Upper and Lower Till Series. Using the above formula, the Lower Till Series has values in excess of 49% whereas the Upper Till Series has values less than 49%.

In Holderness, Madgett found that 45% was the dividing line between Skipsea (Lower) and Withernsea (Upper) till. In Holderness, the pre-Quaternary basement is remarkably consistent, being composed entirely of chalk. North of Flamborough Head, solid lithologies change rapidly from Chalk to Mesozoic Clay to Jurassic limestones and deltaic lithologies. It is this lateral change in basement lithology over which the ice rode coupled with the fact that moving north one is traversing the flow lines of the far-travelled ice that causes the increase in the critical value for the $\frac{\%\ \text{Sand}}{\%\ \text{Sand} + \%\ \text{Silt}}$ ratio which distinguishes between Upper and Lower Till Series, and necessitates modification of Madgett's original formula. The above formula is rather cumbersome, henceforward for the sake of brevity this ratio will be referred to by the symbol 'S'.

(D) CARBONATE CONTENT

(i) AIMS

When fresh till is exposed to atmospheric weathering the immediate sub-aerial till is decalcified by the leaching effect of percolating water (Flint 1949). In Holderness (Catt 1963) showed that the carbonate content of till can be used as an indicator of warmer periods when ice retreated and the till was weathered by atmospheric processes. Thus he showed that the Basement (Wolstonian) till of Holderness has been affected in such a manner and that the overlying Skipsea and Withernsea till belong to a separate, younger ice advance (Devensian). Accordingly, the carbonate content of tills in north-east Yorkshire has been measured at certain sites in order to establish whether any leached horizons exist within the tills.

(ii) SAMPLING

Representative bag samples of about 300-400 grams were collected from each site, several centimetres below the till surface, thus ensuring that a fresh sample unaffected by rainwash was obtained.

(iii) METHOD

These were roughly broken up and oven dried for 24 hours at 105°C, then allowed to equate with room temperature. The till was ground up with a mortar and pestle, removing erratics in the process and passed through a B.S. 10 mesh sieve. About 200 grams were accurately weighed and treated with 3% hydrochloric acid. Each sample was frequently stirred and replenished with fresh acid until all effervescence ceased. The sample was then allowed to settle and the acid carefully siphoned off. The residue was washed with a fine jet of water and allowed to stand so that the water could be siphoned off. This was done five times in succession and was considered sufficient to remove all the dissolved carbonate. The sample was then oven-dried at 105°C for 24 hours and allowed to equate with room temperature and then weighed. The percentage of soluble carbonate in each sample was calculated from the percentage weight loss. As this was simply a reconnaissance study looking for marked reductions in carbonate content within the till sequence it was not considered necessary to use a more sophisticated technique such as that described by Bascomb (1961).

(iv) RESULTS

Table showing carbonate content (% wt) at specific sites. (Table II)

SITE 1 (TA 1470 7585)

Sample point	Carbonate content (%)	Height of Sample point(M)
12	10.14	56
11	9.75	48.1
10	10.65	46.9
9	7.55	45.7
8	8.06	45.1
7	8.47	44.2
6	8.50	41.4
5	10.59	35.6
4	10.61	32.9
3	11.13	31.2
2	11.64	30.9
1	12.11	30.7

SITE 2 (TA 1460 7585)

3	12.75	35.5
2	14.37	33.0
1	10.69	31.5

SITE 3 (TA 1445 7610)

8	10.29	32.3
7	9.55	28.0
6	10.77	25.5
5	11.97	23
4	12.27	21.3
3	11.05	20.1
2	13.07	18.6
1	21.37	17.1

SITE 4 (TA 144 762)

6	8.94	10.1
5	8.88	9.1
4	8.62	8.1
3	8.67	7
2	9.32	5.2
1	8.92	2.7

SITE 5 (TA 1403 7650)

5	7.54	14.9
4	7.83	11.9
3	8.56	9.8
2	10.27	3.8
1	9.66	2.7

SITE 6 (TA 131 773)

7	6.75	31
6	12.97	26.2
5	9.64	23.2
4	9.97	17.2
3	9.84	12.5
2	9.6	7.3
1	10.01	5.5

SITE 7 (TA 1250 8165)

8	3.42	40.5
7	9.78	37.9
6	15.36	31
5	12.54	23.2
4	10.31	19.8
3	11.95	14.6
2	8.57	10.7
1	10.79	6.7

(v) DISCUSSION

None of the sections analysed show decalcification of horizons within the till with the exception of weathered till at sites 6 and 7. The till sequences show a general increase in soluble material towards the base of the successions especially where the base has been sampled e.g. Site 3. This is because the basal layers of the Lower Till Series have incorporated into their matrix, quantities of chalk, originally derived from the chalk scarp by peri-glacial processes. Higher in the Lower Till succession, chalk erratics are less common and consequently the volume of solublematerial within the till decreases. Thus it is not possible to distinguish between the Upper and Lower Till Series on calcium carbonate content, as there is no marked break between the two.

Catt (1963) discovered that the Basement till in Holderness exhibited a leached surface, both visually and quantitatively. In north-east Yorkshire, a suspected streak of Basement till (Site 4) does not show leaching for two reasons. Firstly, it is not representative of the original leached surface of the Basement till and secondly, it is contaminated by incorporation of chalk erratics into the basal layers of the Lower Till Series in which it occurs. Unlike the chalky Skipsea till south of Flamborough Head the laterally equivalent Lower Till series to the north is not chalky throughout and consequently its overall carbonate content is lower; more akin to the Upper Till Series.

The weathered surface of the Upper Till Series shows a reduction in carbonate content illustrating the leaching process of post-glacial weathering and supporting the view that the weathered till is not a separate deposit, i.e. Hessle till (Madgett, 1976).

(E) OTHER TECHNIQUES

(i) X-RAY DIFFRACTION

(a) SAMPLING

Eight samples (about 200 grams each) of fresh till were collected from known horizons at six Holderness sites as follows :

TA 339 285 (weathered Withernsea till)

TA 206 487 (Skipsea till)

TA 182 552 (Skipsea till)

TA 303 333 (Withernsea till)

TA 257 396 (Skipsea till)

TA 400 204 (Withernsea till)

TA 400 204 (Skipsea till)

TA 400 204 (Basement till)

(b) METHOD

A small sub-sample (about 15 grams) was dispersed in de-ionised water on a rotary tumbler and then wet sieved through a B.S. 240 mesh sieve. The clay fraction was thus separated and several drops were removed by pipette and placed on a clean glass slide and allowed to dry at room temperature in a desiccator. The air dry slides were then scanned in an X-ray diffractometer under the following conditions:

40 Kv, 25 MA, Co radiation with Fe filter, Angle of scan $3^{o} - 30^{o}$, Rate of scan 1^{o} per minute, Attenuation 3, Time constant 4, Range 1×10^{3} c.p.s., Lower level 150, Window 200, Chart speed 10.

(c) RESULTS

The variable range in magnitude of individual clay mineral peaks causes extensive overlap of the traces of Withernsea and Skipsea till. Consequently it is not possible to distinguish between the tills on the pattern of the graph trace alone, and as both tills appear to contain the same constituent clay minerals, no diagnostic clay minerals have emerged from the study.

A further 40 samples were collected from coastal sites in north-east Yorkshire and treated in an identical manner. These too did not reveal any distinctions between the equivalents of the Withernsea and Skipsea tills (Upper and Lower Till Series). Heating of the samples to 300^{o} in order to collapse the expanding minerals to distinguish them from Chlorite did not produce any diagnostic results.

(d) CONCLUSION

It is not possible to distinguish between Lower and Upper Till Series on the shape of the trace or magnitude of individual peaks. Overlap between separate samples of the same till and between samples from the two tills is so great that a characteristic curve for each till does not emerge. This is in keeping with the results obtained from Munsell colour, particle size and textural observations which reveal strong lateral and vertical changes within each Till Series. Consequently, XRD analysis was abandoned as it did not readily yield results which would have been valuable for correlation purposes.

(ii) HEAVY MINERAL ANALYSIS

(a) SAMPLING

Heavy mineral crops were obtained from samples of till from the weathered horizon of each measured section in north-east Yorkshire.

(b) METHOD

Sub-samples (about 15 gm) of sand (1-4 phi) extracted during the course of mechanical analyses were treated with bromoform (specific gravity 2.9) in a separating funnel (Milner, 1962) in order to separate the heavy and light minerals. The heavy minerals were then washed in acetone and allowed to dry. The grains were then examined with the aid of a petrological microscope.

(c) RESULTS

The majority of grains were coated in a diagenetically precipitated oxide of iron making identification of the grains and the application of quantitative mineral analysis techniques impossible.

(d) CONCLUSIONS

The coat of iron oxide on individual grains rendered identification of minerals extremely difficult and uncertain. It also precluded the possibility of sub dividing the fractions by electromagnetism as the magnetic coat of oxide would adversely affect weakly magnetic minerals. It was found impossible to use heavy mineral analysis as a means of providing information for correlation purposes. The technique was abondoned in favour of those that were more productive for the purposes of this study.

(iii) POCKET PENETROMETER (CL 700) AND POCKET SHEARMETER (TORVANE)

Extensive field experiments with both of these instruments performed on tills in Filey Bay indicated that no replicable data could be obtained as the hardness and resistance to shear of the tills constantly changes in response to daily and seasonal weather fluctuations. In order to obtain reliable results, till samples would have to be tested in the laboratory under uniform conditions of temperature, humidity and moisture content. In view of these problems the techniques were abandoned.

TABLE 3 X.R.F. DATA

SAMPLE	SITE 1 B	SITE 1 H	SITE 6 C	SITE 6 D	SITE 19 B	SITE 19 D	SITE 44 B	SITE 44 C
METHOD	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF
S_1O_2	52.76	54.55	55.87	54.74	55.26	55.50	55.67	57.03
Al_2O_3	18.41	17.04	16.63	16.66	16.46	17.55	18.20	19.69
T_1O_2	0.96	0.92	0.98	0.90	0.94	0.92	1.09	1.04
Fe_2O_3	4.68	4.23	4.08	3.82	4.14	4.73	4.06	6.50
FeO	1.80	1.90	1.75	2.22	1.61	1.48	1.66	0.77
MgO	2.92	2.87	2.62	2.83	2.99	2.66	2.46	1.73
CaO	3.36	3.91	3.47	4.04	3.94	3.55	2.82	0.47
K_2O	3.00	2.94	2.67	2.81	2.71	3.05	2.85	3.23
MnO	0.06	0.05	0.05	0.07	0.07	0.06	0.04	0.06
P_2O_5	0.16	0.15	0.14	0.15	0.14	0.14	0.13	0.08
S	0.14	0.31	0.29	0.39	0.14	0.12	0.24	0.02
Fe_2O_3	6.68	6.34	6.02	6.288	5.93	6.37	5.90	7.36
L.O.I.	10.62	9.60	9.95	9.52	9.73	9.97	10.03	8.23

(iv) X-RAY FLUORESCENCE

(a) SAMPLING

The following samples were subjected to XRF analysis

Site 1 (B)	Site 19 (B)
Site 1 (H)	Site 19 (D)
Site 6 (C)	Site 43 (B)
Site 6 (D)	Site 43 (C)

(b) RESULTS

See Table 3

(c) CONCLUSIONS

The data obtained shows no diagnostic trends for either Till Series. Despite the marked colour differences between the Till Series, XRF failed to reveal any particular element responsible for the differences which are quantifiable by Munsell Colour notation. It is beyond the scope of this work to investigate the colour difference any further save to state that it is a reliable indicator of provenance when coupled with particle size data.

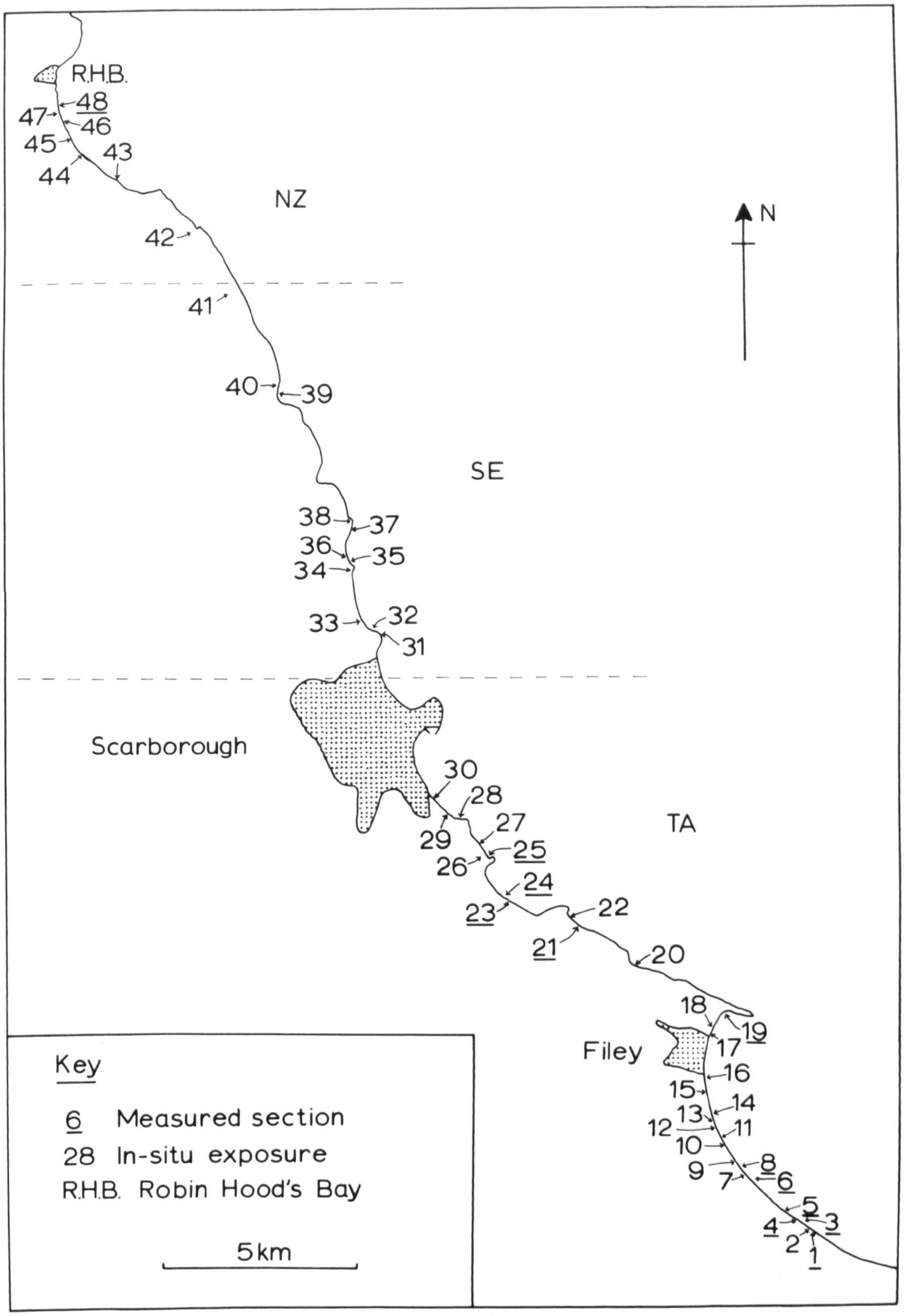


Fig.3. MAP TO SHOW DISTRIBUTION OF COASTAL LOCALITIES

(3) DESCRIPTION OF SITES

The coastal stratigraphy is described from south to north. The first 19 sites are in Filey Bay, the next 11 between Filey Brigg and Scarborough, 12 lie between Scarborough and Ravenscar and 6 are in Robin Hood's Bay (fig. 3).

At the southern end of Filey Bay there exists some of the most complete coastal exposures in the area and these reveal very complex stratigraphical relationships with much lateral variation over a distance of about 1 km. (see fig. 15). Site 1 is the most south easterly exposure in Filey Bay and provides the starting point for the long section shown in fig. 15. In all sections the till beds are numbered from the base upwards and are described systematically in the text. There is no implied correlation of till numbers. The sections figured in the text include Munsell colour notations and occasionally carbonate content expressed as % weight. These are discussed later.

SITE 1 (fig. 4)

(A) The base of the succession consists of an extremely hard, compact till (T1) about 7m. thick resting on the angular chalk gravel which forms the top of the Speeton Shell Bed. 35 cm. above the base of the till there is a 10 cm. thick greenish band (5Y3/1) which is associated with a thin Mesozoic clay/shale erratic and a thin layer of brownish-yellow sand. It is underlain by a warmer brown till (10YR2/2) which has a clay-rich plastic matrix and becomes darker towards the base, containing many very well-rounded, and therefore secondarily derived, igneous erratics.

Above the greenish band, the till is warmer in colour ranging from 10YR3/2 to 10YR4/2. The matrix is sandy and the well-rounded igneous

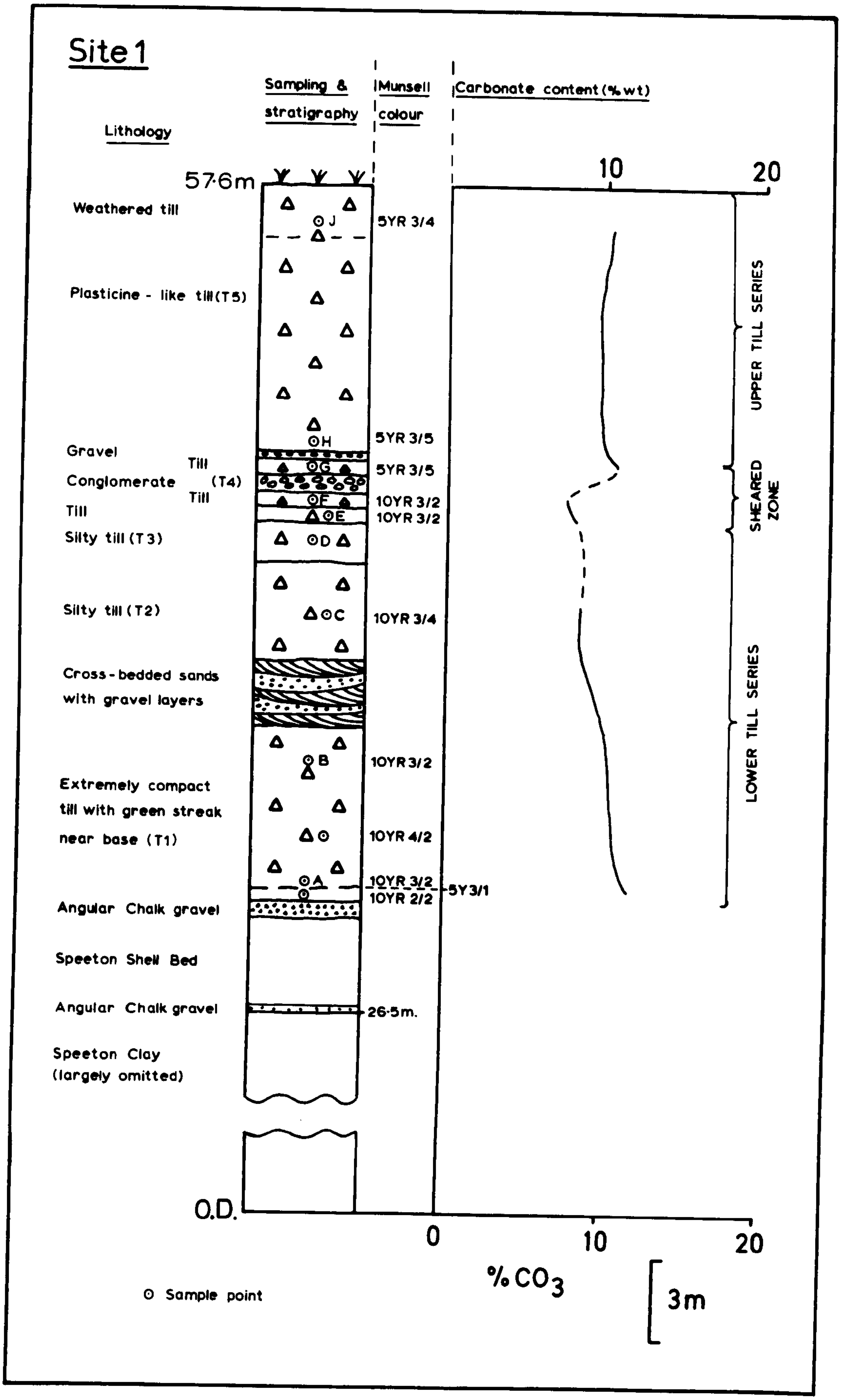


Fig. 4. MEASURED SECTION: SITE 1 (FILEY BAY)

erratics are less numerous.

Within the lowermost metre of this basal till unit, angular chalk erratics are numerous and account for the increase in carbonate content towards the base of the till. These angular chalk fragments have been incorporated into the basal till by ice advancing over a pre-existing peri-glacial surface which is confirmed by the presence of about 0.6m. of angular chalk gravel (see chapter X) above the Speeton Shell Bed and directly below this basal till.

The basal till is interpreted on the basis of Munsell colour and particle size data as being equivalent to the Skipsea till of Holderness. By the same count, the greenish streak of till which it contains is probably re-worked Basement till (Wolstonian). The secondarily derived igneous erratics were probably brought into the area by the Wolstonian glaciation and have been incorporated into the sole of the Devensian ice sheet along with occasional streaks of Basement till and chalk gravel.

Above T1, there occurs 2m. of water-lain sand and gravel in which planar beds dip at about 10-15^{o} to the north-north-east. Occasional foresets indicate a current direction of 027^{o} suggesting that water was draining towards the north-east either within or beneath the ice. The entire sand and gravel unit is faulted and slumped on a small scale, the disturbances being associated with depressions in the bedding and probably originating by the melting of buried ice within the sand and gravel. The faulting, which is a common feature of glacial sands and gravels in north-east Yorkshire, is due to post-depositional compaction.

An extremely tough and compact till (T2) overlies the sand and gravel. It is 4m. thick and lithologically similar to the upper part of the underlying till. It contains some chalk erratics set in a silt/fine sand matrix and has a 10YR3/4 Munsell colour. Above this is 1.3m. of very compact till (T3) with a fine sand/silt matrix within which erratics are infrequent. Both T2 and T3 are part of the Lower Till Series. The overlying till unit (T4) comprises five distinctive beds which are described in ascending order :-

(i) 0.6m of warm brown till (10YR3/2) with a fine sand/silt matrix containing small angular erratics.

(ii) 0.6m of darker coloured till though still 10YR3/2 with a fine sand/silt matrix.

(iii) 0.6m of boulder conglomerate.

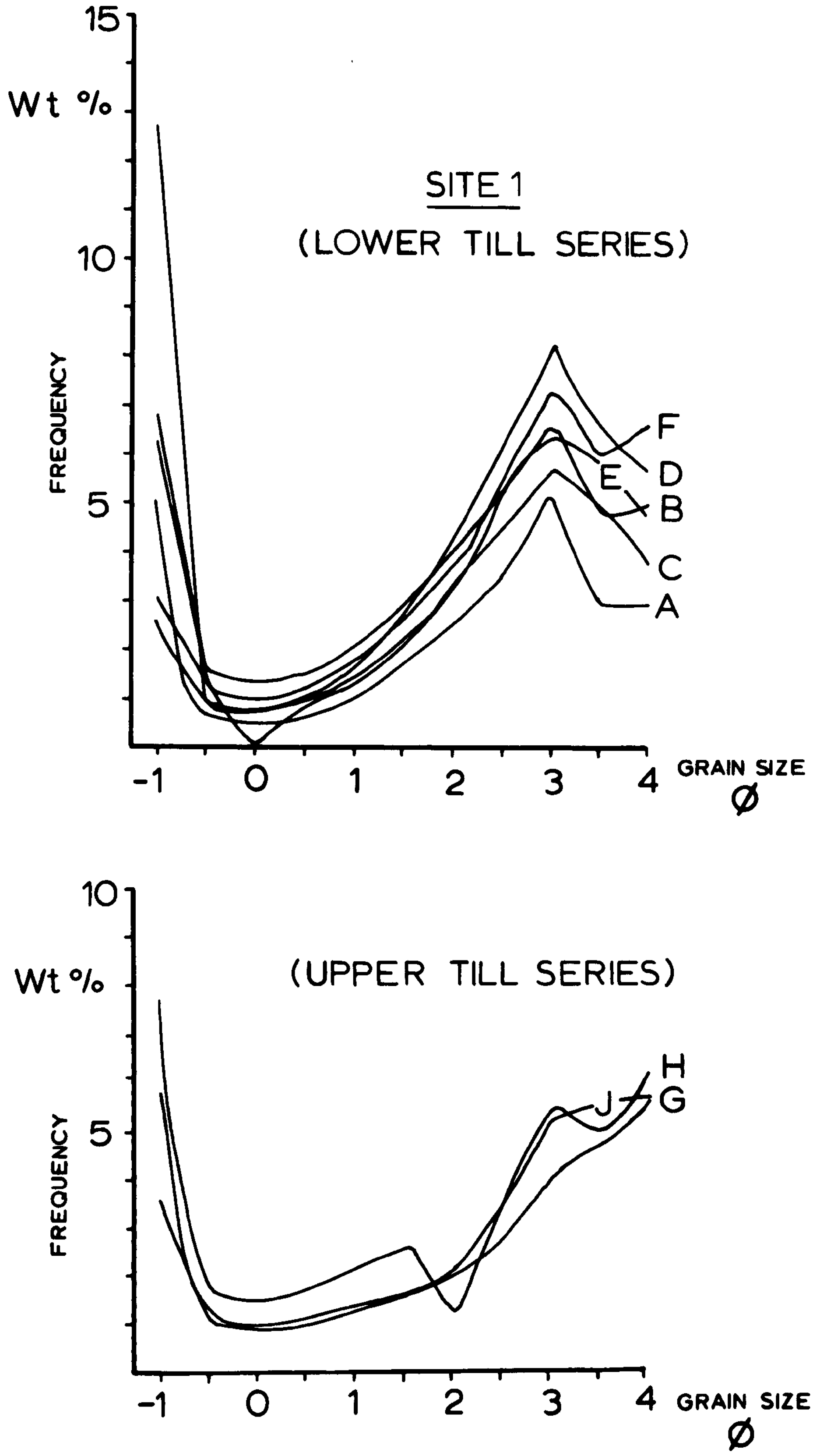
(iv) 0.6m of reddish-brown till (5YR3/5) containing small erratics in a clay/silt matrix which is very soft when wet.

(v) 0.3m of gravel separates (iv) from the 10m thick topmost till.

This five-tier succession is interpreted as thrust slices of melt-out till formed by the shearing processes which occurred between the lower and upper ice masses. The conglomerate is taken as the base of the upper ice mass and therefore is part of the Upper Till Series. It is apparent that the shearing processes occurred in a zone both above and below the actual boundary, which is based on the Munsell colour change and the change in lithology.

The topmost till is reddish-brown (5YR 3/4 - 3/5) with a high clay content in the matrix making it soft when wet. It contains many north-east English erratics, including coal, some of which are quite large. This till is not as well consolidated as the underlying Lower Till Series (≃ Skipsea till of Holderness) and represents melt-out till from the upper ice sheet and is equivalent to the Withernsea till of Holderness. The top 2m. shows vertical blue-faced joints and an increased fine sand content in the matrix which is a weathering phenomenon involving the downwards leaching of clay particles, hence a relative increase in the fine sand content which is complemented in real terms by the weathering of sandstone erratics (Mitchell and Jarvis 1956).

Fig.5. PARTICLE SIZE DISTRIBUTION CURVE



(B) MECHANICAL ANALYSIS (fig. 5)

Curves A - E represent the Lower Till Series (T1, T2, T3) and exhibit a mode which typically lies between the fine and very fine sand fractions (B.S. 120 mesh sieve). Curves F and G are of samples taken from the sheared zone of the sequence (T4 ii and T4 iv). They show an increased silt content producing a mode within the silt and in the case of sample F, a minor peak on the B.S. 120 mesh sieve. This increase in fine material reflects the shearing action that occurred between the two ice sheets. Curves H and J (T5) represent the Upper Till Series, H showing a minor peak on the B.S. 120 mesh sieve due to a quite high fine/very fine sand content. J (weathered till) does not show this subsidiary peak, probably due to chemical weathering breaking down the fine sand and enriching the silt content. This chemical weathering particularly affects the feldspar content of the till which is deposited in a fresh state due to the cold nature of the transportational and depositional environments. (McGown, A., Anderson, W.F., and Radwan, A.M., 1975)

(C) PIPETTE ANALYSIS

The Lower Till Series is characterised by S values in excess of 53%. Within the Lower Till Series the streak of Wolstonian till is distinguished by an S value of 46% thus supporting Munsell colour evidence which suggests the till is not Devensian. Between the Upper and Lower Till Series, S values range between 47% (T4(i)) and 52% (T4(iv)), indicating a shear zone in which Lower Till Series overlies Upper Till Series. The Upper Till Series is characterised by values well below 49% (41% and 32%).

SITE 2 (fig. 6)

(A) The base of the exposure reveals an extremely compact till (T1) with a silt/clay matrix containing quite well-rounded chalk erratics.

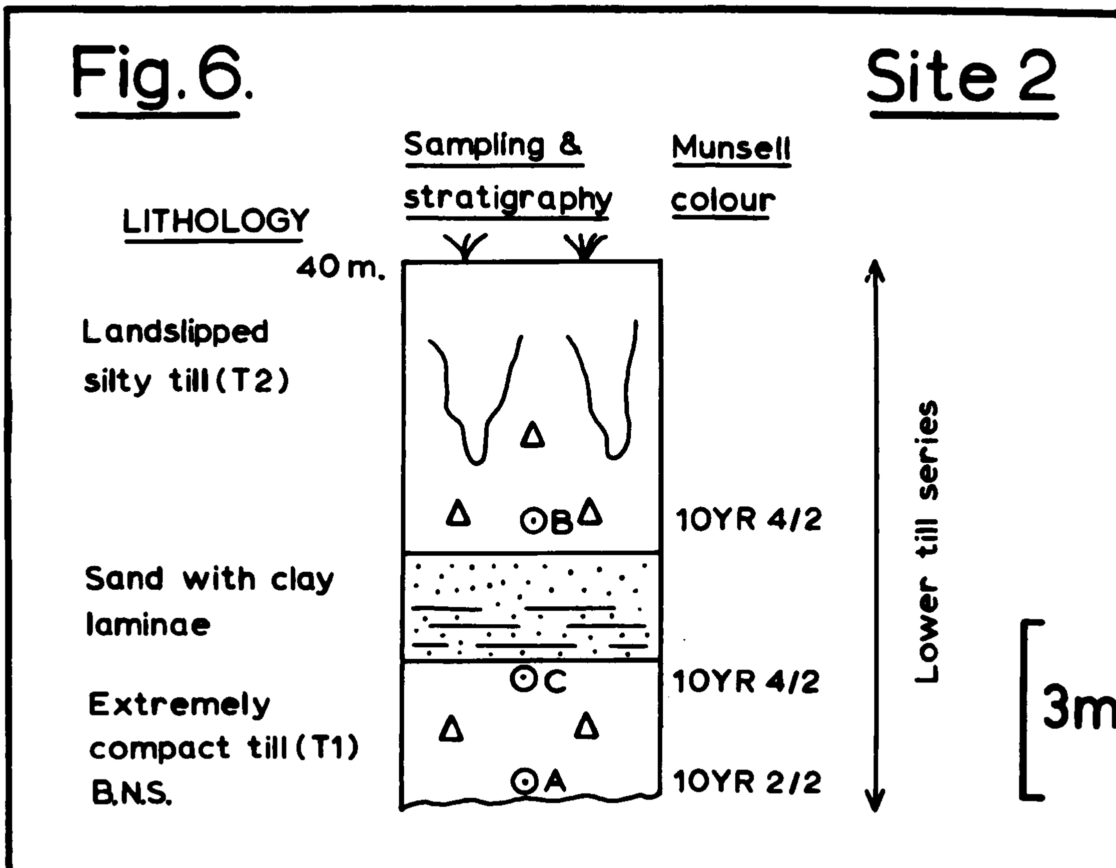


Fig. 6.
Site 2
LITHOLOGY
Sampling & stratigraphy
Munsell colour
40 m.
Landslipped silty till (T2)
B
10YR 4/2
Sand with clay laminae
C
10YR 4/2
Extremely compact till (T1) B.N.S.
A
10YR 2/2
Lower till series
3m

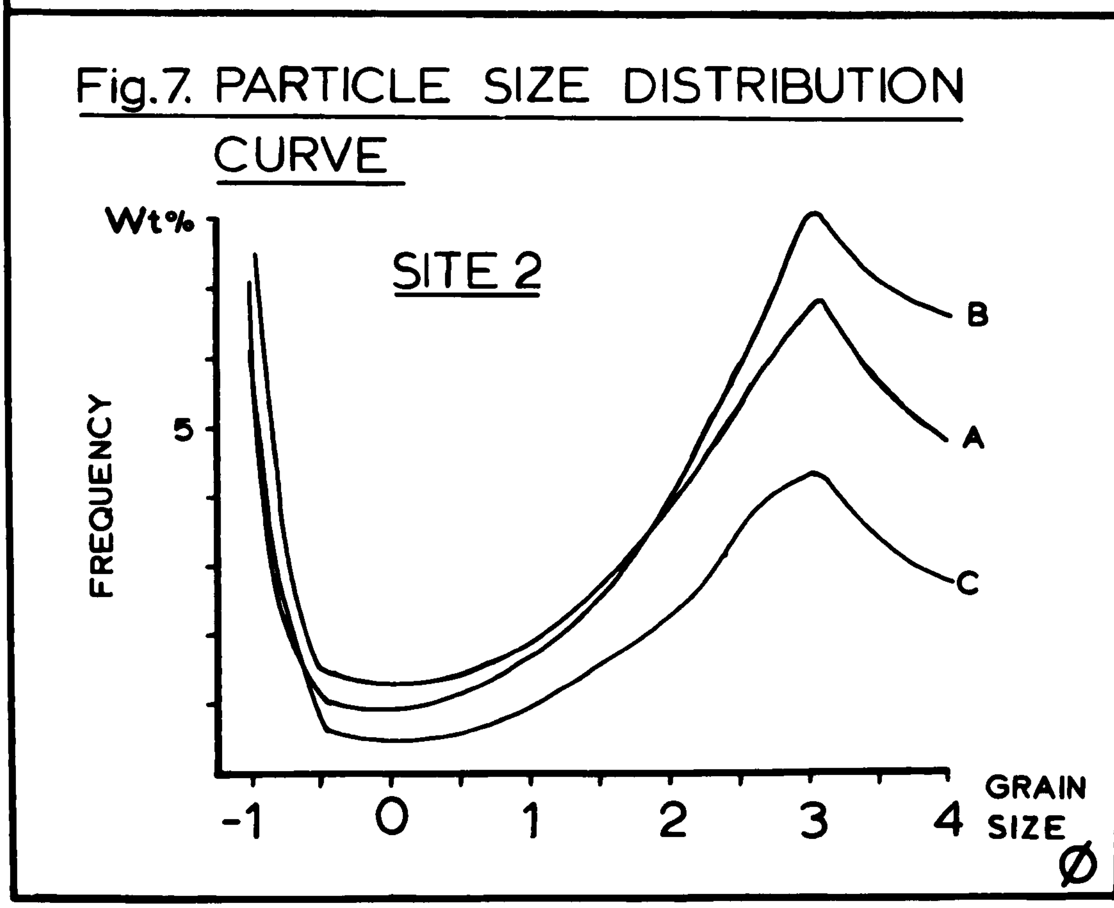


Fig. 7. PARTICLE SIZE DISTRIBUTION CURVE
SITE 2
Wt%
FREQUENCY
5
-1
0
1
2
3
4
GRAIN SIZE Ø
B
A
C

Near the base of the till a raft of Mesozoic clay/shale occurs and 15cm above this there lies a 7.5 cm thick band of angular and sub-angular chalk fragments. The presence of these features plus a Munsell colour notation of 5Y3/1 all indicate the nearness of the base of the till and suggest correlation with the lowest till (T1) at Site 1.

3m of waterlain sand and gravel separate this till from the one above (T2). The lower 2m of the fluvial beds consist of alternate sand and stoneless clay laminae. The sand laminae, some of which display small scale delicate fluvial structures, are up to 7.5 cm thick whereas the clay laminae do not exceed 4cm. The topmost metre of the sequence consists of massive gravel, the entire unit correlating with the sand and gravel between T1 and T2 at Site 1.

T2 is a hard, compact till (10YR 2/2) with small erratics set in a silt/fine sand matrix. It forms the cliff top and is equivalent to T2 at Site 1.

(B) <u>MECHANICAL ANALYSIS</u> (fig. 7)

Curves A - C (A = T1, B = T2, C = T1) all display a mode within the fine/very fine sand fractions consistent with the two tills exposed at this locality being of the Lower Till Series, as indicated by Munsell colour and field observations.

(C) <u>PIPETTE ANALYSIS</u>

T1 and T2 both exhibit high S values (61% and 73% respectively) indicating Lower Till Series.

<u>SITE 3</u> (fig. 8)

(A) The lowest exposed part of the succession is composed of an extremely hard and compact till (5Y3/1). Numerous small sub-angular chalk erratics and some large secondarily-derived, polished, igneous

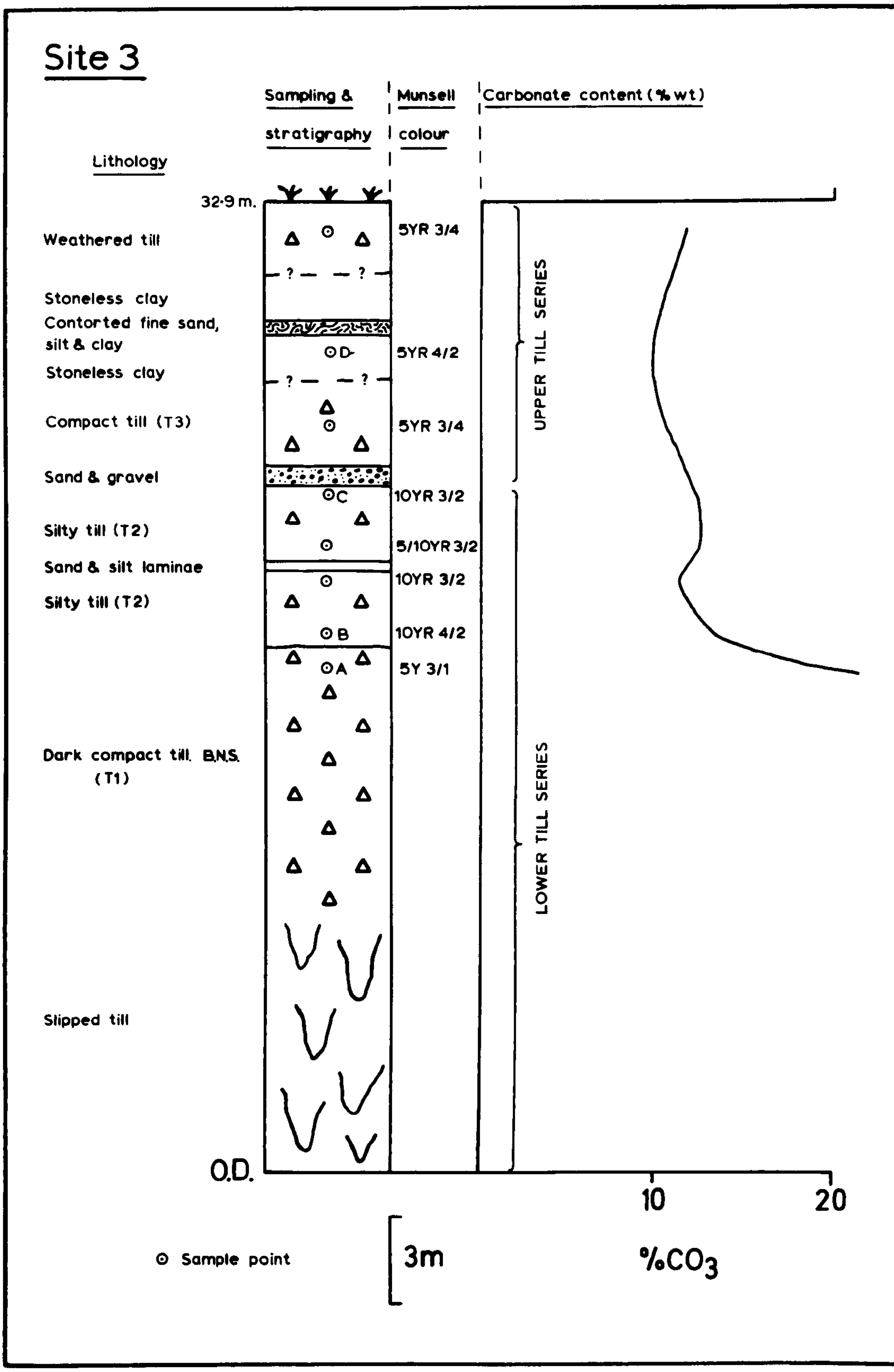


Fig.8. MEASURED SECTION: SITE 3 (FILEY BAY)

erratics are set in a silt-clay matrix. This lowest till (T1) contains streaks of Mesozoic clay/shale and, along with the features mentioned above, indicates that the deposits have been derived from the basal zone of shear planes within the ice thus indicating the nearness of the base of the succession. The till correlates with the lowest tills of sites 1 and 2.

This basal till is overlain by a hard, compact till (T2) with occasional small erratics set in a silt/fine sand matrix. The Munsell colour varies from 5YR - 10YR 3/2 to 10YR 4/2. The till is fissile and exfoliates parallel to the exposure surface. It contains a 30cm thick persistent band of till, silt and sand at 20.7 m OD. The unit comprises 5cm of sand and fine gravel overlain by 7.5 cm of till, this being overlain by 17.5 cm of very finely laminated silt and sand. Above T2, 45cm of coarse massive gravel is overlain by 15cm of planar sand and silt laminations interspersed with occasional leaves of clay. This sequence divides the Lower (T1 and T2) and Upper (T3) Till Series though there is no sign of shearing between the two units.

Above the sand and gravel there is a soft plastic till (T3) with a clay/silt matrix containing sub-angular north-east English erratics including coal and New Red Sandstone. Within T3 there is a 4m thick bed of stoneless, soft laminated clay (5YR 4/2). Within this stoneless clay there is a 0.5m thick bed of severely contorted silt and clay laminations which show injection structures (fig.10), produced during a mobile phase of the melting process. The stoneless clay containing this band is overlain by 2.5m of weathered till (5YR 3/4) and is identical in colour to that which underlies the stoneless clay.

The sands and gravel exposed here at 22.8m O.D. are equivalent to those at 37.5 m O.D. at Site 1, thus T3 here correlates with T5 at Site 1.

Fig.9. PARTICLE SIZE DISTRIBUTION CURVE

(SITE 3)

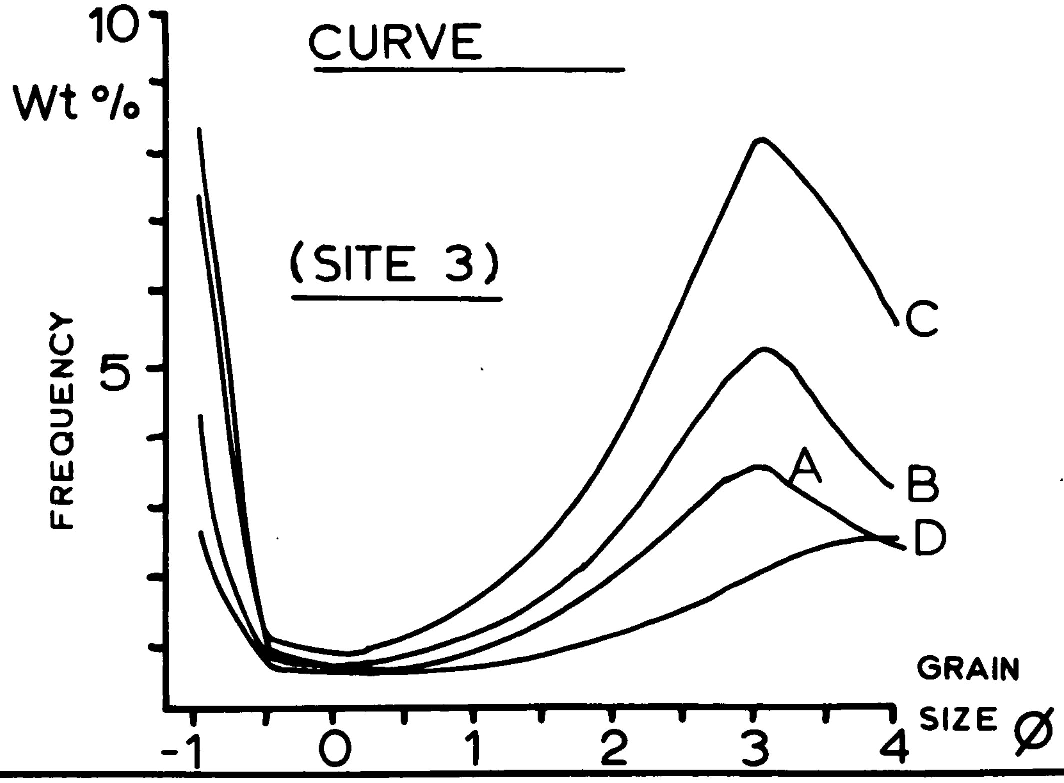
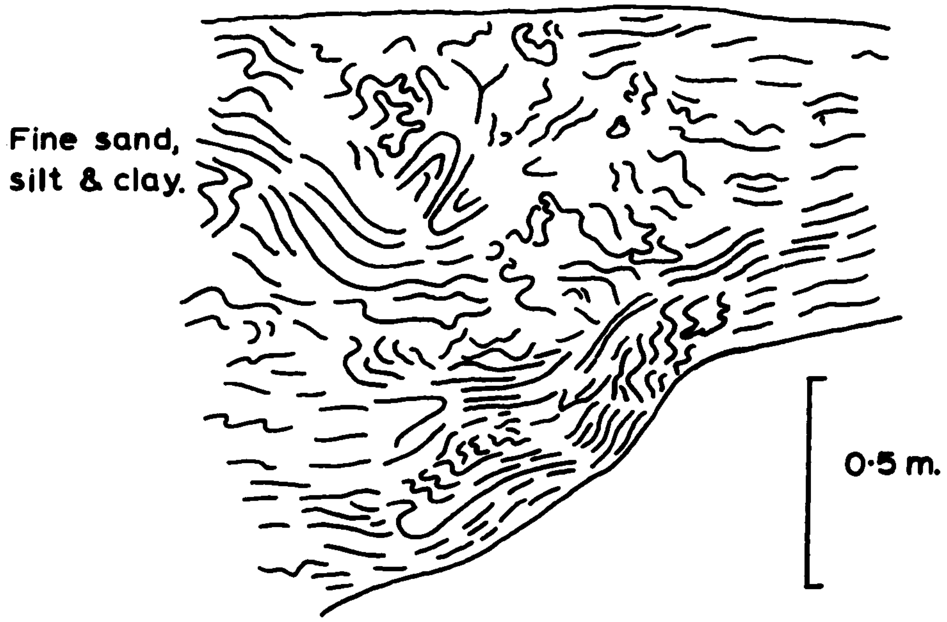


Fig.10. SKETCH OF DEFORMATIONAL STRUCTURES AT ABOUT 29 m. O.D. (SITE 3)



At Site 2 this upper till is absent (see figs. 6 and 15).

(B) MECHANICAL ANALYSIS (fig. 9)

Curves A - C (T1 and T2) represent the Lower Till Series, displaying the characteristic fine/very fine sand mode of this till at other sites. Curve D (T3) is of very different character indicating a till in which the mode lies within the clay-silt fraction. This is in accord with the Upper Till Series, to which this sample belongs.

(C) PIPETTE ANALYSIS

The upper half of T2 indicates Lower Till Series with S values of 60% and 54%. However the lower half of T2 and T1 both provide anomalous S values which range from 25% to 46% and contradict Munsell colour, textural and field observations all of which indicate Lower Till Series. An S value of 42% for T3 confirms that the Upper Till Series is present though the high value of the weathered till (57%) is anomalous and considered to be an indicator of weathering which has produced marked changes in the particle size distribution within the till.

SITE 4 (fig.11)

(A) Immediately south-east of The Gill a near-vertical exposure about 11.3 m high reveals a compact till (T1) containing quite well-rounded and polished, secondarily-derived igneous erratics and small sub-angular chalk fragments set in a clay-silt matrix. The till is quite highly contorted and contains stoneless, fine sand-silt layers. At 3.4m O.D. it is overlain by 2m of compact till (T2) with occasional small erratics set in a fine sand-silt matrix, and which contains several small sand lenticles. T2 is overlain by about 2.5m of sandy till (T3) in which erratics are rare. All three tills have a consistent Munsell colour of 10YR 2/2.

At 6.1 m O.D. they are overlain by 0.5m of cross-bedded sands which

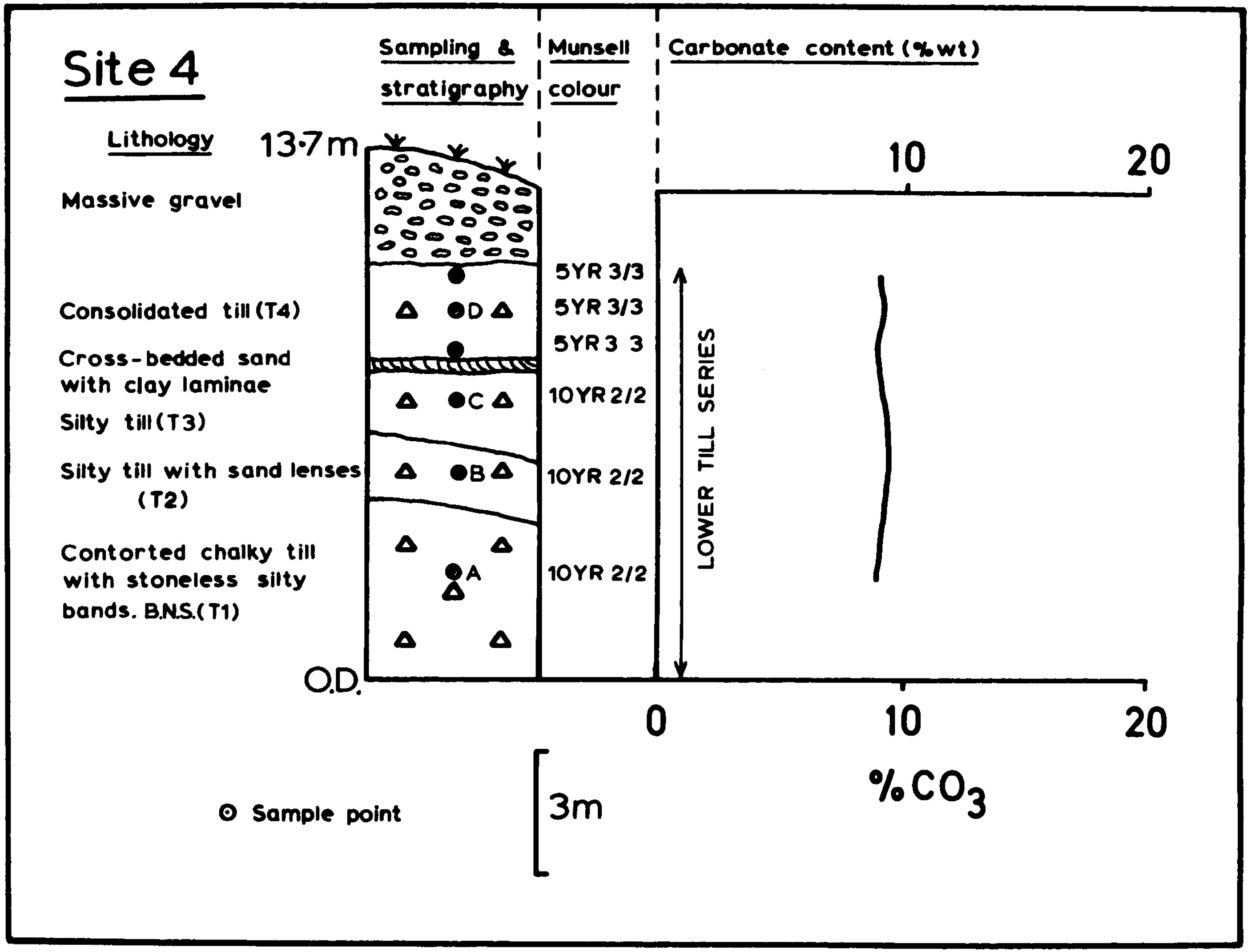


Fig.11. MEASURED SECTION SITE 4 (FILEY BAY)

contain thin clay laminae. These are overlain by 2.5m of reddish till (T4) (5YR 3/3) which contains small erratics set in a fine sand-silt matrix. T4 is overlain by more than 3m of massive torrential gravel. The lithology of this topmost till, coupled with occasional glimpses of the stratigraphy between Sites 3 and 4 suggest that the sequence exposed here lies wholly within the Lower Till Series (see fig. 13).

(B) MECHANICAL ANALYSIS (fig. 13)

Curves A - D (T1 - T4) all display a fine-very fine sand mode which is characteristic of the Lower Till Series and in accordance with Munsell colour and field evidence. The two lower most tills are virtually stoneless as shown by curves A and B.

(C) PIPETTE ANALYSIS

S values in excess of 60% indicate that all four tills are members of the Lower Till Series.

SITE 5 (fig. 12)

(A) At beach level, 4m of compact till (T1, 10YR 3/2) with a fine sand-silt matrix which contains reasonably numerous sub-rounded and sub-angular erratics is overlain by 1m of sand, silt and gravel. This comprises 30 cm of coarse gravel overlain by 70 cm of current bedded sand and silt, the upper 30 cm of which contains thin clay partings and displays structures due either to squeezing or injection whilst in a fluid state. These fluvial beds are overlain by 1m of stony till (T2) similar to that at the base, though slightly reddened (5YR 3/3).

3m of interbedded fine and coarse sand and gravel overlies T2. Each unit displays massive bedding and never exceeds 15cm in thickness, and frequently much less. Colour, lithology and stratigraphic succession suggest this sequence is the lateral equivalent of T3 and T4 at Site 4 and confirm that the Site 4 exposure lies wholly within the Lower ill eries.

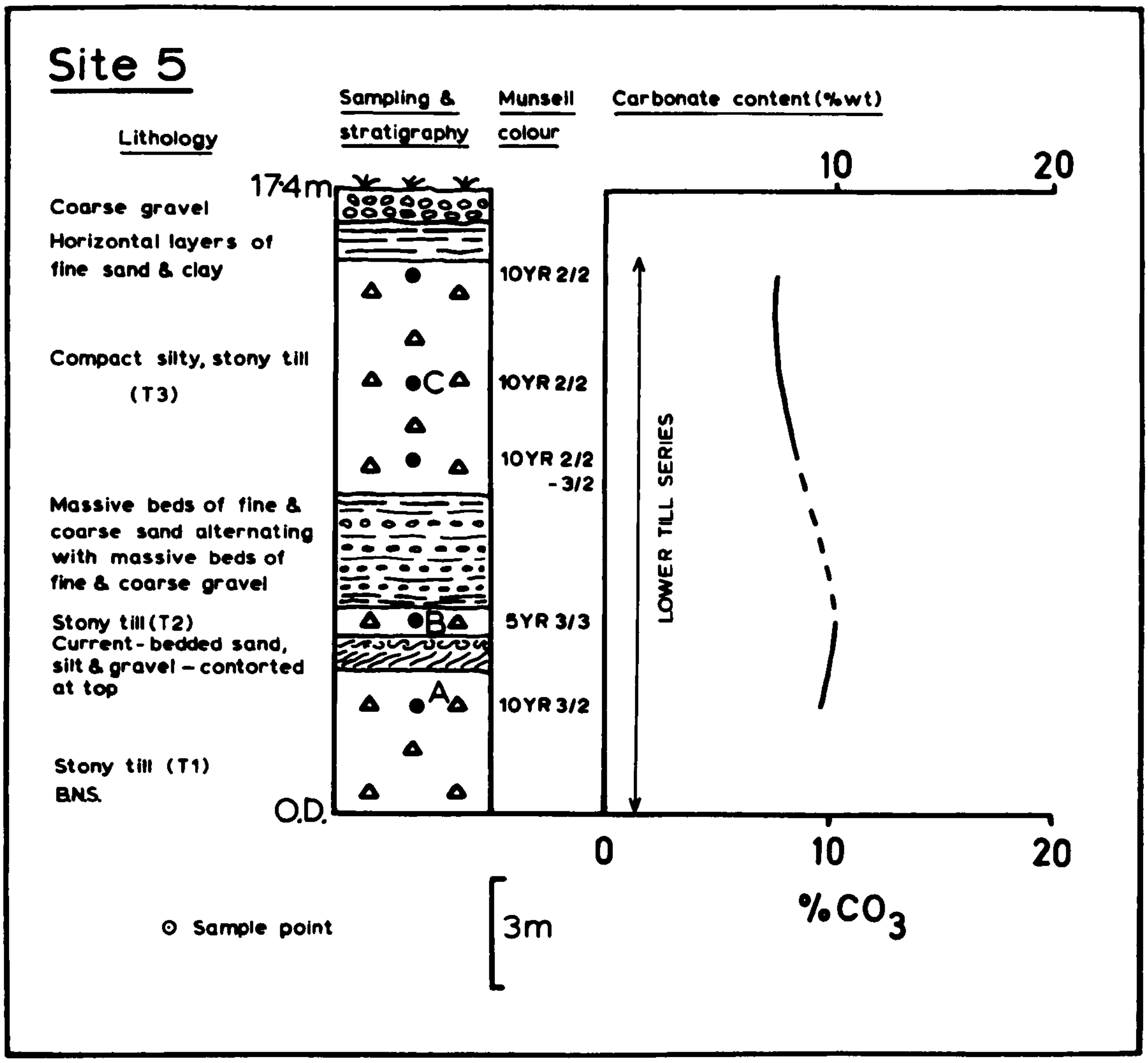


Fig.12. MEASURED SECTION: SITE 5 (FILEY BAY)

Fig.13. PARTICLE SIZE DISTRIBUTION CURVE

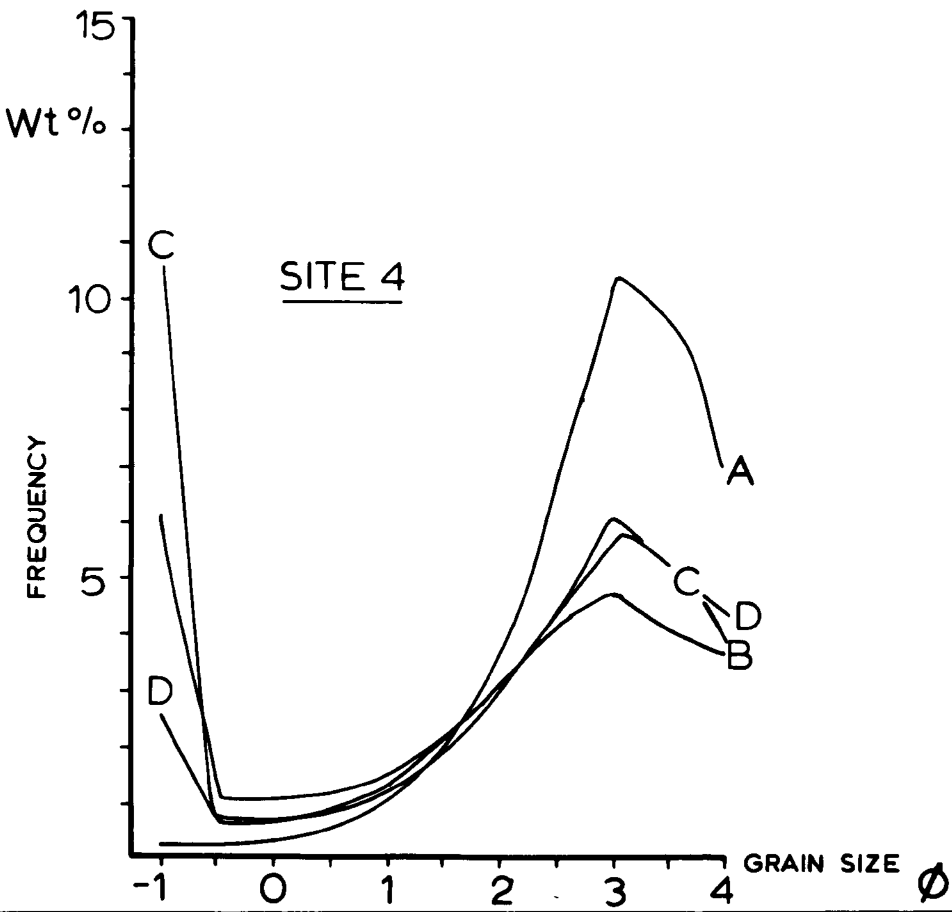
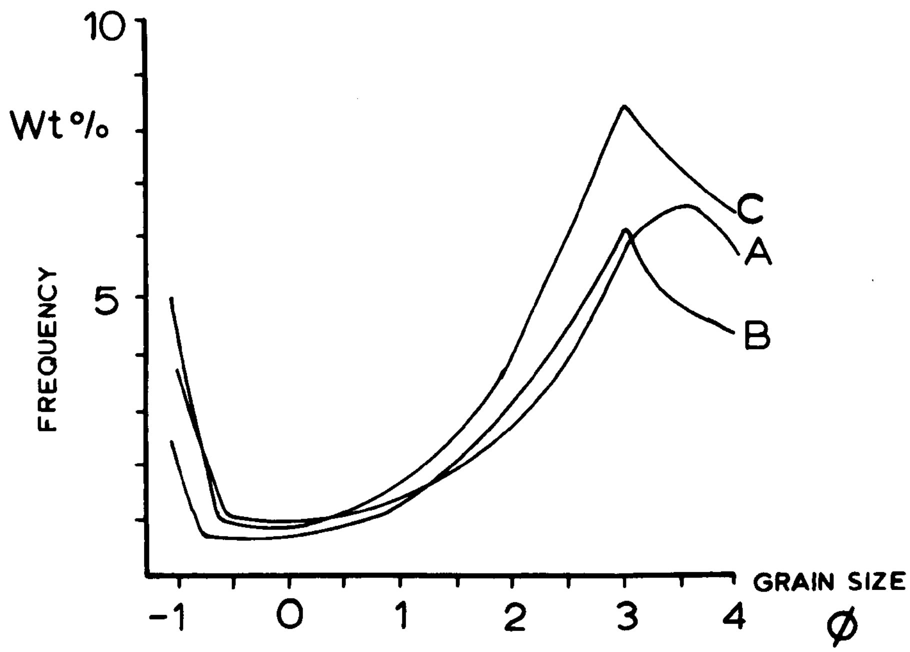


Fig.14. PARTICLE SIZE DISTRIBUTION CURVE



The sand and gravels are overlain by about 7m of compact, quite stony till (T3) with a fine sand-silt matrix and Munsell colour of 10YR 2/2 - 10YR 3/2. It is overlain by 1m of horizontal planar fine sand and clay layers and this in turn by 1m of coarse, massive gravel, whose top is not seen.

(B) MECHANICAL ANALYSIS (fig. 14)

Curves A-C (T1-T3) show that the succession is comprised entirely of Lower ill eries. Curves B and C exhibit a fine-very fine sand mode whereas A exhibits a very fine sand mode. Field observations show that this lowest till (T1) is more tenacious than that above which suggests it has a higher silt-clay content, as shown by curve A.

(C) PIPETTE ANALYSIS

S values all in excess of 50% indicate that the entire exposure consists of Lower Till Series.

The sands and gravels which cap the exposure at Site 5 and which have been extensively quarried, may separate the Lower and Upper Till Series or lie wholly within the Lower. Considering the former, the underlying till sequence would then represent the upper part of the Lower Till Series and as the lowest till in the exposure (T1) does not show features characteristic of basal till, this is probably the case. At Site 5, the base of the Lower Till Series is probably some way beneath O.D.

Traversing to the north-west from Site 1 the base of the glacial succession, excluding the Speeton Shell bed, falls from 30.5m O.D. to some depth below O.D. at Site 5. Correspondingly, the exposures described show a successive dip of all the component beds towards the north-west (see fig.15). This is consistent with borehole evidence from the Vale of Pickering (chapter VII) which shows a lowering of the base of the

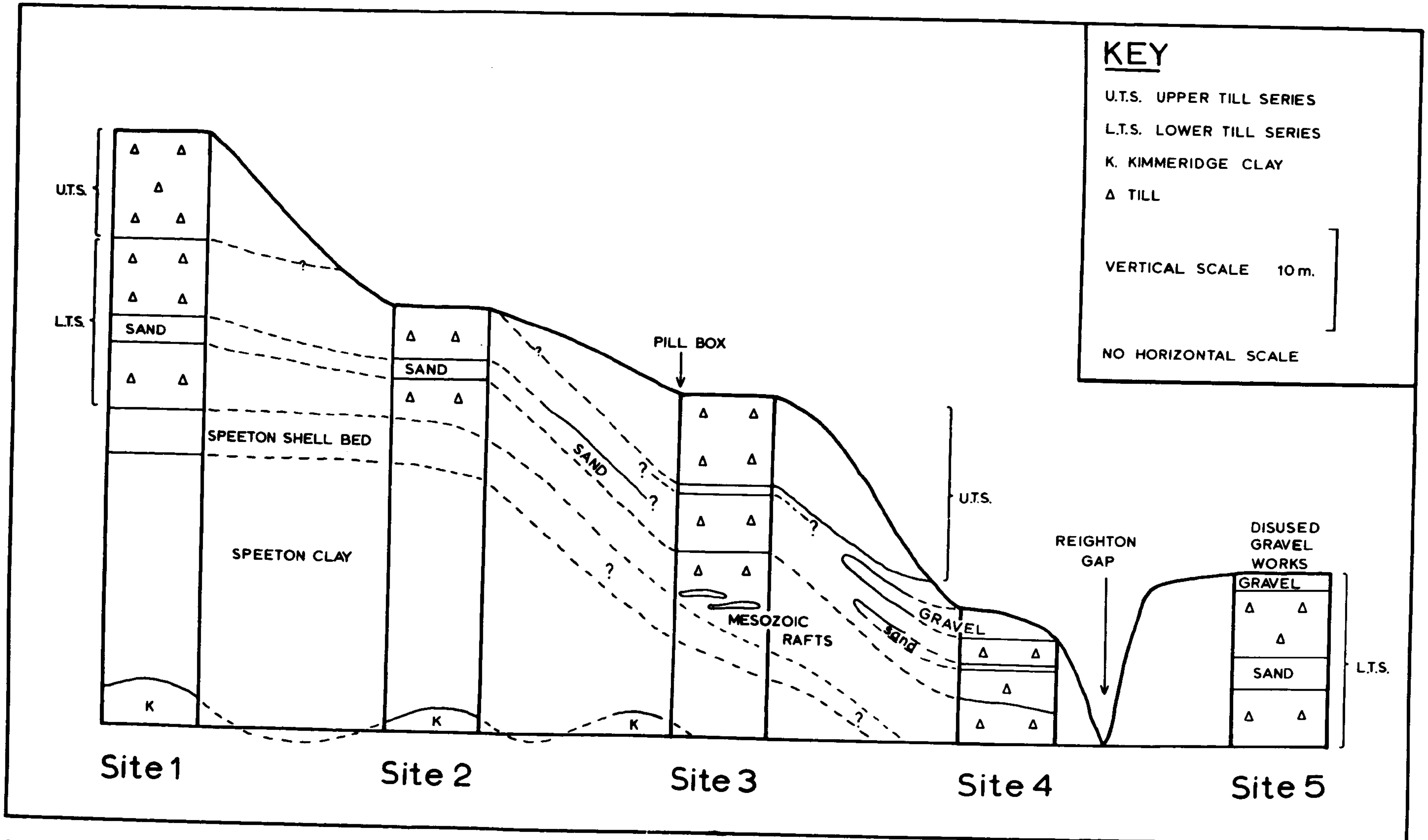


Fig.15. DIAGRAMMATIC LONG SECTION OF SOUTH-EAST FILEY BAY

Devensian towards the mid east-west line of the Vale concomitant with it having been an estuarine environment in pre-Devensian times. It also accords with reported historical exposures of the Speeton Shell Bed at or about O.D. in the Reighton vicinity (See Chapter X).

SITE 6 (fig. 16)

(A) The base of the exposure reveals about 7m of compact, stony till (T1) with a fine sand-silt matrix and 10YR 2/2 Munsell colour. For several tens of metres either side of this section, this basal till is quite strongly flexured into a series of anticlines and synclines and contains lenses of gravel. It is overlain by 2m of equally folded, reddish till (T2, 5YR 3/3) with small angular erratics enclosed in a fine sand-silt matrix. The next till (T3) is 5.8 m thick and does not display folding on the scale of T1 and T2. It is compact with small angular erratics enclosed in a fine sand-silt matrix and has a Munsell colour of 10YR 2/2.

It is succeeded by 2m of fine sand which contains coal streaks. This is overlain by 2.7m of compact stony till (T4) identical in colour and lithology to that below the sand. It is overlain by 1.7m of fine sand, silt and clay laminae which separate the Lower and Upper Till Series. The upper till (T5, 5YR 3/4) is 12.5m thick and moderately stony and compact with a silt-clay matrix which makes it plastic when wet. The top 2m are weathered and friable having a matrix which has been enriched in fine sand and silt by weathering processes, affecting sedimentary erratics. The till is cut by blue-grey faced joints which are also a weathering phenomenon (Madgett 1975).

The sands, silt and clay around 17.1m O.D. divide the Lower and Upper Till Series. The 2.7m of till within the sands (T4) may be a thrust slice representing horizontal shearing between the two ice masses.

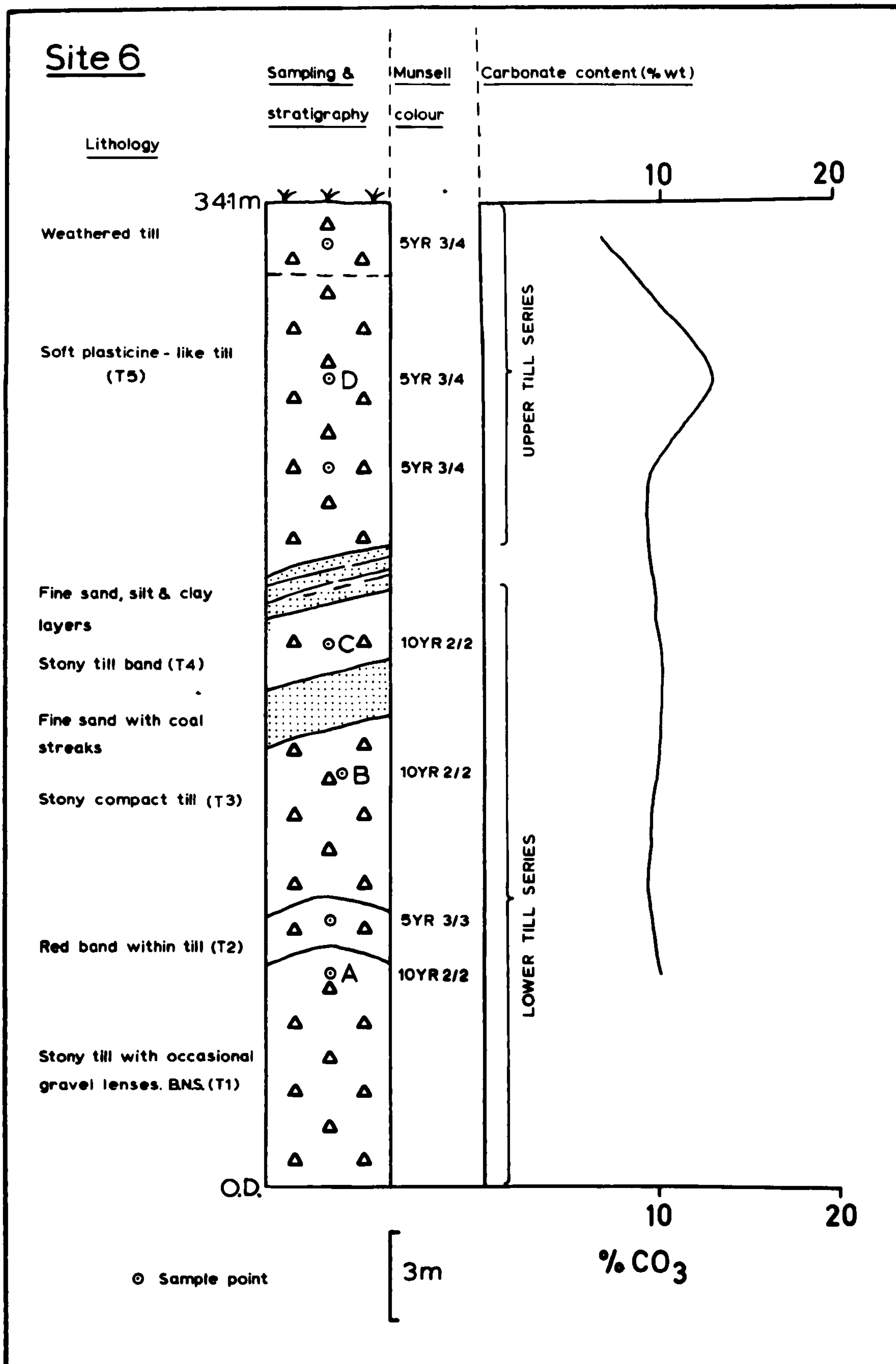


Fig.16. MEASURED SECTION: SITE 6 (FILEY BAY)

On the basis of colour and lithology the Lower Till Series (T1 - T4) correlates with that exposed at Site 5, though the sands and gravels between T1 and T3 at Site 5 are absent at Site 6, thus indicating that sand beds within the Lower Till Series are not laterally extensive.

(B) MECHANICAL ANALYSIS (fig. 18)

Curves A - C are indicative of the Lower Till Series. Curve A (T1) displays a mode in the very fine sand fraction as does T1 at Site 5. Curves B and C (T3 and T4) show the mode has moved to the left, partly into the fine sand category. Curve C (T4) confirms Munsell colour evidence which suggests that it is part of the Lower Till Series. Curve D (T5) illustrates the silt-clay maxima characteristic of the Upper Till Series. Unlike Curve J. of Site 1 (T5), this is not a weathered sample and illustrates that in the main mass of the Upper Till Series, the high silt-clay content is a primary characteristic and not a weathering product.

(C) PIPETTE ANALYSIS

S values in excess of 55% indicate the presence of the Lower Till Series, overlain by Upper Till Series with an S value of 48.8%.

Between Sites 5 and 6 a small exposure of till occurs at TA 1335 7710 though this is not individually figured in the text. It is indicated on fig. 23 which is a long section of the coast from TA 1335 7710 to TA 1298 7749 (Site 8) and has incorporated in it, part of a similar section drawn by Bisat (1940), due to the present exposure being obscured by vegetation and landslipping. At TA 1335 7710 the Upper Till Series is separated from the Lower by 1m of sands and gravels which is in accord with Bisat's observations (1940). North of this locality where the cliff is now obscured Bisat records a silt basin in which he draws attention to the 'Ball beds'. These have been described by Melmore (1934) as being 1.5 m thick, containing 'cobbles of sand' embedded in gutta-percha clay. The balls are about 15 cm in diameter and are composed of very fine grained yellow sand. He considers that they were deposited in a frozen state and the gutta-percha clay settled around them. The northern part of Bisat's section illustrates what he describes as a Purple clay basin. It is visible at present though is in an unstable and dangerous condition. Consequently fig. 17 is a sketch section and not a measured section.

SITE 7 (fig. 17)

(A) The base of the exposure reveals 3m of extremely contorted, hard and compact till (T1) with a fine sand-silt matrix and a Munsell colour of 10YR 3/2, being a lateral equivalent of T1 at Site 6. It is overlain by 13m of fallen blocky chocolate coloured silty till (T2, 5YR 3/3) which contains at least one drab coloured silty band (10YR 4/2). Above the fallen chocolate silt, 8m of chocolate silts overlain by 3m of weathered till are exposed *in situ*. It appears that these chocolate coloured silts have been described by Bisat (1939) as Purple clays and led him to describe Hunmanby Gap as a Purple clay basin, as this sketch section corresponds quite closely to Bisat's section.

(B) MECHANICAL ANALYSIS (fig. 19)

Curve A shows T1 to be characterestic of the Lower Till Series and a lateral equivalent of the basal tills at Sites 5 and 6, having a mode in the very fine sand fraction. It is overlain by a thick sequence of chocolate silts (Curve B) which contain a thin drab silt band (Curve C). However, mechanical analyses reveal that in reality these silts are fine-very find sands with a relatively low silt content.

(C) PIPETTE ANALYSIS

An S value of 52% for T1 confirms that it is part of the Lower Till Series. The chocolate and drab 'silts' have S values of 57% and 47.5% respectively. These values are considered to be erroneous due to the deposit having undergone some form of sorting and removal of the clay fraction.

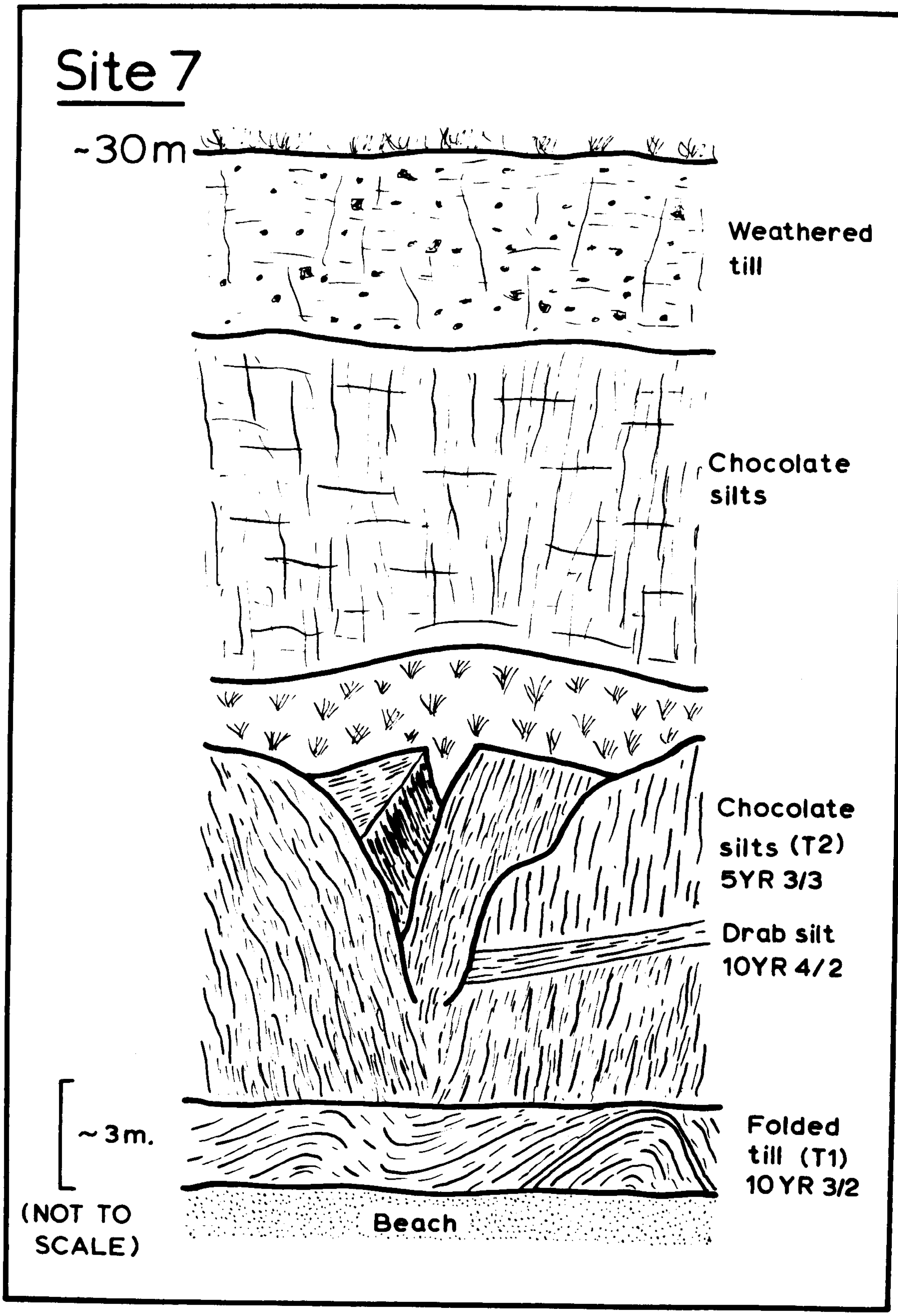


Fig.17. FIELD SKETCH: SITE 7

Fig.18. PARTICLE SIZE DISTRIBUTION CURVE

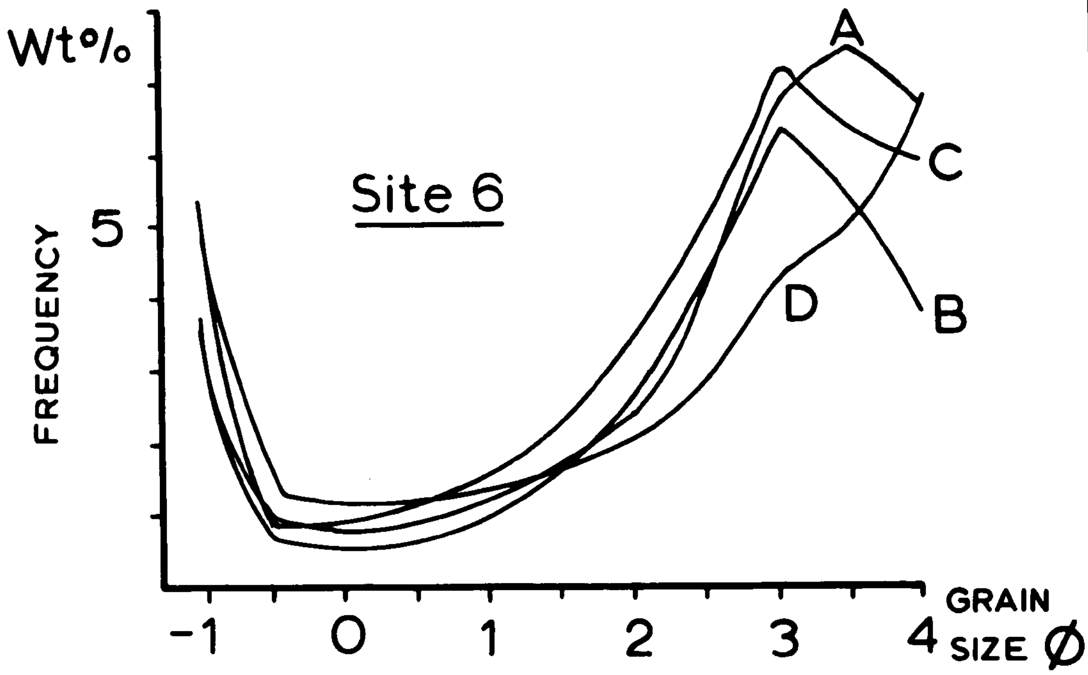
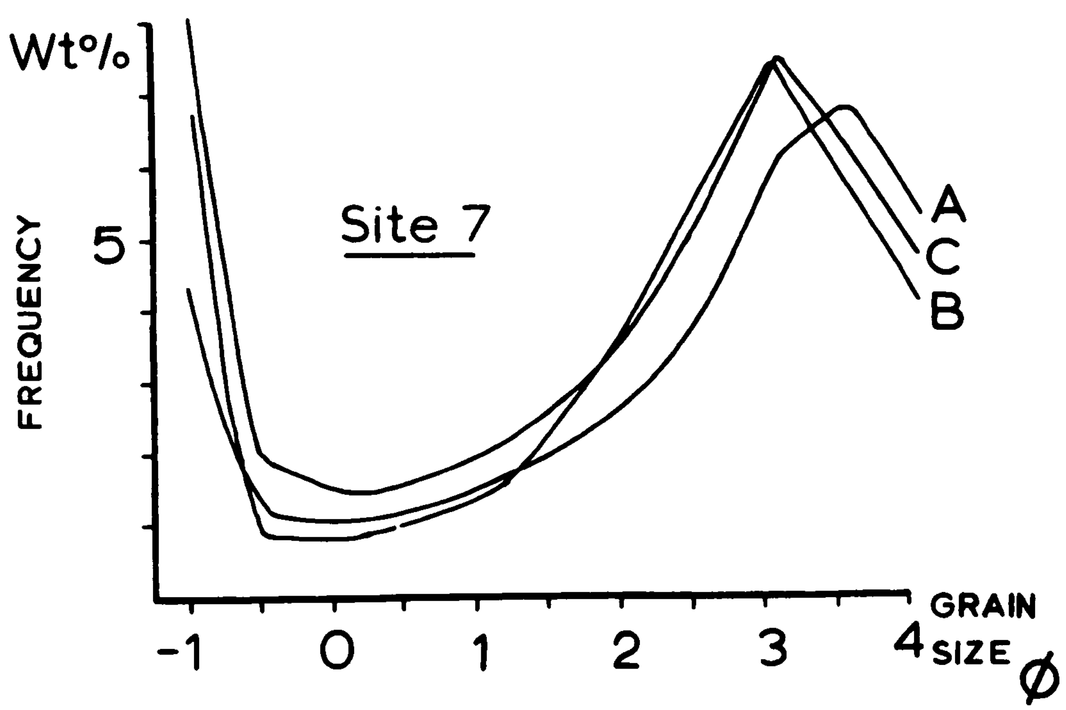


Fig.19. PARTICLE SIZE DISTRIBUTION CURVE



SITE 8 (fig. 20)

(A) Situated 100m north-west of Site 7, it reveals lateral changes in the stratigraphy similar to those indicated by Bisat (1939). At the base of the exposure there is 2m of hard, compact, strongly folded, stony till (T1, 10YR 2/2) with many small erratics enclosed in a fine sand-silt matrix which correlates with the basal tills at Sites 6 and 7. It is overlain by a reddish-brown till (T2, 5YR 4/2), the two being separated by an active rotational slide plane. In the vicinity of the slide plane, T2 is soft and plastic with a clay-rich matrix. It grades upwards into a drier, harder till with angular erratics enclosed in a fine sand-silt matrix. The graduation involves a colour change to 5YR 3/2.

At 7m. O.D. the base of a zone of fine sandy laminations (T3) which are each in excess of 3cm thick is seen. Between 10 and 16m. O.D. the cliff has slipped, due to movement of the slide plane at 4m. O.D., and obscured some of the Lower Till Series which Bisat shows to comprise more of the cliff than is apparent.

The upper cliff comprises 0.7m of very coarse gravel and cobbles overlain by 9m of massive planar beds of gravel and sand with occasional clay layers showing fine laminations. The sands and gravel are capped by 7m of soft plastic till (T4, 5YR 3/4); the top 2m of which are weathered to 5YR 4/4.

(B) MECHANICAL ANALYSIS (fig. 21)

Curve A (T1) is characterised by a mode in the very fine sand fraction which tails-off gradually into the coarse silt fraction. This is a lateral equivalent of the basal till at the three previous localities. Curves B and C (T2) both have a fine-very fine sand mode and are characteristic of the Lower Till Series. Curve D (T3) is characteristic of the Upper Till Series in that it displays a silt-clay maxima with,

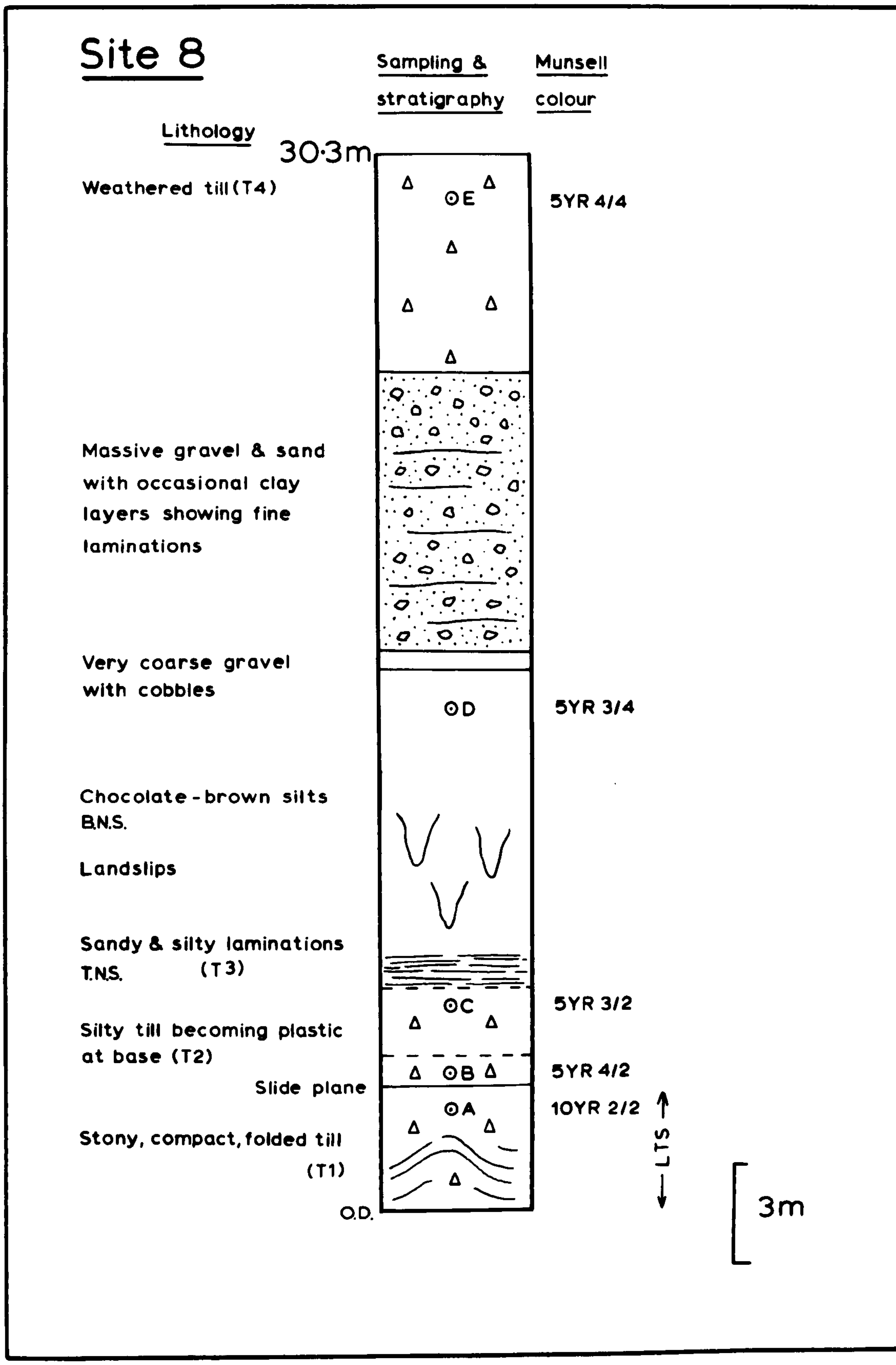


Fig.20. MEASURED SECTION: SITE 8

Fig. 21. PARTICLE SIZE DISTRIBUTION

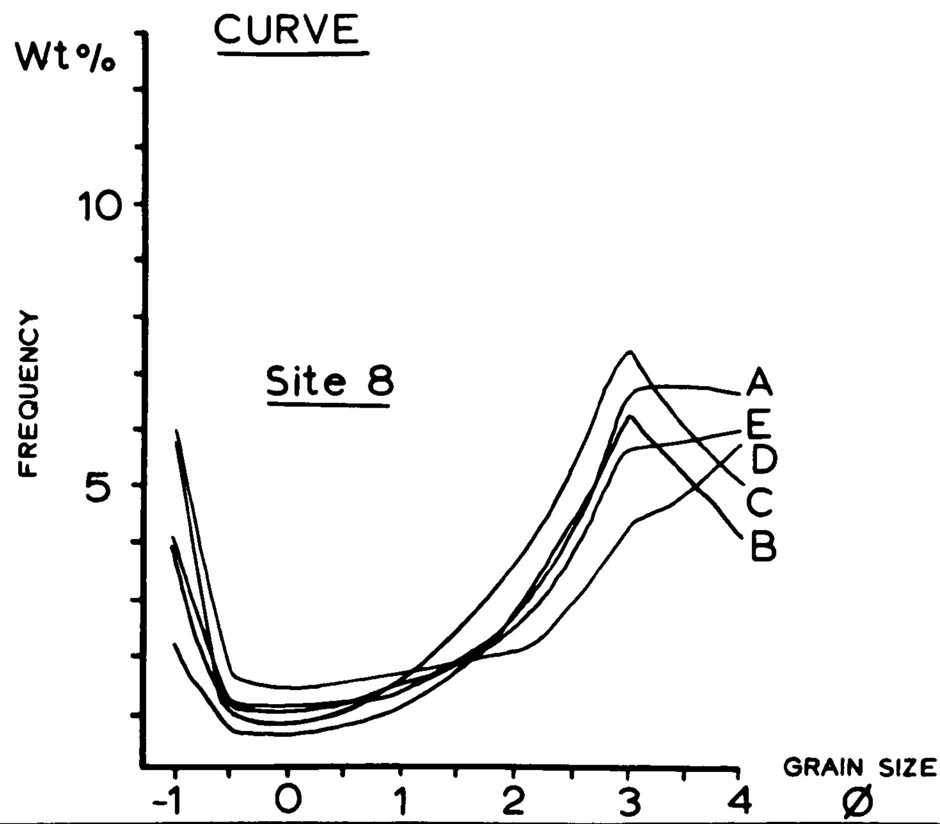
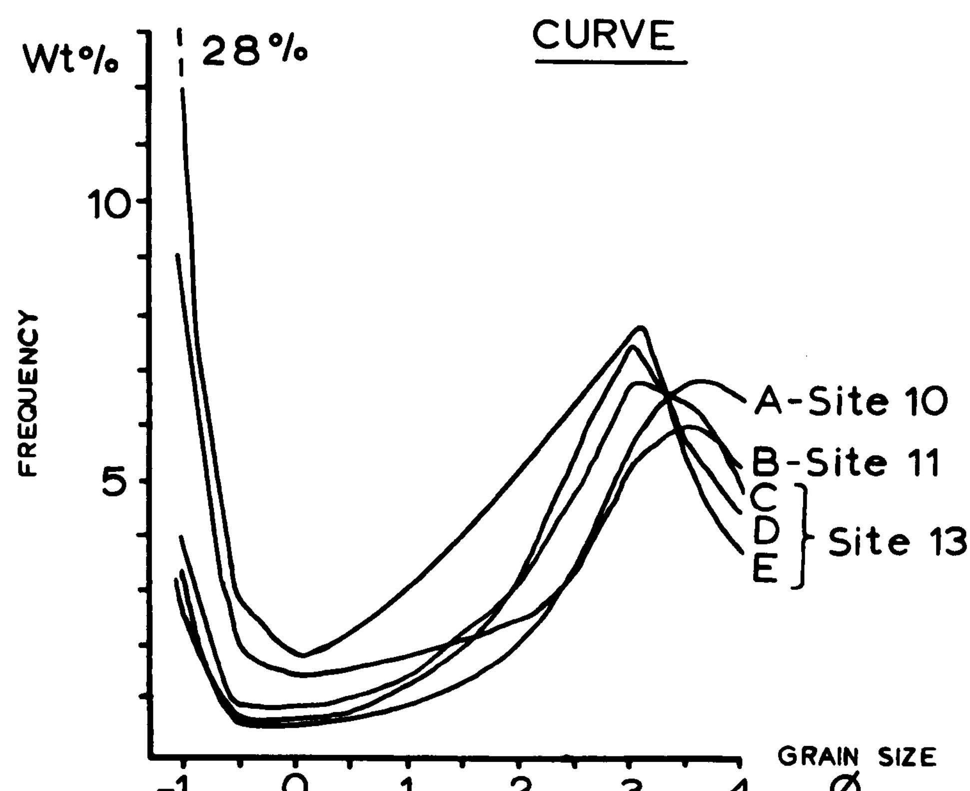


Fig.22. PARTICLE SIZE DISTRIBUTION



in this case, a minor shoulder in the fine-very fine sand fraction. Curve E (T4) shows a decrease in coarse and medium sand and a corresponding increase in the fine-very fine sand fraction producing a very broad maxima that increases gradually towards the coarse silt fraction. This is a weathering phenomenon involving the breakdown of the coarser material with a corresponding increase in the finer components.

(C) PIPETTE ANALYSIS

An S value of 51% for T1 confirms that it is a member of the Lower Till Series. Values of 54% and 56% (3.7m O.D. and 5.5m O.D. respectively) for T2 indicate that it is also a member of the Lower Till Series. An S value of 50% for T3 is considered to be erroneous on the grounds that the deposit is lithologically similar to the chocolate 'silts' at Site 7 where pipette analysis data also proved inconclusive. An S value of 54% for T4 is due to changes in the particle size distribution (i.e. an increase in fine sand) brought about by weathering, and is not accepted as an indication of the Lower Till Series.

Figure 23 illustrates the degree of lateral variation within the tills of north-east Yorkshire. The Lower Till Series is shown to be strongly folded with, to the south of Hunmanby Gap, a thick development of silts between the two Till Series. North of Hunmanby Gap, the variations in lithology are shown to occur within the Upper Till Series, for instance, the thick development of gravels at Site 8. The long section illustrates the development of silts between the two Till Series, hence the apparent contradictions when attempting to assign them to one particular series.

SITE 9

(A) North-west of Butcher Haven, the cliff is composed of hard till of the Lower Series, with a fine sand-silt matrix. Only one till is present,

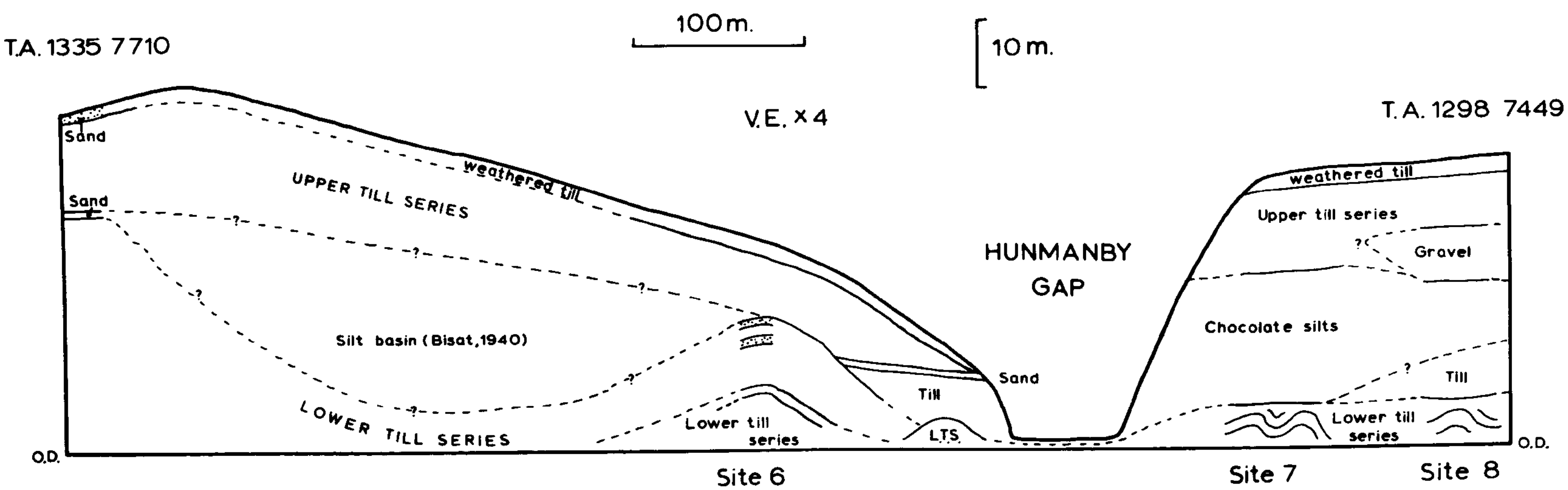


Fig. 23. LONG SECTION OF PART OF FILEY BAY

being a lateral equivalent to that lying between 6.4m and 12.2m O.D. at Site 6. The Lower Till Series rises much higher above O.D. than to the south-east suggesting that the silts, sands and gravels, which are absent here, lie in hollows on the Lower Till Series surface in a lenticular fashion.

SITE 10

(A) At beach level beneath slipped till of the Upper Series, a plastic, compact, grey-brown (10 YR 5/3) till with a clay-rich matrix is exposed. It is quite low in the Lower Till Series and probably corresponds to the greenish till exposed at Hunmanby Gap (see fig. 23).

(B) MECHANICAL ANALYSIS (fig. 22)

Curve A indicates that the grey-brown till belongs to the Lower Series. The mode occurs in the very fine sand fraction which partly accounts for the plastic nature of the matrix which is not characteristic of the Lower Till Series.

(C) PIPETTE ANALYSIS

An S value of 49.5% is not diagnostic in itself, though when supported by Munsell colour, mechanical analysis and field observations, the till can confidently be placed in the Lower Till Series.

SITE 11

(A) At the cliff-foot a very compact, hard, blocky till (10 YR 3/2) is exposed *in situ*. It contains many erratics enclosed in a fine sand-silt matrix and resembles the till exposed at Site 9. It is stratigraphically higher than that exposed at Site 10.

(B) MECHANICAL ANALYSIS (fig. 22)

Curve B shows the till to have a mode in the very fine sand fraction consistent with it being a member of the Lower Till Series. The till is not so plastic as that at Site 10 due to its greater content of coarse material and correspondingly lower proportion of fine.

(C) PIPETTE ANALYSIS

An S value of 55.3% confirms that this till belongs to the Lower Till Series.

SITE 12

(A) A small exposure at beach level shows about 3m of till identical to that exposed at Site 11,. overlain by slipped till of the Upper Series.

SITE 13

(A) A thick sequence of chocolate brown (5YR 3/3 - 3/2) hard, compact, silts (T1) which contain small erratics are overlain by slightly laminose till (T2) which has a fine sand-silt matrix, is rather plastic when wet and contains Mesozoic clay rafts. The presence of well-rounded igneous erratics and rafts of Mesozoic clay suggest this till belongs to the Lower Series. The overlying 2m of weathered till (10YR 5/4) is distinct from the underlying fresh till in that it contains many large randomly arranged sedimentary erratics. It may represent a flow-till or be related to the feather edge of the ice of the Upper Till Series which appears to have not covered the area to the north-west of this site.

(B) MECHANICAL ANALYSIS (fig. 22)

Curves C - E all support Munsell colour and field observation evidence which suggests that the entire cliff is composed of the Lower Till Series. All three display modes in the fine-very fine sand fraction.

(C) PIPETTE ANALYSIS

T1 and T2 have S values of 54.7% and 52.5% respectively which confirms the evidence which indicates they are members of the Lower Till Series.

The weathered till is apparently a member of the Lower Till Series and an S value of 59.8% certainly does not contradict this, though due to the effects of weathering processes on particle size distribution within the till it is not certain how reliable this value is.

SITE 14

(A) Till of the Lower Series (10YR 3/2) overlies fine orange sand (BNS) and is exposed to within 3m of the cliff top. At 21.3m O.D., within the Lower Till Series, there occurs a large Mesozoic shale raft which is overlain by dark coloured (10YR 4/2) rather sandy weathered till which is cut by ashy, grey-faced joints. It appears to have been derived from the underlying fresh till.

(B) MECHANICAL ANALYSIS (fig. 24)
Curves A and B closely resembly each other, both having a mode in the fine-very fine sand fraction indicating that the entire cliff at this point is composed of the Lower Till Series.

(C) PIPETTE ANALYSIS
An S value for A (fresh till) of 49.7% indicates that the till is a member of the Lower Series.

Between Site 8 and Site 14 the Upper Till Series disappears and the cliff is composed entirely of the Lower Series. At beach level between these two sites, two tills are seen. The upper is brownish and the lower is grey-green. The grey-green till is in-situ and represents part of the Lower Till Series. The brownish till also belongs to the Lower Series but it has slipped down from the cliff top, being weathered to a brownish colour by its previous immediate sub-aerial position.

SITE 15

(A) An incomplete exposure reveals a member of the Lower Till Series at beach level (10YR 2/2). At the cliff top (30.5m O.D.), 4m of outwash sands and gravel overlie 2.7m of alternate laminations of purple stoneless clay (5YR 3/4) and sand. The individual sand and clay laminae do not exceed 20cm. The Upper Till Series is not visible at this site.

SITE 16

(A) At the cliff-foot, dark brown till (10YR 3/2) with a fine sand-silt matrix is exposed. It comprises the entire cliff (30.5m) and is weathered at the surface to - 2.5m. There is no colour change. This silty till corresponds laterally to the upper part of the Lower Till Series recorded at Site 1.

(B) MECHANICAL ANALYSIS (fig. 24)

As Munsell colour and field observations suggest, curves C and D (fresh and weathered till respectively) indicate that the entire cliff is composed of the Lower Till Series, both showing a mode in the fine-very fine sand fraction.

(C) PIPETTE ANALYSIS

S values of 55.8% and 49.5% for fresh and weathered till respectively, indicate that the entire cliff is composed of Lower Till Series.

SITE 17 (fig. 26)

(A) At the base of the cliff, compact, silty till (10 YR 3/2), (Lower Till Series) is exposed though its contact with the Upper Till Series is overgrown. Above the Upper Series (soft, red-brown till,(5YR 3/4) at about 29.9m O.D. there lies a sequence of sand and gravel beds which are contorted and faulted due to compaction and the melting of buried ice. These gravels have been referred to by earlier workers (e.g. Bisat1940) as the 'Hessle gravels' and represent a late melting stage of Upper Till Series ice, showing marked cyclic alternations of fluvial environment associated with seasonal ice melt. Above the sands and gravels there

Fig. 24. PARTICLE SIZE DISTRIBUTION CURVE

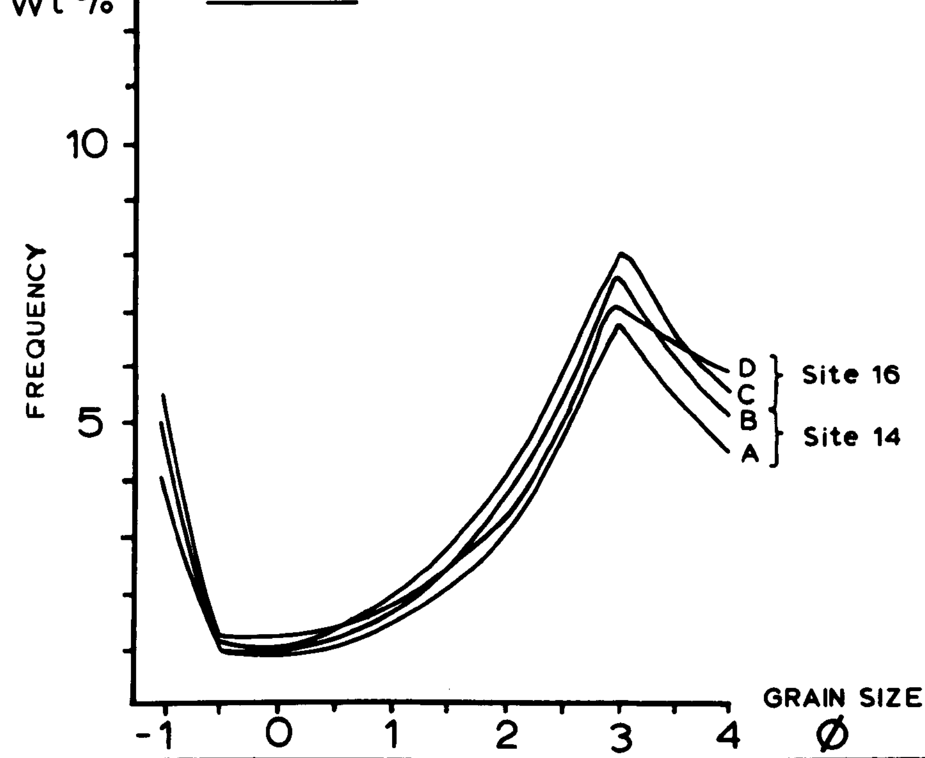
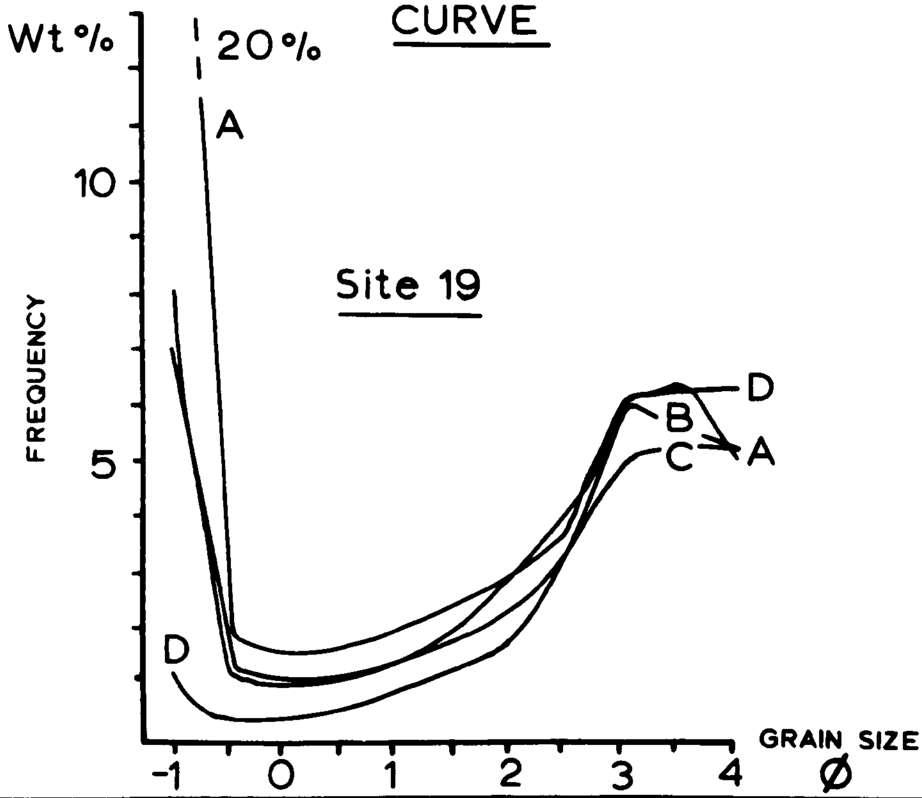


Fig. 25. PARTICLE SIZE DISTRIBUTION CURVE



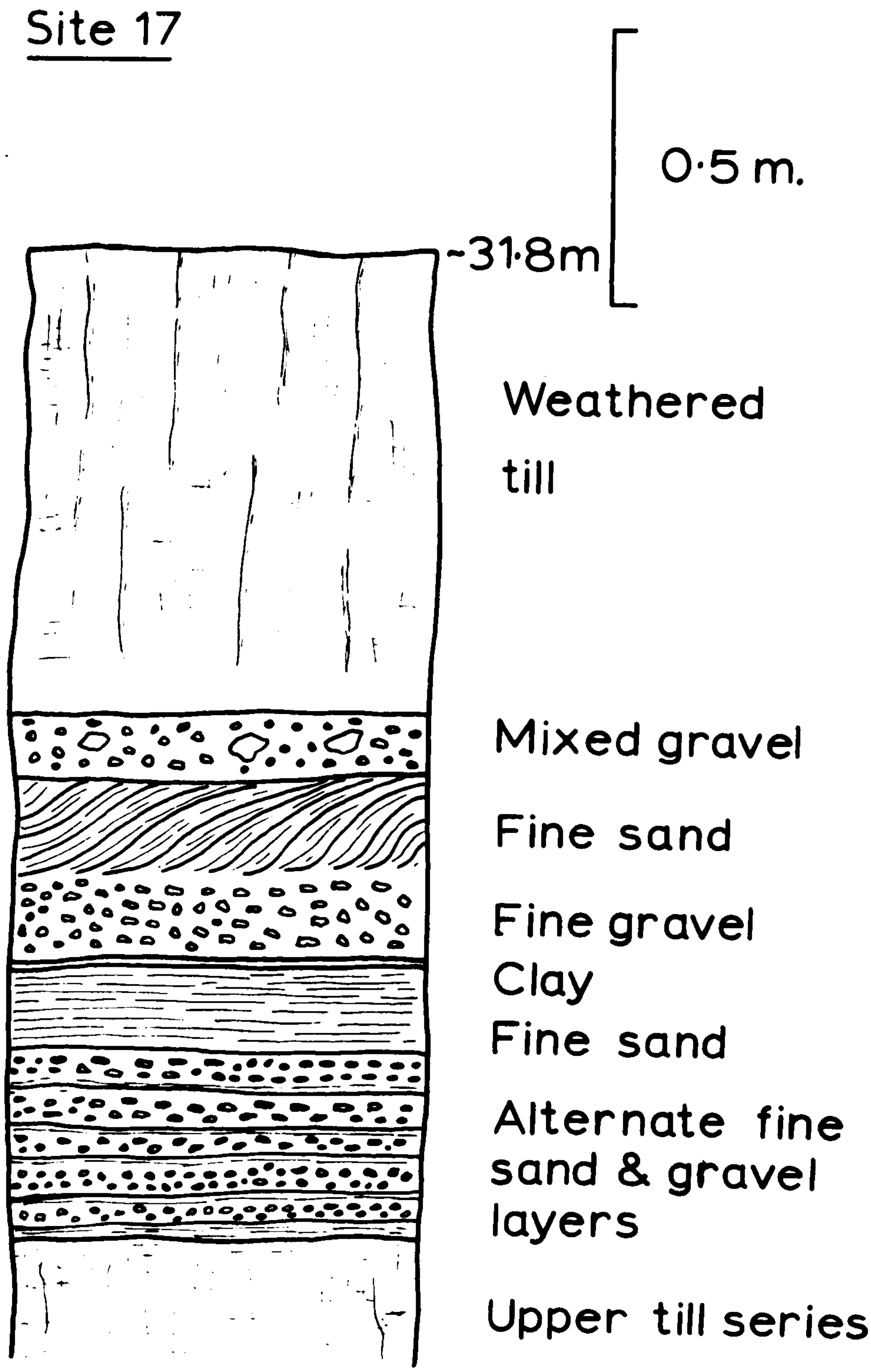


Fig.26. SKETCH SECTION: SITE 17.

is 0.9m of weathered red-brown flow-till (5YR 3.5/4) with a fine sand-silt matrix, produced by the weathering of sandstone erratics. Between Site 16 and Site 17 the Lower Till Series again becomes overlain by the Upper Till Series though it is not possible to see whether sands and gravels intervene.

SITE 18 (fig. 27)

(A) 5m above beach level the Lower Till Series is overlain by the Upper Series with no intervening sands and gravels. The Upper Till Series (5YR 3/3) is compact with a fine sand-silt matrix and is overlain by 4.7m of sands and gravels. These are overlain by weathered till (5YR 3/4) which has a coarse sandy matrix and is extremely friable.

SITE 19 (fig. 28)

(A) At this site (Quay hole), the Lower Till Series (10YR 3/2 - 4/2), which is extremely hard and compact with a fine sand-silt matrix, overlies Corallian limestone. The basal 15cm is rich in Corallian material and the matrix is coloured by it (10YR 5/3). The Lower Till Series is capped by a band of reddish till (5YR 3/3) with a clay-rich matrix, thus it resembles the Upper Till Series.

Between the Lower and Upper Till Series, there occurs 2.7m of sand, gravel, silt and clay (see fig. 29). The gravel shows massive bedding and is overlain by planar silt bands. Following deposition these were partially eroded and replaced by a set of gravel foresets which indicate that water was flowing towards the south-west. A period of quieter deposition ensued, which is represented by interbedded silt and sand, pure clay and silt which displays slump structures. The series is capped by massive sand which contains silt bands.

The overlying Upper Till Series (5YR 3/4) is compact with a clay-rich matrix being characteristically soft when wet. The lowest bed is fissile and exfoliates parallel to the exposure surface when struck.

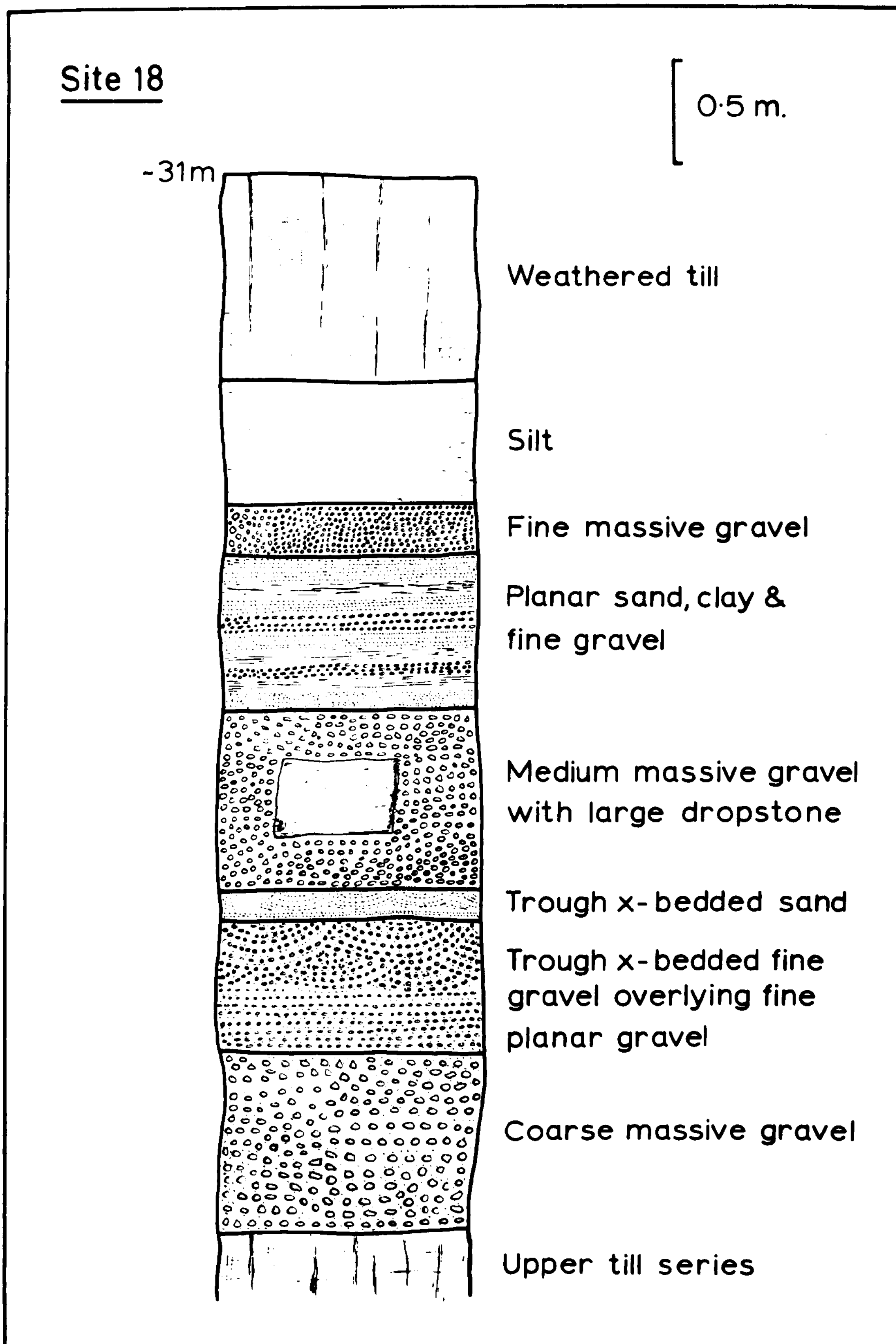


Fig. 27. SKETCH SECTION: SITE 18.(FILEY BAY)

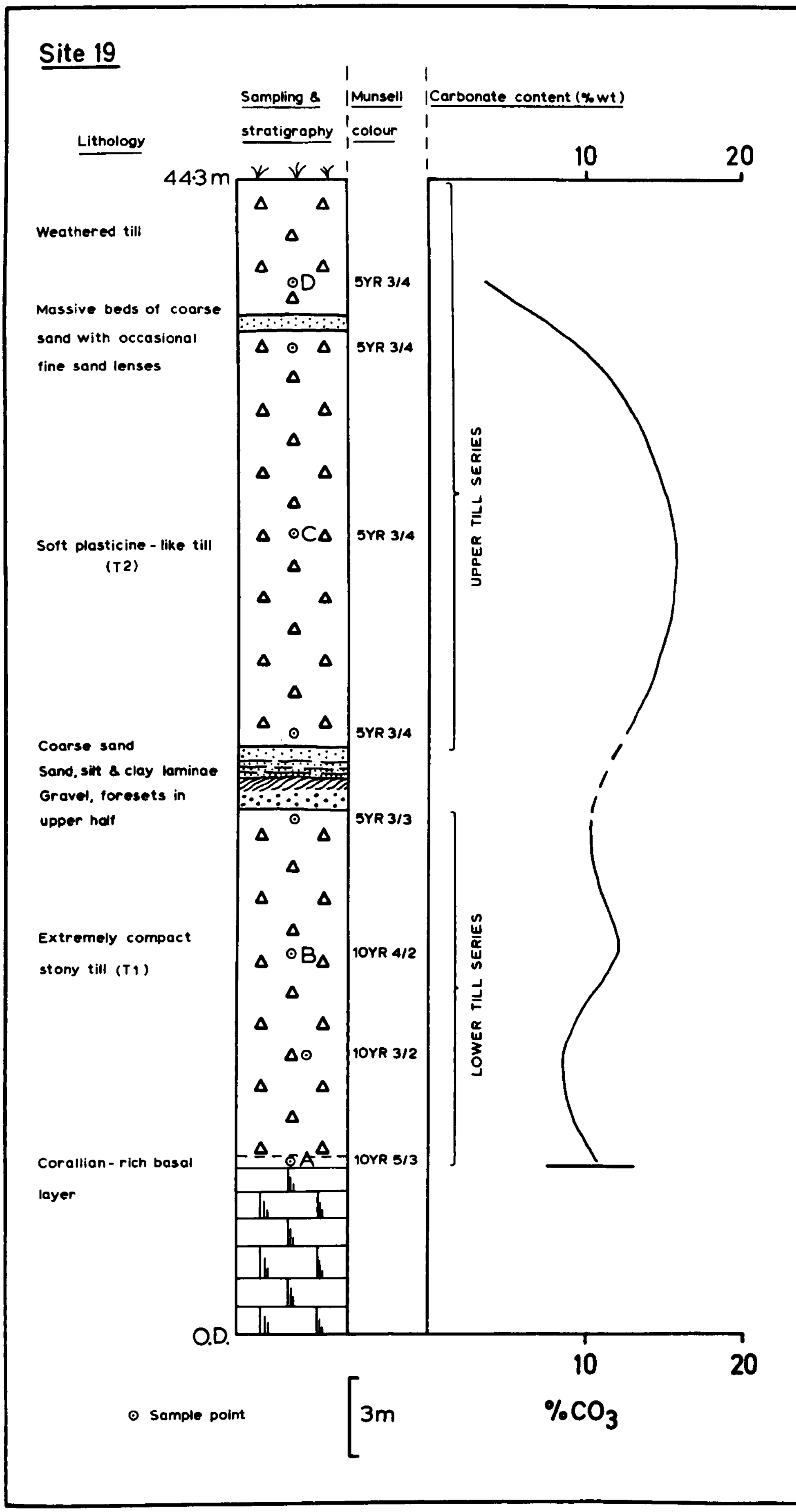


Fig. 28. MEASURED SECTION: SITE 19 (FILEY BAY)

Site 19

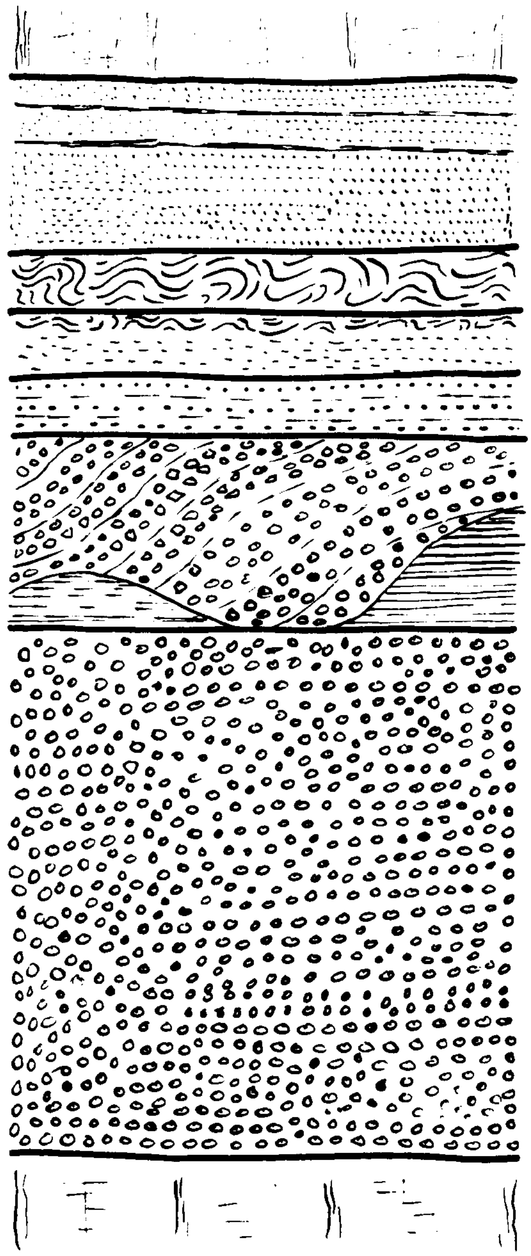


Fig.29. FIELD SKETCH OF FLUVIO-GLACIAL DEPOSITS BETWEEN TILL SERIES: SITE 19 (FILEY BAY)

At 38.4m O.D., 0.7m of coarse sand with occasional fine lenses is overlain by 5.2m of weathered till (5YR 3/4) with a rather sandy matrix.

(B) MECHANICAL ANALYSIS (fig. 25)

Fig. 25 illustrates that the Lower and Upper Tills at this site are distinctly separable by mechanical analysis. Curves A and B (Lower Till Series) exhibit modes in the fine-very fine sand fractions. Curves C and D (Upper Till Series) exhibit modes which extend into the silt-clay fraction. Due to weathering, curve D displays a reduction in coarse material and a corresponding increase in the finer material.

(C) PIPETTE ANALYSIS

S values for samples A and B (73.8% and 53.6% respectively) indicate that the basal till is a member of the Lower Till Series. Sample A indicates the extent of contaminations at the base of the till by material locally incorporated from the underlying Corallian limestone. The S value of 56.1% for sample C is anomalously high - Munsell colour, mechanical analysis, and field observations confirm that this till is not a member of the Lower Till Series. The high S value for sample D (57.2%) is a result of weathering, already described at previous sites.

SITE 20

(A) 15.2m below the cliff top a dark grey (10YR 2/2), hard compact till with a silt and clay-rich matrix (28.6%) overlies Oxford Clay. This till, which contains many well-rounded and polished igneous erratics has been darkened and enriched in silt and clay by incorporation of Oxford Clay into the matrix. 3m below the cliff top, the till (5YR 3/3) is quite compact and hard with a high silt-clay content in the matrix (27.5%). The upper 2m of the till is weathered, (5YR 4/4), quite compact and due to weathering processes affecting the sedimentary erratics, the till matrix is sandy (55.4%).

(B) MECHANICAL ANALYSIS (fig. 30)

Curve A, which exhibits a mode in the fine-very fine sand fraction, tends to support the view that the lower part of the till succession is part of the Lower Till Series which has been contaminated by Oxford Clay. Curve B suggests that the Upper Till Series is present as it displays a broad mode in the very fine sand fraction which passes into silt-clay fraction. Curve C represents the weathered surface of the till and shows the high sand content of the till matrix.

(C) PIPETTE ANALYSIS

High S values (A, 53.2%; B, 52.5%; C, 59.1%) suggest that only the Lower Till Series is present. However, no firm conclusions can be drawn from the data as the incorporation of Oxford Clay into the matrix locally alters the critical S value (49%). Mechanical analysis and Munsell colour indicate that the Upper Till Series overlies the Lower, though the contact is not visible. The presence of secondarily derived igneous erratics confirms that the Lower Till Series is present. On balance the evidence suggests that the Upper Till Series is present.

SITE 21 (fig. 32)

(A) Brown-grey (10YR 2/2), hard, compact, laminose till with a silt-clay matrix rests on Oxford Clay at 25.9m O.D. The Oxford Clay has been partly incorporated into the matrix thus enriching the silt-clay content (48.0%). Towards the top of the succession the silt-clay content of the till matrix decreases (34.8%) and the till becomes sandier, increasing from 33.5% to 41.3%. At the surface the till is weathered to an orange-brown compact state (10YR 4/2 - 5/4).

(B) MECHANICAL ANALYSIS (fig. 31)

Curve A shows a Lower Till Series distribution with a minor maximum in the fine-very find sand fraction. A major mode occurs in the very fine sand-coarse silt fraction and this is consistent with the view that the

Fig. 30. PARTICLE SIZE DISTRIBUTION CURVE

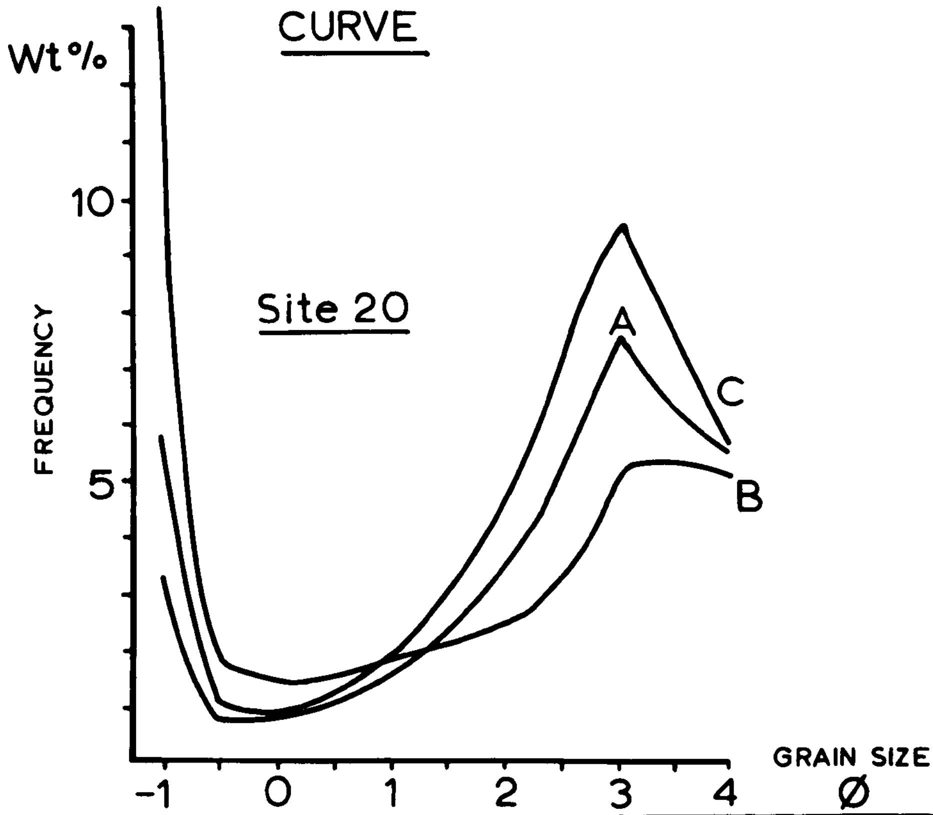
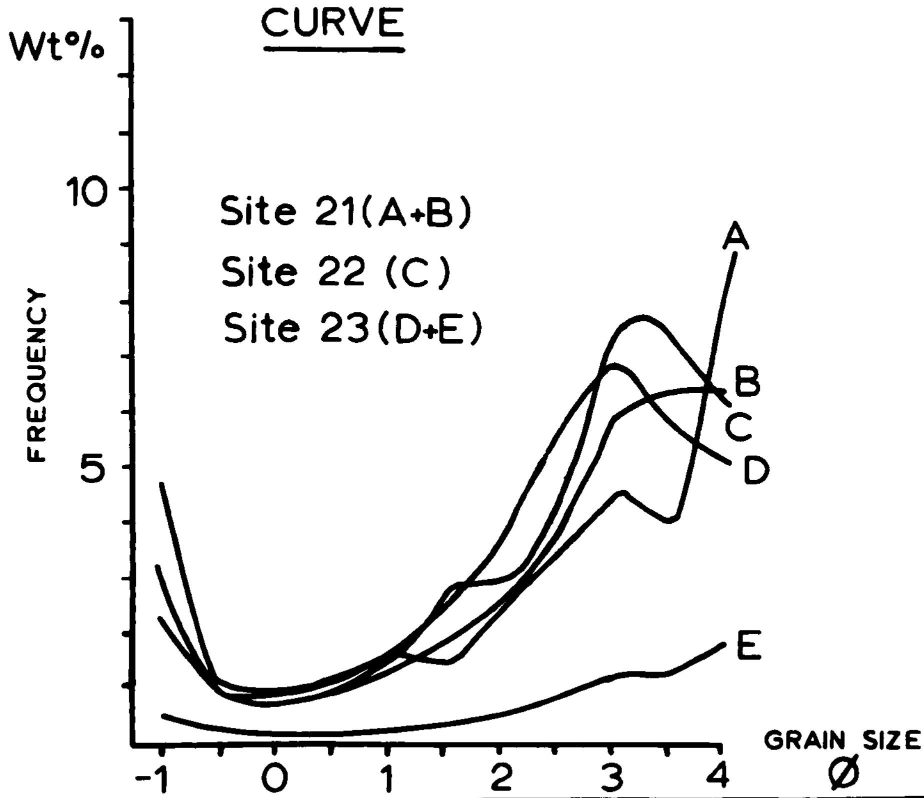


Fig. 31. PARTICLE SIZE DISTRIBUTION CURVE



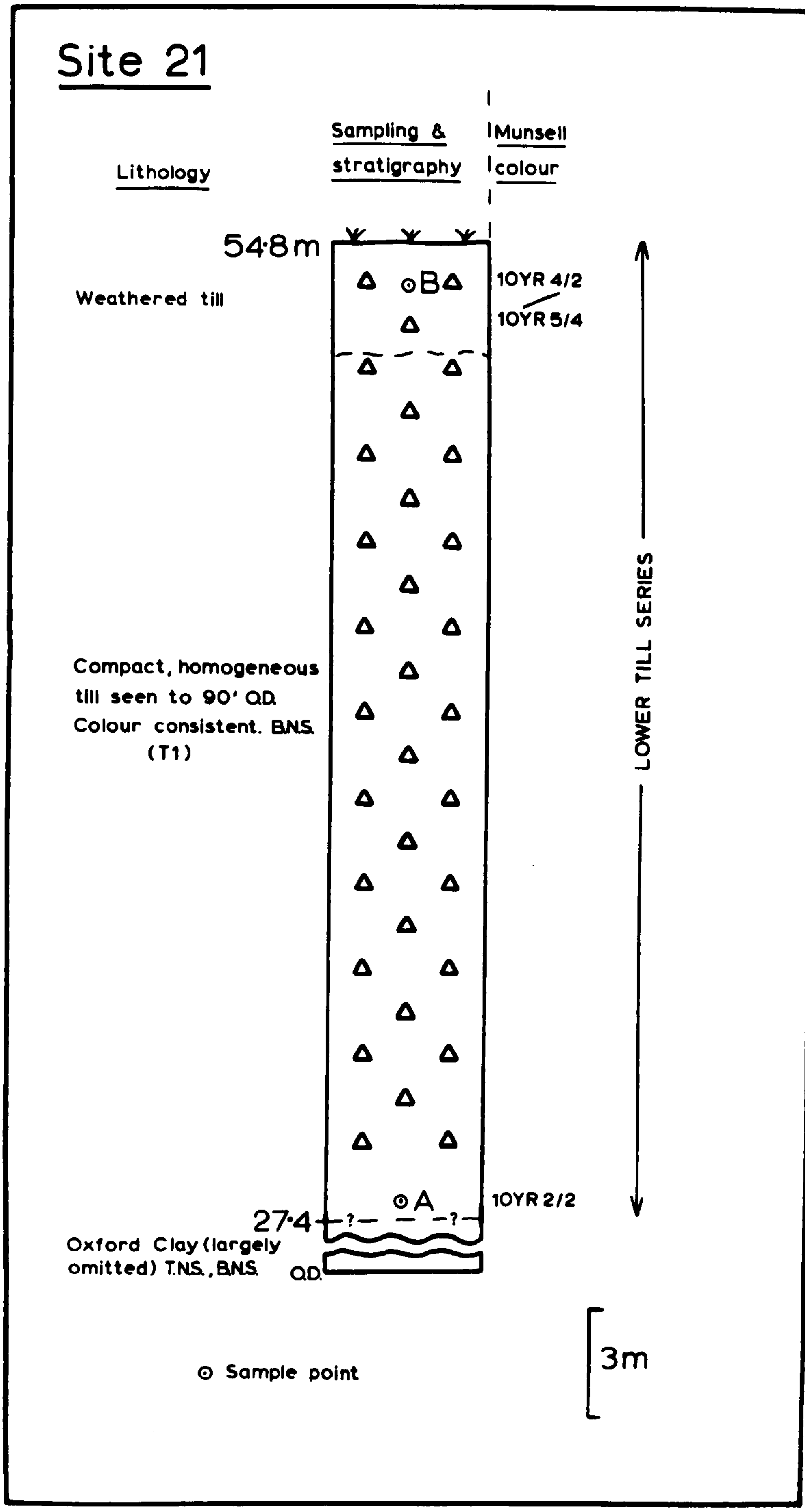


Fig. 32. MEASURED SECTION: SITE 21

lower zones of the till have been contaminated by Oxford Clay, thus increasing the silt-clay content of the till. Curve B exhibits a very fine sand mode which includes part of the silt fraction. The coarser part of the curve corresponds closely with curve A and represents weathered Lower Till Series.

(C) PIPETTE ANALYSIS

S values for samples A and B (54.6% and 50.3% respectively) indicate that the entire cliff consists of Lower Till Series. The S value of 50.3% for the weathered till is accepted in this case as it is possible in the field to see the graduation from weathered till to fresh till of the Lower Series.

SITE 22

(A) The base of the exposure, which is incomplete, reveals 1.7m of grey-brown compact till (10YR 2/2) with a fine sand-silt matrix (B.N.S.). This till belongs to the Lower Series and corresponds to the upper part of the succession at Site 21. It is overlain by 0.7m of gravel with large cobbles and this by 2m of weathered reddish till (10YR 3/4). The weathered till is identical to that at Site 21 and belongs to the Lower Series, the upper being absent at this site. The succession is capped by 0.7 - 1m of light brown soliflucted material which probably originated on the higher land to the south.

(B) MECHANICAL ANALYSIS (fig. 31)

Curve C (fresh till) displays a fine-very fine sand mode consistent with the view that this till is part of the Lower Series.

(C) PIPETTE ANALYSIS

An S value of 52.5% indicates that the till is part of the Lower Series. On Mel-casty Hill (TA 084 839) the Lower Till Series is seen to lie on Oxford Clay. On Gristhorpe Cliff top the cover is very thin and reddish -

obviously a weathered till. The thick sequence seen at Site 21 therefore thins rapidly to the south-east against the flanks of Gristhorpe Cliff and is seen to fill a hollow between Gristhorpe Cliff and Red Cliff Point. Boulder clay is absent along the crest of Lebberston Cliff as far as Killerby Cliff, being thickly deposited in the north-western half of Cayton Bay where it abuts against Tenant's and Cayton Cliff.

SITE 23 (fig. 33)

(A) 12.8m of brown-drab (10YR 2/2) compact, relatively stoneless till (T1) with a fine sand-silt matrix is overlain by 2.7m of sand and gravel. These are overlain by 3m of red-brown (5YR 3/3) till (T2) with a clay-rich matrix. It is virtually stoneless and very well compacted.

(B) MECHANICAL ANALYSIS (fig. 31)

Curve D (T1) indicates Lower Till Series, consistent with Munsell colour evidence. Curve E (T2) indicates a till which is extremely low in sand content (all grades), though there is a slight increase in the very fine sand fraction. It suggests weathering has reached an advanced stage with the breakdown of most of the sedimentary erratics and a consequent increase in the silt and clay proportions (13.5% sand, 28.1% silt, 56.1% clay).

(C) PIPETTE ANALYSIS

S values of 62.0% (T1) and 29.3% (T2) support the evidence which indicates that the Upper Till Series is separated from the underlying Lower Series by sand and gravel.

SITE 24 (fig. 34)

(A) The cliff is overgrown to 10.7m O.D. At 12.2m O.D. a small exposure reveals very wet, stony, grey till (T1, 10YR 4/2) overlain by

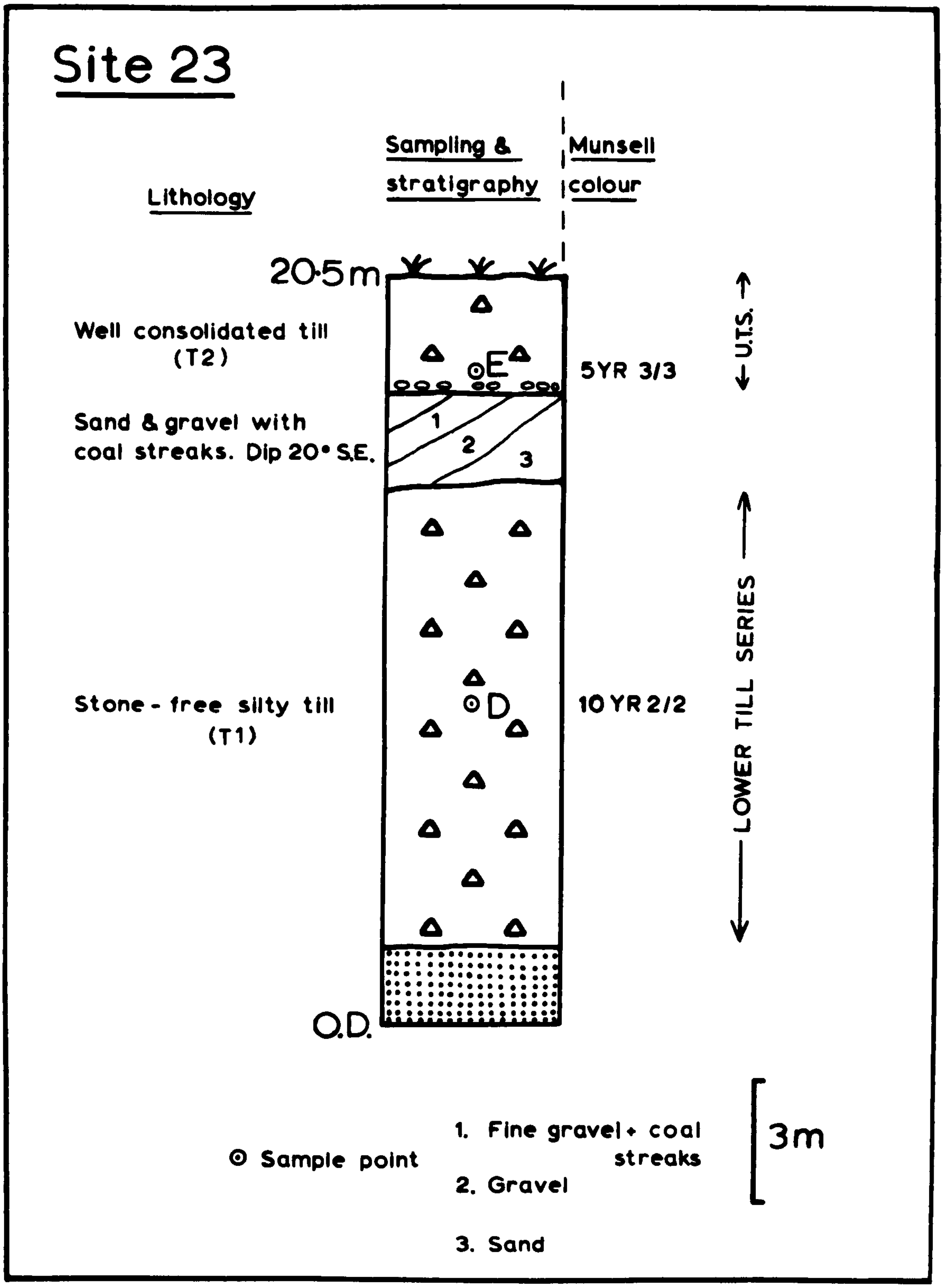


Fig.33. MEASURED SECTION: SITE 23

alternating coarse sand and fine gravel layers (T.N.S.). Above the sand and gravel there is a well-consolidated, red-brown (5YR 3/3) stony till (T2) (B.N.S.). At 23.2m O.D. there occurs a 0.3m thick band of mixed coarse and fine gravel overlain by o.6m of fine sand and till layers which are horizontally bedded in the lower half, the upper half being delicately folded. Above, well-consolidated stony till (T3, 5YR 3/5) passes up into unconsolidated silt (10YR 4/3) which, above a bedding plane at 26.8m O.D., becomes well-consolidated and grades into brown till (T4, 5YR 3/3). Between 31.7 and 32.3m O.D., two 15cm thick bands of gravel occur, the top one being at the base of the surface weathering of the till sequence. It is gravels such as these that have in the past been referred to as the 'Hessle gravels' (e.g. Bisat, 1940).

(B) MECHANICAL ANALYSIS (fig. 35)

Curve A (T1) is indicative of the Lower Till Series with a fine-very fine sand mode and is the lateral equivalent of Curve A at Site 23. Curve B is the lateral equivalent of Curve B at Site 23 and represents the base of the Upper Till Series. Curves C and D (T3 and T4) both indicate Upper Till Series with modes in the very fine sand - coarse silt fractions. Curve E represents weathered T4 (Upper Till Series) and indicates that clay and silt have been preferentrally leached to a lower zone as part of the weathering process.

(C) PIPETTE ANALYSIS

T1 has an S value of 59.2% indicating Lower Till Series. T2 and T3 have S values of 51.2% and 53.8% respectively which indicate Lower Till Series and contradict mechanical analysis and Munsell colour evidence. T4 with an S value of 45.6% confirms the evidence which suggests this is Upper Till Series. The weathered till has an S value of 48.7% indicating Upper Till Series, though this does not take into consideration possible alterations in particle size distribution due to weathering.

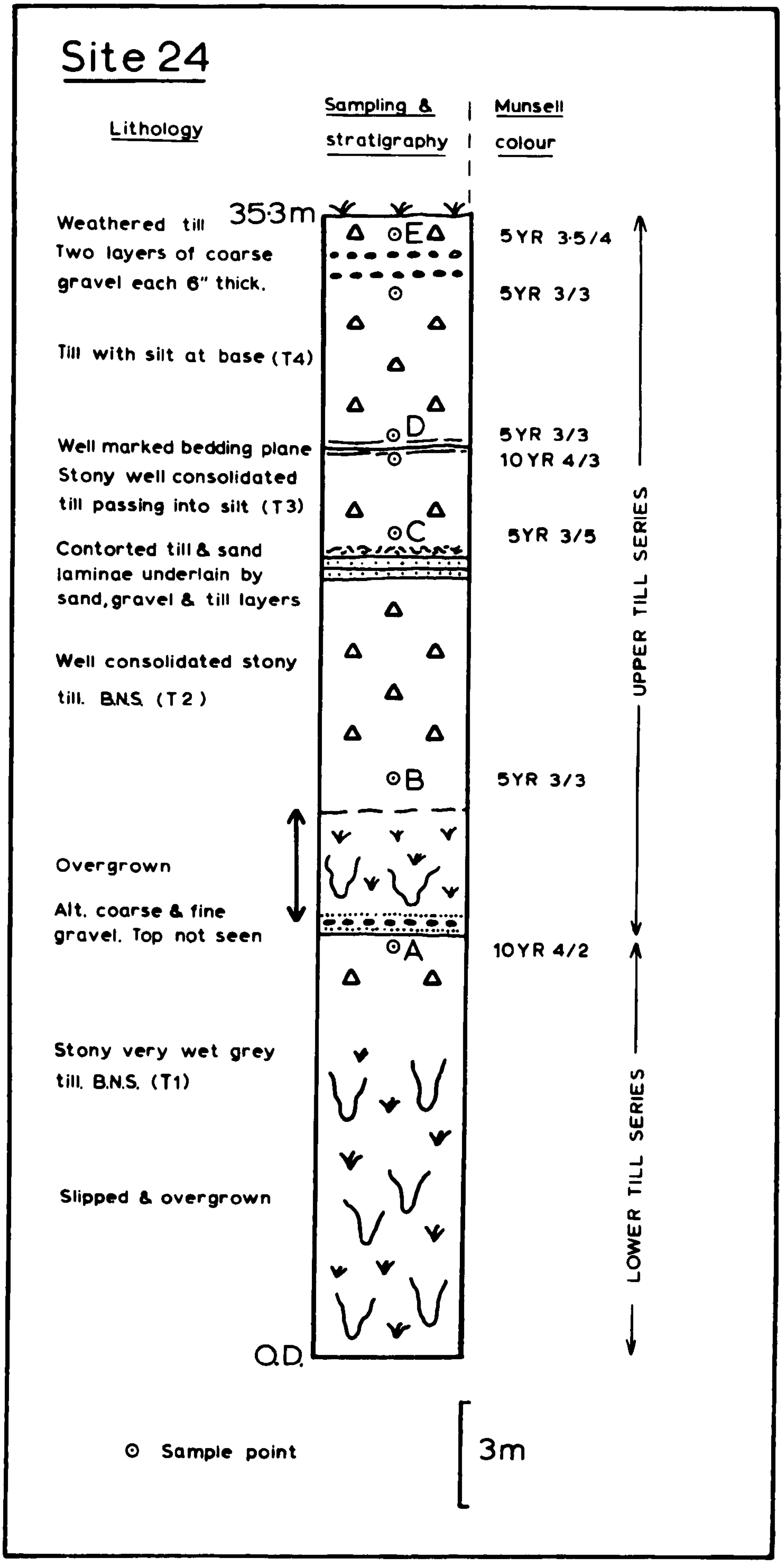


Fig. 34. MEASURED SECTION: SITE 24

Fig. 35. PARTICLE SIZE DISTRIBUTION CURVE

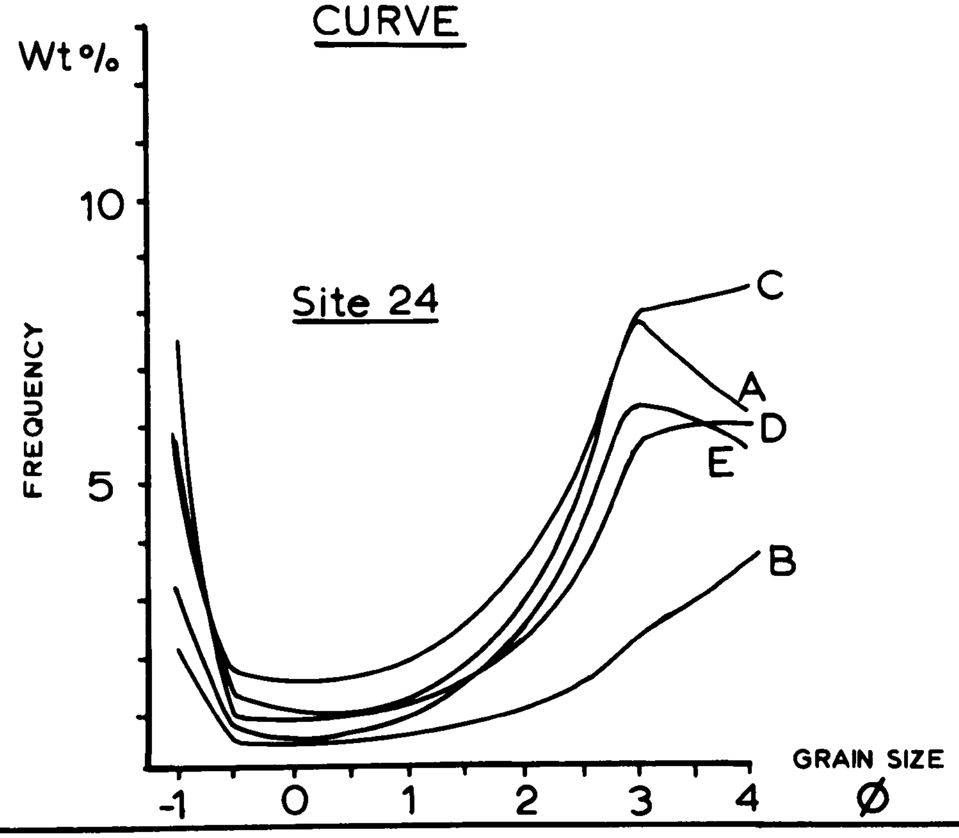
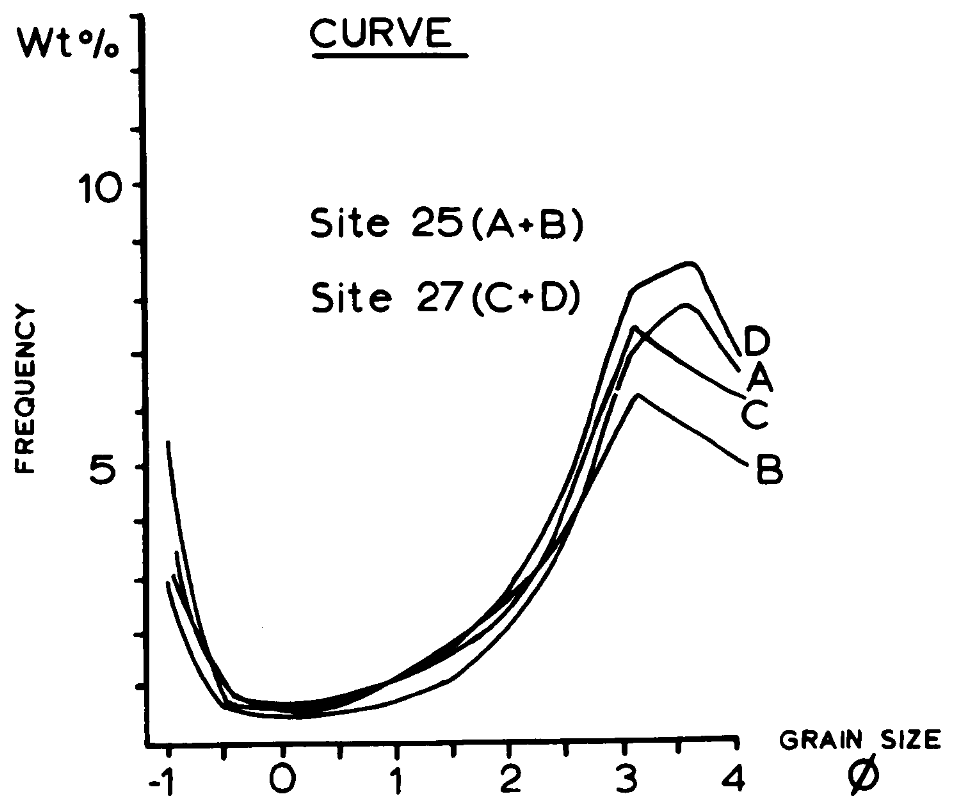


Fig. 36. PARTICLE SIZE DISTRIBUTION CURVE



SITE 25 (fig. 37)

(A) The glacial sequence is completely exposed, resting on Oxford Clay at 21.9 O.D. The lowest till (T1) is massively bedded and jointed, compact and contains many locally derived angular sandstone erratics enclosed in a fine sand-silt matrix. Within the till, gravel lenses occur, along with bands of red sand. The till immediately surrounding the gravel lenses and sand has been reddened by diagenetic weathering of iron compounds. At 38.7m O.D., the till contains a ball of very fine sand which is strongly folded and compressed, surrounded by a ring of folded and faulted fine sand. Beneath the sand, 5-8 cm of stoneless clay occurs. This lower till is brown-grey (10YR 2/2) becoming browner (10YR 3/2), less stony and sandier towards the top.

At 42.7m O.D. T1 is overlain by 1m of red fine sand, interbedded with clay, that contains very small stones. Above, there is 1.7m of fine reddish-yellow sand with coal streaks which is horizontally bedded and in places has been squeezed into gentle small folds and closely cut by small normal faults. It is overlain by 0.3m of white coarse sand that does not show squeezing, and this is overlain by o.35m of red sand which is indurated and not contorted. The sands are overlain by 3m of weathered red-brown (5YR 4/4) compact till, (T2), with a fine sand-silt matrix. This weathered till probably represents the lowest beds of the Upper Till Series, being separated from the Lower Series by the sands. The sands correlate with those exposed in sections at Sites 23 and 24.

(B) MECHANICAL ANALYSIS (fig. 36)

Curve A (T1) illustrates the fine-very fine sand mode of the Lower Till Series. Curve B (T2) also shows the same feature suggesting that it is weathered Lower and not Upper Till Series.

(C) PIPETTE ANALYSIS

Two samples from T1 (base and top) produce S values of 55.8% and 57.0%

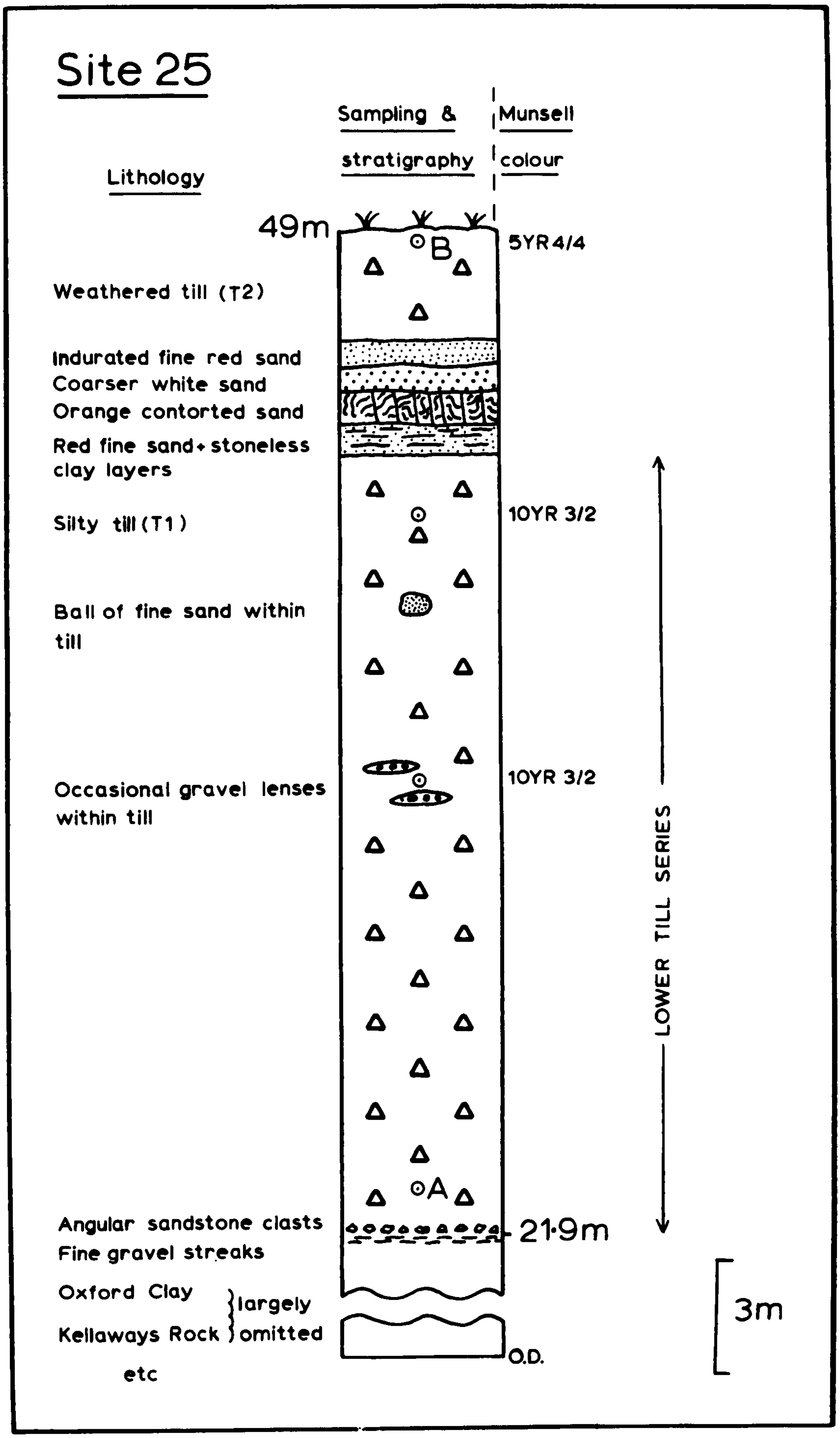


Fig. 37. MEASURED SECTION: SITE 25

respectively, indicating Lower Till Series. T2 has a value of 60.4% which indicates Lower Till Series, though may be anomalous due to weathering.

North-west of this site, the cliff is extensively slipped and overgrown; complete glacial sequences are seldom seen. At Site 26, weathered till containing a channel is exposed. The channel, which is a meltwater feature, is 1.3m deep and 9m wide. It contains massively bedded gravels, sands and silts. The gravels become coarser towards the top of the sequence. The till is quite hard and well cemented but not very compact. The sand content of the matrix has been increased by weathering of sedimentary erratics.

SITE 27

(A) At the base of a 10m high exposure towards the top of the cliff, compact, grey-brown (10YR 3/2) slightly laminar till with a silt-clay matrix identical to the top of the lower till (T1) at Site 25, passes up into weathered till which is highly leached, orange-brown (10YR 5/2) with a sandy matrix.

(B) MECHANICAL ANALYSIS (fig. 36)

Curves C and D (fresh and weathered respectively) indicate that the Upper Till Series is absent. Both display characteristic modes in the fine-very fine sand fractions.

(C) PIPETTE ANALYSIS

The till at the base of the exposure has an S value of 50.7% and is, therefore, Lower Till Series. The weathered till has an S value of 41.4% and is apparently Upper Till Series. However field observations and Munsell colour indicate that the weathered till grades down into fresh till of the Lower Series.

SITE 28

(A) About 2m of weathered till (10YR 4/2) overlies a grey-brown (10YR 2/2), fissile, laminar till with a silt-clay matrix and weathered orange spots. Between the weathered and fresh till there occur bands of coarse and fine sand and silt. The fresh till appears identical to the upper part of the Lower Till Series at Site 25, exfoliating parallel to the exposure surface when struck.

(B) MECHANICAL ANALYSIS (fig. 38)

Curve A (fresh till) suggests that the till is a member of the Upper Series.

(C) PIPETTE ANALYSIS

An S value of 47% also suggests that the till is a member of the Upper Series.

SITE 29

(A) 1.3m of crumbly red-brown (5YR 3/4) weathered till lies on Jurassic bedrock. It is not possible to determine whether this is weathered Lower or Upper Till Series as it is very thin and largely locally derived.

SITE 30

(A) Three metres below the cliff top there is an exposure of relatively stoneless, compact, laminar, grey-brown till (10YR 4/2) with a silty matrix which correlates with the fresh till at Site 28.

(B) MECHANICAL ANALYSIS (fig. 38)

Curve B exhibits a mode in the very fine sand fraction; characteristic of the Lower Till Series.

(C) PIPETTE ANALYSIS

An S value of 44.4% indicates that this till is a member of the Upper Till Series. It is uncharacteristically rich in sand and coarse silt (77.5%). There is no exposure north of this site until Scalby beck.

SITE 31

(A) A compact, grey-brown (10YR 4/2) stony till which is slightly laminar with a fine sand-silt matrix occurs, It exhibits vertical exfoliation flakes similar to those seen at Site 28. The till is overlain by a channel gravel which is coarse at the base and becomes finer upwards and is associated with occasional beds of laminated silt that are partially overlain by fluvial sand.

(B) MECHANICAL ANALYSIS (fig. 38)

Although Curve C shows a definite mode in the fine-very fine sand fraction, this tails-off gradually into the silt-clay fractions suggesting that the till is part of the Upper Till Series.

(C) PIPETTE ANALYSIS

An S value of 43.5% supports mechanical analysis, indicating that this till is a member of the Upper Till Series.

SITE 32

(A) Compact brown till (10YR 3/2) with some rounded igneous erratics enclosed in a silt-clay matrix overlies Oxford Clay which has partly been incorporated into the matrix making the till plastic when wet. This basal till (T1) contains frequent bands of fine to medium gravel each about 15cm thick. Above T1, a brownish weathered till (T2) occurs and is 3-4m thick, containing layers of waterlain gravel.

(B) MECHANICAL ANALYSIS (fig. 38)

Curve D (T1) supports field evidence which suggests that the till matrix contains Oxford Clay as shown by the broad maximum which is partly composed of silt and clay (22.4% and 41.9% respectively), making the till tenacious when wet. The till is a modified member of the Lower Till Series.

(C) PIPETTE ANALYSIS

An S value of 50.7% indicates that T1 is a member of the Lower Till Series.

Fig. 38. PARTICLE SIZE DISTRIBUTION CURVE

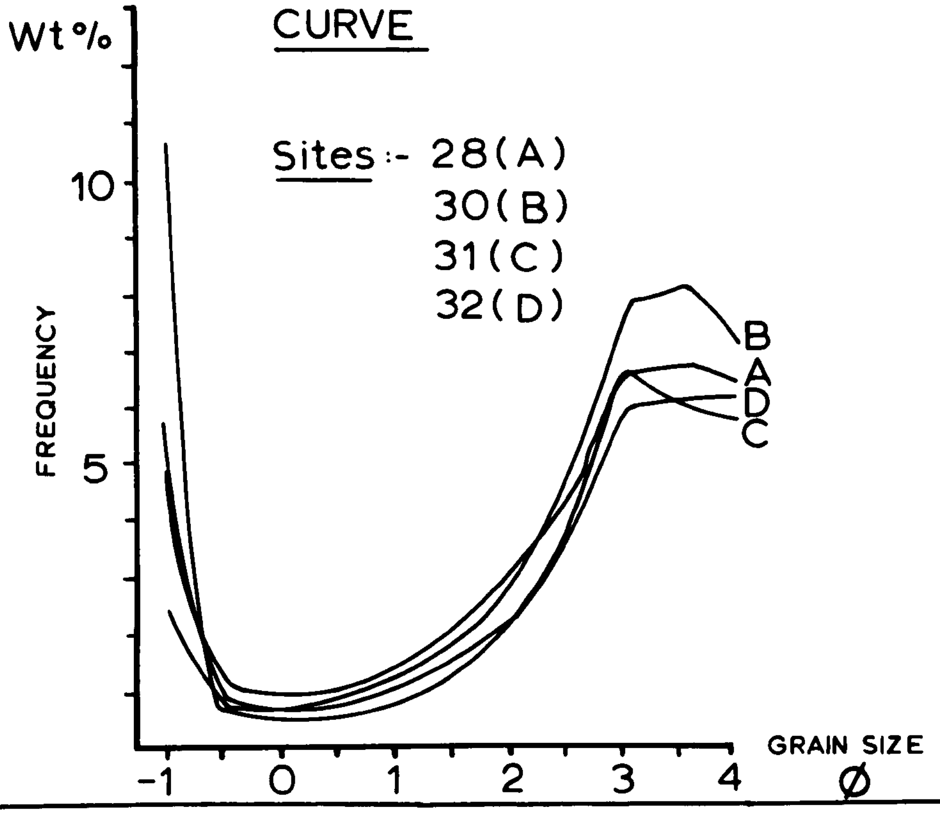
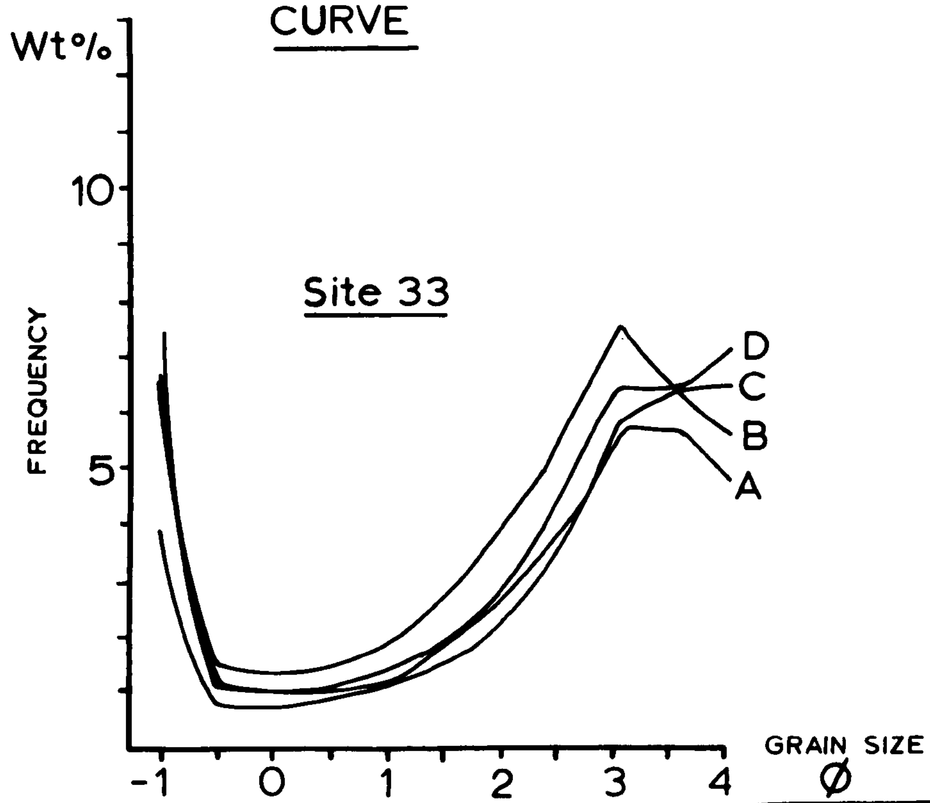


Fig. 39. PARTICLE SIZE DISTRIBUTION CURVE



SITE 33

(A) 12.2 metres below the cliff top, a very compact grey-brown till (10YR 2/2) with a fine sand/silt matrix occurs (T1). It is plastic when wet. Above this till there is 1.7m of grey silt overlain by 3m of fine yellow-brown sand whose fluvial structures have been deformed by squeezing. The sand is overlain by 2.7m of grey, compact stony till (10YR 4/2) with a fine sand/silt matrix. Above the grey till there is 1.3m of laminose, compact red-brown till (5YR 3/4) with a fine sand/silt matrix. The till shows a vertical exfoliar appearance and passes upwards into 2.7m of weathered compact pinkish-red till (5YR 3/4 - 4/4) with a fine sand/silt matrix.

(B) MECHANICAL ANALYSIS (fig. 39)

Curves A and B (T1 and T2 respectively) both indicate the presence of the Lower Till Series, showing a marked maxima in the fine/very fine sand fraction. Curves C and D (T3 and T4 respectively) both represent the Upper Till Series, being separated from the Lower by sands. They show modes which are characteristically largely composed of silt and clay.

(C) PIPETTE ANALYSIS

T1 is obviously a member of the Lower Till Series from field observation and Munsell colour though an S value of 46.5% does not support this. An S value of 59% for T2 does suggest that it belongs to the Lower Till Series. T3 and T4 are both considered to belong to the Upper Till Series and it is suggested that their respective S values (53% and 52.2%) reflect an alteration in the particle size property of the upper till, perhaps due to changing bed-rock lithology over which the ice travelled.

SITE 34

(A) Ten metres above beach level, there occurs ten metres of coarse gravel which contains at least three bands of grey, stony till, each varying from 30 - 45 cm thick. Above the gravel, a bed of fine, structureless sand about 6m thick occurs, overlain by 2.7m of stony, weathered, pinkish-red, (5YR 4/4) compact till with a fine sand/silt matrix.

(B) MECHANICAL ANALYSIS (fig. 40)

Curve A suggests that the weathered till is a member of the Lower Series. The sandy matrix is indicated by the characteristic well-defined mode in the fine/very fine sand fraction.

(C) PIPETTE ANALYSIS

An S value of 54.9% suggests that this till is a member of the Lower Till Series.

SITE 35

(A) Three metres below the cliff top, till is exposed in the flanks of a small drumlin that has been exposed by coastal erosion. Pinkish-red, friable, weathered till (T2) identical to that at Site 34 is underlain by a very compact grey till (10YR 4/2) with a silty matrix (T1). It is rather plastic and tenacious when wet, being identical to the basal till at Site 33.

(B) MECHANICAL ANALYSIS (fig. 40)

Curve B indicates that T1 is a lateral equivalent of the weathered till at Site 34.

(C) PIPETTE ANALYSIS

An S value of 57% indicates that this till is a member of the Lower Series.

SITE 36

(A) 1.7 metres of gravel rests on bedrock at about 33.5m O.D. and is overlain by 0.7m of silt which in turn is overlain by 2m of fine laminated sand. Above the sand, 2m of weathered till is overlain by 1m of till containing many large local boulders.

SITE 37

(A) At least 6.1m of grey-brown compact till (10YR 4/2) with a sandy matrix containing igneous erratics and having a slightly laminar structure is exposed. The upper 3m is weathered and identical to weathered till at Site 36. Lithologically, the till correlates with the vertically exfoliating till of Osgodby Nab (Site 25).

(B) MECHANICAL ANALYSIS (fig. 40)

Curve (C) (fresh till) has a strong fine/very fine sand maxima which indicates that it is part of the Lower Till Series.

(C) PIPETTE ANALYSIS

An S value of 48.1% suggests that the fresh till is a member of the Upper Till Series.

SITE 38

(A) 3m of gravel resting on Upper Deltaic bedrock at 42.7m O.D. is overlain by 2m of weathered till, identical to that at Site 37. North of this point, a thin cover of weathered till exists as far as Cloughton Wyke, where a pre-Devensian valley is infilled with weathered till. On the high land north of Sycarham Farm a thin weathered, bedrock deposit occurs and is thought to be the remains of a locally derived till. Its distribution is sporadic with about half the length of the cliff top being capped by glacially or periglacially contorted bedrock. In Hayburn Wyke (Site 39) thicker till deposits are again encountered.

SITE 39

(A) Over 5m of cemented torrential gravel is exposed on the north side of the valley. It is overlain by compact, grey (10YR 3/2), laminar till which has a fine sand/silt matrix. It is rather plastic and tenacious, being similar in appearance to the lowermost till at Site 33 and others north of Scarborough.

(B) MECHANICAL ANALYSIS (fig. 40)

Curve D displays a strong fine/very fine sand maxima characteristic of the Lower Till Series.

(C) PIPETTE ANALYSIS

An S value of 47.5% suggests that the till is a member of the Upper Series.

SITE 40

(A) 1.7m of compact, blocky, weathered orange till (10YR 6/4) with ash-grey faced joints, caps the cliff top. The till, which has a clay-rich matrix and is quite plastic when wet, is probably local in origin.

(B) MECHANICAL ANALYSIS (Fig. 40)

Although Curve E has affinities with the Upper Till Series it is not possible to definately correlate with other sites due to the local nature of the till as indicated by erratic content. The site is part of highland which was probably covered by thin ice thus precluding the influx of vast thicknesses of ice containing distantly-derived material.

(C) PIPETTE ANALYSIS

An S value of 40.8% suggests this till belongs to the Upper Series (see discussion).

SITE 41

(A) The cliff top (61m O.D.) is capped by 2m of weathered till which contains many far-travelled erratics. The deposit is directly derived from melting ice, being thoroughly unsorted.

SITE 42

(A) 2m of gravel, comprising much local material with an occasional granitic pebble is underlain by 1m of stoneless, laminated, oragge-yellow (10YR 5/4), soft, sandy clay. This deposit is the result of

Fig. 40. PARTICLE SIZE DISTRIBUTION

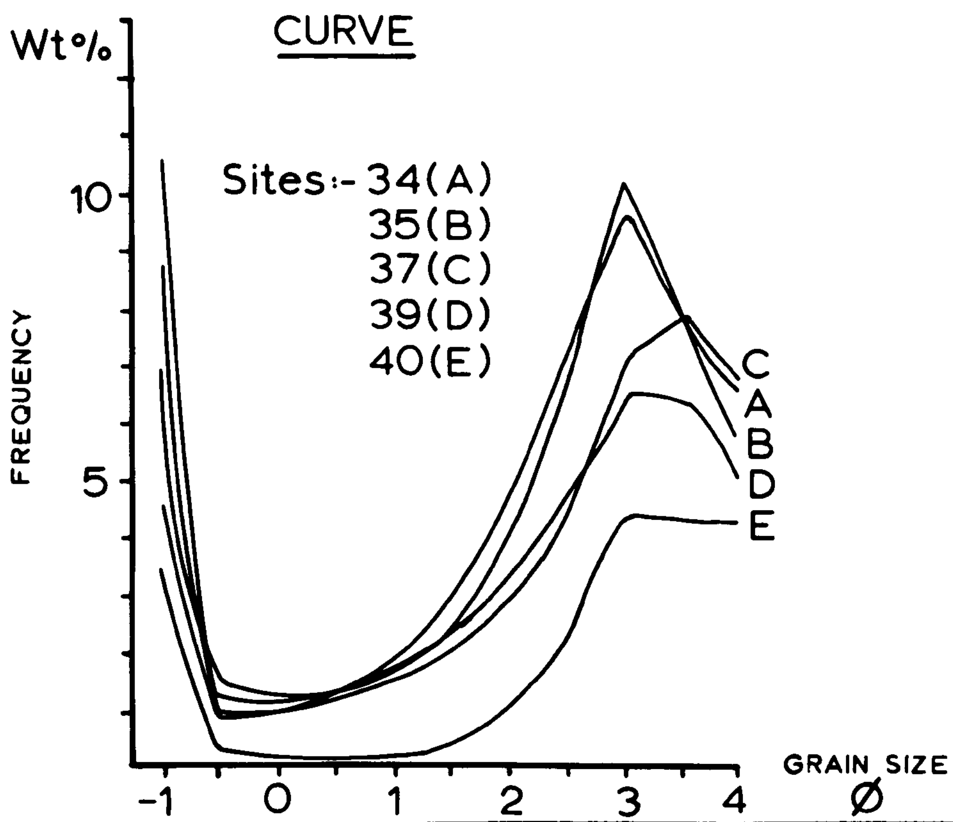
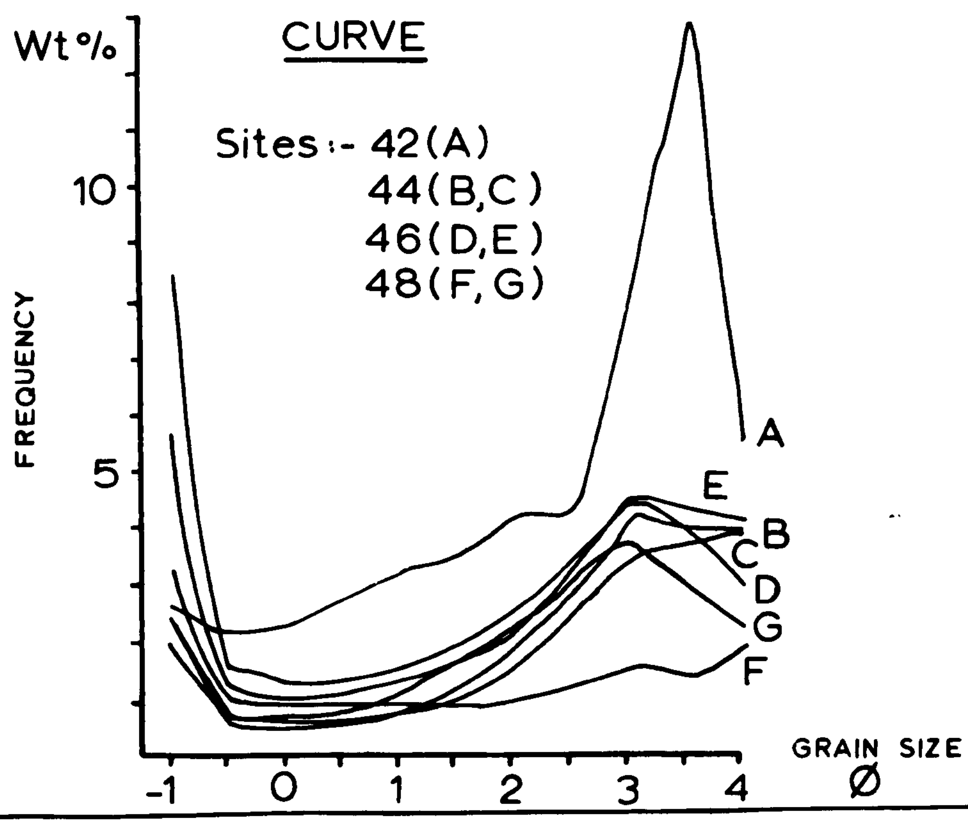


Fig. 41. PARTICLE SIZE DISTRIBUTION



glacial abrasion of the underlying shaly bedrock and is not a true boulder clay.

(B) MECHANICAL ANALYSIS (fig. 41)

Curve A supports the view that this deposit is locally derived as it is not suggestive of either the Lower or Upper Till Series.

(C) PIPETTE ANALYSIS

Although appearing to belong to the Lower Till Series (55.4%) this is a locally derived till which does not relate to the Upper or Lower Till Series.

North of this site, there lies Robin Hood's Bay with its thick till sequences.

SITE 43

(A) Coarse gravel occurs at the cliff top (39.6m O.D.) and overlies the Lower Till Series.

SITE 44

(A) Much of the cliff is slipped though the top 10m exposes sand and gravel with till above and below. That below the gravel (T1) is a warm brown (10YR 4/2), tough, compact till with a fine sand/silt matrix. It contains many small shale erratics and belongs to the upper part of the Lower Till Series. The overlying sand and gravel (3m thick) contains many coal streaks which reveal the numerous small normal faults which cut the sequence. It is overlain by 10m of pinkish-red (5YR 3/4), weathered till (T2) which has a sandy matrix. The sand and gravel separates the Lower and Upper Till Series.

(B) MECHANICAL ANALYSIS (fig. 41)

Curve B indicates that the lower till (T1) belongs to the Lower Series, having a maximum in the fine/very fine sand fraction. Curve C (T2) has a maximum in the silt/clay fraction thus indicating the Upper Till Series.

(C) PIPETTE ANALYSIS

S values of 52.2% (T1) and 41.9% (T2) confirm that the Upper Till Series overlies the Lower.

SITE 45

(A) The Lower Till Series is overlain by 1.3m of sand and gravel with 0.7m of weathered till above, lithologically identical to that at Site 43.

SITE 46 (fig. 42)

(A) Grey (10YR 3/2), very tough, compact till (T1) with a fine sand/silt matrix is exposed at beach level. The till is well jointed and has a blocky appearance. At 32m O.D. it is overlain by a layer of sand 0.7m thick and which contains silt bands. The two lithologies are intimately mixed in fine layers and display fluvial structures. The sand and silt is overlain by a brownish-pink (5YR 4/2), compact, hard stony till (T2) with a fine sand/silt matrix which exfoliates at the surface and corresponds to the upper part of the Lower Till Series at Osgodby Nab and also at Site 43.
Above, about 5m below the cliff top, plastic red-brown till (5YR 3/4) occurs (T3). It is compact, finely laminar, has a clay-rich matrix and is very soft when wet. This belongs to the Upper Till Series and is separated from the Lower Series by a bed of sand.

(B) MECHANICAL ANALYSIS (fig. 41)

Curve D supports field observations in indicating that T2 lies in the upper part of the Lower Series. T3 (Curve E) exhibits a maximomwhich extends into the silt clay fraction indicating that is is part of the Upper Till Series.

(C) PIPETTE ANALYSIS

S values of 50.3% (T2) and 47.5% (T3) show that the Upper Till Series overlies the Lower.

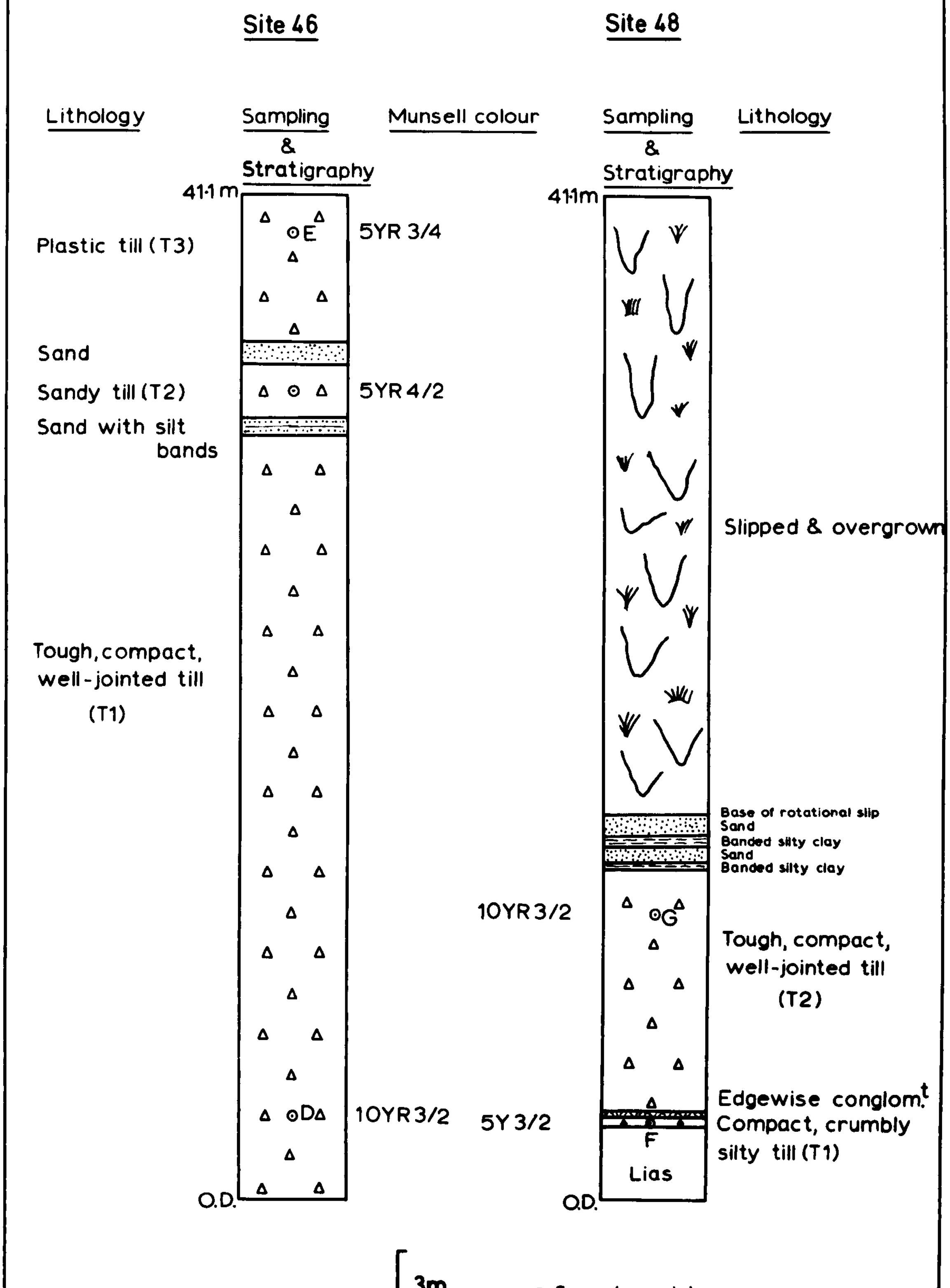


Fig. 42. MEASURED SECTIONS IN ROBIN HOOD'S BAY: SITES 46 & 48

SITE 47

(A) An exposure of weathered till near the cliff top lithologically resembles weathered Lower Till Series.

SITE 48 (fig. 42)

(A) At the base of the succession, about 15cm of grey-brown-green (5Y 3/2), compact till (T1) with a fine sand/silt matrix and many sedimentary erratics is overlain by 15cm of edgewise conglomerate (McClintock, 1931). Texturally, the till closely resembles the Basement till of Holderness in that it is rather silty and crumbly. Above the edgewise conglomerate, a grey, (10YR 3/2), very tough, compact, well-jointed and blocky lodgement till (T2) with a fine sand/silt matrix occurs.

At 10.7m O.D., it contains 0.3m of brownish-drab (10YR 4/2) banded, stoneless silt/clay which is overlain by 0.7m of fine, structureless sand. This is overlain by 0.3m of banded, stoneless, silt/clay which in turn is overlain by 1m of massively bedded fine sand.

The cliff above this point is slipped and overgrown but from occasional exposures it appears to comprise brown flaky silty till identical to T1 at Site 43. The Upper Till Series is not exposed at this site.

(B) MECHANICAL ANALYSIS (fig. 41)

Curve F reveals that T1 is of a different origin to T2 as it has only a slight very fine sand maximum. Similarly, it does not resemble the Lower Till Series wherever they overlie bedrock, e.g. Oxford Clay at Site 20, Corallian at Site 19. This till may be Wolstonian and therefore equivalent to the Basement till of Holderness.

Curve G (T2) is typical of the Lower Till Series with a maxima in the fine/very fine sand fraction.

(C) PIPETTE ANALYSIS

T1 has an S value of 33.8% compared to 60.8% for T2. This illustrates the particle size differences between the two tills which are also indicated by mechanical analysis and supports the view that the two tills have differing origins and ages.

North of Site 48 the cliffs are extensively slipped and overgrown as far as Bay Town. North of Bay Town, solid bed-rock rises rapidly above O.D. and comprises the greater part of the cliff, making the glacial succession inaccessible.

(4) DISCUSSIONS AND CONCLUSIONS

(A) COMPARISONS WITH HOLDERNESS

The glacial succession in north-east Yorkshire is broadly similar to that of Holderness (Catt and Penny 1966) with which it correlates laterally. The tills exposed in the coastline of Holderness are remarkably consistent, displaying a three-tier succession of Basement, Skipsea and Withernsea tills with the Dimlington silts occuring between the Basement (Wolstonian) and Skipsea till (Devensian) (Madgett, 1975). This consistency of lithology and sequence is due to the topographic consistency of the underlying bed-rock which forms a horizontally eroded chalk platform at some depth below O.D. and which provided an unobstructed path for the advancy of ice from the north-east, and a uniform topographic basement for the melting of the ice.

North of Flamborough Head, the pre-Devensian topography was much more varied, ranging from the soft Mesozoic clay area of Filey Bay and the resistant chalk buttress of Flamborough Head to the south of it; to the high middle Jurassic cliffs e.g. Ravenscar, within which are the lower embayments of Robin Hood's Bay and Cayton Bay. In contrast to Holderness, therefore, north-east Yorkshire provided many topographic barriers to the ice advance and an extremely varied pre-Devensian basement upon which melting occurred. The result is greater within-till diversification than in Holderness with the additional formation of till which is largely local in origin. Because of this greater diversification, the tills of north-east Yorkshire have been named as the Lower and Upper Till Series. The Lower is correlated with the Skipsea and the Upper with the Withernsea of Holderness.

Within the North Sea basin it is considered that northern Pennine ice was overridden by ice originating in County Durham and that the compound glacier thus formed moved southwards between higher land to the west and Scandinavian ice to the east. Pressure from the Scandinavian ice caused the compound glacier to impinge on the coast-line wherever there were no barriers and consequently, melting of the ice has produced, in such areas as Filey Bay, a two-tier depositional sequence, similar to that of Holderness. Exposures of till along the tops of the middle Jurassic cliffs frequently do not reveal a two-tier till sequence; instead only one till is present as the high cliffs acted as a barrier to the advance of the lower layers of the compound glacier. Identification of the till deposited in such situations is problematical for three reasons :-

(i) It has been locally modified by the inclusion of local Jurassic material thus masking any pre-existing Holderness-type characteristics.

(ii) Madgett (1975) has shown that the areal distribution of the Withernsea till in Holderness is not as great as that of the Skipsea till. If this condition also applies to north-east Yorkshire then it cannot be assumed that the upper layers of ice at all sites are those which deposited the Upper Till Series. At some sites, the upper layers of ice may have been those which deposited the Lower Till Series.

(iii) The till is frequently deeply weathered and is characterised by an increase in the sand content due to the breakdown of sandstone erratics and a relative increase due to the preferential leaching of clay particles (Mitchell and Jarvis 1956). Thus, coupled with the absence of a two-tier till sequence the identification of a single layer of till on the high Jurassic cliffs is rather tentative.

Wherever low lying topographic barriers existed e.g. Carr Naze, and both Lower and Upper Tills are present, the basal zone of the Lower one has been lithologically altered to a certain extent by incorporation of the underlying bed rock. Thus at Site 19 (Filey Brigg area) this alteration is manifested by a change in Munsell colour together with changes in the particle size distribution as reflected in the S ratio and mechanical analysis curves. In such situations the S ratio is rather unreliable for correlation with areas whose glacial sequence is more in character with the typical Holderness type sequence. Madgett (1975) discovered a value of 45% derived from the formula was a consistantly reliable indicator for the separation of the Skipsea and Withernsea tills in Holderness. Skipsea till showed values in excess of 45% whereas Withernsea till showed values below 45%.. In north-east Yorkshire the modified critical value stands a little higher at 49% wherever a typical Holderness-type sequence exists. Traversing from Holderness to north-east Yorkshire involves traversing the flow lines of the ice and thus the change can be attributed to the gradually changing provenance and flow route of the ice.

The S value has been shown by results to be a reliable indicator in the deep embayments of the coast though it becomes unreliable wherever till has been weathered or has incorporated local material into the matrix. Mitchell and Jarvis (1956) showed that in some cases the weathering processes may simply produce an accumulation of sand size particles.

especially if the parent material was a till containing a high percentage of sandstone fragments. Alternatively, the weathering processes may produce clay particles which may be translocated within the region of weathering to a lower level by the percolation of surface water down through the soil (Madgett 1975). It is these two weathering processes which produce the apparent contradictions between mechanical and pipette analyses when attempting to determine the provenance of thin and weathered till resting on Jurassic bedrock. Certain of the sites described in (3) have been influenced in these ways and merit further discussion.

(i) SITE 3

T3 exhibits an S value of 42% indicating Upper Till Series, in accord with mechanical analysis. The weathered till has an S value of 57% which is the result of weathering processes breaking down sandstone erratics and thus increasing the sand content of the till from 26.3% to 33.7%.

(ii) SITE 7

The chocolate silts (T2) described in the field observations are in reality chocolate coloured fine sands. The high percentage of sand in the deposit (41.2%) produces an S value of 57% which, due to lithological variation at this site, bears no relationship to the S values of other tills in the vicinity.

(iii) SITE 13

The increase in S value from 52.5% to 59.8% between the fresh and weathered till is an example of the increase in sand content of Lower Till Series through weathering processes.

(iv) SITE 16

Visual observations indicate that the entire cliff is composed of the Lower Till Series in which case the fall of 6.3% between the S values of fresh and weathered till respectively is regarded as erroneous, as it contradicts the normal weathering pattern. It is possible that the weathered till is in part the feather edge of the incoming Upper Till Series which caps the cliff top from this point northwards, and that this is responsible for lowering the S value.

(v) SITE 19

The incorporation of Corallian limestone into the basal zone of the till has increased the S value to 73.8% indicating that there has been a sizeable addition of sand (61%). In this particular instance the sand is largely composed of uncomminuted limestone ooliths.

The weathered surface till has an S value of 57.2% which is a result of sand particles being introduced into the horizon by the weathering of erratics.

(vi) SITE 20

On balance the evidence indicates that the Lower Till Series forms the base of the exposure. An S value of 53.2% supports this though it may have been locally modified by incorporation of Oxford Clay into the till. The S value of the weathered till (59.1%) has been raised by the increased proportion of sand in the till (55.4%) derived from the weathering of sandstone erratics and therefore this may possibly be modified Upper Till Series.

(vii) SITE 23

An S value of 29.3% for T2 is considered to be the result of extreme alteration to the particle size distribution of the till by weathering processes. The proportions of sand (13.5%) and silt/clay (58.4%) suggests that much of the original sand has been altered to silt/clay particles and cemented to give the till a very well-compacted and semi-lithified appearance.

(viii) SITE 24

This site clearly demonstrates the changes in particle size distribution which the Upper Till Series undergoes due to weathering. Weathering increases the S value of fresh till from 45.6% to 48.7% and mechanical analysis indicates that this change can be attributed to a rise in the proportion of sand in the weathered till from 21.3% (fresh) to 29.3%. The rise is due to the weathering of sandstone erratics and breakdown of silt particles to clay which increase from 37.8% to 46.2%.

(ix) SITE 27

Munsell colour, field observations and mechanical analysis all indicate that the Upper Till Series is absent. The high proportion of sand in the till (40.5%) and lower clay content (27.3%) suggest that the S value is erroneous and should be higher.

(x) SITE 32

This site is comparable to Site 20 in that the till has incorporated Oxford Clay into its matrix and displays a high proportion of silt/clay (41.9%) which has lowered the S value to 50.7%.

(xi) SITE 33

This site illustrates how incorporation of Oxford Clay lowers the S value of the Lower Till Series (46.5%). This is confirmed by the overlying till, which has no Oxford Clay incorporated and has an S value of 59%. The Upper Till Series is proved to be present by mechanical analysis; the high S values (53% for T3 and 52.2% for T4) are due to enrichment of the sand fraction by weathering processes.

(xii) SITE 34

As with other sites, it is possible that the S value of 54.9% has been raised by weathering to give an apparent Lower Till Series value. However, field observations indicate that this weathered till is the lateral equivalent of fresh Lower Till Series at Site 35.

(xiii) SITE 37

Field observations indicate that the till is a member of the Lower Series as supported by mechanical analysis. The S value of 48.1% is considered to be erroneous as it is rather low, suggesting contamination of the till matrix by Oxford Clay, though this does not appear to have occurred. As the till rests on local sandstone its particle size distribution has probably been locally modified.

(xiv) SITE 39

Field observations reveal a tenacious, clay-rich till of the Lower Series, with a rather low S value (47.5%). However, this has been lowered by incorporation of silt (26.7%) into the till matrix.(40.5% sand, 26.7% silt, 32.8% clay).

(xv) SITES 40 and 42

It is not possible to assign the till exposed at either of these sites to the Lower or Upper Till Series. They are largely locally derived and therefore do not correlate with the more distantly derived tills at other sites.

(B) PARTICLE SIZE DISTRIBUTION

At Site 19, uncomminuted limestone ooliths have been incorporated into the basal 15cm of the Lower Till Series indicating that no shearing of Corallian material to an en-glacial position has occurred. The intact state of the ooliths and the absence of shearing indicates that the material is locally derived and has undergone only a short transport distance. The coarse grained mode of the till confirms this local bedrock source (Dreimanis and Vagners 1969).

The Lower and Upper Till Series are distinguishable by their particle size properties as described by Dreimanis and Vagners (1969). They concluded that the coarse-grained mode of till is larger than the fine-grained mode if the bedrock source is local. If the bed rock source is distant, the fine grained mode becomes predominant. For source areas of intermediate distances, the balance between the two modes may depend greatly upon the resistance of the particular rock type to comminution during glacial transport.

Both Till Series in north-east Yorkshire have been transported about the same distance, and accepting the compound glacier structure, it becomes apparent that much of the erosion of the North Sea basin has been carried out by the Lower ice. The Upper ice was more passive and not continuously and actively eroding underlying bedrock. This over-simplification of an extremely complex internal glacial structure offers an explanation for the particle size differences, rather similar to those described by Dreimanis and Vagners, which occur between the Lower and Upper Till.

The Lower ice was constantly incorporating into its mass, very coarse sedimentary material from the present North Sea floor. This was comminuted within the ice to produce a large mode within the fine/very fine sand fraction. The constant supply of coarse material ensured that this mode remained in the sand fraction. Sites such as 19 illustrate the incorporation of local material firstly into the sole of the ice, and with increasing distance away from the source, into the main mass of the till by en-glacial shearing e.g. Site 13.

Conversely, the Upper Till was not so active erosionally and as the supply of material was largely derived from softer rocks than the Lower Till Series, e.g. New Red Sandstone, and not constantly replenished en route, the mode tends to be in the silt/clay fraction. The S ratio relies upon this fundamental difference between the Upper and Lower Till Series which is best displayed by simple frequency distribution curves. The ratio holds good in north-east Yorkshire wherever far-travelled ice penetrated the area without undue local modification e.g. Filey, Cayton and Robin Hood's Bay. Wherever till has been deposited from ice which has been eroding the high Jurassic sandstone terrain of north-east Yorkshire, the S ratio tends to increase, due to the short transport distance preventing the locally derived sandstone from become thoroughly comminuted. Conversely, wherever till has locally incorporated Oxford Clay the S ratio is lowered due to the enriched silt/clay content of the matrix. e.g. Site 33.

(C) GLACIO-TECTONICS

Within the Lower Till Series, en-glacial rafting occasionally occurs. Material was plucked from the sub-glacial floor and incorporated into the ice intact. Rafts of soft Mesozoic clay at Sites 3, 13 and 14 show little sign of comminution and indicate up-shearing in excess of 50m vertically due to basal obstruction of the ice in the area of Filey Bay. This is consistent with evidence from the Speeton Shell bed which indicates extensive contortion of the Mesozoic clays and overlying pre-Devensian material (see Chapter X). The obstruction is considered to be the rising ground flanking Flamborough Head and the chalk scarp of the Yorkshire Wolds, which would be even more prominent features of the landscape if sea level was some 100m lower than at present. It was responsible for the formation of narrow band tills in Filey Bay which are considered to be a direct depositional reflection of thrust slices within the ice. Traversing to the N.W., away from the influence of the chalk scarp, the narrow band tills give way to thick sequences of Holderness-type lodgement till.

Certain coastal exposures (Sites 1 and 6) show that shearing occurred between the Lower and Upper Till Series. Lithological and Munsell colour investigations reveal the occurrence of thin beds of Lower Till Series above the base of the Upper Series which represent slices of Lower ice which have been sheared upwards into the base of the Upper ice.

This is quite in keeping with the behaviour of tiered glaciers at the present day such as those described in the Karakorum by Versin (in Sharp 1948).

(D) LITHOLOGICAL VARIATIONS WITHIN THE TILLS

The tills of Filey Bay are similar to those of Holderness and allow the observation of variations within the till that are not strictly of local origin. At Site 6, the Lower Till Series is seen to contain a red band (Bisat 1939). Mechanical analysis shows that this is a reddening of the Lower Till Series, a feature which Bisat noticed in Holderness. However, the red band is not as persistent as Bisat claimed it to be in Holderness where he included it in two of his stratigraphic successions (1939, 1954).

In north-east Yorkshire it is not possible to identify a particular red band; instead measured sections reveal a reddening of the Lower Till Series towards the top which is combined with an increase in the sand content and a decrease in the clay content. South of Carr Naze the base of the Lower Till Series is characteristically quite rich in clay (up to 57%) due to comminution of constituents towards their respective terminal modes. This is a reflection of the degree of crushing and shearing that occurs in the basal zone of the ice. Higher in the Series, material is not comminuted to the same extent and constituent minerals do not approach so nearly their respective terminal modes, hence the till is more sandy. Visual observations of some of the sand fractions show the grains are coated in haematite and this accounts for the reddening associated with increased sand content.

Very complex variations are seen around the contact between the Lower and Upper Till Series at Sites 7 and 8, and others have been reported by Bisat (1940). Mechanical and pipette analyses and field observations all suggest that the boundary is at the base of the transitional series, not at the top. The transitional series is therefore the product of incorporation of Lower Till Series into the Upper Till Series.

(E) AREAL EXTENT OF THE TILLS

The Upper Till Series is not so extensive as the Lower. The distribution is a reflection of the manner in which the ice arrived in the area - as an overrider on the Lower Till Series ice and is comparable to the situation which exists in Holderness (Madgett 1975). From Site 8 northwards the Upper Till Series is absent as far as Site 17. Between these two sites the entire cliff is comprised of Lower Till Series.

It is rather curious that the Upper Till in Filey Bay is absent from the central position of what was probably a lobe of ice extending inland from the north-east. The area is now the lowest lying part of the Filey Bay till plain with several small basins which contain late/post glacial peats. The formation of these basins may in part be due to the absence of the Upper Till Series. The Upper Till Series is present as far north as Site 20 but then is absent along Gristhorpe Cliff. It reappears again in Cayton Bay where a lobe of Upper Till Series ice existed as an overrider on Lower Till ice.

Thin and weathered Upper Till Series exists as far as Site 33 but is absent between Site 34 and Hayburn Wyke. Beyond Hayburn Wyke the till has a very local character and undisputed till of the Lower and Upper Series does not occur again until Robin Hood's Bay, where ice could advance inland.

On the high land to the south of Robin Hood's Bay the ice cover was quite thin. It eroded the local Jurassic bedrock and consequently the thin weathered till is of a highly local nature and cannot be correlated with the till to the north and south which is of a more distant character. In Robin Hood's Bay a thick sequence of Lower and Upper Till Series is exposed illustrating basal melting typical of Holderness.

Robin Hood's Bay is the only locality in north-east Yorkshire where till of a probable Wolstonian age is seen to underlie the Devensian deposits. At Site 48 the Lower Till Series is separated from an underlying till by 0.15m of edgewise conglomerate (McClintock 1931). This consists of brecciated fragments of what was originally a horizontally banded silt. The deposit is waterlain and probably formed in a pro-glacial lake before being frozen and brecciated by the advancing ice. It has been deposited on till which mechanical and pipette analyses and Munsell colour show to be of completely different character to undisputed Devensian tills. The crumbly texture of the till is very similar to that of the Basement till of Holderness and coupled with the fact that the till pre-dates the major Devensian ice advance, it is considered to be Wolstonian.

CHAPTER IV - STONE ORIENTATION

(1) INTRODUCTION

Very early work on ice movement in the area entailed recording striations which have occasionally been exposed on bedrock surfaces at several coastal localities. Muff and Sheppard (1896) recorded a set of N - S trending glacial striae on a newly exposed surface at 122m O.D., to the north of Robin Hood's Bay. Stather (1897) described striations on the north side of Carr Naze at two sites 200m apart. The more easterly of the two, near the second doodle trended from 20° to 30° (true) with a mean of 24°. The other exposure near Spa Nab showed a range of orientation between 10° and 30° (true) with a mean of 18°. The Spa Nab exposure corresponds closely with observations made by Lamplugh (1891) on the southern side of Carr Naze.

No previous stone orientation analyses have been undertaken in the area as a whole, though the northern and southern extremities have been investigated by Andrews and Smith (1970) and Catt (1963) respectively. The present work supports the findings of these workers and shows that they are applicable to the intervening stretch of north-east Yorkshire's coastal tills.

(2) TECHNIQUE

The technique adopted is basically that used by Andrews and Smith (1970). Due to the lack of horizontal surfaces at coastal sites, most observations were made in the vertical plane. The till face was cut back to prevent obtaining a preferred orientation due to weathering. At some sites the extremely tough nature of the till limited the cutting back to a matter of only several centimetres. Once cleaned up, the face was inspected for stones with a long axis/intermediate axis ratio of at least 2:1. Stones with a long axis length of less than 1cm were discarded as were stones with no apparent long axis. Stones were carefully removed from the till (Hill 1968), and if suitable for measurement, were replaced in the cavity. A sharpened brass rod was then inserted into the till beside the stone parallel to the long axis. The orientation of the rod was recorded and corrected for magnetic variation. Instead of recording 100 stones from each site, three sets of 25 stones were selected from the same height and within a distance of 1m of the previous set (Young 1969). This method is less time consuming in the field than sampling 100 stones and has been shown by Harrison (1957) and Andrews and King (1968) to be statistically sound and more reliable than 100 stones from one site.

(3) PRESENTATION OF DATA

Data are presented as simple rose diagrams, after grouping into 10° class intervals as follows 5° - 14°, 15° - 24° etc. Each concentric division represents 1% starting with 0 at the centre.

(4) DISTRIBUTION OF SITES

From previous work in north-eastern England (Kendall 1902, Penny and Catt 1967, Francis 1970) the concept of a two-tier glacier off the present north-eastern coastline, and which advanced inland in the lower lying areas in a south-westerly direction is firmly established. Consequently the stone orientations performed in this work (see figs. 44, 45, 46) are not primarily concerned with the regional direction of ice movement but are intended to illustrate the lateral and vertical variation within and between Till Series which occurs at selected sites (fig. 43).

SITE 1

Fig. 44.1 (1m above the base of the succession) does not indicate a definite longitudinal maximum though the absence of a transverse maximum emphasises the broad N.E. - S.W. trend of ice movement. In this basal zone where a large proportion of well-rounded, elongated, quartzite

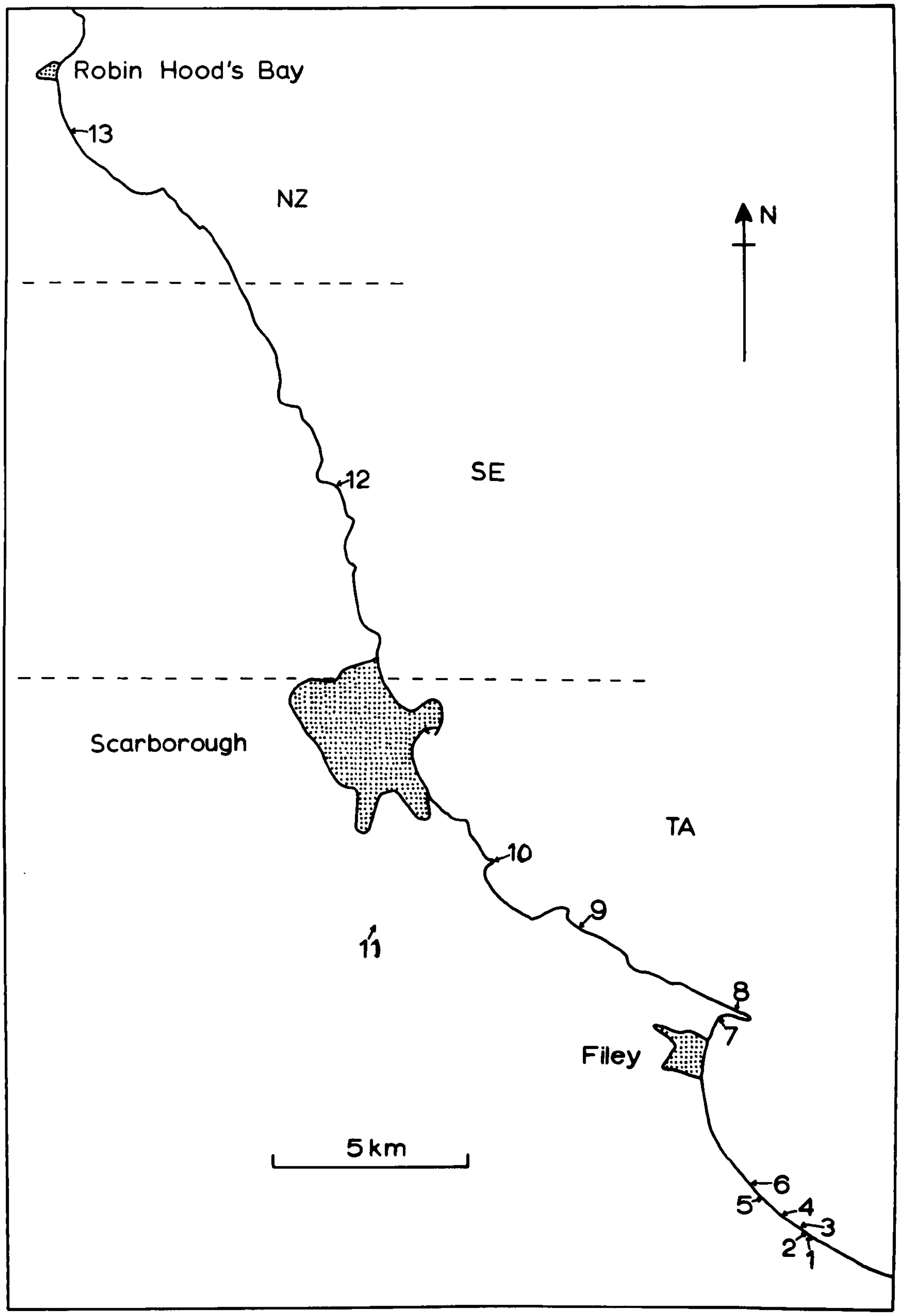


Fig. 43. MAP TO SHOW DISTRIBUTION OF STONE ORIENTATION SITES

erratics were sampled one would expect a strong transverse maximum due to basal thrusting and rolling.(Holmes 1941). However quartzite erratics are not characteristic of the Lower Till Series and it is probable that they have been locally secondarily derived from pre-existing glacial deposits. Their distribution within the till is limited to the basal layers indicating that they are not far-travelled (Dreimanis and Vagners 1969) and therefore their shape is not an indicator of shearing processes occurring within the sole of the late-Devensian ice.

The basal ice may have exhibited a strong longitudinal maximum some distance upstream which has been partially modified by the ice advancing against the flanks of the Flamborough peninsula. This advance may have precipitated basal thrusting and shearing which has caused rotation of elongated erratics from a longitudinal position towards a transverse one, though the end-point was not achieved, due to ice movement ceasing soon after meeting the rising ground. Alternatively the orientation may be attributed to deformation and flow of the till under the great stress exerted upon it at this point (Andrews and Smith 1970) as indicated by the extensive development of narrow band tills hereabouts.

Fig. 44.2 (T2) demonstrates a strong NNE - SSW longitudinal maximum with a minor transverse maximum. The diagram illustrates that this particular till unit has been free from internal shearing processes and that the till is true lodgement till.

Fig. 44.3 (T3). This till unit is a member of the Lower Till Series and displays a different main fabric structure to the underlying T2. It is a thinner till unit and appears to have been produced by shearing within the Lower Till Series, hence the bedding plane separating the two units. It displays a longitudinal maximum which trends NE - SW with the development of a N - S transverse maximum. The shearing which produced a bedding plane between T2 and T3 has partially rotated stones from a longitudinal towards a transverse position (Glen, Donner and West, 1957).

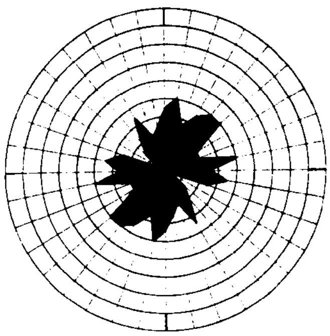
Fig. 44.4 (T4A). This is a thin till immediately below the zone of shearing indicated by Munsell colour and particle size distribution, which occurs between the Lower and Upper Till Series. Stone orientations indicate that this till has been affected by internal shearing, totally destroying any longitudinal maximum which may have existed and producing instead a distribution in which no particular trend is emphasised.

Conversely, till unit T4B (fig. 44.5) which is a thin till overlying T4A, displays quite a strong longitudinal maximum with a slight anti-clockwise displacement illustrating how the shearing processes have subdivided the Lower Till Series into a sequence of narrow band tills (Donner and West, 1956, Glen, Donner and West, 1957) some of which have been internally disturbed to a greater degree than others. These narrow band tills are a direct reflection of the tectonic structure of the late-Devensian ice in this area.

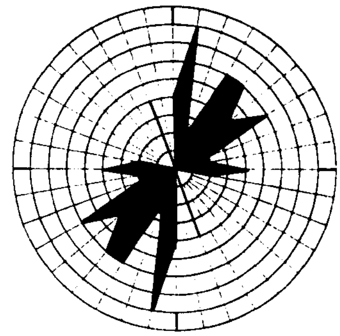
Fig. 44.6 (T5) shows a maxima trending NNW - SSE in keeping with the Upper Till Series at other sites. In this ice-marginal position the Upper Till Series may have been moving laterally over the underlying Lower Till Series ice thus creating the shear observed between the two Till Series.

SITE 2

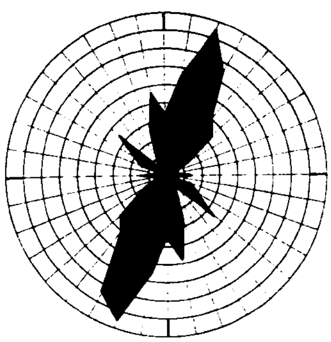
Fig. 44.7 (Basal T1). The two maxima indicate the rotation of longitudinally orientated stones towards a transverse rolling position associated with basal shear in the ice.



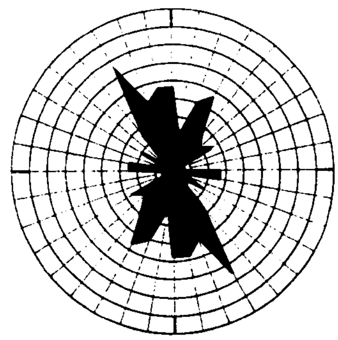
44·1



44·5



44·2



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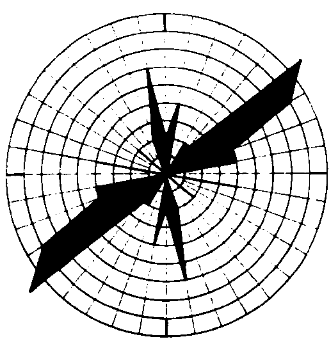

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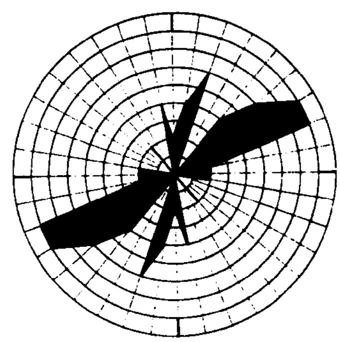

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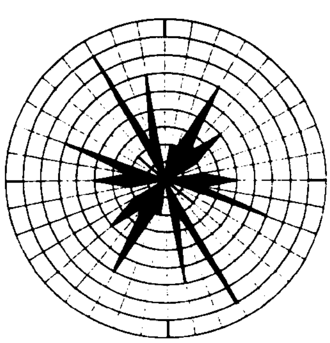

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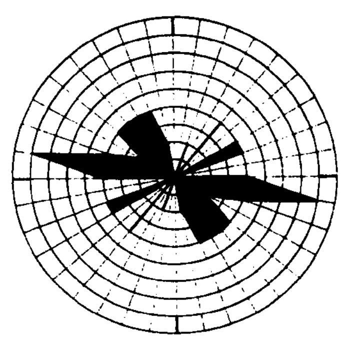

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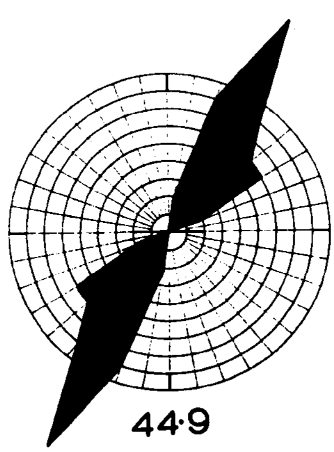


44·9

Fig. 44.8 (Top of T1) illustrates the further development of this trend with the transverse maximum being dominant indicating that erratics have been almost entirely rotated into a transverse rolling position.

Fig. 44.9 (T2). A strong longitudinal orientation consistant with findings from other localities suggests the till is a lodgement till and supports correlations in Chapter 3 based on Munsell colour and particle size data.

SITE 3

Fig. 45.1 (T1). A NNE - SSW longitudinal maximum is accompanied by a minor transverse maximum trending ENE - WSW produced by rotation of stones from the longitudinal maximum. This analysis is within the basal zone of rolled, secondarily-derived, igneous erratics though, unlike Site 1, it shows a prominent transverse maximum, indicating that rotation of erratics from a longitudinal position occurred at this point.

Fig. 45.2 (T2) shows a prominent longitudinal maximum trending NNE - SSW similar to T2 at Site 1, plus a minor transverse maximum. As no rotation of erratics due to shearing has occurred, the till is interpreted as a true lodgement till.

Fig. 45.3 (T3) displays a strong longitudinal maximum trending ENE - WSW plus a minor transverse one. It is a true lodgement till which does not indicate shearing.

Fig. 45.4 (T3). This diagram indicating sense of dip shows a large percentage of erratics "dipping-up glacier". This imbrication indicates lodgement till. (Holmes, 1941).

SITE 4

Fig. 45.5 (T1). A strong longitudinal maximum with very minor transverse development correlates laterally with the second till units of all three previous sites and indicates lodgement till with no internal shearing. It also supports the view that the lowest till unit is not exposed at this site (Chapter 3) due to the glacial beds dipping to the north-west.

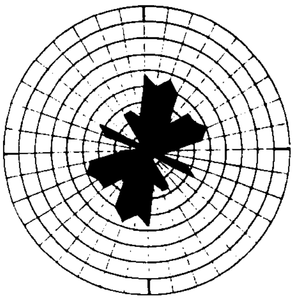
SITE 5

Fig. 45.6. This stone orientation in the Lower Till Series indicates strong longitudinal maximum and minimal transverse development. The analysis suggests that the Lower Till Series has been sampled well above the base as there is no indication of basal shear and consequent rotation of stones to a transverse position. This finding is consistent with borehole evidence from the Vale of Pickering (Chapter VII), which indicates that the glacial beds dip towards the north-west on the south side of the vale. (Chapter 3 fig. 15).

SITE 6

Fig. 45.7 (T1). A strong NE - SW maximum indicates an undisturbed lodgement till which, with evidence from other sites within the Lower Till Series, suggests the base of the till sequence is at some depth below this sample point.

Fig. 45.8 which includes the sense of dip, shows that most of the erratics "dip up-glacier" thus indicating lodgement till with imbricated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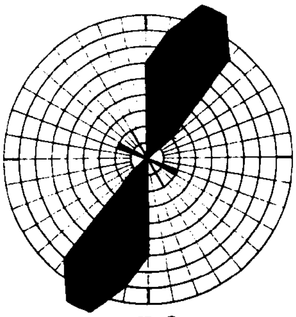
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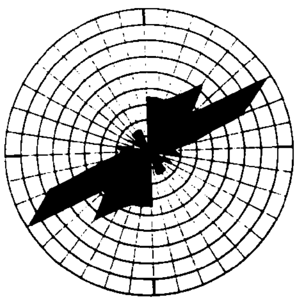
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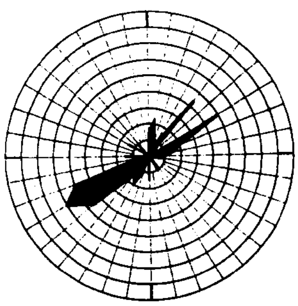
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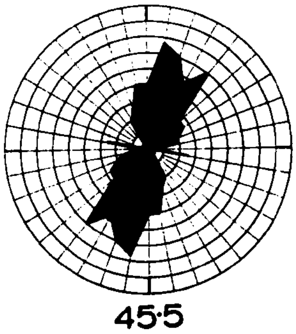
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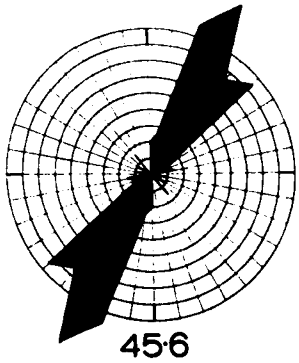
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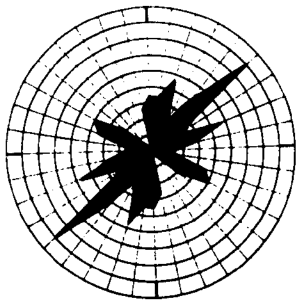
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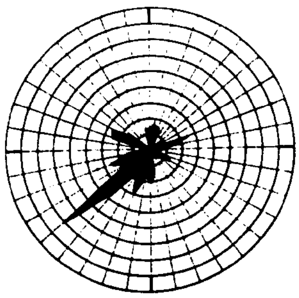
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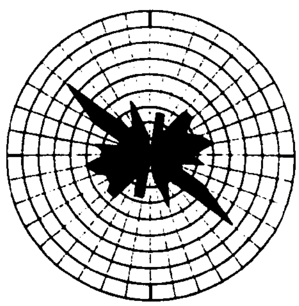
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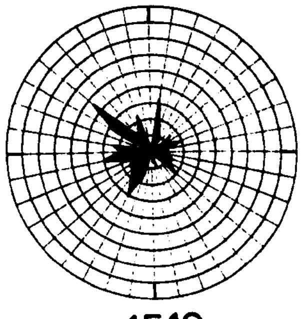
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erratics (Holmes, 1941).

Fig. 45.9 (T2) indicates a NW - SE longitudinal maximum with a broader ENE - WSW transverse maximum. There are two possible interpretations :-

(a) Rotation of erratics by shearing has enlarged the original transverse maximum at the expense of the original longitudinal maximum.

(b) The longitudinal maximum indicated is the original, indicating that a layer of ice was moving at 90° to that below.

The latter possibility is probably the case as there is quite extensive development of narrow band tills at this site indicating independent movement of individual layers of ice which may be associated with the strong folding of the Lower Till Series at the base of the succession. (Chapter 3 fig. 16).

Fig. 45.10 (T2) which includes the sense of dip shows a high concentration of stones in the south-west quadrant with a further development in the north-west. Possibly, the south-western concentration is the original, being imbricated in the direction of flow; the north-western concentration having developed by sliding of the ice to the NW following the formation of the large anticline in the Lower Till Series to the south-east of this site.

SITE 7

Glacial striations on the Corallian pavement, originally observed by Lamplugh (1891), have been visible over the last few years. Fig. 46.1 records 10 of these striations. (28°, 70°, 39°, 23°, 31°, 31°, 22°, 44°, 29° and 26°. One line represents one striation. The mean is 34°(true) which lies to the east of those observed by Stather (1897) on the north side of Carr Naze (not visible at present).

Fig. 46.2 (T1) indicates a N - S longitudinal maximum with a minor transverse development which does not lie at right-angles to the longitudinal maximum but is normal to the mean trend of the basal striations.

SITE 8

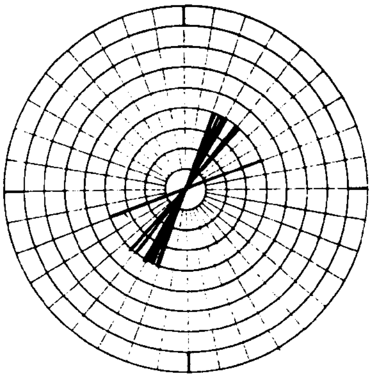
20m south of Site 7 there occurs a lens of over folded gravel within which platy pebbles have their long axes orientated normal to the fold axis. The feature (fig. 47) indicates compression from N - S suggesting that either the basal till was subject to flow after deposition or was disturbed by over riding pressure from the north, probably by the upper ice of the Lower Till Series as there is no sign of shearing or folding between the Lower and Upper Till Series, and the Lower Till Series here is a true lodgement till. The absence of numerous pebbles orientated parallel to the fold axis in the axial planar zone indicates that very little near horizontal shear occurred. (Banham 1966).

SITE 9

Fig. 46.3 (T2). This till is rather similar to Site 1 (T5) in that it shows a NW - SE flow direction. Assuming that the direction is correct, then it indicates a south-easterly flow of the Upper Till ice parallel to the coast which is compatible, with drumlin orientations to the south of Filey. However, this site does not occur within the drumlin belt and coupled with the fact that there is no evidence of shear between the Lower and Upper Till Series at Site 7, the diagram is considered to show an enlarged transverse maximum.

SITE 10

(Fig. 46.4, T1). The Lower Till Series which here flowed from the NNW to the SSE has been deflected by the Jurassic cliffs of Gristhorpe Bay which obstructed the general south-westerly ice movement. The southerly flow over Carr Naze illustrates the pivoting effect around the easterly limit of the high land. Further inland at Site 11 (Fig. 46.5) the basal till has resumed a south-westerly flow in a manner similar to that which occurs south of Flamborough Head (Catt, 1963) and within Robin



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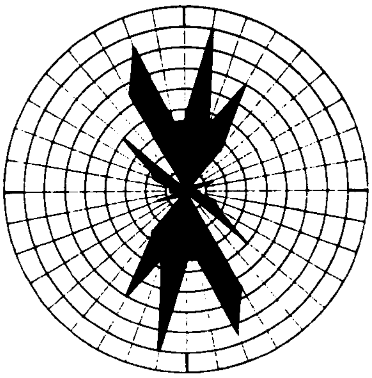

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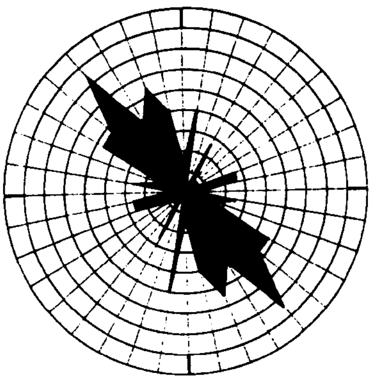

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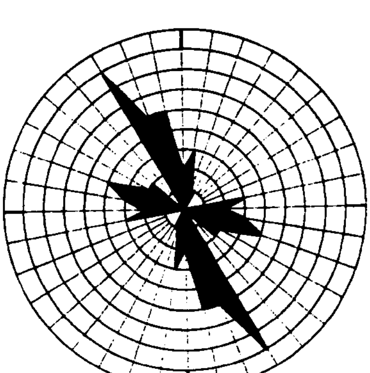

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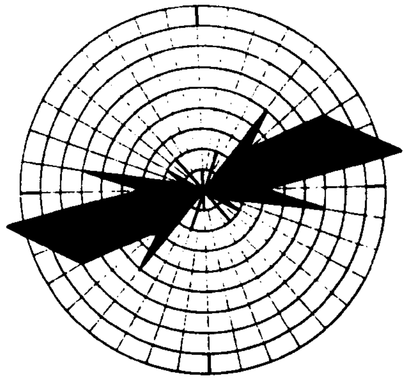

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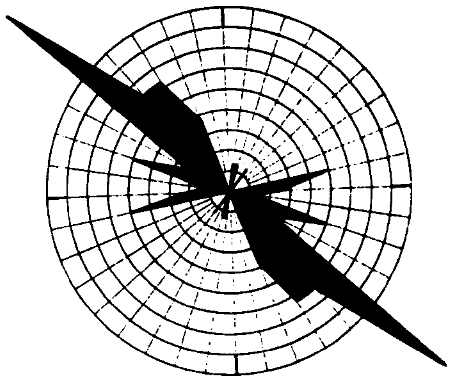

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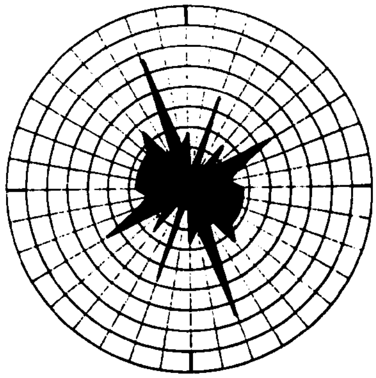

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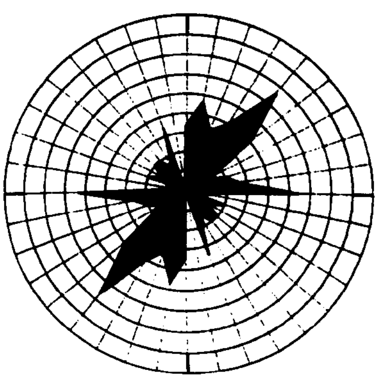

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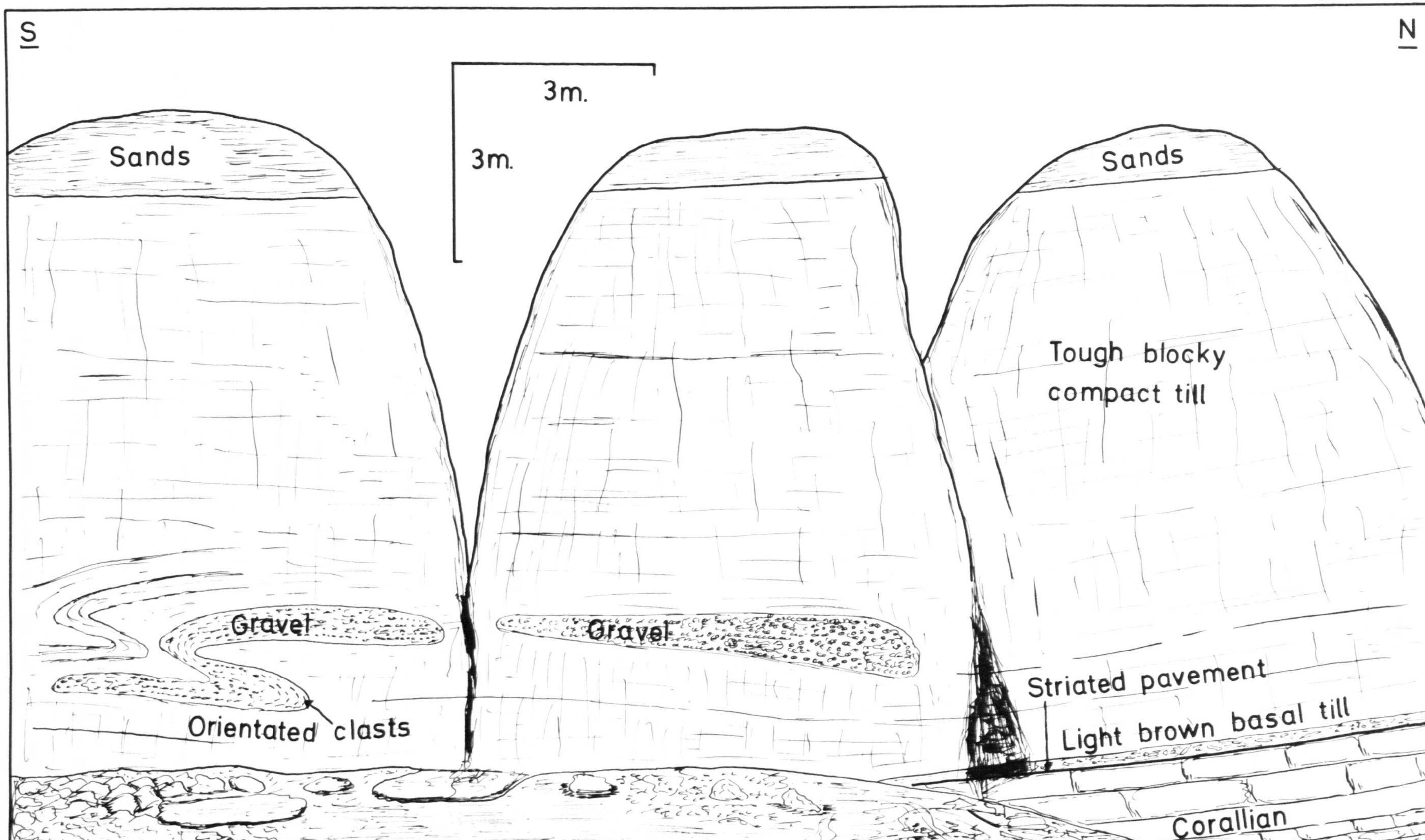


Fig. 47. FIELD SKETCH OF FOLDED LOWER TILL SERIES AT T.A. 1250 8165 (SITE 8)

Hood's Bay (Andrews and Smith 1970). A similar mechanism occurs in Cayton Bay where Site 12 (fig. 46.6) illustrates how Osgodby Nab deflected it to the south-east. The Jurassic Bay head cliffs of Cayton Bay were overridden by ice though they presented a partial obstruction to the Lower Till Series ice, some of which travelled south-eastwards to Carr Naze before entering the Vale of Pickering.

North of Cayton Bay, till exists as plugs in pre-glacial valleys with only a thin veneer of weathered till along the Jurassic cliff tops. Site 13 (fig. 46.7) indicates the dispersed nature of data obtained from the thin weathered tills which may indicate flow of the till during ice-melt or re-orientation of stones by peri-glacial and weathering agents. Within the drift-plugged pre-glacial valleys, orientations are more compact e.g. Site 14 (fig. 46.8) which indicates that ice flowed into Robin Hood's Bay from the north-east.

From the evidence of striations (Stather 1897) and the work of Andrews and Smith (1970) it appears that the ice pivoted around the high land north of Robin Hood's Bay in a manner akin to that which occurred at Carr Naze and Flamborough Head (Catt 1963).

(5) CONCLUSIONS

North-east Yorkshire was invaded by ice which came from the north-east. Unlike Holderness, where there were no barriers to ice advance, local variations in ice flow occur due to pre-late Devensian topographical control. In low lying areas such as Robin Hood's Bay and Filey Bay ice was able to enter from the north-east. However, high land along the northern margins of these low areas acted as a partial obstruction forcing basal ice to travel south eastwards before pivoting westwards to invade the land. This mechanism was observed by Catt (1963) to the south of Flamborough Head and suggested by Andrews and Smith (1970) as occurring in Robin Hood's Bay. This present work supports Andrews and

Smith's suggestion and indicates that the same mechanism operated on basal ice in Filey Bay. High land for many kilometres north-west of Carr Naze partially blocked the inland advance of the basal ice; Cayton Bay accommodating only a limited amount. The lower layers were forced to flow south-easterly until able to begin to enter the Vale of Pickering near the present position of Filey.

Towards the south-eastern end of Filey Bay, the ice was obstructed by the flanks of the Flamborough peninsula which provided an uphill gradient against which the ice flowed. This has resulted in much en-glacial shearing and the formation of many narrow band tills which are laterally impersistent over long distances making correlation difficult.

Holmes (1941) suggested that transverse maxima may arise by rotation of elongated erratics due to basal thrusting. Glen, Donner and West (1957) have shown that transverse maxima are especially noticeable in narrow band tills; their occurrence being explained by the laws of fluid mechanics. In north-east Yorkshire, ice pressing against escarpments such as the Flamborough peninsula may have been under sufficient pressure to mobilise the narrow band till matrices and create the transverse orientations observed.

Traversing north-westwards across Filey Bay away from the Flamborough peninsula, these narrow band tills gradually coalesce to form massive beds of lodgement till e.g. Carr Naze, where the Devensian succession is more akin to that of Holderness. This accords with the changing stress pattern within the ice reflecting a reduction in the number of en-glacial shear planes.

The Filey Bay drumlin field (see fig. 57) provides orientation data which indicates that the Upper Till Series ice, which largely produced the drumlins, was flowing westwards into the Vale of Pickering parallel to and confined by the chalk escarpment to the south. The drumlins are late Devensian features probably formed when ice stood at the Wykeham line. Their relationship to the Wykeham complex indicates that they lie in an area intermediate between the high up-glacier stress levels of the North Sea basin area and the low stress levels of the glacier snout. High stress levels within the glacier created by ice moving against the subsurface gradient into the Vale of Pickering initiated the formation of drumlins. Once initiated, the stress required to maintain the deformation is much less than that required to create it hence the drumlin field extends down glacier until the stress level falls below the critical value necessary for maintainance of the drumlinoid form. This mechanism, described by Smalley and Unwin (1968) explains why the drumlins occur in a region of vertical and lateral compression of the ice.

Beyond the Filey Bay drumlin field the ice pursued a relatively stress-free path into the Vale of Pickering.

Narrow band tills are well developed in Cayton Bay where en-glacial shearing developed in the basal ice in response to pressure generated by the ice pressing against the Jurassic bay-head scarp. Till is poorly exposed in the Scarborough district though here pressure within the ice was partially relieved by ice being able to advance into Hackness and Harwood Dale. Narrow band tills are present to the north of Scarborough indicating a certain degree of en-glacial shearing as the ice rose over the Devensian equivalent of the present day Jurassic sea cliffs. In Robin Hood's Bay, narrow band tills are absent suggesting that the ice was not under stress, confirmed by fig. 42.

On the high land between these low lying areas, till is thin and has been affected by cryogenic and weathering processes which render stone orientation data meaningless.

CHAPTER V - THE THORNTON DALE TILL

(1) DISTRIBUTION

Fox-Strangways (1881) mapped till at the foot of the Corallian dip-slope between Thornton Dale and Ebberston. Field mapping and aerial photographs show the till to lie on small hills of Kimmeridge Clay which it has partially protected from Flandrian erosion. At the western extreme of the till area, a horn of till extends southwards into the Vale of Pickering for 1.5 kilometres. This is a remnant of the terminal moraine associated with this earlier of two proposed late-Devensian ice advances. West of the terminal moraine there lies a similar horn-like feature composed of sand and gravel which is separated from the moraine by the valley of Thornton Dale beck incised between the two. The sand and gravel is considered to be a kame complex deposited at the foot of the ice cliff when melting began at the Thornton Dale limit. Similar modern-day gravel-till associations have been recorded on Baffin Island (Andrews and Smithson, 1966).

The southern till margin lies wholly within the area delimited by the break of slope revealed by aerial photographs. At SE 860 825, which is within the break of slope but outside the till limit, a freshly cut gutter exposed 1m of mottled blue-brown clay. Nearby, (SE 859 825) excavations revealed consolidated blue-black Kimmeridge Clay with a blue-brown weathered crust with yellow mottling. This indicates that the break of slope is the point at which the weathered Kimmeridge Clay passes beneath the Flandrian deposits to the south.

The northern till margin is linear, trending E - W and falling from 77m O.D. in the west to 62.5m O.D. in the east. Immediately north of the till margin there occurs a 100m wide belt of medium, orange-yellow sand. North of this, augering reveals soft, grey silt which overlies compact, slightly laminated, blue-grey clay containing plant remains and brown-orange weathered spots. To the north, this grades laterally into blue-grey clay with brown-orange inclusions and within the top 1.2m of which there occur many angular oolitic limestone fragments which have frequently weathered into individual oöliths (see fig. 51).

The till can be traced eastwards as far as Weas Dale. It is most easily identified around Thorntondale and becomes increasingly difficult to distinguish towards the east. An isolated patch also occurs in the Ebberston district. The distribution is shown in fig. 48.

(2) DETAIL OF AUGERING

Site 1 Yellow-orange silty till containing many limestone fragments proved at - 0.5m BNS.

Site 2 0.7m of yellow, stoneless fine sand/coarse silt BNS.

Site 3 10cm of greyish-yellow silt is underlain by 5cm of rolled fragments of oolitic limestone within a blue clay matrix. This is underlain by yellow-brown till containing many rolled oolitic limestone fragments. BNS.

Site 4 The south bank of the railway cutting exposes 2m of compact yellow-brown till which contains many oolitic limestone and Kimmeridge Clay erratics. BNS.

Site 5 0.3m of yellow-brown sandy till in base of gutter 1.3m deep. BNS.

Site 6 10cm of pale fawn silt overlies 0.3m of dark brown silt with occasional grey laminations which overlies dark grey silt. BNS.

Site 7 0.3m of fawn, fine sand overlies 0.3m of brown fine sand which overlies orange-brown sandy till. Proved to - 1m.

Site 8 Yellowish-brown stony sand at - 0.7m. BNS.

Site 9 1m of fawn silt. BNS.

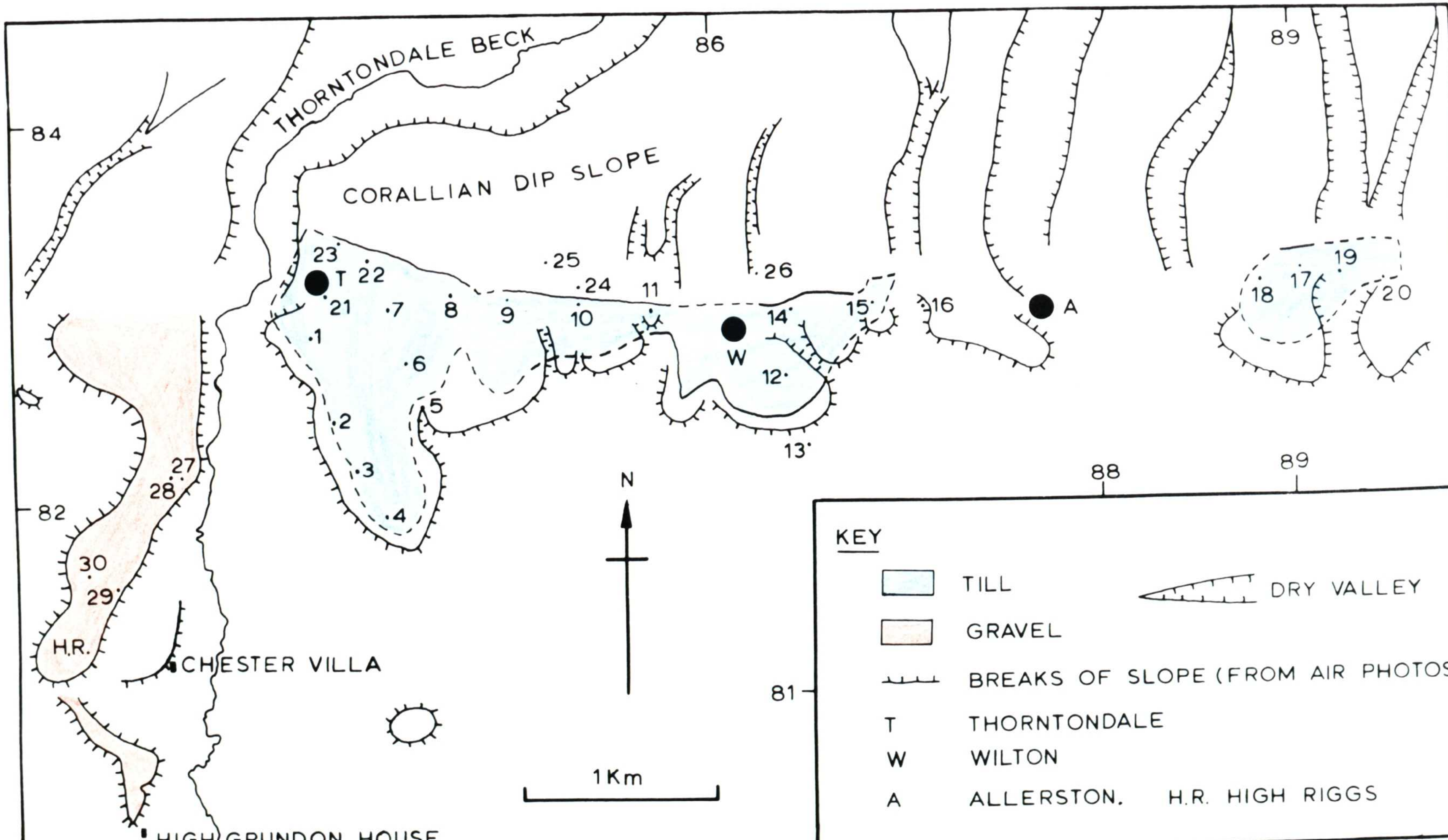


Fig.48. MAP SHOWING DISTRIBUTION OF THORNTONDALE TILL

Site 10 1m of reddish-brown sandy till containing local stones. BNS.

Site 11 0.7m of sandy brown till underlain by 0.3m of sand. BNS.

Site 12 1m of blue-grey, soft, silty clay containing small local stones. BNS.

Site 13 0.7m of soft, light grey silt. BNS.

Site 14 0.3m of yellow-orange sand containing a small amount of clay. BNS.

Site 15 0.7m of brown sand containing a small amount of clay. BNS.

Site 16 0.5m of yellow, medium sand at surface. BNS.

Site 17 0.7m of blue-grey, compact lacustrine clay. BNS.

Site 18 0.7m of blue-brown, laminated lacustrine clay. BNS.

Site 19 1m of soft, grey post-glacial silt. BNS.

Site 20 Very thin, silty dark brown earth which contains angular limestone fragments.

Site 21 2.1m of pinkish brown till containing numerous local erratics. BNS.

Site 22 1m of pinkish-brown till (BNS) containing numerous striated local erratics is overlain by about 0.3m of medium yellow-brown sand and some gravel and this by 0.2m of angular soliflucted limestone fragments.

North of this exposure augering at 25m intervals along a S-N traverse revealed at least 1m of blue-grey lacustrine clay overlying the till. The lacustrine clay was traced by augering to a point just below the O.S. 84m contour.

<u>Site 23</u> 0.6m of clay containing soliflucted oolitic limestone fragments overlies 10cm of blue lacustrine clay which rests on pinkish-brown till (BNS). 25 yards south of this site the till occurs at the surface with no cover of lacustrine clay.

<u>Site 24</u> A S - N traverse reveals a 100m wide belt of orange-yellow medium sand. North of this, augering at 25m intervals reveals soft, grey silt which overlies compact, slightly laminated, blue-grey clay containing plant remains and brown-orange weathered spots. To the north, this grades laterally into blue-grey clay with brown-orange inclusions and within the top 1.2m of which there occur many angular oolitic limestone fragments which have frequently weathered into individual ooliths.

<u>Site 25</u> 0.6m of blue-grey clay with very rare oolitic limestone fragments overlies blue-brown stoneless clay. The the north dark orange-brown sand occurs at the surface.

<u>Site 26</u> An exposure of angular and frost shattered passage beds is overlain by 2m of pale fawn sand which is a weathered product of the underlying rock.

<u>High Riggs Gravel Deposit</u>

This linear feature extends 2.5km southwards into the Vale of Pickering. The core is composed of Kimmeridge Clay. Augering reveals the following details :-

<u>Site 27</u> Recent deposits overlying red-brown clay containing local stones. BNS.

<u>Site 28</u> Gravel comprising local stones. BNS.

<u>Site 29</u> Laminated, compact, blue-grey lacustrine clay overlying Kimmeridge Clay.

Site 30 Blue-grey/orange clay (BNS) of post-glacial origin.

The extent of the deposit has been delimited by aerial photographs which show a southern extension of the feature reaching to High Grundon House (SE 830 803) and a small lobe in the vicinity of Chester Villa (SE 832 812). It is assumed that these are expressions of sub surface topography which have been virtually obscured by a thin veneer of Flandrian deposits.

(3) MUNSELL COLOUR

The till is consistently 10YR 5/4 wet and 10YR 7/4 dry.

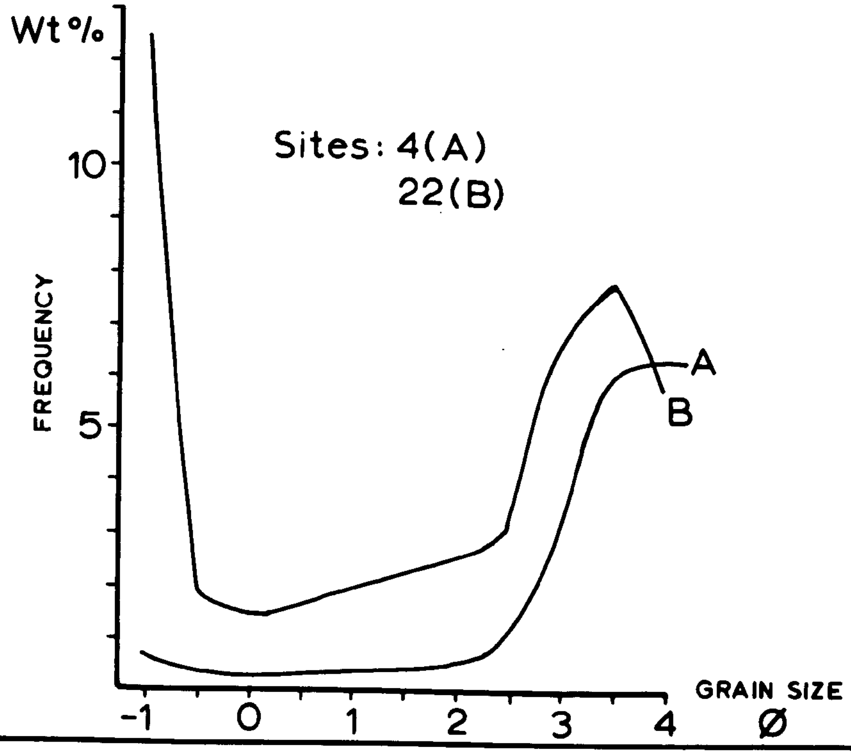
(4) MECHANICAL ANALYSIS

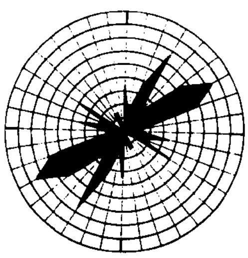
This illustrates the local differences in the till due to differing lithological derivation. Fig. 49(B) (Site 22) shows a high coarse content composed of pebbles of oolitic limestone. The maxima in the fine sand mode represents the breakdown of oolitic limestone to individual ooliths. The decline of the curve towards the silt and clay fractions indicates that a large proportion of the ooliths have not been fragmented and are therefore locally derived (Fig.49(A) (Site 4) indicates till lacking in resistant erratics. The till has incorporated much Kimmeridge Clay, which it overlies, into its matrix and this has been comminuted thus the maxima lies in the coarse silt/ clay fractions.

(5) PIPETTE ANALYSIS

Till at the northern margin (Site 22) contains 49% sand, 33% silt and 18% clay consistent with it being derived from resistant oolitic limestone. Much of the sand is composed of oolith-sized grains. At the southern margin (Site 4) the till contains 20% sand, 38% silt and 42% clay reflecting derivation from fine grained material, i.e. Kimmeridge Clay.

Fig. 49. PARTICLE SIZE DISTRIBUTION CURVE





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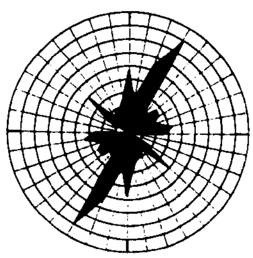

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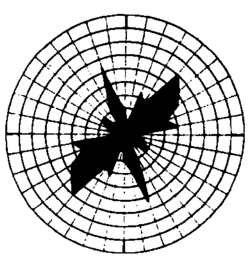

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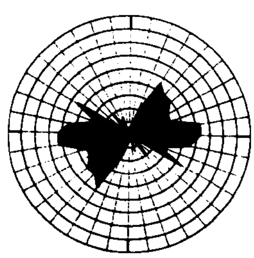

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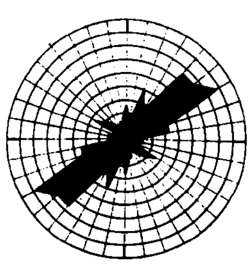


50·5

(6) STONE ORIENTATIONS

Stone orientation analyses were performed at Sites 4, 21 and 22.

SITE 4

Figs. 50.1 and 50.2 are based on 3 x 25 erratics sampled on a vertical face trending W - E. Both show a strong N.E. - S.W. trend though Fig.50.2 shows a secondary N.N.W. - S.S.E. maximum,which is considered to be a longitudinal maximum.

SITE 21

Fig. 50.3 is based on 3 x 25 erratics sampled on a vertical face trending N. - S. It shows a strong N.E. - S.W. trend which is interpreted as a transverse maximum(Galloway, 1956).

SITE 22

Figs. 50.4 and 50.5 are based on 3 x 25 erratics sampled on horizontal surfaces. Fig. 50.4 shows a strong longitudinal E. - W.trend with a transverse N.E. - S.W. maximum. The E. - W. trend is consistent with the clear cut northern edge of the till indicating advance into the Vale of Pickering from the east. Fig. 50.5 shows a N.E. - S.W. trend which is interpreted as a transverse maximumdue to shearing within the ice and the rolling of elongated erratics in position which was almost marginal to the ice lobe (Galloway, 1956).

All the analyses indicate that ice movement was from the east to the west and not north to south. Supporting evidence for this is as follows:-

(a) The linear nature of the northern till margin suggests east-west ice movement.

(b) The form of the terminal moraine suggests that it is terminal to ice lying in the eastern Vale of Pickering.

(c) The erratic content of the till varies markedly between the north and south extremes of the moraine indicating that it lies at right-angles to the ice flow-lines which were parallel to the east-west trending contact of the Corallian oolite and Kimmeridge Clay.

(d) The position of the till with respect to the Wykeham limit in the eastern Vale of Pickering is comparable with the first of two late-Devensian glacial sequences in the southern Vale of York (Gaunt, 1976). This early ice advance is known to have been very similar to the areally less extensive main Devensian advance in that the later advance followed approximately the flow lines of the earlier.

(e) High Riggs gravel deposit mirrors the form of the terminal moraine and thus appears to have been produced at the foot of ice lying in the eastern Vale of Pickering (Andrews and Smithson, 1966). Prior to late-Devensian incision of Thornton Dale and its tributary valleys and subsequent Flandrian aggradation in the Vale of Pickering, the till and gravel deposits were probably more closely linked.

(f) To the east of SE 850 834 the Lower Limestone is replaced due to faulting by the Passage Beds which at Site 26 display a 2m thick weathered profile which is in situ. The weathered profile consists of fine sand and occasional clasts of parent rock which become larger and more numerous towards the base of the succession. It has been suggested that the profile is a product of tropical (interglacial) deep-weathering (Bullock, Carroll and Jarvis, 1973) and is comparable with red mottled soil profiles on Harwood Dale Moor which have been attributed to Ipswichian weathering. (Bullock, Carroll and Jarvis, 1973). If this is the case, the undisturbed nature of the poorly consolidated weathered material indicate that it has not been overridden by ice and support the view that the Thorntondale ice entered the Vale of Pickering from the east and is not locally derived from the North Yorkshire Moors.

(7) <u>INTERPRETATION</u>

Ice entered the Vale of Pickering from the east and extended as far west as a line extending from Thornton Dale in the north to around Knapton in the south. The advance pre-dates the main Devensian (Wykeham) ice advance and is comparable with a similar advance which has been postulated in the southern Vale of York (Gaunt, 1976) and also in Ireland and the English Midlands (Mitchell, 1972) dated at around 20,000 BP. Evidence from Continental Weichselian glaciostratigraphy (Lundqvist, 1974) suggests that two cold phases occurred in the late-Devensian and it is possible that these two ice advances are a product of these colder periods.

The relationship of the till with the compact lacustrine clay along the northern till margin suggests that the main lacustrine phase of the western vale, when lacustrine conditions prevailed over most of the Kimmeridge Clay hills in the area, is related to the melting of this earlier ice advance to Thornton Dale. Detailed augering and mapping has shown that the lacustrine clay does not entirely cover the Thornton Dale till as would be the case if the clay was of later Devensian age (i.e. related to ice melt at the Wykeham line). Instead, the blue lacustrine clay has been deposited around the till whilst ice stood at the Thorntondale line. Beyond the Thorntondale line, gravel carried by meltwater was deposited within a clay matrix to produce the High Riggs Gravel complex. The clay matrix is largely derived from the underlying Kimmeridge Clay which was reworked by the lake waters.

Lacustrine clay, partly derived from reworked Kimmeridge Clay extends eastwards as a 250m wide band along the northern till margin for 2.8 kilometres reaching a maximum height of 76.8m O.D. The possibility that the ice advanced over the lacustrine clay is ruled out by the lack of clay in the locally derived till matrix and absence of discoloration. At Site 23 the existence of blue lacustrine clay resting on the feather

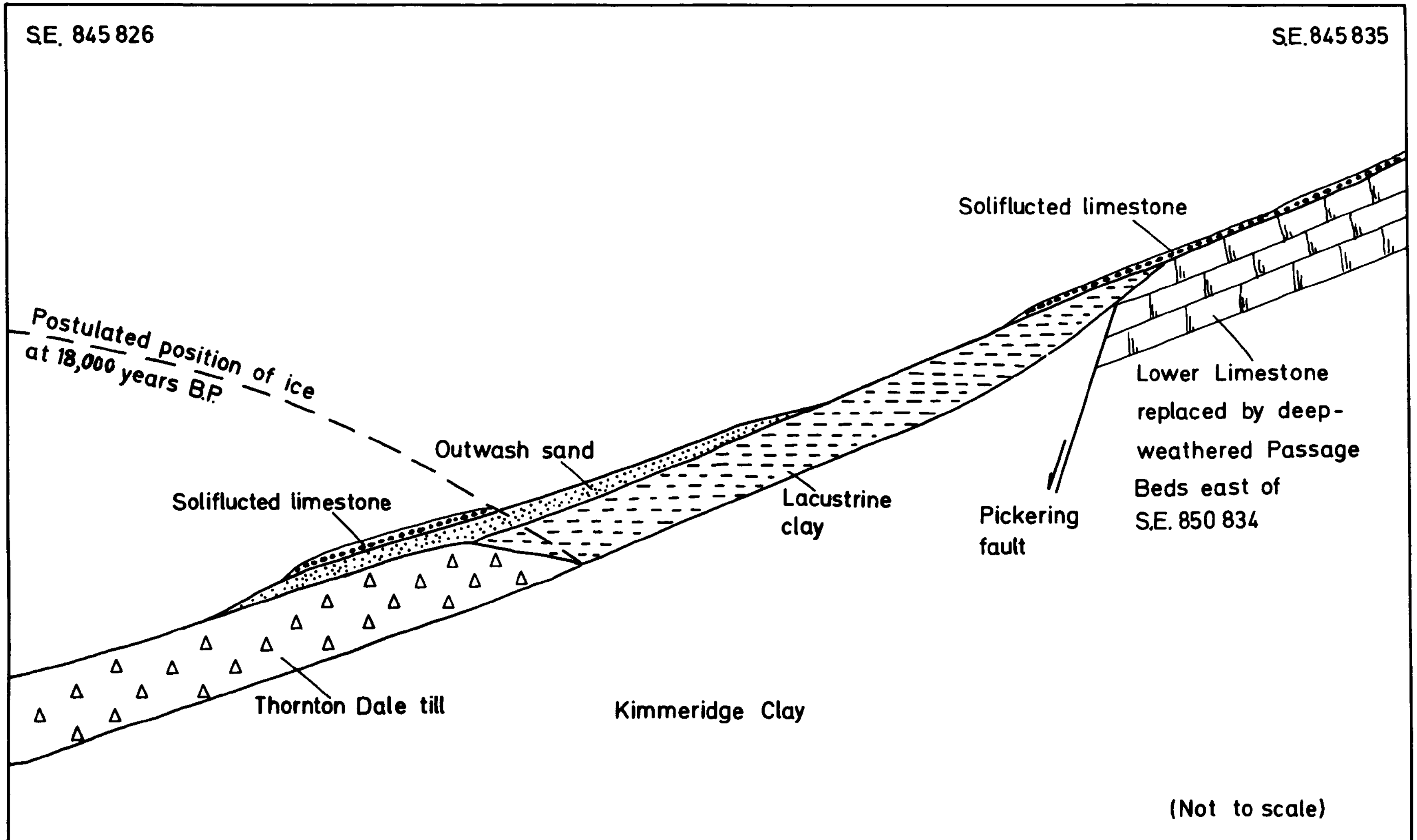


Fig. 51. IDEALISED SKETCH SECTION ACROSS NORTHERN MARGIN OF THORNTONDALE GLACIAL COMPLEX

edge of the till but not on the main mass indicates that ice stood at Thornton Dale whilst the lake was standing at about its highest level.

Sites 24 - 26 inclusive illustrate the nature of the northern till margin. Lacustrine clay lies parallel to the till margin and is overlain by outwash sands which form a 100m wide band north of the till and also overlie it (Site 22). North of the sand, the upper layers of the clay contain oolitic limestone fragments derived by solifluction from the Corallian dip-slope to the north. This soliflucted material extends at least as far south as Site 22. (See fig. 51)

The compact, laminated blue-grey clay along the northern till margin is lithologically identical to that found in greater quantities in the western vale. At many sites it contains plant remains (i.e. occasional birch twigs) which were derived from the surrounding landscape during the lake's existence. The presence of the lake whilst ice stood at Thornton Dale explains why blue lacustrine clay is found at levels up to 103m O.D. in the western vale yet is totally absent in the much lower eastern vale outside the limits of the main Devensian (Wykeham) ice advance. The actual extent of the lake is discussed in more detail in Chapter VI. Meltwater from the Thornton Dale ice is thought to have drained into the Vale of York via the Kirkham Priory meltwater channel.

CHAPTER VI

LATE DEVENSIAN AND FLANDRIAN DEPOSITS OF THE WESTERN VALE OF PICKERING

To the west of a line between Thornton Dale and Malton there occur a number of small hills whose summits rise up to 40m above the level of the Vale of Pickering. The area was originally investigated by Fox-Strangways (1881) who mapped boulder clay on many of the hills. His finds were doubted by Kendall (Fox-Strangways, 1895) and the matter has never been truly resolved. Consequently, all of Fox-Strangway's boulder clay areas have been investigated by detailed augering and digging of trial pits; this chapter being an account of the findings. The hills are all located on Fig. 52 and each is dealt with systematically and accompanied by O.S. maps (see map pocket) showing auger sites and trial pits. Data are presented for each hill area as follows :-

(i) Brief topographical description and location

(ii) Detail of augering

(iii) Detail of trial pits

(iv) Selected hand specimen descriptions and moist Munsell colour notations.

The chapter is concluded with a discussion of results in relation to Fox-Strangway's conclusions.

(1) DETAIL OF INDIVIDUAL HILL AREAS (IN ALPHABETICAL ORDER)

(A) THE BROATS

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 68 (SE 69 85)

A small, low hill, 1 km south of Kirby Moorside, which rises about 8m above the surrounding floor of the Vale.

(ii) DETAIL OF AUGERING

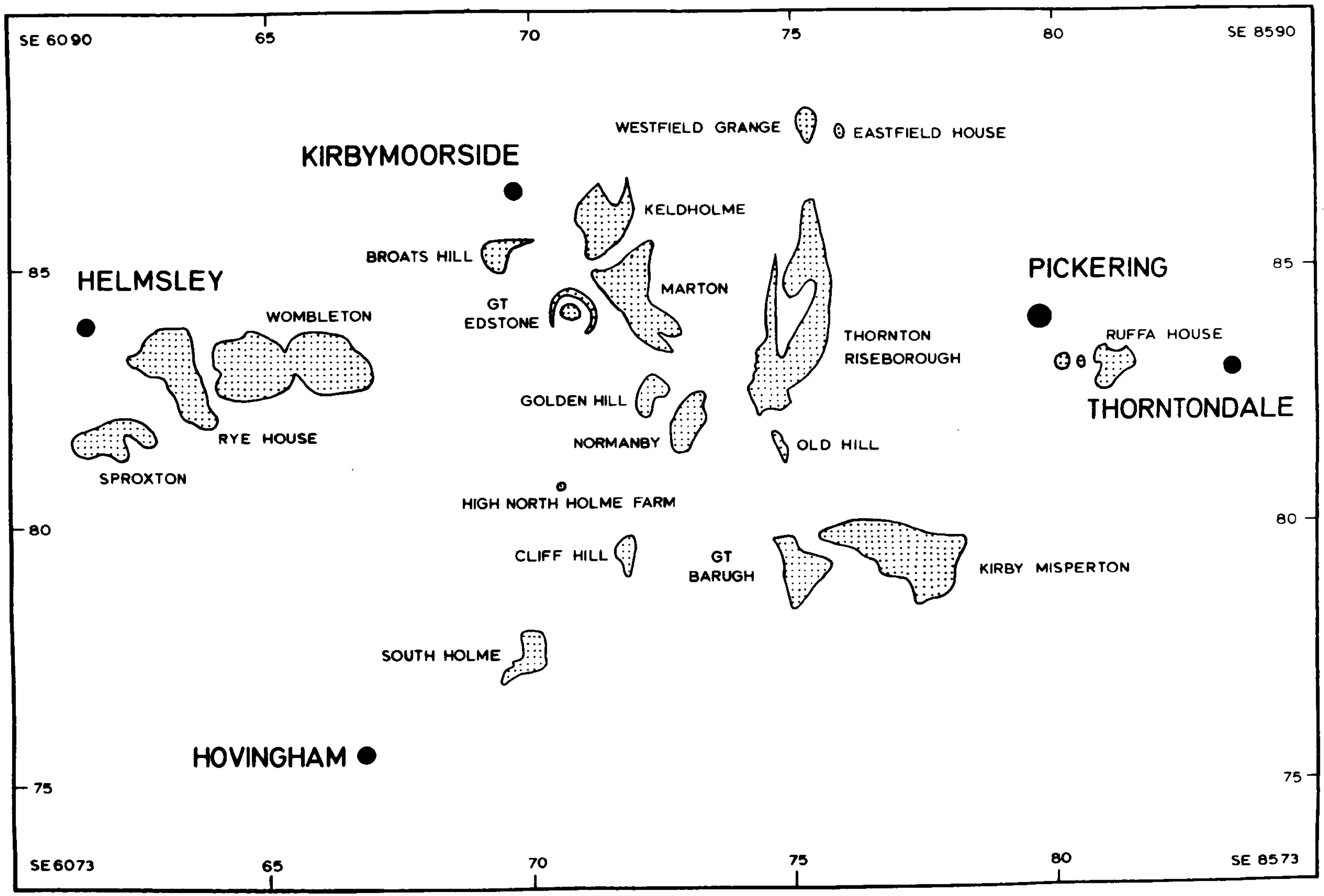


Fig.52. THE KIMMERIDGE CLAY HILLS OF THE WESTERN VALE OF PICKERING

SITE 1 Orange and blue laminated lacustrine clay with plant remains proved at - 0.3m BNS

SITES 2, 3, 4 and 5 As above

(iii) No trial pits

(iv) No hand specimens

(B) CLIFF HILL

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheets SE 77 and 78 (SE 71 79)

A prominent hill rising about 15m above the surrounding flat land and situated immediately south of Salton. The eastern slope is quite steep.

(ii) DETAIL OF AUGERING

SITE 1 Sand proved to - 1.3m BNS

SITE 2 1m of heavy clay soil which contains traces of blue lacustrine clay and well-rounded Jurassic sandstone pebbles is underlain by an impenetrable gravel which contains many calcite cleavage fragments.

SITE 3 Blue stony lacustrine clay which contains rounded Jurassic sandstone pebbles and oolitic limestone fragments plus many dark shaly patches which resemble fragments of Kimmeridge Clay proved at - 0.5m. At - 2m, the pebbles are quite large and rounded. At - 2.3m, the blue clay contains plant remains; at - 2.7m the clay becomes stone-free. This grades downwards into a more compact blue clay which at - 3.7m contains many dark shaly inclusions and resembles oxidised Kimmeridge Clay.

SITE 4 Sand underlain by lacustrine clay at - 1.3m BNS

SITE 5 Wet, silty loam proved to - 1.1m BNS

SITE 6 Blue lacustrine clay at - 1.1m (BNS) below silty loam.

SITE 7 Blue lacustrine clay proved at - 0.8m and base seen at - 3m.

SITE 8 2m of mixed sand, silt and gravel. BNS

SITE 9 Blue lacustrine clay proved at - 0.5m. BNS

SITE 10 Silty loam proved to - 1.5m. BNS

(iii) TRIAL PITS

SITE 9 15cm of blue surface clay grades into the underlying orange clay which contains many plant remains and birch twigs. At - 0.7m this passes back into blue clay. 30m to the west another pit 0.9m deep revealed a brownish sandy silt that was proved by auger to overlie soft, blue-grey clay at - 1.3m. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 7 (- 0.6m). Munsell colour N4 - 10YR 5/4

Slightly weathered, weakly laminose grey and orange lacustrine clay (alternating laminae) which contains some well-rounded, quite large oolitic limestone fragments.

SITE 7 (- 1 to - 1.6m). Munsell colour N4 - 10YR 5/4

Predominantly grey lacustrine clay with moderate yellowish-brown weathered spots which contains small rolled fragments of oolitic limestone and rare small plant remains (shreds of tree bark).

SITE 7 (- 1.7m). Munsell colour N4 - 1oYR 5/4

As above, except Kimmeridge Clay flakes present.

SITE 7 (- 2.5m). Munsell colour N1 - 1oYR 4/2

An intimate mixture of black Kimmeridge Clay and brown-orange lacustrine clay which contains rounded fragments of oolitic limestone which have partially weathered into individual ooliths. Strands of tree bark (birch?) are also present. The contrasting orange and grey clay shows occasional laminations.

SITE 7 (- 3m). Munsell colour 5Y 2/1

Largely composed of re-worked Kimmeridge Clay flakes with very rare moderate yellowish brown spots (10YR 5/4). It represents the base of the Quaternary succession, proving that the core of Cliff Hill is composed of Kimmeridge Clay.

(C) EASTFIELD

(i) TOPOGRAPHY AND LOCATION

O.S. 1 : 25,000 sheet SE 78 (SE 75 87)

A small area of boulder clay mapped by Fox-Strangways which has no surface expression.

(ii) DETAIL OF AUGERING

SITE 1 Very thin soil resting on Jurassic limestone.

(iii) No trial pits

(iv) No hand specimen descriptions

(D) GOLDEN HILL

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 72 82)

A promdnent hill 1km S.W. of Marton whdch rises about 24m above the surrounding Vale. The Kimmeridge Clay core of the hill is quarried for refractory purposes.

(ii) DETAIL OF AUGERING

SITE 1 Reddish-brown loamy clay with local sandstone fragments proved to - 0.7m.

SITE 2 Below .15m of red-brown loamy clay, 0.55m of laminated blue and orange-red clay which contains many rolled fragments of sandstone and oolitic limestone occurs. BNS

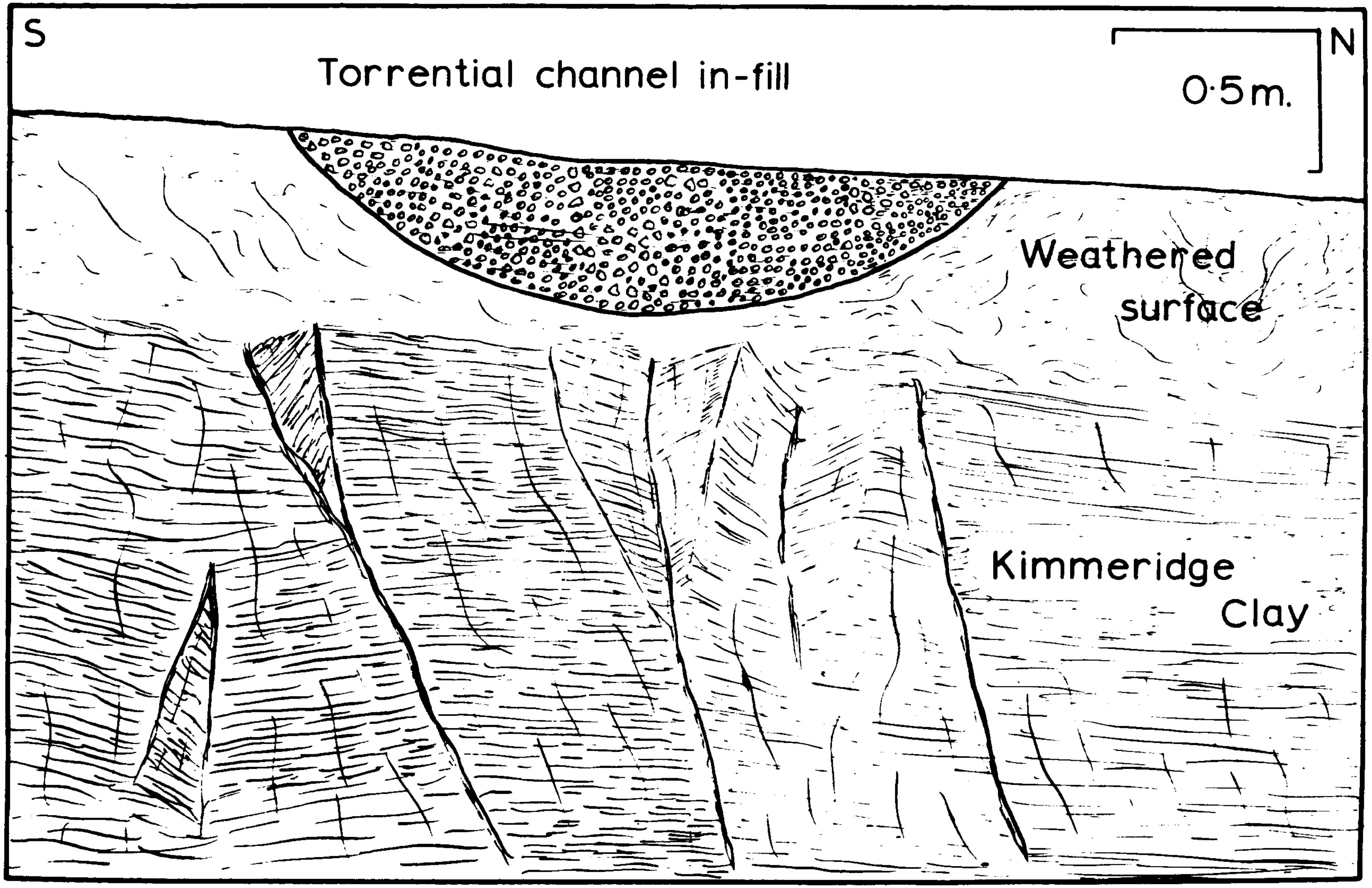


Fig.53. CHANNEL EXPOSED IN GOLDEN HILL QUARRY

SITE 3 Kimmeridge Clay at surface.

SITE 4 0.15m of red-brown loamy clay passes down into blue-black clay which contains many weathered brown flecks. (weathered Kimmeridge Clay).

(iii) No trial pits. Excavations in the western quarry face have exposed a stream channel infilled with rounded Jurassic sandstone cobbles derived from the North Yorkshire Moors (Fig. 53). The significance of the channel is discussed later.

(iv) No hand specimen descriptions.

(E) GREAT BARUGH

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheets SE 77 (SE 75 79)

The hill, upon which Great Barugh village lies, rises about 15m above the surrounding floor of the Vale. The N.W. slope of the hill is steepest.

(ii) DETAIL OF AUGERING

SITE 1 1m of fine sand overlies 0.15m of lacustrine clay which is underlain by wet gravel. BNS

SITE 2 Blue-yellow lacustrine clay with woody plant remains proved at - 1.1m. BNS

SITE 3 Very coarse sandstone gravel with a sandy matrix penetrated to - 0.7m. BNS

SITE 4 Blue lacustrine clay with wood fragments proved at - 0.8m. BNS

SITE 5 Lacustrine clay proved at - 1m and seen to - 4m. BNS

SITE 6 1.7m of orange gravel with an orange clay/sand matrix. BNS

SITE 7 2.1m of orange gravel with an orange-yellow clay/sand matrix. BNS

SITE 8 Blue lacustrine clay proved at - 1.3m beneath recent alluvium.

SITE 9 1m of blue lacustrine clay which contains a lense of orange gravel overlies Kimmeridge Clay.

SITE 10 Blue lacustrine clay proved beneath alluvium at - 1.7m.

SITE 11 Blue lacustrine clay proved below recent alluvium at - 1.7m. Sandstone gravel occurs at - 2.1m. BNS

SITE 12 Impenetrable sandstone gravel encountered at - 1.3m below recent alluvium.

SITE 13 1.3m of gravel underlain by unconsolidated silty alluvium. BNS

(iii) TRIAL PITS

SITE 14 Beneath 0.9m of loamy soil, gravel consisting of small waterworn stones (all local sedimentaries) in a scant matrix of blue brown clay was proved. BNS

SITE 15 0.2m of waterworn stones within a weathered (soil) matrix. BNS

SITE 16 A sandy brownish loam passes into a silty blue-grey deposit with orange weathered spots and is seen to - 0.9m (BNS). It contains occasional waterworn pebbles, including quartz.

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 4 (- 1m) Munsell colour N3 - 10YR 5/4

Compact dark grey lacustrine clay with occasional brown streaks which contains small oolitic limestone and sandstone fragments.

SITE 5 (- 4m) Munsell colour 10YR 2/2

Homogeneous, compact, stoneless, lacustrine, finely laminated clay.

SITE 7 (- 1.8m) Munsell colour 5YR 4/4

Predominantly an orange gravel with occasional light olive grey spots (5YR 6/1) which has a sand/clay matrix and contains assorted local stones of various sizes, all of which are waterworn.

(F) GREAT EDSTONE

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 70 84)

A very prominent hill 2km south of Kirby Mills which rises 30m above the floor of the surrounding Vale. All slopes are steep, the northern one displaying several late-Devensian solifluction lobes.

(ii) DETAIL OF AUGERING

SITE 1 1m of blue grey silt which contains some local stones. BNS

SITE 2 1m of lacustrine clay with plant remains and much poorly sorted angular and fragmented local stones. BNS

SITE 3 Proved 1.3m of blue lacustrine clay which becomes quite well consolidated with depth.

SITE 4 Blue lacustrine clay passes into weathered Kimmeridge Clay at - o.7m.

(iii) No trial pits

(iv) No hand specimen descriptions.

(G) HELMSLEY

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 68

An elongated hill about 24m high lying to the south east of Helmsley between the Rivers Riccal and Rye.

(ii) DETAIL OF AUGERING

SITE 1 1m of blue lacustrine clay with silt laminations and small local stones. BNS

SITE 2 1.3m of orange and grey lacustrine clay. BNS

SITE 3 0.15m of orange lacustrine clay overlies blue lacustrine clay with plant remains. BNS

SITE 4 1m of orange gravel with a matching sand and clay matrix is underlain by blue lacustrine clay with plant remains. BNS

SITE 5 1m of orange clay and grey silt laminations (BNS) underlie 0.7m of made ground.

SITE 6 Blue lacustrine clay (BNS) exposed at - 1.3m in base of ditch.

SITE 7 Sandy deposit with many stones (local) proved to - 0.7m. BNS

(iii) TRIAL PITS

SITE 8 0.5m of blue grey silty clay with orange laminated bands and orange weathered spots which contains occasional local stones. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 8 (- 0.9m). Munsell colour N7 - 5YR 5/6

Light grey weathered clay, with extensive development of light brown mottling, which contains frequent sub angular fine grained sandstone pebbles. The matrix is highly weathered and contains individual sand grains from the weathering of contained stones.

(H) KELDHOLME

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 71 85)

The hill forms the southern extreme of the divide between the River Dove and Hutton Beck and rises 30m above the floor of the surrounding Vale.

(ii) DETAILS OF AUGERING

SITE 1 Only possible to auger 0.3m in sandy material with a stony layer beneath.

SITE 2 Orange and grey laminated silt (BNS) below 0.9m of soil.

SITE 3 1.2m of orange clay with many sandstone pebbles. BNS

SITE 4 1.7m of laminated blue lacustrine clay, which in the lowermost 0.3m is darker and well consolidated and passes through a zone of alternate orange and dark blue laminations into weathered Kimmeridge Clay.

SITE 5 0.9m of laminated lacustrine deposits, which contain many small sandstone fragments, overlie Kimmeridge Clay which is seen to - 1.1m.

SITE 6 0.7m of made ground underlain by 0.7m of laminated lacustrine blue-brown clay. BNS

SITE 7 As above

SITE 8 1.1m of clay which contains much sand derived from the breakdown of rounded sandstone pebbles, many of which have been broken into angular fragments. BNS

(iii) No trial pits

(iv) No handspecimen descriptions

(J) KIRBY MISPERTON

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheets SE 77 and 78

A prominent hill extending between the villages of Kirby Misperton and Little Barugh and rising 15m above the surrounding flat land.

(ii) DETAIL OF AUGERING

SITE 1 A stony lacustrine clay grades at - 0.9m into a laminated clay and silt with very few stones. At - 1.3m, blue-grey silt occurs. At - 1.7m angular orange gravel occurs and has been proved to - 2.3m. With depth, it becomes coarser and impenetrable. BNS

SITE 2 1m of recent silt with plant remains overlies orange gravel which becomes impenetrable at - 1.3m. BNS

SITE 3 Lacustrine clay with plant remains proved at - 0.7m which at - 1m passes into silty clay and this in turn into impenetrable orange gravel at - 1.3m. BNS

SITE 4 2m of lacustrine clay with plant remains overlies oxidised Kimmeridge Clay.

SITE 5 0.7m of silt which is gravelly at the base overlies blue lacustrine clay proved at - 1.0m.

SITE 6 0.7m of sand and silt overlies 0.15m of orange sandstone gravel, below which blue lacustrine clay was proved. BNS

SITE 7 2m of silt and alluvium overlies blue lacustrine clay with plant remains. BNS

SITE 8 1.5m of lacustrine clay with plant remains contains dark shaly material that resembles re-worked Kimmeridge Clay. It is underlain by a very wet impenetrable orange gravel.

SITE 9 Lacustrine clay at - 0.5m proved to - 3m. BNS

SITE 10 Orange clay and silt with sandstone pebbles passes into orange gravel at - 1m which is seem 2.3m. BNS

SITE 11 1.5m of clay and silt with sandstone pebbles is underlain by very wet orange sandy gravel (proved to - 1.7m).

SITE 12 1.1m of clay and silt with sandstone pebbles overlies clay with plant remains and small rounded stones. At - 1.5m this passes into blue lacustrine clay with many woody fragments (proved to - 1.8m).

SITE 13 1.8m of clay and silt with sandstone pebbles overlies 5cm of orange sand. The sand is underlain by blue lacustrine clay with occasional stones and many plant remains.

SITE 14 1.5m of clay and silt with sandstone pebbles is underlain by orange sand and gravel which at - 2.3m grades back into clay and silt with sandstone pebbles. BNS

SITE 15 1m of blue/orange mottled clay and silt overlies orange sand and gravel. BNS

SITE 16 1.7m of clay and silt laminae with occasional stones overlies impenetrable orange gravel. BNS

SITE 17 0.7m of silt is underlain by 0.3m of clay with small Jurassic pebbles. At - 1m this is underlain by blue lacustrine clay which contains many woody plant remains. BNS

SITE 18 0.7m of clay with stones overlies orange sand and gravel. BNS

SITE 19 1.8m of laminated clay and silt with many small stones which contains woody plant remains in the blue clay laminae towards the base. BNS.

SITE 20 3m of laminated clay, silt and sand which contains stones from the North Yorkshire Moors. Plant remains are evident at - 2m and flakes of Kimmeridge Clay at - 3m.

SITE 21 2m of recent, unconsolidated laminated clays and sand underlain by silt. BNS

SITE 22 1m of orange gravel underlain by blue laminated clay. BNS

SITE 23 2m of laminated deposits containing numerous oolitic limestone fragments. BNS

(iii) TRIAL PITS

SITE 13 0.9m of gravel in a blue-orange clay matrix which augering has proved to - 1.8m.

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 1 (- 1.8m). Munsell colour 5YR 4/6

Rounded and angular fine grained sandstone fragments and small rolled quartz pebbles set in a sand matrix which contains some clay.

SITE 1 (- 2m). Munsell colour 10YR 4/6

Gravel comprising large and small rolled quartz pebbles along with small fine grained sandstone pebbles set in a medium grained sand matrix which contains a small amount of clay.

SITE 9 (- 1.5m). Munsell colour N3- 10YR 5/4

Dark grey lacustrine clay with brown weathered spots which contains numerous fragments of oolitic limestone and scattered individual ooliths plus occasional very fine crushed twigs.

SITE 9 (- 3m). 5Y 2/1 - 5Y 3/2

Predominantly an olive black clay with occasional weathered olive grey spots, though it is not weathered as extensively as shallower samples and is largely made up of haphazardly arranged fragments of Kimmeridge Clay with some individual ooliths and fragments of oolitic limestone. It also contains some individual quartz sand grains which suggest that weathered sandstone has been incorporated into the deposit. However, the lithology suggests it is largely derived from Kimmeridge Clay.

<u>SITE 10</u> (- 0.5m) N7 - 5YR 5/6

Grey clay, which is extensively weathered to light brown, and contains many fine and medium grained sub-rounded sandstone fragments which are extensively weathered, breaking down into individual grains which frequently form a weathered corona around the unweathered core of each sandstone fragment.

<u>SITE 12</u> (- 1.3m) Munsell colour 5Y 4/1 - 10YR 5/4

Lacustrine olive grey clay, with occasional moderate yellowish brown weathered spots, which contains many tiny fragments and individual ooliths of Jurassic limestone, some fine grained sandstone fragments and rounded quartz pebbles, plus crushed fragments of very fine twigs.

<u>SITE 12</u> (- 1.5m) Munsell colour N4 - 10YR 5/4

Lacustrine clay which shows a moderate degree of weathering and contains rolled quartz pebbles, rolled fine grained sandstone pebbles and fragments of oolitic limestone and individual ooliths, plus birch (?) twigs and occasional small fragments of Kimmeridge Clay.

<u>SITE 13</u> (- 2m) Munsell colour N4 - 10YR 5/4

Lacustrine clay with many fragments and individual ooliths of Jurassic limestone plus flakes of Kimmeridge Clay and crushed fine twigs.

<u>SITE 18</u> (- 0.3m) Munsell colour N6 - 10YR 6/6

Orange lacustrine clay which contains fragments of oolitic limestone plus individual ooliths along with fragments of fine grained sandstone. It is quite extensively weathered as shown by the variation of colour.

(K) MARTON HILL

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78. An elongated hill 38m high extending north-west for 2km from the village of Marton (SE 7383). Eastern and south-eastern slopes of the hill are quite steep.

(ii) DETAIL OF AUGERING

SITE 1 Below 1.7m of pure blue-grey lacustrine clay weathered Kimmeridge Clay was encountered and which graded into fresh Kimmeridge Clay at -2.3m.

SITE 2 Below 1.9m of pure blue-grey lacustrine clay, weathered Kimmeridge Clay was proved to -2.2m.

SITE 3 1.3m of lacustrine clay with blue and orange laminations is underlain by 3m of orange brown silt. At -4.3m a darker lacustrine clay than that above the clay occurs. (BNS). It is identical to that which overlies weathered Kimmeridge Clay at other localities.

SITE 4 1.1m of blue-grey lacustrine clay which contains orange laminations at its base is underlain by a 2cm thick ferruginous hard-pan which overlies weathered Kimmeridge Clay (proved to -1.7m).

SITE 5 0.7m of blue-grey lacustrine clay passes into blue, orange and brown laminated clay. This laminated clay becomes better consolidated with depth and has been proved to -1.3m.

SITE 6 0.8m of blue lacustrine clay is underlain by 0.3m of clay with orange laminations. Below -1.1m the clay becomes darker and better consolidated, resembling weathered Kimmeridge Clay and has been proved to -1.3m.

SITE 7 1.7m of blue laminated lacustrine clay with alternating laminae of brownish-orange silt towards the base and contains plant remains, including quite large birch twigs.

SITE 8 1.3m of brown-orange clay which contains numerous fragments of originally rounded sandstone cobbles overlies blue lacustrine clay which contains plant remains. BNS

SITE 9 2m of blue lacustrine clay that is laminated towards the base becomes darker and better consolidated below - 1.7m. BNS

SITE 10 2m of blue lacustrine clay passes directly into Kimmeridge Clay through a 0.3m zone of darker and well consolidated laminated clay.

(iii) TRIAL PITS

SITE 11 0.7m of stoneless blue-grey/yellow mottled clay. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 2 (-2m) Munsell colour 10YR 2/2

Entirely composed of fragments of shaly Kimmeridge Clay.

SITE 11 (-0.7m) Munsell colour N6 - 5YR 5/6

Predominantly grey clay with light brown weathered spots which contains occasional small rounded Jurassic mudstone fragments and rare angular white flints and small manganese dioxide nodules.

(L) NORMANBY HILL

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 73 82)

A prominent hill immediately north-west of Normanby which rises 31m above the surrounding Vale floor. The eastern slopes of the hill are quite steep.

(ii) DETAIL OF AUGERING

SITE 1 0.7m of sandy material with occasional local stones is underlain by laminated orange and grey clay. BNS

SITE 2 Laminated blue lacustrine clay with brown silt laminae and plant remains proved beneath 0.5m of soil. BNS

SITE 3 Laminated blue and orange lacustrine clay with plant remains proved beneath 0.5m of soil. BNS

SITE 4 Laminated blue lacustrine clay with orange silt laminae and plant remains proved beneath 0.5m of soil.

SITE 5 Orange brown clay with blue grey laminations and many local stones is underlain by stoneless lacustrine blue clay. BNS

SITE 6 Laminated blue and orange lacustrine clay at the surface is underlain by an orange silt with occasional blue flecks. BNS

SITE 7 Laminated blue lacustrine clay with orange silt laminae and plant remains proved beneath 0.5m of soil. BNS

(iii) TRIAL PITS

SITE 1 Olive-grey stony clay (all stones local) proved to 0.7m. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 1 (-0.7m) Munsell colour 5Y 5/2 - 5YR 5/6

Weathered and rather friable light olive grey clay, with some light brown mottling, which contains frequent small sub-rounded sandstone pebbles and tends to be sandier than true lacustrine clay.

(M) NORTH HOLME

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 705 808)

A barely discernable circular rise on the floodplain of the River Dove, on which North Holme House is situated.

(ii) DETAIL OF AUGERING

SITE 1 Stiff blue lacustrine clay with occasional local rounded stones and some decomposed plant remains (BNS) proved beneath 0.7m of soil.

(iii) No trial pits

(iv) No hand specimen descriptions

(N) OLD HILL

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 74 81)

An elongated north-south trending hill rising about 5m above the Vale floor and being a continuation of Thornton Riseborough Hill.

(ii) DETAIL OF AUGERING

SITE 1 1.2m of blue lacustrine clay with plant remains and brown silt laminae overlies weathered Kimmeridge Clay.

(iii) TRIAL PITS

SITE 1 0.9m of yellowish-brown clay with very few stones is underlain by at least 0.4m of blue clay with occasional oolitic limestone fragments. BNS.

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 1 (-0.6m) Munsell colour N3 - 10YR 5/4

Originally a dark grey stoneless partially laminated lacustrine clay which is largely weathered to moderate yellowish-brown and is closely penetrated by rootlets, each tube having a yellowish-brown corona.

SITE 1 (-1.2m) Munsell colour N4 - 10YR 5/4

Predominantly medium dark grey lacustrine clay, with some moderate yellow-brown weathered streaks, which shows occasional crude laminations (alternate grey and orange) and contains small oolitic limestone fragments and fine plant remains. This clay is not as weathered as the overlying yellowish-brown clay.

(P) RUFFA HOUSE

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 88 (SE 81 83)

An apron-like feature which surrounds the east, south and west sides of Botton Hill and extends south-south westerly into the Vale to a point 150m beyond the old railway line.

(ii) DETAIL OF AUGERING

SITE 1 Weathered Kimmeridge Clay exposed in ditch at - 0.7m.

SITE 2 Blue-grey silt with brownish-yellow inclusions and which contains some local stone proved at -1m. BNS

SITE 3 1.7m of blue-grey silt containing sandstone fragments overlies blue and orange clay with plant remains. BNS

SITE 4 0.7m of blue clay which contains occasional sandstone fragments and plant remains. BNS

SITE 5 1m of blue-grey silt overlies blue-brown laminated clay which contains occasional sandstone fragments and abundant plant remains. BNS

(iii) TRIAL PITS

SITE 2 0.7m of blue-orange clay overlying at least 0.3m of blue clay which is compact and shaly towards the base, resembling re-worked Kimmeridge Clay.

SITE 4 (Ruffa House roadworks) 0.4m of light brown fine sand/coarse silt containing local rounded and sub angular sedimentary stones w hich are concentrated towards the base overlies about 8cm of blue-grey laminated clay. This contains many rounded stones which are all local in origin and is underlain by about 0.25m of orange brown weathered clay with some blue-grey partings, which contains much sub-angular and angular local rock which through weathering has increased the sand content of the clay. Beneath the laminated clay there exists grey clay with plant remains. BNS

SITE 6 0.7m of bluish clay with occasional orange spots and laminae. BNS

SITE 7 Kimmeridge Clay rises to within 1m of the surface. The blue-grey stony clay is absent, it is therefore laterally impersistent. The sequence shows Kimmeridge Clay overlain by lacustrine clay with stony layers which is capped by more recent alluvium.

(ii) HAND SPECIMEN DESCRIPTIONS

SITE 2 (-0.3m) Munsell colour N3 - 10YR 5/4
Predominantly dark grey lacustrine clay with some moderate yellow-brown weathered spots, which is weakly laminated and stoneless, but contains frequent very fine crushed twigs (Birch?).

SITE 4 (-0.5m) (Blue stony clay band) Munsell colour 5Y 4/1 - 10YR 6/6
Blue clay which contains oolitic limestone and sandstone fragments plus frequent small MnO_2 nodules ...cks and also many fine crushed plant remains.

SITE 4 (-0.8m) (Orange-brown clay) Munsell colour N4 - 10YR 5/6
Predominantly orange (weathered grey) clay with quite a high sand and silt content due to weathering of the large number of contained sandstone fragments. It also contains rounded fragments of oolitic limestone and black manganese dioxide nodules.

SITE 4 (-0.9m) (Blue clay) Munsell colour N4 - 10YR 5/4
Predominantly grey stoneless lacustrine clay with some orange weathered streaks.

SITE 6 (-0.7m) Munsell colour N5 - 5YR 5/6
Predominantly grey weathered clay, with some orange mottling which

contains small sub-angular fine grained sandstone and oolitic limestone pebbles.

SITE 7 (At surface) (Kimmeridge Clay) Munsell colour N4
Dense, compact, shaly and uniform in colour.

(Q) SOUTH HOLME

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 Sheet SE 67 and 77 (SE 70 77)

An even and regular hill occupying about half a square kilometre and rising about 9m above the level of the surrounding flat land.

(ii) DETAIL OF AUGERING

SITES 1 and 2 1m of fine sand with occasional sandstone fragments underlain by lacustrine clay with plant remains. BNS

SITE 3 1m of lacustrine clay underlain by fine-grained orange stone (hardpan)

SITE 4 2m of silt which contains clay laminae.

SITE 5 0.5m of fine sand underlain by 0.5m of silty sand which overlies 0.7m of lacustrine clay. BNS

SITE 6 Lacustrine clay proved beneath soil at -0.7m. BNS

SITE 7 Stony sandy soil proved to -0.7m. BNS. No foreign erratics.

SITE 8 1m of laminated sand and silt with lacustrine clay at base. BNS

SITE 9 Lacustrine clay proved at -0.7m. BNS

SITE 10 Lacustrine clay (BNS) at - 0.7m.

SITE 11 Lacustrine clay proved beneath sands at -1.3m. BNS

SITE 12 Lacustrine clay proved beneath fine sand at -1.0m. BNS

SITE 13 2m of fine sand proved (BNS) Waterlogged at base.

(iii) TRIAL PITS

SITE 3 0.8m of lacustrine clay is underlain by about 5cm of ferruginous fine grained stone which in turn is underlain by 0.25m of blue lacustrine clay identical to that above. With increasing depth the clay becomes harder and darker, resembling the oxidised surface of Kimmeridge Clay. At -2m it contains greenish brown reduction spots that are harder than the clay and have a shaly texture (BNS).

Nearby, in another auger hole, no hardpan was encountered. At -1.7m, blue lacustrine clay passed directly into oxidised Kimmeridge Clay.

A previous auger hole sunk at this locality was continued and the obstruction previously encountered at -1.0m was penetrated. It proved to be a fine grained orange stony layer and is interpreted as a ferruginous hardpan. At -1.3m blue lacustrine clay passes into oxidised Kimmeridge Clay.

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 3 (-0.8m) Munsell colour N4 - 10YR 5/4

Predominantly grey stoneless, compact, laminated, lacustrine clay which has occasional moderate yellowish-brown weathered patches.

SITE 6 (-0.7m) Munsell colour 5YR 3/2 - 5YR 4/4

Very finely laminated, virtually stoneless greyish-brown clay with some moderate brown weathered spots.

(R) SPROXTON

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 Sheet SE 68 (SE 61 81)

It is not possible to feature map this locality from aerial photographs. The area in question occupies about 1sq.km and has been mapped by Fox-

Strangways (1881) as boulder clay on Kimmeridge Clay.

(ii) DETAIL OF AUGERING

SITE 1 Excavations revealed laminated clay and silt (BNS) at -0.7m below made ground.

SITE 2 Sand proved at -0.6m passing into finely laminated grey-blue silt and brown-purple clay with plant remains at -1.1m.

SITE 3 1.3m of laminated blue and orange lacustrine clay with plant remains and small local stones. BNS

SITE 4 As Site 3

SITE 5 Orange clay and grey silt laminations with frequent local stones and small woody plant remains. BNS

SITE 6 Orange and blue laminated clay with small stones. BNS

SITE 7 Soft blue-grey lacustrine clay. BNS

SITE 8)
)
SITE 9) Impenetrable ground
)
SITE 10)

(iii) No trial pits

(iv) No hand specimen descriptions

(S) THORNTON RISEBOROUGH

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 sheet SE 78 (SE 75 83). An elongated hill trending north-south and projecting into the Vale of Pickering as a ridge which rises up to 43m above the surrounding Vale floor. The ridge is about 4km long and has gentle western slopes and a very steep east and south-eastern one.

<u>SITE 1</u> 1.8m of laminated clays and silts with stones. BNS

<u>SITE 2</u> 1m of laminated clay and sand is underlain by 0.7m of brown silt which in turn is underlain by laminated blue clay. BNS

<u>SITE 3</u> 1.8m of laminated lacustrine clay and silt with occasional stones. BNS

<u>SITE 4</u>)
)
<u>SITE 5</u>) Same as Site 3
)
<u>SITE 6</u>)

<u>SITE 7</u> 1.8m of laminated silty clay overlies orange gravel with clay. BNS

<u>SITE 8</u> 1m of orange sand and gravel which contains some clay. BNS

<u>SITE 9</u> 1.7m of lacustrine clay with many sandstone and oolitic limestone pebbles underlain by orange gravel. BNS

<u>SITE 10</u> 1.3m of heavy brown/grey lacustrine clay with rolled fragments of oolitic limestone fragments and plant remains. BNS

<u>SITE 11</u> 0.7m of laminated orange sand and gravel with some clay in the matrix. BNS

<u>SITE 12</u> 1.1m of alternating orange and grey silt laminae which contains frequent sandstone fragments. BNS

<u>SITE 13</u> 0.6m of laminated clay and silt which contains much sandstone passes into an orange gravel with a high clay content. The gravel became impenetrable at -1.1m. BNS

<u>SITE 14</u> 1.6m of alternately laminated orange clay and grey silt which contains rounded sandstone fragments. At -1.7m, the deposit becomes quite gravelly and orange coloured. Plant remains were fairly frequent

at the base of the auger hole.

SITE 15 1.6m of laminated silt and fine sand overlies a very wet gravel with a high sand and clay content. The gravel is locally derived from the North Yorkshire Moors.

SITE 16 0.7m orange and grey clay and silt overlies a clay rich orange gravel entirely composed of local stone. BNS

SITE 17 0.7m of loam with local stones. BNS

SITE 18 Blue lacustrine clay with silt laminae, some local stones and plant remains proved to -0.7m

SITE 19 Alternate laminations of orange clay and grey silt with some local stones proved to -0.7m

SITE 20 Predominantly blue lacustrine clay, with occasional very thin leaves of orange clay and orange flecks, which contains local stones and plant remains.

SITE 21 Orange lacustrine clay with many tiny rounded local stones and occasional laminations. BNS

(iii) TRIAL PITS

SITE 6 0.9m of blue and orange mottled clay which contains occasional stones proved by augering to change colour to brown and become more compact at -1.1m. BNS

SITE 18 1.3m of reddish-brown clay with some stones is underlain by reddish-brown wet silt. BNS

SITE 22 0.6m of blue and orange mottled silty clay which contains frequent local stones is seen to rest on Kimmeridge Clay in a railway cutting.

SITE 23 0.6m of predominantly yellow spotted and laminated lacustrine clay overlies at least 0.3m of predominantly blue lacustrine clay. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 6 (-1m) Munsell colour N4 - 5YR 5/6

Originally grey clay which has a light brown mottled appearance due to weathering and contains waterworn fine grained sandstone pebbles.

SITE 18 (-0.7m) Munsell colour 10YR 5/4 - 5YR 5/6

Rather yellowish clay when moist which contains well-rounded and polished quartz pebbles, fine grained rounded sandstone pebbles, MnO_2 inclusions and fragments of oolitic limestone, plus rare small brown and white flints. The weathered appearance and friable texture does not suggest a clay-rich matrix; the sample resembles weathered till.

SITE 23 (-0.8m) Munsell colour N4 - 10YR 6/6

Medium dark grey clay, with occasional dark yellowish orange spots, which contains rare North Yorkshire Moors fine grained small rounded sandstone fragments and shows occasional rather vague alternate orange and grey laminations.

(T) WESTFIELD GRANGE

(i) TOPOGRAPHY AND LOCATION

1:25,000 O.S. Sheet SE 78 (SE 75 87)

This area lies half a kilometre to the west of Eastfield House and has been delimited by Fox-Strangways (1881). It straddles the western interfluve of the River Seven and has no topographic expression.

(ii) DETAIL OF AUGERING

SITE 1 0.8m of sandy silt with many small local stones. BNS

SITE 2 15cm of blue-grey sandy silt with small local stones. BNS

SITE 3 0.3m of pale yellow-grey fine sand/coarse silt with some clay which contains many limestone fragments and rests on Jurassic limestone proved beneath 0.3m of soil.

SITE 4 0.8m of orange brown sand with interbedded laminated grey silt which contains many local stones and some rounded quartz pebbles and overlies Jurassic limestone.

(iii) NO TRIAL PITS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 4 (-0.7m) Munsell colour N7 - 10YR 5/4
Grey and orange laminated silt which contains tiny yellow fragments of fine grained sandstone and larger pieces of coarser material.

(U) WOMBLETON

(i) TOPOGRAPHY AND LOCATION

O.S. 1:25,000 Sheet SE 68. (SE 64 83 to SE 67 83). This area consists of two hills of equal size which rise about 16m above the surrounding Vale. They lie to the north and north east of Harome and occupy an area of about 3 sq. kilometres.

(ii) DETAIL OF AUGERING

SITE 1 0.7m of clay-rich gravel which contains much sandstone and local rock. BNS

SITE 2 Orange and grey laminated silt with small stones proved to -1m.

SITE 3 Blue-grey lacustrine clay with occasional sandstone fragments and frequent orange partings proved to -0.3m

SITE 4 Excavations revealed a conglomerate in a clay matrix. BNS

SITE 5 Orange and light grey laminated silt proved at -0.8m beneath made ground.

SITE 6 0.7m of orange clay with many angular local stones. (BNS). Within the clay matrix, light blue-grey and orange laminations alternate.

SITE 7 1m of orange clay with grey laminations which contains many rounded and angular stones. BNS

SITE 8 1m of very soft, silty, stoneless clay with orange and grey laminations. BNS

SITE 9 Brown-orange sandy clay with sandstone fragments proved to -0.5m.

SITE 10 0.7m of orange clay and grey silt laminations with occasional sandstone pebbles which overlies at least 1.2m of well mixed sand and clay with many angular fragments of local sandstone. BNS

SITE 11 0.5m of orange clay and grey silt laminations overlies 0.5m of alternating laminations of blue clay and orange sand which is underlain by blue lacustrine clay with plant remains. BNS

SITE 12 0.3m of orange clay and grey silt laminations overlies 0.7m of angular local gravel with a sand/clay matrix which is underlain by blue lacustrine clay with plant remains. BNS

SITE 13 1m of orange gravel with much sand and clay in the matrix (BNS) exposed in ditch 1m deep.

SITE 14 0.7m of brown-orange silt overlies 0.6m of orange clay-rich gravel with occasional grey layers. It is underlain by 15cm of orange clay which in turn overlies blue lacustrine clay with plant remains. BNS

SITE 15 Blue lacustrine clay at surface. BNS

SITE 16 Orange sandy clay with numerous rounded local stones seen in excavations for post-holes.

SITE 17 0.3m of stony sandy material. BNS

SITE 18 0.8m of laminated lacustrine clay comprising blue clay and brown silt laminae. The silt laminae tend to be thicker than the clay. BNS

SITE 19 Blue lacustrine clay (BNS) which at -0.3m contains a thin layer of grey silt with gravel.

(iii) TRIAL PITS

SITE 4 Laminated blue and orange silty clay with many local stones which are oriented parallel to the laminations. BNS

SITE 20 Grey silt/clay with occasional sandstone fragments and some orange weathered spots and laminated bands seen to -0.9m. Proved to -1.7m by auger. BNS

(iv) HAND SPECIMEN DESCRIPTIONS

SITE 1 (-0.5m) Munsell colour 10YR 5/4

Wholly orange sandy clay which contains oolitic limestone and sandstone fragments. The sandstone is highly weathered, decomposing into individual grains which has increased the sand content of the clay.

SITE 4 (-0.5m) Munsell colour 5Y 6/1 - 5YR 4/6

Crude alternate grey and orange laminations appear to be parallel to the crude lineation exhibited by the stone content of the clay. The stones are moderately large, generally well-rounded sandstone and oolitic limestone fragments, though some are quite angular. The texture of the matrix is similar to that of weathered till, being rather sandy and not having a very high clay content, though dispersion in water shows that some clay is present. The clay does not superficially resemble true lacustrine clay.

SITE 14 (-1.1m) Munsell colour 10YR 4/2 - 5YR 5/6
A clay-rich deposit which contains many angular North Yorkshire Moors stones of various sizes and which exhibits many light brown weathering spots which give it a mottled appearance. Fine sand in the matrix produces a texture not unlike that of till (in particular, Lower till series of the coast).

SITE 20 (-0.9m) Munsell colour 5Y 6/1 - 5YR 5/6
Predominantly grey clay with orange mottling and occasional small sandstone fragments and rare Kimmeridge Clay flakes.

Following this regional investigation which involved a programme of widespread augering on all of the suspected boulder clay localities (Fox-Strangways, 1881) supported by analysis of available aerial photographs, a scheme of detailed augering was undertaken on Marton Common in order to elucidate more clearly the stratigraphic relationships between the Kimmeridge Clay, compact lacustrine clay, locally derived waterworn stones and the poorly consolidated silty alluvium. In this survey, the sample sites bear no relationship to the previous survey and to avoid confusion they are identified by grid reference and displayed separately in fig. 64.

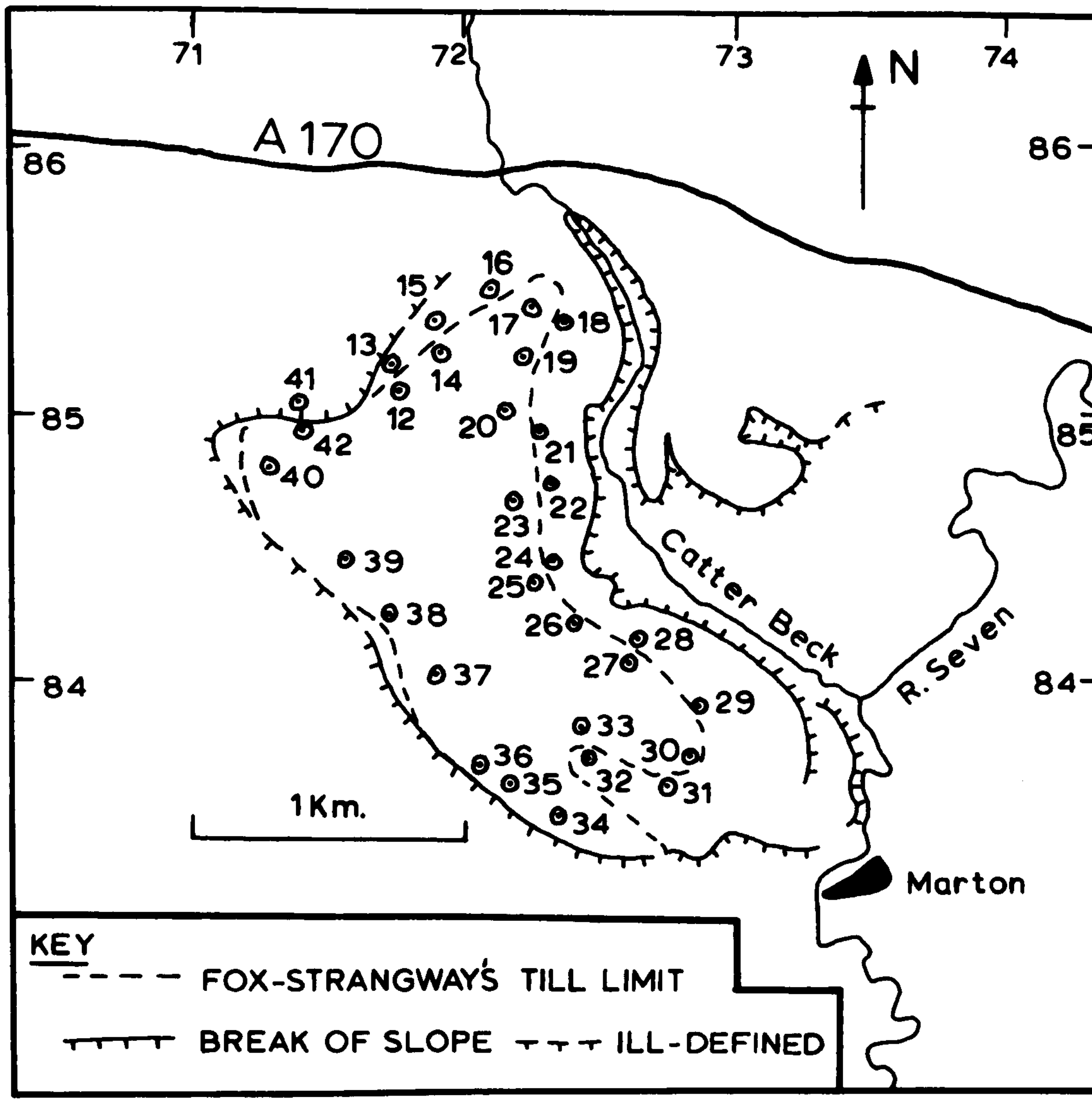


Fig.54. MARTON HILL AUGER SITES 12-42

MARTON COMMON

DETAILED AUGERING

(12) SE 7178 8508 1m of stoneless, soft, pure yellow grey clay.

(13) SE 7173 8518 0.7m of orange/blue grey, soft, stoneless clay.

(14) SE 7190 8523 0.7m of clay with hard manganese dioxide inclusions passing into pure orange/blue, soft, wet clay with plant remains proved to -1m.

(15) SE 7189 8535 0.3m of brown rather silty clay overlies 0.3m of fawn gravelly clay. This passes down into an orange/blue, soft, sticky, stoneless clay. Proved to 1m.

(16) SE 7209 8547 Stoneless soft orange/blue clay proved to 0.3m.

(17) SE 7225 8540 0.7m of soft, stoneless, mottled yellow-grey clay. BNS

(18) SE 7236 8535 0.3m of soft, stoneless, yellow/blue-grey clay. BNS

(19) SE 7221 8522 Rather compact stoneless orange/grey-brown clay with some manganese dioxide inclusions proved to 0.5m.

(20) SE 7215 8502 0.3m of stoneless soft yellow/blue clay. BNS

(21) SE 7226 8494 0.3m firm brown silty clay. BNS

(22) SE 7231 8474 0.3m orange-brown/blue, compact, stoneless clay with manganese dioxide inclusions. BNS

(23) SE 7218 8466 0.3m brown-grey silty clay with occasional local stones. BNS

(24) SE 7232 8445 0.3m blue/brown orange, soft, stoneless clay. BNS

(25) SE 7225 8437 0.5m of predominantly orange clay with odd blue-grey spots and occasional stones. BNS

(26) SE 7240 8422 0.3m of stoneless brown-orange silty clay which appears to be relatively recent. BNS

(27) SE 7260 8407 0.3m of soft yellow-brown stoneless clay with an occasional blue-grey streak. BNS

(28) SE 7263 8416 0.3m brown-orange/blue-grey, mottled, stoneless firm clay. BNS

(29) SE 7285 8391 0.4m of brown silty clay with manganese dioxide nodules passing into yellow/blue, soft, stoneless clay with occasional small manganese dioxide fragments. Proved to 0.5m

(30) SE 7282 8372 0.3m of orange/brown stoneless, rather silty clay. BNS

(31) SE 7273 8363 0.3m of brown, stoneless, silty clay passing into orange silty clay. Proved to 0.5m.

(32) SE 7245 8371 Stony field surface (all of local origin) underlain at 10cm depth by orange/blue stoneless clay. BNS

(33) SE 7241 8381 0.3m of rather tenacious orange-yellow/blue silty stoneless clay. BNS

(34) SE 7234 8349 0.3m of blue-grey/yellow mottled, stoneless clay (BNS). Immediately to the south, thick peat occurs, in a strip about 20m wide trending NW - SE. South-west of this, Kimmeridge Clay fragments have been brought to the surface in plough cuttings.

(35) SE 7199 8364 0.3m of quite firm, stoneless, mottled orange/grey clay. BNS

(36) SE 7205 8367 Stony (local) field surface underlain by mottled grey-orange stoneless clay. BNS

(37) SE 7189 8403 Rather stony field surface underlain by predominantly yellow silty clay with occasional grey streaks. BNS

(38) SE 7172 8425 0.3m of firm blue-brown, stoneless, silty clay with manganese dioxide inclusions. BNS

(39) SE 7156 8446 0.4m of orange-grey clay with occasional stones. BNS

(40) SE 7127 8479 0.3m of brown-orange, stony, silty clay, Impenetrable below 0.3m. BNS

(41) SE 7140 8499 0.3m of compact yellow-grey stoneless silt. BNS

(42) SE 7141 8494 A grey/brown silty clay with ferrugious weathered patches and manganese dioxide inclusions which is stony below 0.3m. BNS

(2) DISCUSSION AND CONCLUSIONS

Widespread augering over all of the hill areas and detailed augering on Marton Common coupled with close scrutiny of aerial photographs proved conclusively that no till exists in the Western Vale of Pickering. Investigation of Fox-Strangway's field slips (Institute of Geological Sciences Library, Leeds) revealed many discrepancies between his field notes and the published Geological Survey maps (Sheets 53 and 54). His field slips recorded 'clay with stones' over Kimmeridge Clay at Cliff Hill yet this appears as till on the Geological Survey sheet 53.

Shallow augering over the hill areas invariably reveals quite compact blue-grey, laminated, lacustrine clay with occasional plant remains and small, rolled oolitic limestone fragments. The clay becomes increasingly compact with depth and darker coloured due to incorporation of the underlying Mesozoic Clay. On the hill flanks, below the 30.5m contour, poorly consolidated, blue-grey, silty alluvium wedges out against the rising ground. The summits are covered by up to 3m of the compact lacustrine clay (e.g. Cliff Hill). Others (e.g. Golden Hill) have Kimmeridge Clay exposed at the surface.

Deep augering has revealed that all of the hills have a core of Mesozoic Clay and that they are structural features. Through a programme of deep boring in the north western Vale of Pickering the hill areas have been proved to be eroded remnants of upstanding fault bounded blocks (Richardson, personal communication). This evidence refutes the conclusions of Fox-Strangways (1881) who may have interpreted some of the hills as glacial depositionary features.

The compact lacustrine clay contains fairly numerous stones which are wholly local in origin, all being derived from the North Yorkshire Moors. They range from quite large, rounded, (waterworn) Jurassic sandstone cobbles to small rolled and angular oolitic limestone fragments. Channel gravel deposits occasionally occur (Golden Hill, Kirby Misperton) and are slightly younger or contemporaneous with the lower beds of the compact lacustrine clay. At Golden Hill, where the compact blue-grey clay is absent, quarrying has revealed a channel which rests on Kimmeridge Clay on the hill summit (fig. 53). It is entirely filled with waterworn sedimentary rocks from the North Yorkshire Moors.

The origin of the gravels is problematical. The possibility that they are relicts of a pre-Devensian erosion surface can be discounted as they are enclosed within the early-late Devensian lacustrine clay and are entirely composed of unweathered sandstone and limestone clasts. The lack of any sedimentary erratics in the pre-Devensian remanie drift of the North Yorkshire Moors points to the effectiveness of weathering as an agent for removing sedimentary rocks, especially limestone and supports a much younger age for the channel gravels.

In order to envisage how the gravels have come to occupy their present known positions (e.g. summit of Golden Hill) it is necessary to postulate that the western Vale of Pickering contained local accumulations of fallen and blown snow which may have been compacted to firn. During the early-late Devensian when ice at the Thorntondale limit began to melt in response to climatic amelioration it is envisaged that the firn in the western Vale also melted or partially melted giving rise to a series of interconnecting lakelets whose areal extent and depth changed rapidly in response to the melting process. It is probable that as the hill summits of the western Vale emerged from beneath the snow cover, melting of the snow adjacent to the hill areas would be accelerated thus encouraging the formation of lakelets in the vicinity of the hill flanks. The lakelets are envisaged as having water levels which oscillated during their existence and whose surfaces periodically froze in response to seasonal climatic variations whilst ice melt began to occur at the Thorntondale line.

Prior to this period the higher land of the North Yorkshire Moors was ice free and strongly affected by permafrost. Evidence for this comes from the widespread development of tundra polygons in the eastern moors (Dimbleby, 1952, Shotton, 1960; Péwé, 1965). They are only exposed where peat is absent and as the western moors are entirely peat covered, it is probable that they exist there too. The initial melting of the active layer resulted in the release of large quantities of water and clasts of local rock. It is possible that some of the water may have come from the melting of firn which probably accumulated in the southerly draining valleys of the moors, e.g. Rosedale. The local rock debris released by melting of the permafrost was carried southwards by surface runoff over the surface of the melting firn which occupied the western Vale of Pickering where it was deposited on the firn surface as spreads of thin waterworn gravel and as channel infills. These streams occasionally flowed over the emerging Mesozoic clay hill summits eroding channels which are now filled with locally derived waterworn gravel. (e.g. Kirby Misperton, Golden Hill). The random distribution of the waterworn stones within the lacustrine clay (e.g. Marton Common) indicates that the stones have been let down into the clay from above whilst the clay was accumulating. It is suggested that they have been dropped into the clay as the melting process proceeded and a lacustrine environment began to predominate over a more frigid periglacial one.

The areal extent and duration of the lacustrine conditions is rather uncertain. The presence of local clasts in the lacustrine clay indicate that ice-borne rocks were being dropped into the clay during its deposition though the supply of material off the moors ceased at an earlier stage. This is quite in keeping with the normal process of deglaciation as there is a time lag between climatic amelioration and ice melt. The low albedo of the ice free moors would ensure that melting of the permafrost was more rapid than melting of the firn in the western Vale thus surface runoff from the moors would be occurring whilst the firn level in the western Vale was still quite high. The low stratigraphic and in-situ position of the channel gravels within the lacustrine clay indicate that they were being deposited at an early stage of the melting process, and were not being deposited from floating ice,

It is not possible to make sound deductions regarding fluctuations in the lake level, though the stratigraphy and distribution of the stony lacustrine clay suggests that they did occur. The summit of Golden Hill indicates that it occupied a sub-aerial position when the channel gravel was deposited and the absence of any overlying clay suggests that the lake did not rise above this level. At Kirby Misperton, the presence of channel gravels within the clay indicates that they were deposited in a sub aerial position and then a rise in lake level submerged them, hence their covering of clay. The apron-like form that much of the stony clay assumes around the lower flanks of the hills indicates that the water level was below the summits of the hills when the stones were released from floating ice.

During this early-late Devensian period it is considered that the Kirkham Priory channel was in existence (see Chapter IX) and consequently there is no evidence of a barrier capable of impounding deep water in the Western Vale. Had deep water been impounded in the Western Vale, one would expect a covering of clay to occur over the entire area which was submerged, especially if the clay had been derived from the fines being released by the melting Thorntondale ice. Instead, the distribution of the clay is closely related to the distribution of

Mesozoic clay though at Golden Hill Mesozoic clay outcrops at the surface with no lacustrine clay veneer. It is possible that lacustrine clay was never deposited at this locality, though possible that it was removed by the fluvial activity which deposited the channel gravels.

In the Marton Common area, the compact blue-grey lacustrine clay passes gradually through weathered Kimmeridge Clay into fresh Kimmeridge Clay. This observation, plus the established link between the lacustrine clay and Mesozoic clay hills indicates that the lacustrine clay is, in the main, re-worked Mesozoic clay. There is no evidence of areally extensive lacustrine conditions in the Western vale, hence the absence of shorelines and related features, but there is evidence for an interconnecting series of lakelets whose waters re-worked the exposed Mesozoic clay and incorporated into it the occasional birch twig and small oolitic limestone and Jurassic sandstone fragments. The re-worked clay is laminated and is texturally and lithologically indistinguishable from undisputed glacio-lacustrine clay in the Yorkshire Dales.

The presence of birch twigs in the re-worked Mesozoic clay suggests that the lacustrine phase occurred at a time when the surrounding landscape was partially vegetated. This is in keeping with conditions postulated by Jones (1977) in Kildale though the author finds the Kildale radio carbon date (16,713±340 B.P.) unacceptable for the western Vale of Pickering. The date is considered to be too early on the grounds that it does not allow sufficient time for the advance and retreat of ice in the more southerly Holderness area. The advance of ice into this area is known to post-date 18,240±250 years B.P. (Penny, Coope and Catt 1969).

The lower lying, silty, unconsolidated alluvium wedges out against the flanks of the Mesozoic clay hills and indicates that the high level lacustrine phase was followed by a lower and shallower phase. The high level western lacustrine phase occurred when ice stood at Thornton Dale. Lacustrine clay of this age is not found to the east of Thorntondale, supporting the view that ice occupied that area. However, the lower lying silty alluvium covers much of the eastern Vale of Pickering, hence it post dates the Thorntondale ice and is considered to be of Flandrian age.

(A) SUMMARY OF EVENTS

(i) Ice was standing at the Thorntondale line with local accumulations of firn in the western Vale of Pickering. The western North Yorkshire Moors were ice-free and strongly affected by permafrost.

(ii) Climatic amelioration caused melting of the permafrost on the North Yorkshire Moors and surface run-off carried large quantities of locally derived rock fragments onto the firn surface in the western vale where it was deposited in extensive sheets and also as channel infills which occasionally traversed the crests of some of the Mesozoic clay hills which protruded through the firn.

(iii) The firn began to stagnate *in-situ* and many of the Mesozoic clay hills began to emerge and became surrounded by lakelets whose waters re-worked the Mesozoic clay to produce a laminated lacustrine clay. Occasional birch twigs were washed into these lakelets from the higher land to the north on which vegetation was becoming established.

(iv) Fluctuations in the levels of the lakelets caused channel gravels to be covered by lacustrine clay.

(v) A gradual decline in water level caused the last of the gravel originally deposited on the firn surface to be deposited around the flanks of the Mesozoic clay hills.

(vi) Ice retreated from the Thorntondale line to the Wykeham line though the precise date of this event is not known and there is no indication of the conditions which prevailed in the western Vale of Pickering during this period.

There is no evidence of the existence of Lake Pickering (Kendall, 1902) whilst ice stood at Thorntondale; instead it is proposed that a number of small, short-lived lakelets existed in the vicinity of the Mesozoic clay hills and that their areal extent and height above O.D. fluctuated rapidly in response to the melting process. Some of the lakelets may have been interconnected during part of their existence. The relationship of till and lacustrine clay at Thorntondale (Chapter 5) suggests that lacustrine conditions occurred at the ice front though it is not possible to say how extensive these were.

CHAPTER VII

LATE DEVENSIAN DEPOSITS IN THE EAST AND CENTRAL VALE OF PICKERING

The information presented in this chapter has been derived from three sources.

1 (A) Borehole records obtained by drilling in the Vale of Pickering by the Central Electricity Generating Board, North Yorkshire County Council and various independent contractors (Oakley and others, 1942 and 1944). All of the information referred to is housed in the Institute of Geological Sciences Library, Leeds.

2 (A) Shallow augering and air photo interpretation in the region of Hummocky till topography in the eastern vale.

2 (B) Coastal exposures of late-Devensian sequences in Filey Bay.

(1) PRESENTATION OF DATA

(A) BOREHOLE EVIDENCE

A borehole traverse (C.E.G.B.) between Malton and Seamer illustrates the complex lateral and vertical variations within the waterlain Devensian deposits of the Vale of Pickering. A reasonably consistent series of lacustrine lithologies occur in the west and can be traced eastwards for some considerable distance. They gradually give way to lithologies which, at the eastern end of the traverse, reflect the close proximity of melting ice.

Boreholes prove the pre-Quaternary basement of the Vale to be a very stiff, dark grey, shaly clay with occasional white fossil shell fragments. This is assumed to be Kimmeridge Clay, though Ampthill Clay may also be present (Richardson, pers. comm. ...). Mesozoic clay is proved at depths ranging from 5.8 to 9.75m (15.55 to 11.6m O.D.) and forms a topographic high north-west of Malton (see fig. 55). Boreholes 18 and 21 (fig. 56) prove Mesozoic Clay at 13.12m O.D. and 14.18m O.D. respectively thus indicating another topographic high 1km north-west of Scampston. No other boreholes to the east strike Mesozoic clay due to

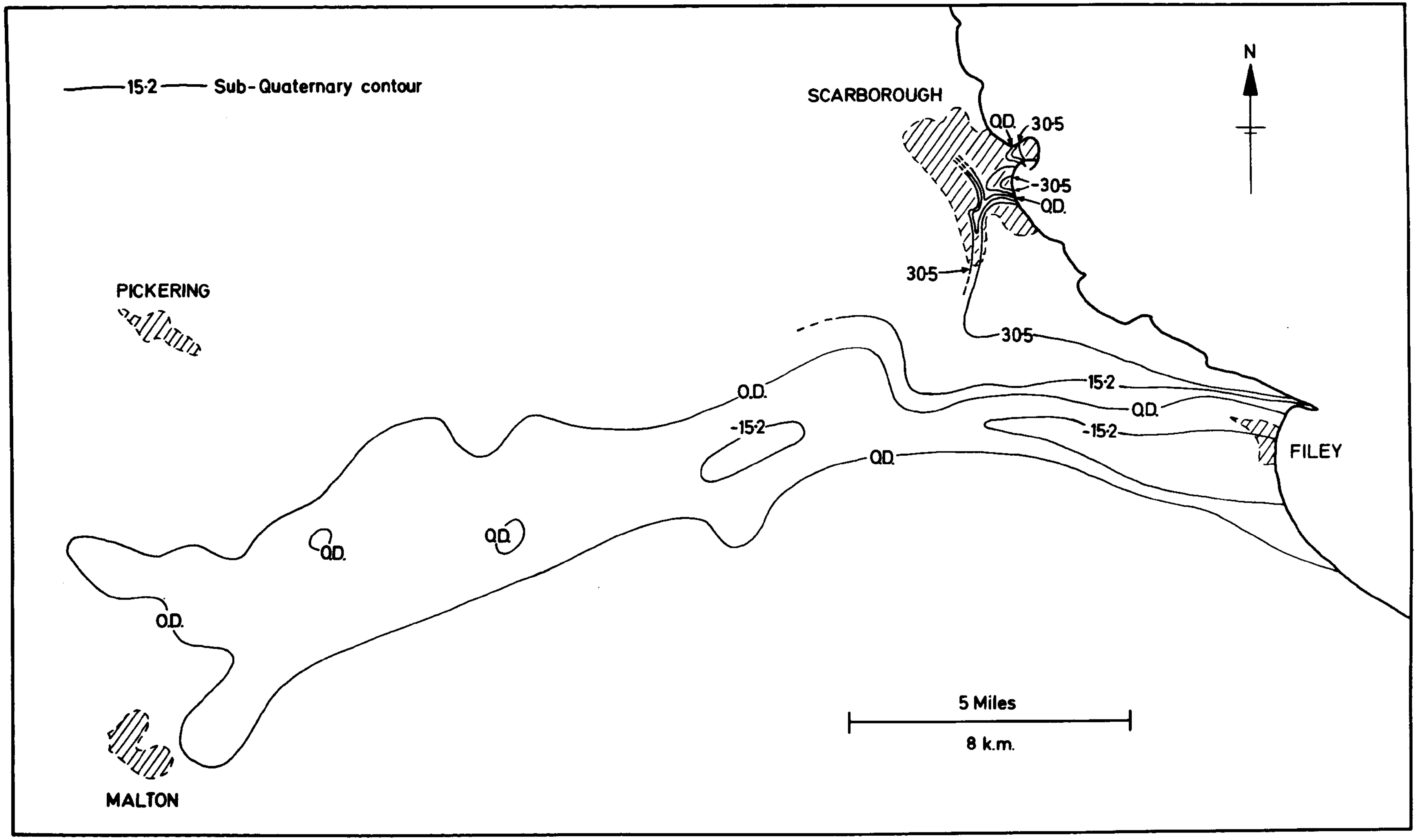
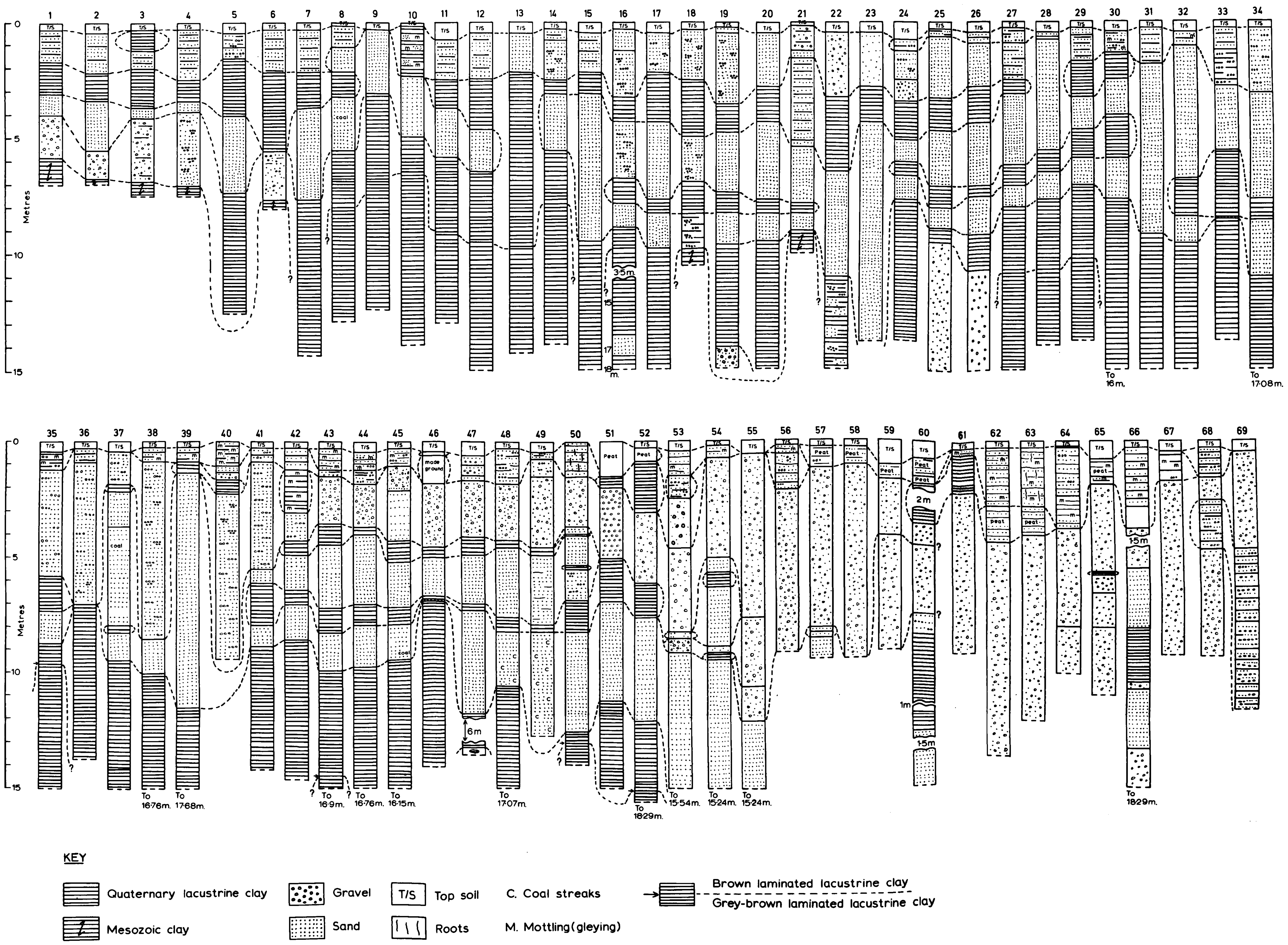


Fig. 55. PRE-DEVENSIAN TOPOGRAPHY OF EASTERN VALE OF PICKERING BASED ON BOREHOLE DATA

Fig. 56. SELECTED SECTIONS IN THE QUATERNARY DEPOSITS OF THE VALE OF PICKERING BETWEEN MALTON AND SCARBOROUGH



their shallow nature and the presence of a trough which descends in places to -15.25m O.D, and extends seawards towards Filey (see fig.55).

The Mesozoic clays are overlain by a variety of lithologies. Boreholes 1 and 2 reveal compact, becoming very compact with depth, mixed chalk gravel and fine-medium, brown, clayey sand, which overlies Mesozoic clay-shale. Borehole 3 reveals a moderately dense fine gravel and clayey sand. In borehole 4 a very similar lithology also overlies Mesozoic blue-grey shale. Borehole 6 proves dense chalk and flint gravel and a little clayey sand. Borehole 18 reveals a very stiff grey-green clay and occasional chalk gravel overlying Mesozoic clay. Borehole 21 reveals a medium dense, brown, fine, silty sand over stiff, dark blue-grey shaley clay. The other deepêr boreholes in which Mesozoic clay-shale is not proved suggest that laminated clay may overlie the Mesozoic clay. Borehole 8 proves 4.72m of firm, becoming stiff, grey, laminated clay with silty fine partings to 8.7m O.D. Numerous other boreholes (e.g. 10-13, 27, 35) show the grey clay to be overlain by firm, brown laminated clay with silty, fine partings. No boreholes show this two-tier clay sequence to actually overlie Mesozoic clay, though borehole 52 proves clay to 4.28m O.D. It may overlie the gravel and sand deposits proved in boreholes 1, 2, 3 and 4 as in borehole 19 it is underlain by 0.91m of very dense, fine gravel with a little sand. In borehole 47 the brown laminated clay is underlain by 0.3m of stiff, grey silt and pockets of clay. These are the only boreholes in the traverse which reveal the base of the brown/grey clay sequence hence it is not possible to conclusively determine the correct sequence of the lower members of the stratigraphic succession.

The laminated two-tier clay sequence is always overlain by medium-dense, brown, fine sand which is occasionally silty and may contain some gravel. In boreholes 1, 2, 3 and 4, the basal gravelly deposit is overlain by brown, fine, occasionally silty, sand. The clay sequence is stratigraphically higher than the basal gravel deposits and as it is always associated with topographically low areas of the vale it may represent an early, late-Devensian lacustrine phase in this area. The basal gravel contains chalk and flint fragments indicating that it is partly derived from the chalk scarp to the south-east. These deposits are probably quite extensive and represent an early Devensian peri-glacial climate with active solifluction. This was followed by a lacustrine phase with deposition of laminated clays in basins and low lying areas. No deposition is recorded over topographic highs such as those which existed north-west of Malton.

The entire area was then covered by a sequence of sands which are laterally quite extensive though occasionally absent (e.g. boreholes 6 and 13). The sand is moderately dense, medium brown and contains traces of clay, silt and gravel and varies in density from loose to compact. Within this sandy sequence, lenses of firm, brown laminated clay occur (e.g. boreholes 16 - 20). Traversing eastwards, variations within this unit become more extreme and complex with extensive lenses of firm, grey-brown laminated clay which occasionally contain silty, fine partings.

East of borehole 52 the laminated clays previously described are absent, with rare exceptions (e.g. borehole 54). They are replaced by sand and gravel which exceeds 15m thickness (e.g. borehole 55). There is much vertical and horizontal variation and this is attributed to the close proximity of the melting ice which produced the deposits. The Mesozoic basement in the eastern Vale dips to the east, consequently the early, late-Devensian brown and grey laminated clays dip below the younger fluvio-glacial sand and gravel complex. The sands and lenses of firm brown clay in the western vale grade laterally into the eastern sand

and gravel; the two being contemporaneous. The deposits in the west are quite well sorted and formed at the distal end of an outwash plain. Those in the east represent a fluvially active environment at the proximal end of the outwash plain within the late-Devensian ice limit. The deposits are coarser than those in the west and more poorly sorted.

In the western Vale of Pickering, above the medium-dense, brown sands there occurs a laterally extensive layer of firm, brown laminated clay which occasionally grades laterally into a soft to firm, brown laminated silty clay. This is the uppermost clay horizon and represents the youngest of the lacustrine phases. The extensive distribution of the deposit indicates the widespread nature of the fairly deep and quiet water necessary for its accumulation. At this stage of the late-Devensian, drainage in the vale was impeded, with surface hollows filled with quite large areas of standing water. The covering of silty alluvium on the western Vale surface suggests that these conditions also occurred during the Flandrian period.

Above the firm, brown, laminated clay, there occurs a series of fluvial deposits comprising sand with varying amounts of clay and gravel. The gravel occurs as inseparable units within the sand, the whole frequently being mottled due to post-glacial weathering. The clay that occurs within the sequence is light brown-grey and mottled (e.g. borehole 10) and is derived from the same source as the sand and gravel. The sequence represents the final melting stage of the ice during the late-Devensian. The Vale of Pickering had been extensively infilled with earlier deposits of clay and sand hence large areas of deep water were not available for the deposition of clay. Instead, the vale became a reasonably well-drained area over which trains of sand and gravel were spread with isolated and short-lived pools existing in hollows on the sand and gravel surface, where limited accumulations of silt and clay developed.

East of the Wykeham moraine (borehole 50) peat becomes prominent in the upper deposits of late-glacial age (Starr Carr). It formed in the area of impeded drainage which existed behind the Wykeham moraine which may have still presented a slight obstruction to westward drainage.

(B) CONCLUSIONS

Taken as a whole, the traverse shows a western environment which is basically lacustrine with fluvial incursions. Traversing eastwards, these fluvial phases are seen to be related to the melting of the ice at the Wykeham line, east of which coarse deposits of gravel predominate. In the central Vale of Pickering the medium-dense, brown sands are derived from the melting Wykeham ice. Later, the upper sand and gravel was deposited by water flowing through the Seamer valley (Geol. Surv. Maps 53 and 54).

In the early, late-Devensian the area was glaciated as far west as a line extending from Thorntondale to around Knapton. In keeping with other areas, such as the southern Vale of York, (Gaunt 1976) this ice advance was rapid and short-lived leaving a terminal moraine at Thorntondale. The boreholes show no ground moraine or outwash material which can be assigned to this early, late-Devensian ice melt.

Detailed shallow boring in the western Vale has shown that small isolated lakes existed at high topographic levels, whilst ice stood at the Thorntondale line. As the firn in the western Vale began to melt and disintegrate, these lakes drained and meltwater from the ice deposited trains of sand and gravel over the floor of the vale. Clay accumulated in isolated pools of still water on the outwash plain. The rapidly changing surface of the outwash plain ensured that isolated lacustrine areas were short-lived and account for the rapid changes of lithology in the lower sequences of the western vale, both vertically and laterally.

Following retreat of ice from the Thorntondale line, the next melting phase occured at the Wykeham line, followed by a later one which deposited sand and gravel at the mouth of the Seamer valley. It is not possible to distinguish between deposits of these two phases in the traverse though it is possible to see a gradual decrease in grain size from east to west indicating a decrease in fluvial competence towards the distal end of the late-Devensian outwash plain. Towards the western end of the traverse it is not possible to distinguish between Thorntondale, Wykeham and Seamer derived sands and clay. The sequence shows that this area was one of isolated lacustrine areas within a fluvial environment during all three meltwater phases.

To the east of the Wykeham moraine, the surface deposits consist of a large proportion of peat indicating impeded drainage in this area during the Flandrain period, compatible with the findings of Clark et al (1949, 1950) and Walker and Godwin (1954). This interpretation is based on the investigation of borehole records held in the Institute of Geological Sciences Library in Leeds. Due to the limited number of individual records available, it is not possible to correlate laterally over long distances. However, it is possible to obtain information which can be used to re-construct the regional environment of the Vale from the early, late-Devensian to the present day especially when coupled with the detailed information obtained by shallow augering and presented in Chapter VI.

(2) FIELD INVESTIGATIONS

(A) TILL SURFACE TOPOGRAPHY

East of the Wykeham moraine, Jurassic basement rocks comprising Mesozoic clays to the south of the Filey fault and Corallian limestones to the north are covered by thick Lower and Upper Till Series. The Upper Till Series is exposed at the surface along the northern edge of the Vale at least as far west as Seamer and dips to the south beneath the Flandrian deposits. The contact between the two lithologies is quite intricate (fig. 57) comprising many embayments and islands of till surrounded by Flandrian peat and alluvium.

Detailed analysis of available aerial photographs in the eastern Vale of Pickering has revealed a marked break of slope between the hummocky till topography and Flandrian peat deposits which occupy hollows on the till surface. By checking these breaks of slope in the field by closely spaced shallow augering along selected traverses it was found that aerial photographs provide a reliable means of mapping the distribution of Flandrian deposits in the area. The break of slope thus mapped is shown in Fig. 57 and is considered to be an accurate delimitation of the areal extent of Lake Flixton (Clark et al, 1949, 1950).

The Filey area is bounded to the south by the chalk scarp which passes inland from the Flamborough peninsula to Hunmanby where it intersects the easterly facing scarp of the Hunmanby fault. 1km. west of Muston, this scarp swings round to form Flotmanby Brow which overlooks the Vale of Pickering. The Filey area is bounded to the west by the low lying Vale of Pickering with its Flandrian deposits of peat and alluvium.

South of Filey, a large drumlin field extends in a belt from Reighton north-westwards to the Chapel Hill-Mile Haven road. In the south-east drumlins trend 290° true veering to due north in the north-west. They roughly follow the trend of the Hunmanby fault and Flamborough chalk scarps which strongly influenced ice movement in the area. North of the Chapel Hill-Mile Haven road and south of Filey the topography has a general north-west/south-east trend which is not a continuation of the drumlin belt. It is an open type of landscape; drumlins are not recognisable in the field and the Ordnance Survey contour pattern and aerial

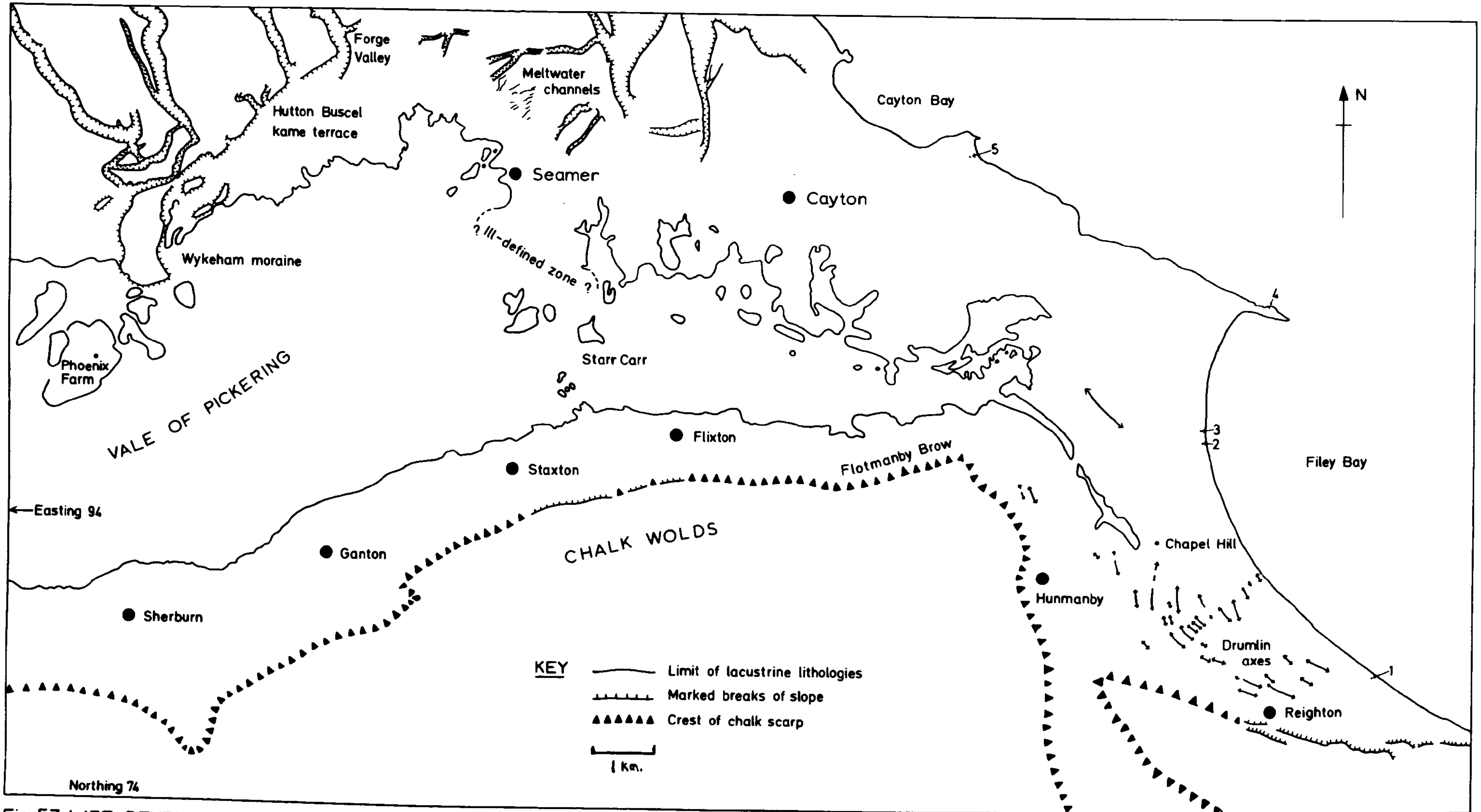


Fig. 57. LATE DEVENSIAN FEATURES OF THE EASTERN VALE OF PICKERING

photographs do not reveal any diagnostic topographic features. North of Filey, the surface topography is virtually a reflection of the Jurassic basement topography, dipping towards the south.

(B) FLUVIO-GLACIAL FEATURES

(i) THE HUTTON BUSCEL KAME TERRACE

The Hutton Buscel kame terrace was deposited in an ice marginal position between Forge Valley and Wykeham whilst ice stood at the Wykeham line. Quarrying along the length of the kame terrace has revealed a variety of lithologies and clast size ranging from silt to large boulders. Some of the material has been derived from the North-eastern moors, though some of the clasts have been derived from the ice against which the feature formed.

The kame terrace is a continuation of the Wykeham moraine which was deposited when ice retreat halted at the Wykeham line. Gravel was deposited at the ice margin, extending eastwards to Forge Valley. Melt water issuing from Forge Valley flowed westwards and graded the surface of the kame terrace producing the fluvial structures occasionally visible in the gravel workings near Hutton Buscel. The lack of gravel within Forge Valley and the ice marginal shape of the kame terrace and Wykeham moraine suggest that most of the material was derived from the stagnating ice. If the gravel was deposited by meltwater entering Lake Pickering (Kendall, 1902) then the distal end of the feature would appear deltaic in plan and would not curve southwards around the ice margin. Further support for the derivation of the gravel from the adjacent ice is afforded by the ice marginal gravel deposits to the east of the Forge Valley outlet.

Further consideration of the Hutton Buscel Kame terrace is given in Chapter IX.

(ii) SEAMER GRAVEL DEPOSIT

The Seamer gravel deposit is composed of a variety of lithologies whose grain size ranges between fine sand and coarse gravel. The deposit outcrops over about two square kilometres and delimits the westerly extreme of the exposed Upper Till Series in the Vale of Pickering. The gravel was deposited after deposition of the Hutton Buscel Kame terrace when the ice had retreated from the Wykeham line and meltwater was issuing from the Seamer valley. Flandrian peat and alluvium abuts against the southern margin of the gravel forming a marked break of slope visible on aerial photographs.

The significance of the Seamer gravel deposit is discussed further in Chapter X.

(C) COASTAL EXPOSURES OF LATE-DEVENSIAN SEQUENCES

Occasional exposures of late-Devensian sequences have been revealed by coastal erosion between Speeton and Cayton Bay. Attention was first drawn to these deposits by Phillips (1836); the site that he described in Filey Bay still being visible. Close examination of the upper zone of the coastal cliffs along the entire section of coast between Flamborough Head and Robin Hood's Bay has revealed five sites showing late-Devensian sequences (see fig. 57) and these are described below, beginning with the most southerly.

SITE 1 (fig. 58) TA 145 761

5cm of basal grey clay and gravel grades into till of the Upper Series, representing the partially leached and weathered surface of the upper till series. This weathering occurred during late glacial pollen zone 1. The gravel is a remanié deposit produced by removal of some of the clay content by surface run off. The extremely thin weathered veneer capping the till sequence indicates a short period of weathering and the thickness of the remanie gravel suggests only a limited removal of

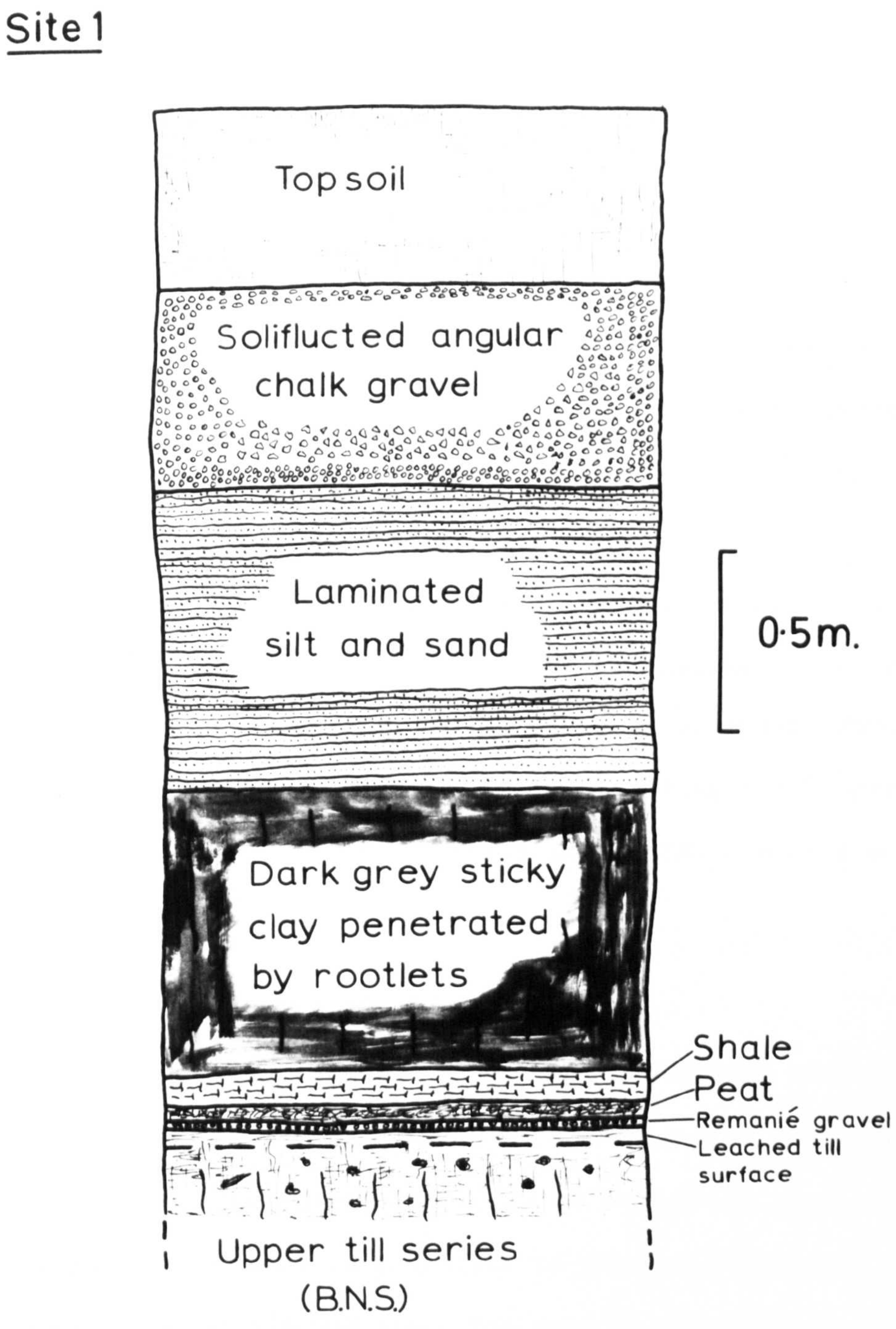


Fig. 58. MEASURED SECTION: SITE 1

fines.

This is overlain by 5cm of peat which is largely composed of flattened Birch twigs. A cursory inspection of the pollen content revealed a large proportion of Betula nana. A radio carbon assay on the peat produced an age of 11,380±260 years B.P. (Birm.506) thus suggesting that it is of Allerød age.

8cm of blackish-green shale which weathers to a rusty orange colour overlies the peat and probably represents the colder termination of the Allerød interstadial. During the post-Allerød cold phase, the basin became waterfilled producing 65cm of dark grey sticky clay. This is overlain by 80cm of laminated fine sand and silt which contains some loess indicating a colder and drier environment. The late-glacial sequence is capped by 52cm of soliflucted angular chalk gravel derived from the chalk scarp to the south and representing a cold period with seasonal freeze-thaw activity probably attributable to the post-Allerød cold phase.

SITE 2 (fig. 59) TA 1145 7960

2m. of glacial outwash sand and gravel which contains many large striated erratics is overlain by up to 5cm of peat. The surface of the outwash material is weathered and this is thought to have occurred in pollen zone 1. The peat is identical to that at Site 1 and is considered to be of Allerød age. The peat is overlain by about 18cm of white, calcareous laminated silt which has been derived from the chalk scarp around Reighton towards the end of the Allerød interstadial. The sequence is capped by 15cm of grey shale which is very similar to that which overlies the peat at Site 1 and probably represents the colder termination of the Allerød interstadial or possibly the post-Allerød cold phase.

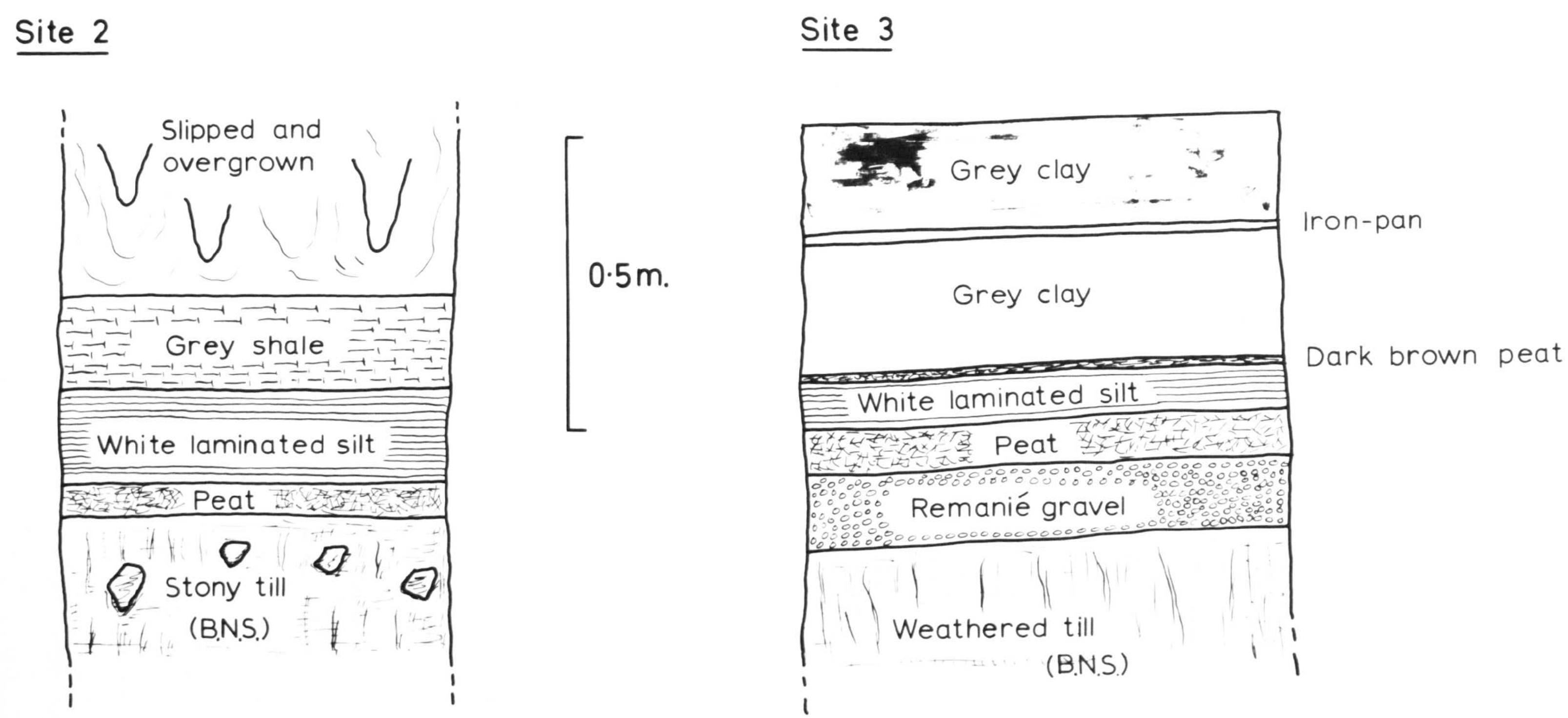


Fig. 59. MEASURED SECTIONS: SITES 2 & 3

SITE 3 (fig. 59) TA 1192 7978

This site is that described by Phillips (1836). 15cm of grey, gravelly remanie deposit overlies weathered Upper till series, having been produced by pollen zone 1 weathering. The peat which overlies the remanie deposit is about 7cm thick; contains flattened birch twigs and is considered to be of Allerød age. 7cm of white, calcareous laminated silt overlies the peat and corresponds to that exposed at Site 2. The calcareous silt is overlain by 1cm of dark brown fibrous peat which in turn is overlain by about 50cm of grey clay which is considered to be equivalent to the dark grey sticky clay at Site 1. The 1cm thick orange ferruginous band within the grey clay is a Flandrian hardpan.

SITE 4 (fig. 60) TA 127 817

This small exposure is on the north side of Carr Naze. Upper till series is overlain by 10cm of bluish-grey, sandy clay which in turn is overlain by about 1cm of stiff dark blue clay. Both of these lithologies are considered to belong to pollen zone 1. They are overlain by 1cm of irregular lenticles of peat. In keeping with the other sites in Filey Bay, this is considered to be of Allerød age and the overlying 8cm of light blue, stiff clay may have been deposited during the termination of the Allerød interstadial or post-Allerød cold phase.

SITE 5 (fig. 60) TA 084 839

At this site, till of the lower series is overlain by a sequence of sand, gravel and soliflucted clay with stones. Several of the gravel horizons contain mammalian remains, herbivorous teeth of an ungulate being fairly common. The topmost horizon contains numerous bones of an ungulate including a tibia (Bos primigenius) and many vertebrae and rib fragments. The sequence is considered to be of early, late-glacial age.

(D) CONCLUSIONS

(i) DISCUSSION

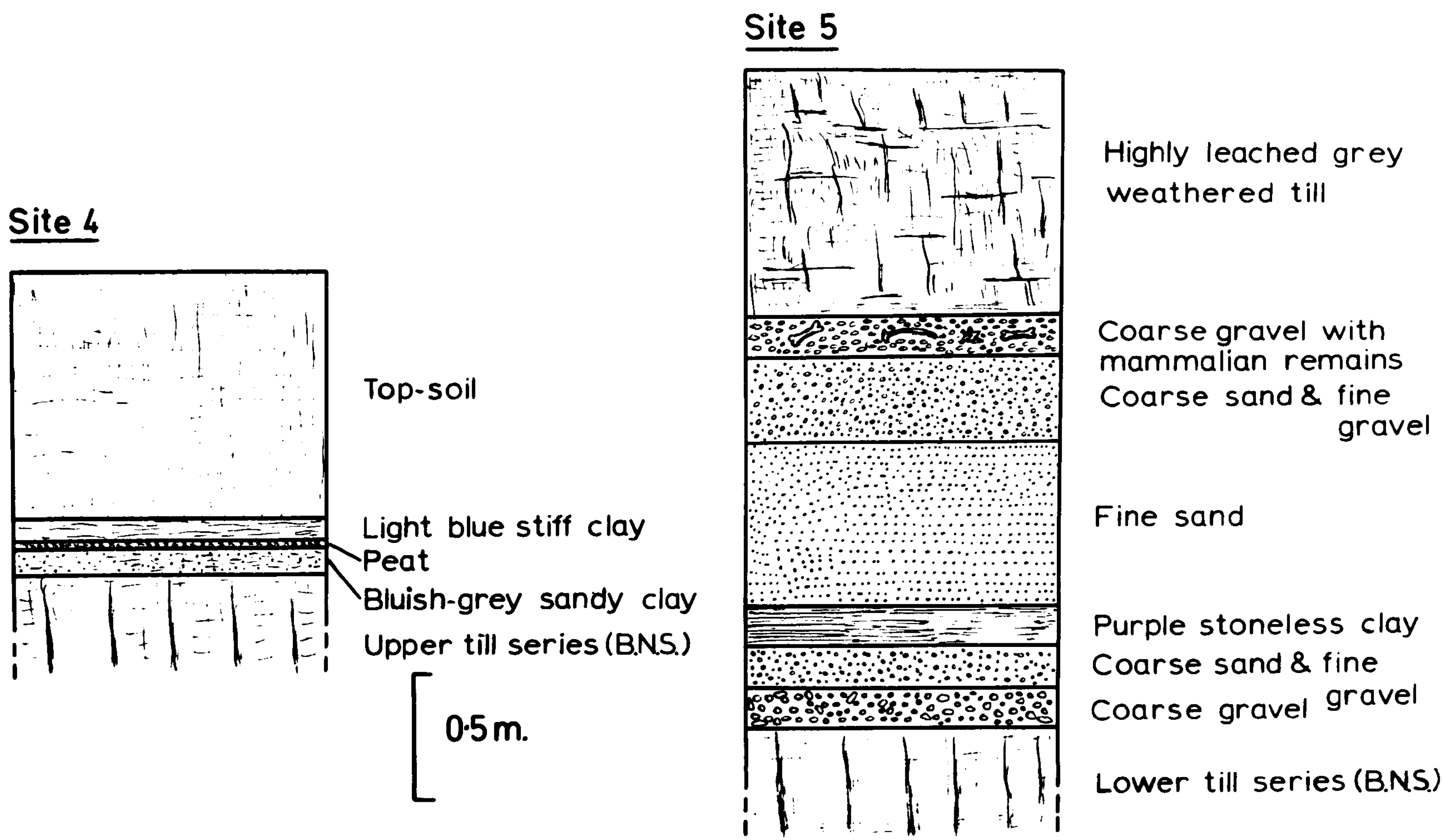


Fig. 60. MEASURED SECTIONS: SITES 4 & 5

The five sites described above give a reasonable indication of the late-glacial climatic conditions in North-east Yorkshire. Tundra conditions followed the retreat of the late-Devensian ice and these are indicated at the various sites, and at Site 1 in particular, by weathering of the till surface and development of remanie gravels.

The Allerød interstadial has been identified by radio-carbon dating (but not by pollen analysis) at Site 1 and it is considered that the layers of peat which occur at the other sites and show similar stratigraphic relationships to Site 1 are also of Allerød age.

The Allerød interstadial was followed by the post-Allerød cold phase when corrie glaciers developed in northern highland parts of Britain. In the lowland areas the period was characterised by blown sand accumulating in drier situations and soliflucted material in wetter ones. Both of these conditions prevailed at different times in north-east Yorkshire with a period of loess accumulation being followed by solifluction at Site 1. At the other sites wetter conditions prevailed with clay and shale being deposited in hollows on the late-glacial landscape.

(ii) <u>SUMMARY OF EVENTS</u>

(a) Advance of early, late-Devensian ice to the Thornton Dale-Knapton line with associated periglacial phenomena, e.g. ice-wedge polygons on North Yorkshire Moors. Accumulation of firn in western Vale of Pickering.

(b) Isolated high level lakelets in western vale when melting began with deposition of laminated blue-grey clay over Mesozoic clay hills and around Thorntondale.

(c) Retreat of ice and melting of firn in western vale with water draining into the Vale of York via the Kirkham Priory meltwater channel.

(d) Period of mild solifluction with deposition of oolitic limestone gravel along foot of Corallian dip slope on northern side of vale.

(e)Standstill of late Devensian ice at the Wykeham line.

(f) Deposition of firm brown laminated clay in central and western Vale of Pickering.

(g) Onset of melting at the Wykeham line and formation of Hutton Buscel kame terrace (activation of Forge Valley meltwater channel). Deposition of brown sands in the central Vale of Pickering.

(h) Continuous retreat of the ice to the east of Seamer and deposition of firm brown laminated clays in the central vale.

(j) Activation of Seamer valley meltwater channel with deposition of sands, gravel and clay over the surface of the central Vale of Pickering. Removal of southern horn of Wykeham moraine.

(k) Accumulation of late glacial sequences exposed in Filey Bay.

(l) Mottling and weathering of surface deposits and formation of Flandrian peat and alluvium in areas of impeded drainage. Lacustrine conditions in Star Carr vicinity.

CHAPTER VIII PERIGLACIAL DEPOSITS AND FEATURES

In North-east Yorkshire, evidence of Devensian periglacial environments is found on the higher land of the chalk Wolds, the North Yorkshire Moors and the flanks of the Flamborough peninsula. The evidence is two-fold; comprising exposures of periglacial deposits and the occurrence of widely distributed ice-wedge polygons. Ice wedge casts are occasionally visible along with cryoturbation features such as festoons and vertically orientated clasts in gravel workings and sand pits.

(1) PERIGLACIAL DEPOSITS

These invariably consist of material which has a solifluctual origin and are distributed in surface exposures around the margin of the eastern and central Vale of Pickering. Boreholes reveal that the deposits also extend beneath the late-Devensian infill of the Vale. The thickness of the deposits, which are comprised of angular chalk fragments to the south of the Vale and oolitic limestone to the north, varies considerably. Assuming that thickness is partly related to the duration of the pene-contemporaneous periglacial conditions, it is considered that deposits of differing ages are exposed.

(A) SOUTHERN VALE OF PICKERING

(i) KNAPTON GRAVEL PIT (SE 889 749, 73m O.D.)

In this gravel pit, which is situated on the flanks of the chalk scarp 1.2km. south-east of Knapton Hall, there occurs a spectacular sequence of waterlain and soliflucted angular chalk gravel. Quarrying has exhumed a natural trench trending east-west along the chalk scarp at 75 m. O.D. which has been formed by land-slipping. Speeton Clay is occasionally exposed in the floor of the gravel pit and it is evident that rotational movement of the overlying chalk has occurred along the contact of the two lithologies. Evidence for this is found in the eastern quarry face where brecciated solid chalk dips at 68° to the south. The crest of the slipped chalk mass can be traced for about 100m to the west, along the northern edge of the gravel pit. North of the slipped chalk, angular lithified chalk gravel dips steeply to the north (fig. 61). To the south of the solid chalk there occur numerous beds of steeply dipping waterlain, lithified, angular chalk fragments. The steepest dips are adjacent to the remnants of slipped solid chalk, the dip decreasing southwards to about 40°S. The beds range in thickness from 0.5 - 2m, the total stratigraphic thickness being in the order of 16m. Certain beds show frequent small scale normal faulting with throws of up to 1m to the north, indicating post-depositional compaction.

The extreme southern part of the eastern face reveals a complex sequence of soliflucted angular chalk gravel. The basal beds of waterlain gravel dip at 35-45° south and have been overidden by younger layers of soliflucted gravel into which the underlying gravel has been partially drawn. Between these merged sections there exist short exposures which reveal marked unconformable truncation of the underlying beds.

The overriding beds consist of distinct solifluctual units. Traversing the face of the exposure from south to north it is possible to trace each unit and observe an increase in clast size and angularity of the individual clasts towards the lobe.head. The lobes, which are exposed in longitudinal section have large bulbous noses comprising large angular chalk fragments up to 0.1m across. Two solifluction lobes occur, the upper one having overridden the lower and advanced further to the north. They both abut against the upper beds of the southerly dipping waterlain chalk gravel and have partially bulldozed into it, being deflected upwards for a short distance along the dip-slope. Within these two upper solifluctual units, occasional structureless sand lenses occur.

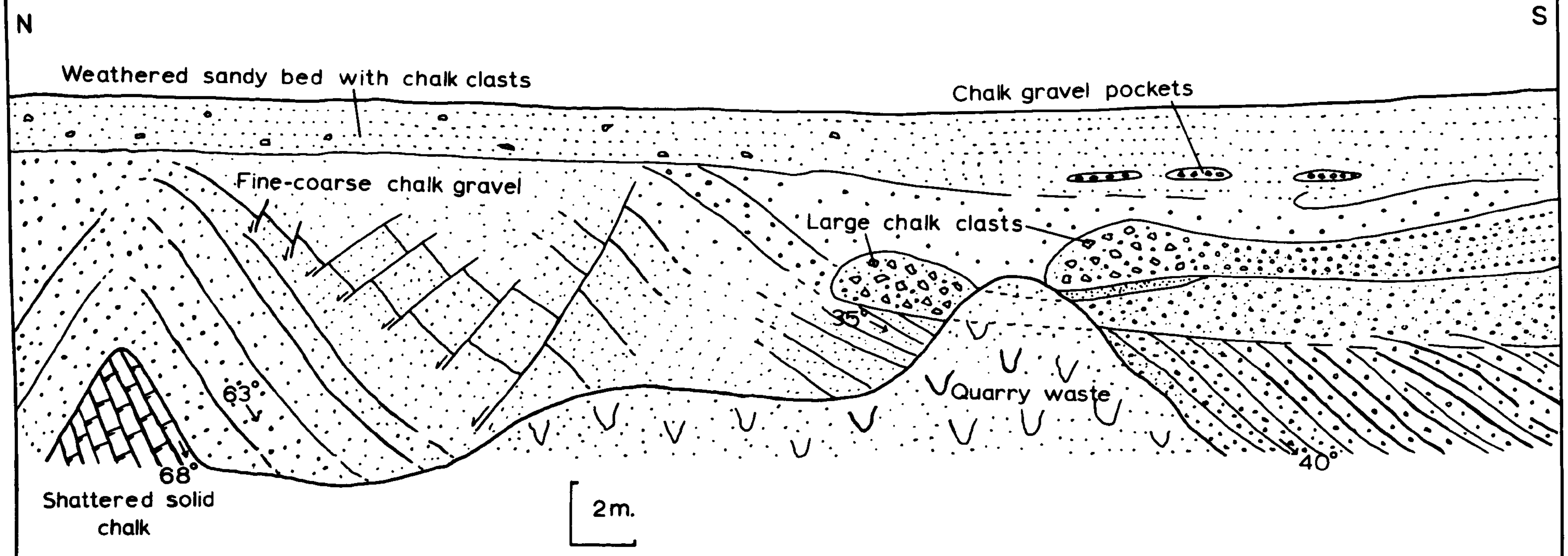


Fig. 61. SKETCH OF EAST FACE OF KNAPTON GRAVEL PIT

The precipitous southern face of the chalk pit is about 9m high and is cut along the strike of the fine-medium waterlain chalk gravel. The gravel is extremely compact and semi-indurated and contains occasional bands of dark clay up to 1cm thick which follow the strike. The uniformity of clast size within this sequence, compared to the overriding soliflucted gravel lobes seen in the eastern face, indicate that the chalk gravel is well sorted and has probably undergone more than one process of weathering and transport between derivation from the chalk scarp and deposition. The chalk was originally derived from the chalk scarp by cryogenic processes, hence its angular nature. The uniformity of clast size within each depositionary unit suggest that it has undergone sorting in water prior to deposition.

To the east of Knapton Gravel Pit, the lower flanks of the chalk scarp are covered in a fairly thick and topographically irregular layer of angular chalk gravel. The upper part of the chalk scarp is cut by short and irregular dry valleys which pre-date the main Devensian ice advance. Several of these trend north-westerly across the chalk scarp and indicate that drainage was partially controlled by the presence of ice at or about the crest of the chalk scarp whilst the valleys were being cut. The high level of ice in this area is not compatible with the early, late-Devensian Thornton Dale limit thus the valleys may be of Wolstonian age.

Wolstonian meltwater activity is considered to have been responsible for deposition of the waterlain angular chalk gravel on the lower chalk scarp flanks along with the occasional glimpse of soliflucted chalk gravel below the Devensian infill in the central Vale of Pickering.

The rotational slipping of solid chalk in Knapton Gravel Pit occurred prior to the deposition of the waterlain chalk gravel. The chalk gravel which overlies the slipped chalk mass displays primary dips due to deposition in a trench-like feature by water probably flowing westwards along the chalk scarp. If rotational slipping occurred after deposition of the chalk gravel then the steep dips to the north of the slipped mass would have been in the order of 90° prior to slipping which obviously is impossible for a primary dip. The normal faulting seen in the chalk gravel sequence is therefore due to post depositionary compaction and not to rotation.

Following deposition of the waterlain angular chalk gravel, the next event recorded at Knapton is a true solifluctual phase which was responsible for deposition of the soliflucted lobes exposed in the eastern face. The noses of the advancing lobes illustrate the extremely coarse nature of the angular chalk. Proximally, the material becomes finer and each unit tapers laterally to thicknesses less than those of the waterlain gravels, which display a remarkable uniformity of thickness throughout the exposure. This difference between the two lithologies illustrates the differing processes which have influenced the nature of the two lithologies. The soliflucted gravel has undergone cryogenic derivation from the chalk scarp and has been transported downslope by periglacial sub aerial processes which have caused the deposit to become coarser and thicker distally, forming a distinct solifluction lobe. Conversely, the older waterlain gravel has undergone further fluvial processes which have formed a well sorted sequence of angular gravel with individual beds displaying a marked constancy of thickness.

The uppermost beds of waterlain chalk gravel in Knapton Gravel Pit display occasional solution features which are filled with fine structureless sand and silt. These features are identical to similar features observed by Catt et al (1974) in Eppleworth Quarry near Cottingham. These were interpreted as being Ipswichian solution hollows which were infilled by loess, preceding the main Devensian ice advance.

It is suggested that the features observed in Knapton Gravel Pit are of a similar age and origin.

Soliflucted chalk gravel has frequently been observed in the Vale of Pickering though nowhere has it been exposed in the quantities present at Knapton Gravel Pit. It occurs beneath the Devensian infill in the Vale of Pickering (Chapter VII) and is exposed occasionally along the foot of the chalk scarp where undulating terrain to the east of Knapton is a surface expression of the underlying accumulations of gravel.

(ii) COASTAL SITES

Soliflucted chalk gravel occurs in coastal exposures above and below the Speeton Shell Bed (TA147758) representing two periglacial surfaces. The earlier surface pre-dates the shell bed whilst the later one post-dates the Wolstonian ice advance which isoclinally folded the Speeton Clay, lower angular chalk gravel and part of the Speeton Shell Bed. The upper periglacial surface may correlate with the waterlain angular chalk gravel in Knapton Gravel Pit. (For tectonic and stratigraphic details of the Speeton Shell Bed, see Chapter X)

(iii) HESLERTON SAND PIT

Well-sorted angular chalk gravel is exposed in the northern part of Heslerton Sand Pit. It is considered to be laterally continuous with the waterlain gravel of Knapton Gravel Pit and the gravelly topography to the east of Knapton which extends in a linear belt along the foot of the chalk scarp to West Flotmanby. In Heslerton Sand Pit, the gravel contains a large proportion of medium-fine, orange-brown sand and is seen to a depth of 4m.

At the southern end of the pit, 7m of waterlain sand (B.N.S.) overlies the chalk gravel. The sand displays sparse fluvial structures and occasional imbricated pebbles which indicate a northerly flow of water, downslope into the Vale of Pickering. The sand post-dates the deposition of the waterlain gravels, having been fluvially reworked with the gravel in Heslerton Sand Pit. It is laterally extensive along the flanks of the chalk scarp extending to East Flotmanby and the Settrington embayment in the west and may have been deposited marginally to the early, late-Devensian Thorntondale ice. The sands are deposited up to 45m O.D. along the chalk scarp, this height being compatible with outwash deposits produced by the Thornton Dale ice along the northern margin of the Vale of Pickering.

(B) NORTHERN VALE OF PICKERING

(i) THORNTONDALE

Periglacial deposits occur along the northern margin of the Thornton Dale till where oolitic limestone has become incorporated into lacustrine clay on the flanks of the Corallian dip slope. In Thornton Dale, a section at Church Lane reveals meltwater gravels overlain by a thin angular oolitic limestone layer indicative of a solifluction phase which post-dates the Thornton Dale till.

During the early Devensian, the North Yorkshire Moors were affected by periglacial conditions which caused the accumulation of gravel on the moor surface which was later deposited by fluvial processes as spreads of gravel and channel infills in the western Vale of Pickering following the onset of melting at the Thornton Dale limit. Periglacially derived deposits are also exposed overlying the lower limestone in Thornton Dale Quarry. Here, lower limestone is overlain by 1.2m of platy limestone fragments though no vertically orientated clasts were found. This is overlain by 0.5m of soliflucted material containing small limestone clasts. Above this, there occurs about 0.15m of orange/brown silty loess which contains occasional small limestone clasts. The sequence is capped by 0.3m of soliflucted material comprising limestone clasts up to 10cm long set in an orange/brown silty matrix. It is considered that the loess bed is equivalent to that described by Catt et al (1974) in other parts of North-east England and that the overlying soliflucted bed contains a large proportion of re-worked loess indicating how unconsolidated deposits are removed from limestone areas by gelifluction and surface run-off when perma frost renders the sub strata impervious.

(2) PERIGLACIAL FEATURES

Periglacial features are common in certain gravel and sand pits in the Vale of Pickering and on the surface of the North Yorkshire Moors. In gravel and sand pits, ice wedge casts are visible in profile; they range from short and broad to slender and deep structures depending upon the lithology in which they have formed and probably upon the penecontemporaneous frequency of temperature fluctuations about-6°C (Péwé, 1965).

On the high surface of the North Yorkshire Moors, extensive areas of tundra polygons occur (Dimbleby, 1952) though the improved quality of recent aerial photographs has shown these features to be more extensive than Dimbleby realised. Tundra polygons are widely accepted as having formed in perennially frozen ground in ice-free situations, (Shotton, 1960), and modern day examples from high latitude arctic areas support this (Taber, 1943, Black, 1952., Friedman et al, 1971) though the exact mechanism of formation is rather uncertain (Washburn, 1956) and may vary between sites. Aerial photographs provide an excellent means for detecting fossil tundra polygons by the change in vegetation which occurs between the central area of the polygon and the more poorly drained and topographically lower linear belt immediately above the fossil ice wedge cast. In the central area Heather is the predominant plant whereas Cotton Grass predominates in the more poorly drained ice wedge cast zone. This technique has been used elsewhere to successfully map large areas of tundra polygons (Svensson, 1963, 1967, 1972).

(A) ICE WEDGE CASTS

On the southern side of the Vale of Pickering, ice-wedge casts occur in Knapton gravel pit and Heslerton sand and gravel quarry.

Two ice-wedge casts have been seen in Knapton gravel pit though quarrying has since removed them. They both occurred in the upper soliflucted chalk horizon on the north side of the pit and are shown in fig. 62. The smaller one is the older of the two, having formed whilst the sand unit in which it occurs was accumulating. The high altitudinal position and structureless nature of the sand suggest that the formation of the ice wedge cast was terminated by burial due to aeolian processes. The sand is considered to have been derived from the more extensive deposits on the lower ground to the north which are exposed at Heslerton.

The larger ice-wedge cast is the younger of the two and contains a large amount of soliflucted chalk gravel which has slumped in from above. The sequence shows that the deposition of aeolian sand was interspersed by periods of solifluction. Sandy lenses have been incorporated into the gravel as it overrode frozen sand. The upper layer of chalk gravel, which slumps into the ice wedge cast, indicates that melting of the ice in the cast occurred before deposition of the overlying beds which are undisturbed.

In Heslerton sand and gravel quarry, 7m of fine, waterlain sand (B.N.S.) contains occasional, slender ice-wedge casts in the order of 2-6m deep and 10-15cm wide. The Horizontal stratification of the sand dips about 5cm in the centre of each cast. They formed in a short cold

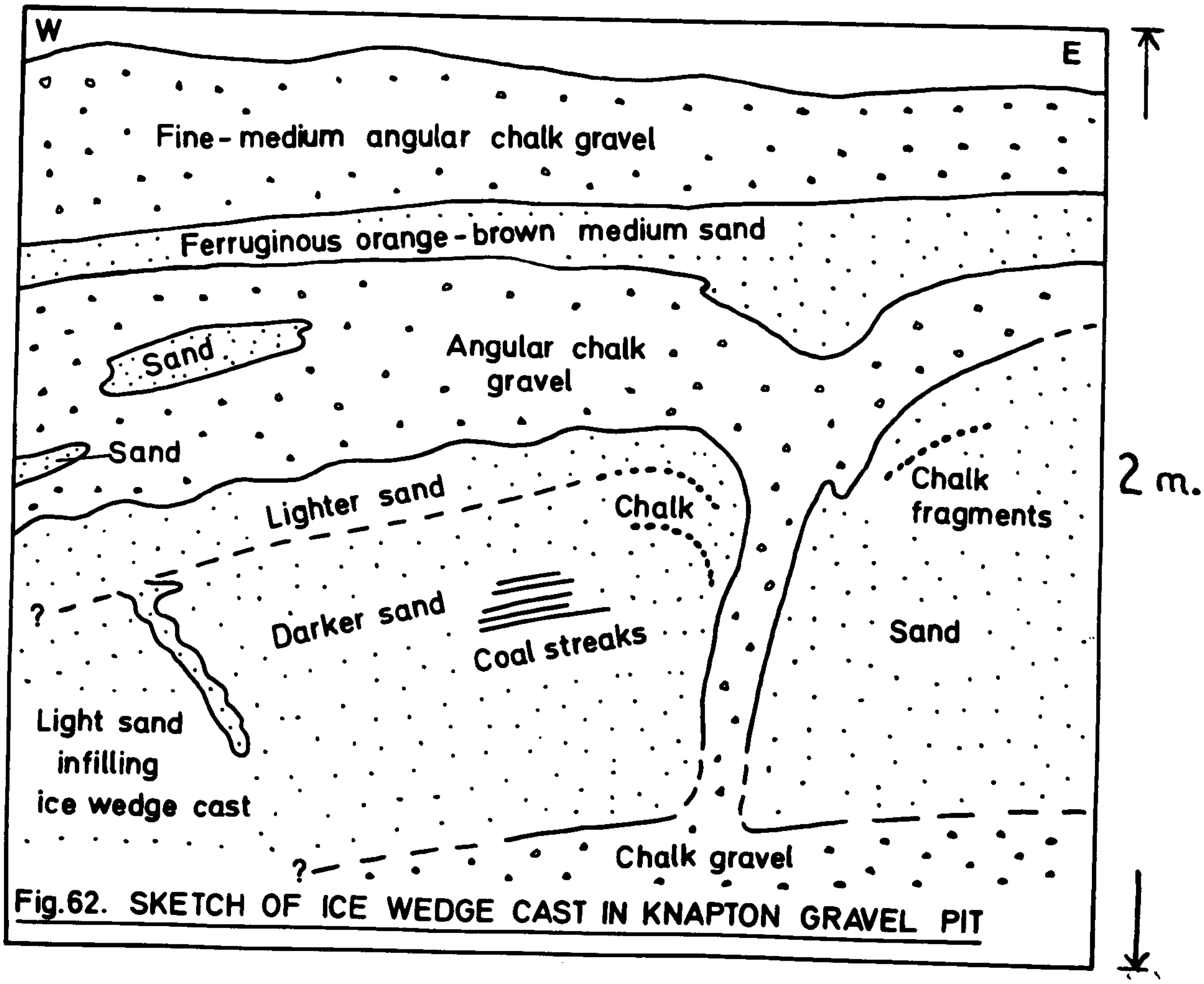


Fig.62. SKETCH OF ICE WEDGE CAST IN KNAPTON GRAVEL PIT

period, and have deeply penetrated the sand, facilitated by its unconsolidated nature. At the northern end of the gravel pit, ice-wedge casts and festoons within the chalk gravel are probably contemporaneous with those in the sands.

(B) COASTAL SITES

On the south-east side of Carr Naze, up to 2m of Coralline oolite has been cryoturbated prior to the main Devensian ice advance. It is strongly brecciated and festooned, indicating quite intense periglacial activity.

In Robin Hood's Bay, evidence of periglacial activity is seen at the base of the Lower Till Series. The edgewise conglomerate (Site 48, Chapter 3) comprising a brecciated, banded silt, represents rhythmic deposition in a shallow periglacial lake over which the main Devensian ice advanced when it was frozen, brecciating the floor deposits but enabling them to be preserved as fragments and not completely reworked. Though not in-situ, the fact that the edgewise conglomerate overlies suspected Wolstonian till suggests that it may be of a similar age to the Dimlington Moss Silts (Penny, Coope and Catt, 1969).

(C) TUNDRA POLYGONS

(i) DISTRIBUTION

The most striking periglacial features in north-east Yorkshire are the tundra polygons of the Tabular Hills and high moors. These were first described by Dimbleby (1952) who stated that they all occur on Lower Calcareous Grit surfaces to the east of Newton Dale. He mapped twelve separate polygon areas, though the improved quality of more recent aerial photographs (Meridian Air Maps, July 1969) has revealed another sixteen separate areas, Fig. 63 shows those areas originally delimited by Dimbleby, which are still visible despite the more mature forest cover, plus the further sixteen separate areas discovered during the

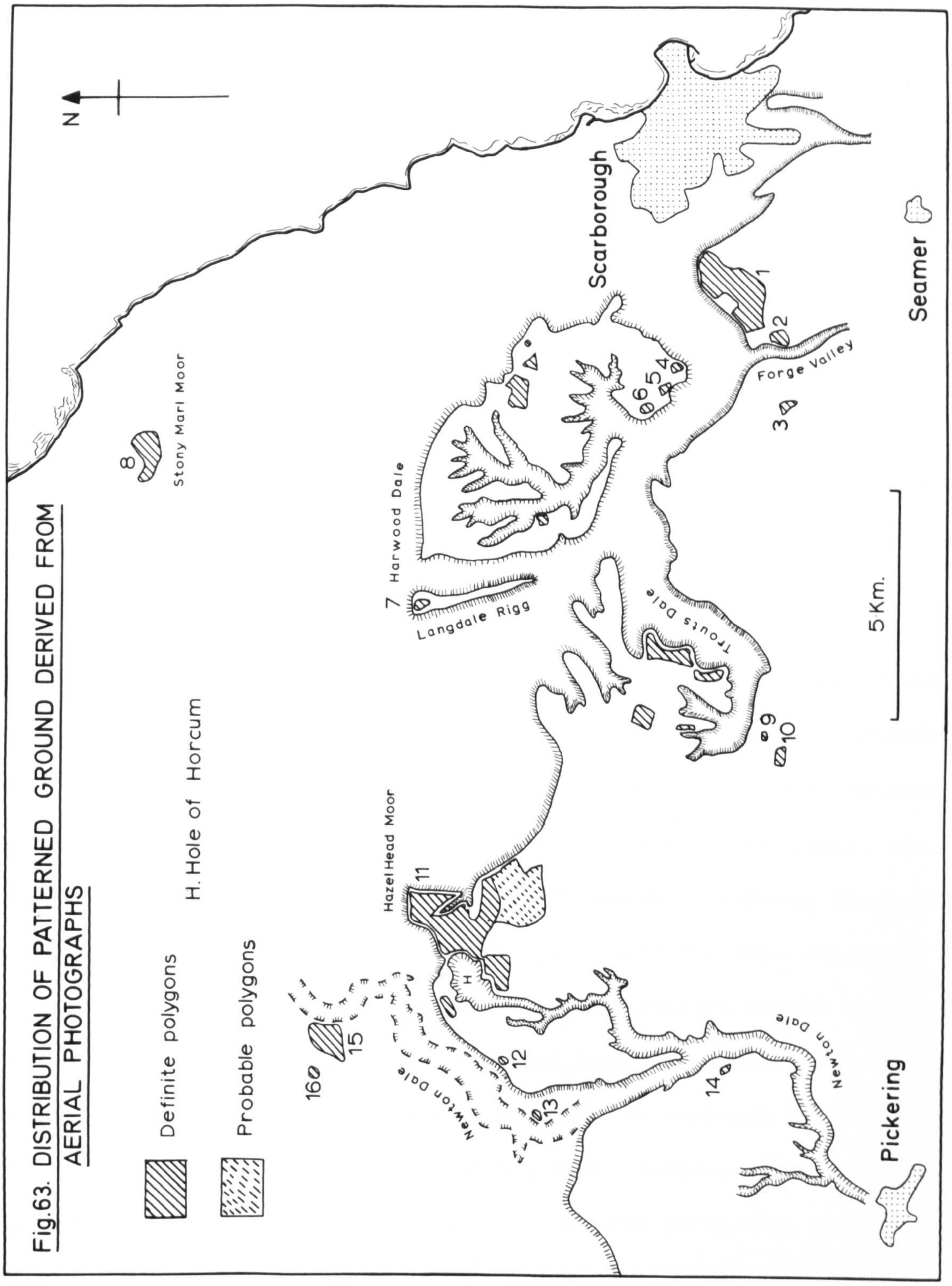


Fig.63. DISTRIBUTION OF PATTERNED GROUND DERIVED FROM AERIAL PHOTOGRAPHS

course of this study. Only one of these, (Stony Marl Moor) does not occur on Lower Calcareous Grit; instead the polygons occur on Estuarine Beds (≡ Ravenscar Group). The absence of polygons to the west of Newton Dale is attributed to the thicker peat covering there.

The polygons appear on aerial photographs as faint lines of Cotton Grass amongst darker Heather. In the field, the Cotton Grass occupies shallow linear depressions which are the surface expression of the polygonal pattern. Individual polygons are up to 25m across.

(ii) FIELD EXCAVATIONS

Two of the polygon areas were investigated in the field by digging a trench normal to one of the sides of each polygon. On Hazel Head Moor (SE 857939) a trench 8m long and trending 300^{o}(true) was dug from within the polygon to a point outside it.

Fig. 64 illustrates the stratigraphy of the southern face of the trench. Beneath the surface depression, weathered Lower Calcareous Grit extends downwards some distance and many of the loose stones exhibited vertical long axes. This is overlain by up to 0.2m of grey clay and local, sub-angular pebbles surrounded by moss and plant remains. Beneath the moss, a Flandrian ferruginous hardpan has developed where the free drainage of the overlying beds becomes restricted. Plant remains within the moss are concentrated as a mat at its base though they do occasionally occur at higher levels. Many of the pebbles are totally enclosed by the moss, suggesting that it was growing on a loose, stony surface which it could easily penetrate. The evidence suggests that this particular polygon and therefore the entire area of tundra polygons on Hazel Head Moor were active during the late-Devensian; the mat of moss representing a late-Devensian tundra surface. The ice-wedge cast of the polygon does not contain any till.

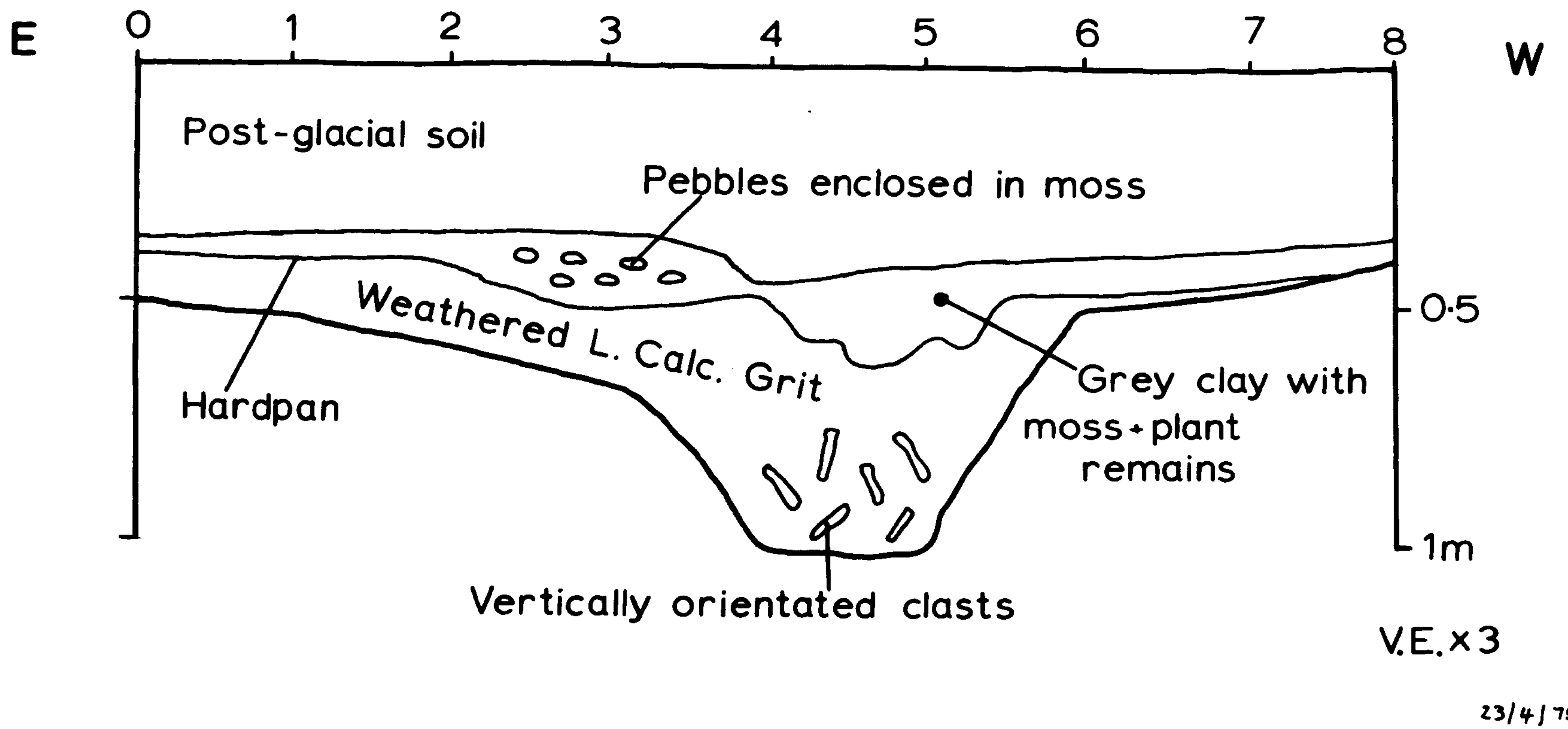


Fig. 64. SECTION ACROSS ICE WEDGE POLYGON ON HAZELHEAD MOOR

A second excavation was carried out on Stony Marl Moor (NZ 956008). A 3m long trench trending 270° (true) was dug across a marked surface depression which aerial photographs had revealed to be part of a small polygonal network developed at 230m. O.D. on Estuarine Beds (= Ravenscar Group). Fig. 65 illustrates the stratigraphy of the southern face of the trench. At both ends, pale yellow, weathered Estuarine Beds was exposed; the central fissure being filled with an orange/grey-brown, highly leached and weathered till which contains foreign igneous erratics. It is separated from the overlying laminated, stony, grey silt by a Flandrian ferruginous hardpan at the base of the free-draining zone. The top 10cm of the succession comprises post-glacial peat.

This polygon is similar to some of those excavated by Dimbleby (1952) in that it contains pre-Devensian till. The till is well outside the known Devensian limits, both laterally and altitudinally and indicates that in a pre-Devensian glacial period some of the highest areas of the North Yorkshire Moors were covered by ice. This is in accord with the pre-Devensian remanie drift of the Yorkshire Wolds (Bisat, 1940). The pre-Devensian age of the till associated with the tundra polygons is supported by the complete absence of sedimentary erratics which have been removed by weathering processes.

The presence of weathered till in the ice-wedge fissure can be interpreted in one of two ways. Either the till is a remanie deposit which has entered the fissure from the surrounding area by solifluction during the Devensian period or the tundra polygon was already in existence prior to deposition of the till. It is doubtful whether an area of tundra polygons would survive glacial encroachment, and as the surrounding area is thinly covered in highly weathered till, it is probable that the polygons have developed beneath a thin cover of weathered till and that the till in the ice-wedge fissures has slumped

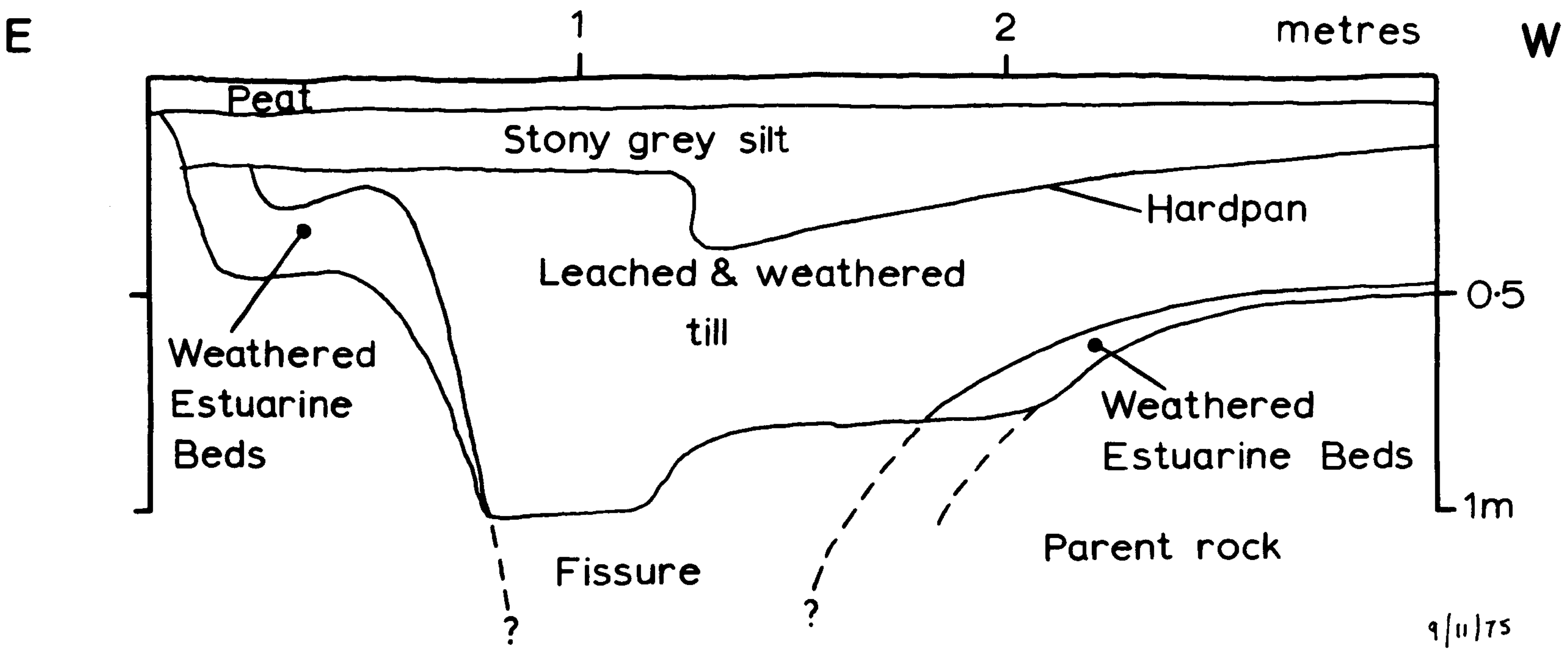


Fig. 65. SECTION ACROSS ICE WEDGE POLYGON ON STONY MARL MOOR.

in from the surrounding area, However, due to the weathered and friable nature of the till, no slump structures are visible.

(iii) PARTICLE SIZE DATA

(a) WEATHERED TILL (fig. 66)

Two samples of weathered till from within the ice-wedge cast (Curves A and B) exhibit a low coarse content and a major mode in the fine-medium sand fraction. The sample obtained from on the nearby moor surface (Curve C) also exhibits a low coarse content with a major mode in the medium-fine sand fraction. The low coarse content reflects the removal of all sedimentary erratics by weathering. It is entirely composed of foreign igneous erratics which in the samples obtained comprise quartz and Cheviot erratics.

(b) LAMINATED STONY SILT (fig. 67)

Curves A and B illustrate the rather stony nature of this deposit coupled with its high fine sand and coarse silt content. Pipette analysis indicates that it has a very low clay content (74.5% sand,17.4% silt,8.1% clay) suggesting that the deposit is aeolian, hence the laminations and that the coarse material has been incorporated during accumulation. The stratigraphy indicates that the aeolian phase followed a period of solifluction and possibly correlates with loess found on the Yorkshire Wolds by Catt et al (1974) and therefore is late Devensian, pre-dating the main Devensian ice advance. The relationship of the loess to the weathered till within the ice wedge cast indicates that the polygons pre-date the deposition of the loess.

(3) CONCLUSIONS

It is apparent that several phases of periglacial activity have occurred in north-east Yorkshire. It is not possible to erect a sequence of events with absolute dates but it is possible to date each periglacial period relative to the others where more than one occur at one site and

Fig.66. FREQUENCY DISTRIBUTION CURVE

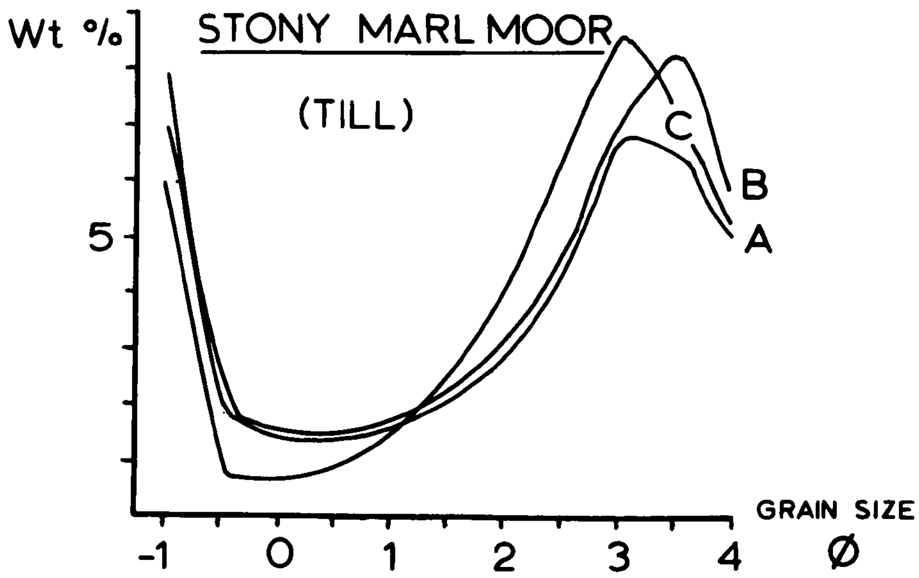
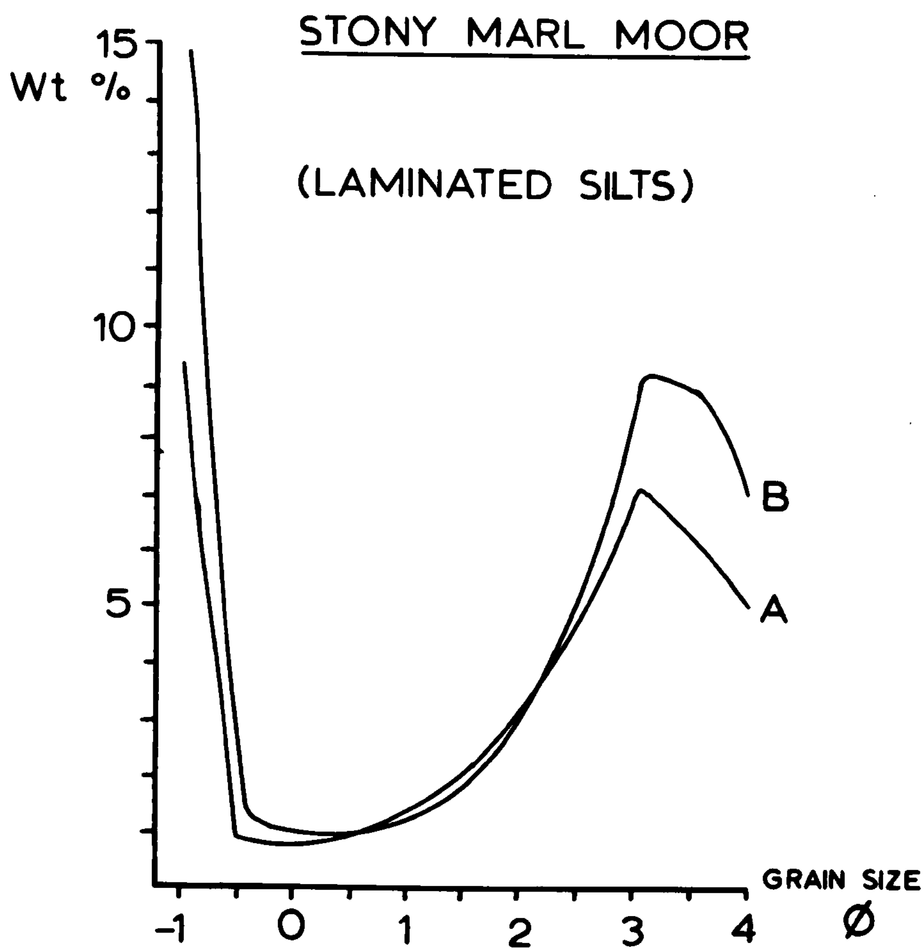


Fig.67. FREQUENCY DISTRIBUTION CURVE



to offer occasional tentative correlations between sites. The earliest known phase of periglacial activity is of pre-Hoxnian age and is represented by the chalk gravel which underlies the Speeton Shell Bed. The tectonic relationships of the Speeton Shell Bed and underlying gravel indicate that the chalk gravel pre-dates the Shell Bed (see Chapter X).

The next phase of periglacial activity is represented by the derivation of angular chalk gravel from the Wolds chalk scarp which were later deposited as waterlain gravels in a sub-marginal position to ice lying in the Vale of Pickering. The loess filled solution hollows on the surface of this gravel are considered to be of Ipswichian age in which case the gravels are Wolstonian, though they may be older.

The Heslerton Sands are considered to be younger than the waterlain chalk gravel on the grounds that the gravel has been reworked during the deposition of the sand at Heslerton. It is not possible to absolutely date the Heslerton Sands though the indications are that they are yonnger than the supposed Wolstonian gravels though they may still be of late-Wolstonian age and represent a period of Wolstonian meltwater activity in the Vale of Pickering. However, their distribution bears a close relationship to the known distribution of the early, late-Devensian Thornton Dale ice and they may have been derived from this source. The absence of any indication of glacial overriding suggests that they are not older than the Thornton Dale ice as altitudinally, they occur within its limits.

The Knapton waterlain chalk gravels and Ipswichian solution hollows which they contain are overlain by loess and soliflucted chalk gravel which represents a further period of periglacial activity. The soliflucted chalk gravel has incorporated lenses of aeolian sand and a similar sequence is visible in Thornton Dale Quarry where soliflucted limestone fragments overlie loess. Both sites are thought to correlate with the late-Devensian loess and head sequence at Sewerby (Catt et al, 1974). The available exposures do not indicate how the sequence is related to the Thornton Dale ice maximum.

It is possible that the loess has been derived from the outwash of the advancing Thornton Dale ice and that the period of solifluction which overlies the loess is also represented by the soliflucted limestone gravel, above the outwash sands associated with the Thornton Dale till in Thornton Dale. This period of solifluction was followed by a period of cryogenic activity in which the Knapton soliflucted gravel and Heslerton sands and chalk gravel were penetrated by ice wedge casts and individual chalk clasts became vertically orientated.

Coastal exposures show that the deposition of the Speeton Shell Bed was followed by a period of solifluction though there is no evidence to determine whether this is of early Wolstonian or late Devensian age. The gravel pre-dates the main Devensian ice advance but it is not possible to draw conclusions regarding its relationship to the streak of Wolstonian till contained within the Devensian Lower Till Series at this site.

On Carr Naze, cryogenic activity which has produced festoons in the Coralline oolite pre-dates the main Devensian ice advance in the area. In Robin Hood's Bay, the edgewise conglomerate which overlies Wolstonian till and underlies Devensian Lower Till Series is considered to be of similar age to the Dimlington Moss Silts and to have originated under similar climatic conditions.

The youngest periglacially derived deposits visible in coastal exposures are the late-glacial soliflucted chalk gravels of Filey Bay. It is possible that the limited development of cryogenic stnuctures in the Knapton soliflucted gravel and Heslerton Sands and gravels occurred during this short cold phase.

On the high moor surface, the extensive areas of tundra polygons indicate a long and complex history. The presence of weathered pre-Devensian till in some of them and absence in others suggests that the polygons have been active through more than one glacial period and that they have been reactivated in subsequent ones.

CHAPTER IX

CHRONOLOGY AND GEOMORPHOLOGICAL FEATURES OF LATE DEVENSIAN ICE RETREAT

(1) TECHNIQUE

Much has already been written on the meltwater channels of the North Yorkshire Moors. Kendall (1902) wrote at great length on the sequence of events which formed the channels, erecting a complex system of lakes and overflow channels. More recently, Rachel Hirst (1963) documented a great deal of quantitative data relating to the channels. In the light of this past work, it is not necessary to undertake any such studies. Instead, this investigation has been performed by means of aerial photographs which allow the observer to study the inter-relationships of the separate channels - an extremely difficult task to perform in the field. Most detailed attention has been directed towards the smaller channels existing on O.S. 2½" sheet numbers SE 99 and part of TA 09 and NZ 90. During the course of this detailed study, the following observations were made.

(2) DISCUSSION (See Map Folder)

(A) THE EASTERN MOORS AND VALE OF PICKERING

At the northern edge of the study area, Nigh Middle Sike and Biller Howe Dale Slack both breach the watershed between the head of Iburndale and Fylingdales Moor. Both channels carried water away from Iburndale for a limited period, towards the Robin Hood's Bay ice. Far Middle Sike (NZ 90,00) probably took water southwards to Grey Heugh Slack and thence into Biller Howe Dale Slack. At the junction of the two, a sand pit (NZ 910 ,020) indicates that fluvial deposition occurred. The water continued southwards around the elbow to Ling Hill plantation and then flowed for a short period along an ill-defined asymmetric channel heading south-south-easterly to the west of Biller Howe Farm, across Biller Howe Turf Rigg to Hollin Gill. It then flowed to the west of 'The Island' and into Jugger Howe Dale.

During this period, ice extended to the west of Biller Howe Dale - Jugger Howe Dale as the minor channel described above traverses a slope with a north-easterly aspect. The channel is the most westerly of the late Devensian meltwater channels and probably had a sub-marginal origin, therefore delimiting the maximum extent of the ice in the area. The sand at NZ 91 02 was deposited submarginally.

The next stage of the ice retreat involved local marginal oscillations. Between Billira Cottage and Grouse Hill the ice withdrew about ½km and meltwater then flowed to the east of Brown Rigg. In the north, withdrawal of ice caused the abandonment of Far Middle Sike in favour of Nigh Middle Sike. Sections of the Biller Howe Turf Rigg channel were also probably abandoned. Following these local withdrawals, the ice then withdrew clear of the Biller Howe Dale line and at the same time blocked Brown Rigg Moor channel. Water began to flow in large quantities along the line of Biller Howe Dale and Jugger Howe Dale, fed by a melting ice lobe in the Kirk Moor Gate area. A large sand and gravel deposit indicates the presence of meltwater which was temporarily checked before flowing out of the Kirk Moor Gate basin into Biller Howe Dale.

The Kirk Moor Gate area consists of a deep basin which was impounded to the east by Robin Hood's Bay ice and with the Biller Howe Dale intake to the south-west standing at 165m O.D. North-east of Kirk Moor Gate, two features exist which are ice marginal in origin. One is a linear ridge extending south-westwards for about 0.5km from Brow Top; the other is a channel running along Standing Stones Rigg. These delimit the northern margin of the Robin Hood's Bay ice.

Along the southern margin, a more complex situation exists. A small channel at Wind Hill carried water westwards whilst a much broader one (St Ives) connects Kirk Moor Gate to Stoupe Beck embayment. This is a rather ill-defined channel which may have carried water northwards. To the east of St Ives a small up-and-down channel exists, indicating a sub-glacial channel which operated under hydrostatic pressure. In post-glacial time, the Kirk Moor Gate sand deposit has been incised by Ramsdale Beck to form a marked bench on the north and south sides of the stream's headwaters.

Stoupe Beck embayment contained an extensive lobe of ice which on melting cut several large channels leading radially away from the ice front. At the northern extreme the St. Ives channel carried water into Kirk Moor Gate. Pond Farm, Blacksmith Hill and Jugger Howe channels all carried water southwestwards into the main Jugger Howe Slack. Blacksmith Hill channel led directly away from the centre of the lobe and is seen on aerial photographs to have a symmetrical cross section. Pond Earm channel has a lower southern margin and Jugger Howe channel has a lower northern margin. They are respectively assymmetrical marginal channels to the northern and southern edges of the Stoupe Beck ice lobe.

Extending north-eastwards from the southern margin of Jugger Howe channel (NZ 946 007), a linear feature can be traced with steadily increasing altitude towards the top of the Alum Quarry on Stoupe Brow at 221m O.D. The feature disappears along the eastern side of Stoupe Brow though it reappears at Coney Well Spring at 235m O.D. and can be traced with decreasing altitude to the south of Moorfield Farm as far as Staintondale Moor. It reappears once again 0.7km north of the Falcon Inn and extends southwards to the road. It is interpreted as being the trim-line of the ice in the Stoupe Beck embayment and the Staintondale area. It delimits the unglaciated area of Stony Marl Moor on which polygons and weathered pre-Devensian till exist.

From the Falcon Inn (SE 972 981) the ice limit was adjacent to a marked scarp which runs south-eastwards into Oxdale Slack. The ice overrode Ripley's Bank (TA 00 95) and penetrated to the north-west into Harwood Dale about as far as Raven Gill, the ice margin being marked by a line of gravel deposits to the north-east of Moor End Road. Gravel also occurs around Castle Beck Farm (SE 952 975) though the morphology of Jugger Howe Slack indicates that the ice went as far as Helwath Wood. Aerial photographs reveal that Castle Beck originally rose at a spring at SE 948 997, though the spring water now flows down Helwath Beck into Jugger Howe Slack. A small dry valley at SE 951 978 is a remnant of the lower reaches of the pre-Devensian Raven Gill and Bloody Beck, and in fact all the land north of Castle Beck Wood and west of Castle Beck as far as Helwath (SE 950 991) is a dip-slope remnant of the moors to the east of Jugger Howe Slack. Thus it is concluded that the area was occupied by ice which penetrated northwards from Harwood Dale and which caused Jugger Howe Slack meltwater to traverse the original valley side in an ice-marginal position and thus entrench itself.

At the western extreme of Harwood Dale there is aerial photographic evidence which suggests that the upper reaches of the River Derwent have been diverted due to the activity of meltwater and a lobe of ice in the area. At present, the river becomes incised at SE 928 966 and now flows into Langdale. This incision is identical to that of Raven Gill (SE 946 981) which is due to a lowering of base level by Jugger Howe Slack. North of Hagg Wood a former channel flows from SE 935 955 to SE 942 952, being the former course of the River Derwent before meltwater incised the head of Langdale and the present Harwood Dale Beck. It is concluded that the headwaters of the present River Derwent drained through Harwood Dale into the sea in the Burniston-Scalby area.

The south-western limit of ice in Harwood Dale is marked by the scarp slope of the Hackness Hills. Occasional gravel patches along the scarp foot indicate meltwater activity and isolated tundra polygon areas on the Hackness plateau close to the scarp edge indicate that the area was ice-free during the Devensian.

Sub-glacial meltwater features are common in Harwood Dale. Two other channels; one south of Harwood Dale village and the other in the vicinity of Grange Farm (SE 969 953), both indicate water flowing under hydrostatic pressure against the slope of the sub-glacial topography. Between Thirley Beck Farm (SE 983 948) and Lindhead Bridge (SE 993 938) an esker 400m long gives way to a channel 800m long. It is a fine example of gravel being deposited in a sub-glacial channel. Between Lindhead Bridge and Quarry House a channel flows parallel to the contours and then swings down slope: another example of sub-glacial control of meltwater.

0.5km north of Beacon Farm (SE 991 925) a narrow, linear feature about 800m long is interpreted as the crest of a small esker, two more of which occur 300m south-east of Kirklees Farm (SE 986 939) and correspond to a gravel deposit on the Geological Survey map (Sheets 35 and 44).

Ice lay against the scarp to the east of Harwood Dale Forest and meltwater from this produced two separate channel systems. The first consists of a pair of channels which took water away from the ice lobe lying in the Falcon Inn (SE 972 981) vicinity, and drained down the dip-slope into Harwood Dale. The second system comprises the Cloughton complex, consisting of channels which have been strongly influenced by the presence of ice. For at least part of its length, the Harwood Dale Forest scarp slope has formed one side of an ice-marginal channel. In places (e.g. SE 995 964) remnants of a two-sided channel exist. The channel drains into Oxdale Slack which itself is ice-marginal in origin, as indicated by till on Ripleys Farm dip-slope as far as the south-western edge of the channel. Secondly, if the contours of the dip-slopes either side of the channel are connected, then the channel is seen to cut them acutely indicating that ice to the south-east hindered topographic control of drainage. This mechanism is also demonstrated by Quarry Banks channel.

East of the A171, four sub-parallel inter-connecting channels carried water southwards. Their intakes decrease in height from west to east and their symmetrical, though occasionally asymmetrical cross-sections (e.g. Rock Haven TA 011 953) indicate that they formed in a sub-glacial and occasionally sub-marginal position. It is difficult to determine the age of formation of the individual channels as they may all have been operating together. However, the easterly decrease in intake altitude indicates that the most easterly was the last to operate.

North of the channel intakes there is a large and monotonous tract of land which was occupied by ice and which only occasionally shows channel development e.g. Rigg Hall and Tofta Farm. South of the channel zone, the same is true. Thick till deposits indicate an extensive lobe of ice which extended into Harwood Dale beyond Castle Beck Farm. Both these ice lobes occupied topographic basins; the intervening channel zone acted as a topographic barrier between the two.

The southern ice lobe was very extensive, occupying the Scarborough embayment and depositing up to 40m of till (Oakley and others, 1942-1944). According to the distribution of till, ice extended into Hackness about 0.5km beyond Ox Pasture Hall (SE 999 892) though a linear gravel belt deposited against the flanks of Irton Moor Scarp as far as the intake of Forge Valley suggests that its deposition was controlled by ice lying to the north. The high scarps of Irton and Seamer Moor to the south and Suffield to the north were ice-free, as testified by the presence of isolated areas of tundra polygons.

Some of the water draining into Harwood Dale flowed sub-glacially to the east. The remainder drained southwards down Langdale, causing a degree of incision at the head of Langdale comparable to that at Raven Gill (35m) and which diverted the headwaters of the River Derwent into Langdale in Flandrian times. There is no evidence to suggest that Langdale was initiated by this meltwater. The water flowed into Hackness and through Forge Valley, where its path was obstructed by an ice lobe extending into the Vale of Pickering as far west as Wykeham.

Along the northern margin of this ice, the Hutton Buscel Kame terrace was deposited.

North-west of Wykeham, a complex series of channels has developed, in part due to the gravel of the Wykeham moraine blocking the exit of Sawdon Beck. The original valley trended south-eastwards from the marked elbow on Sawdon Beck to the railway cutting. This became blocked and the water forced to flow towards Sleet Hill and then down the dip-slope to Ruston. Beedale Beck has also been diverted from its original course in the lower reaches. An abondoned course which operated for a short period after the formation of the Kame terrace occurs between Martin Garth and Ruston Cottage Pasture, but with later erosion of the terrace, was abandoned in favour of the present course. The existence of these dip-slope valleys prior to the deposition of the kame terrace, plus the lack of any deposits indicative of a deep lake in Hackness suggest that Forge Valley was already in existence as a watershed-breach in late-Devensian time.

Conversely, the Seamer valley is seen from aerial photographs to be a Devensian breach of the Tabular Hills' north facing scarp. Until the advent of the Devensian ice, the dip-slope of Falsgrave Moor was a continuation of Oliver's Mount dip-slope and the stream in Edge Dell flowed down-dip towards Seamer. Devensian ice breached the scarp allowing meltwater to flow southwards and thus cut the present valley and deposit the vast tracts of gravel now worked at Seamer. There may have been a physical connection between ice in the Scarborough and Seamer areas as the till deposits are continuous between the two.

Meltwater channels on Seamer Moor indicate that moderate quantities of water drained from the Scarborough embayment over the scarp crest indicating that ice stood above 91m O.D. at the intake of Weydale. Further north, on Seamer Moor, a large spread of gravel between 152m and 182m O.D. indicates that meltwater spilled over the crest at this point. The trend of Weydale across the dip-slope indicates a sub-marginal origin. The channel bifurcates at Weydale House, one branch terminating at 61m O.D. at Holm Hill Plantation, the other descending to 45.5m O.D. at Irton Manor. A large spread of gravel north of Holm Hill Plantation is connected by a slightly raised linear feature to a small ice-marginal channel system which connects with the gravel deposits north of East Ayton. In the lower regions of Seamer Moor, areas of subdued hummocky gravel are traversed by small channels normally about 100m long though occasionally up to 400m. They trend at about 45° to the dip-slope and occasionally swing down-dip where the overlying ice allowed.

Both Forge valley and Seamer valley were important outlets for northern meltwater. Forge valley served the ice lobe melting in Hackness and the more northerly ones via Lang Dale and Jugger Howe Slack. It operated first whilst ice stood at Wykeham. The Wykeham moraine is the only surface expression of the remaining deposits though aerial photographs reveal that the perimeter of the moraine is surrounded by uneven topography composed of sand and gravel which has been subdued by a cover of more recent Flandrian alluvium. Borehole evidence (C.E.G.B.) shows that the vale to the west of the Wykeham area is largely composed of fluvio-glacial sand and gravel derived from Forge valley.

The Seamer valley meltwater phase followed the Wykeham phase though it is difficult to determine how much time elapsed between the two. Both were probably operating together though Seamer valley was increasing in activity as Forge valley declined, as ice lay between East Ayton and Irton when the Weydale channel was active. The main mass of the Seamer gravel was not confined by ice, as was that of Forge valley. Instead, the ice retreated east of Seamer and was probably stagnant in the coastal zone before the Seamer valley meltwater reached its peak.

Between Seamer valley and Deepdale a broad shallow channel traverses the dip-slope, being of sub-marginal origin and operating at a similar time to those on Irton Moor. In Deepdale, the absence of gravels indicates that it existed as a pre-Devensian watershed breach though it carried some Devensian meltwater. The intake has a humped profile, indicating sub-glacial flow of water under hydrostatic pressure. East of Deepdale the watershed and dip slope do not show any notable sign of meltwater activity hence it is assumed that in this area ice stagnated with consequent less vigorous meltwater activity.

(B) NEWTONDALE AND KIRKHAM PRIORY CHANNEL

Kendall (1902) considered that Newtondale and Kirkham Priory channel were late-Devensian features. Changing opinions on glacial geomorphology due to more recent work (Peel 1949 and 1956, Sissons 1958, Gregory 1962) have made it increasingly difficult to accommodate Kendall's views and consequently they have frequently been modified. Of all that Kendall wrote on the North Yorkshire Moors (1893, 1902, 1903(a), 1903(b)) his account of Newtondale is probably in greatest need of review.

From Gregory's work in eastern Eskdale it is apparent that Newtondale was not supplied with the volumes of water that Kendall envisaged. In

Eskdale, Gregory discovered that the ice dispersed in a two-stage fashion. Firstly, an ice-marginal drainage phase occurred and as the ice stagnated and fragmented, en-glacial, sub-glacial and supra-glacial drainage become dominant. This two-phase melting process is apparent in most of the areas of north-east Yorkshire occupied by ice lobes, particularly Harwood Dale.

If Newton Dale had been formed in the Devensian it would have formed in the first or ice-marginal meltwater phase. Its greatest dimensions are 850m wide and 116m deep; the total volume of material displaced from Newtondale being in the order of 7-8 hundred million cubic metres. Brief air photo interpretation of the Murk Esk valley reveals many marginal channels at around 198m-228m O.D. on Park Rigg and a wealth of sub-glacial features on the valley floor. Gregory supports Kendall's views on the existence of Lake Wheeldale which drained for a short period via Moss Slack and later via Goathland Church channel towards Newton Dale. However, Goathland Church channel is lower than Fen Bog hence this channel did not supply water to Newton Dale; instead the water drained sub-glacially towards the north. This is compatible with the channel being younger than Moss Slack and thus operating at a stage when ice in the Goathland area was beginning to down waste and develop sub-glacial drainage.

Gregory interprets Moss Slack and its feeders as marginal channels at their time of operation. Despite the arguments of Hollingworth (1952) and Linton (1951, 1952) a large patch of polygons on Simon How Moss indicates that the maximum extent of the ice beyond Moss Slack was less than 2.5km. Kendall (1902) maps the maximum extension of the ice as being at Moss Slack. From these combined factors it is apparent that these was not enough ice in the Goathland area above the intake of Newton Dale, or meltwater derived from Lake Wheeldale to remove at least 700 million cubic metres of material from Newton Dale. Had there been enough ice in Goathland, to provide the water over the necessary period of time to cut Newton Dale then the surface gradient of the ice, according to known ice limits, would have been such that a southerly flow of ice over the watershed would have occurred.'

It is more likely that Newton Dale existed in virtually its present form and that a small quantity of meltwater in the first late-Devensian melting phase flowed down Newton Dale, producing the small fan of torrential material on which part of Pickering stands. Borehole evidence from the Vale of Pickering does not prove the required volume of the torrentially deposited lithology that, according to Kendall would have been removed from Newton Dale in a very limited period of late-Devensian time, though as the sides of Newton Dale are largely composed of Oxford Clay this particular argument in favour of a pre-Devensian origin is not a strong one.

Iburn Dale is of similar size to the Goathland valley and at its head there is evidence of sub-glacial drainage over the watershed to Biller Howe Dale. As the ice down-wasted, this outlet was abandoned in favour of sub-glacial drainage to the north. It is probable that the quantities of water flowing over to Biller Howe Dale were similar to those flowing into Newton Dale, yet the incision that has occurred at the head of Biller Howe Dale is only a fraction of that which has occurred in Newton Dale. On this basis it can be assumed that the degree of incision in the upper reaches of Biller Howe Dale is comparable to the enlargement that has occurred in Newton Dale during the late Devensian.

On the same basis, it is unlikely that Langdale or Forge valley were entirely cut by late-Devensian meltwater. The capture of the headwaters of the River Derwent indicate down cutting of at least 35m which is comparable with the deepest sections of Biller Howe and Jugger Howe Slacks.

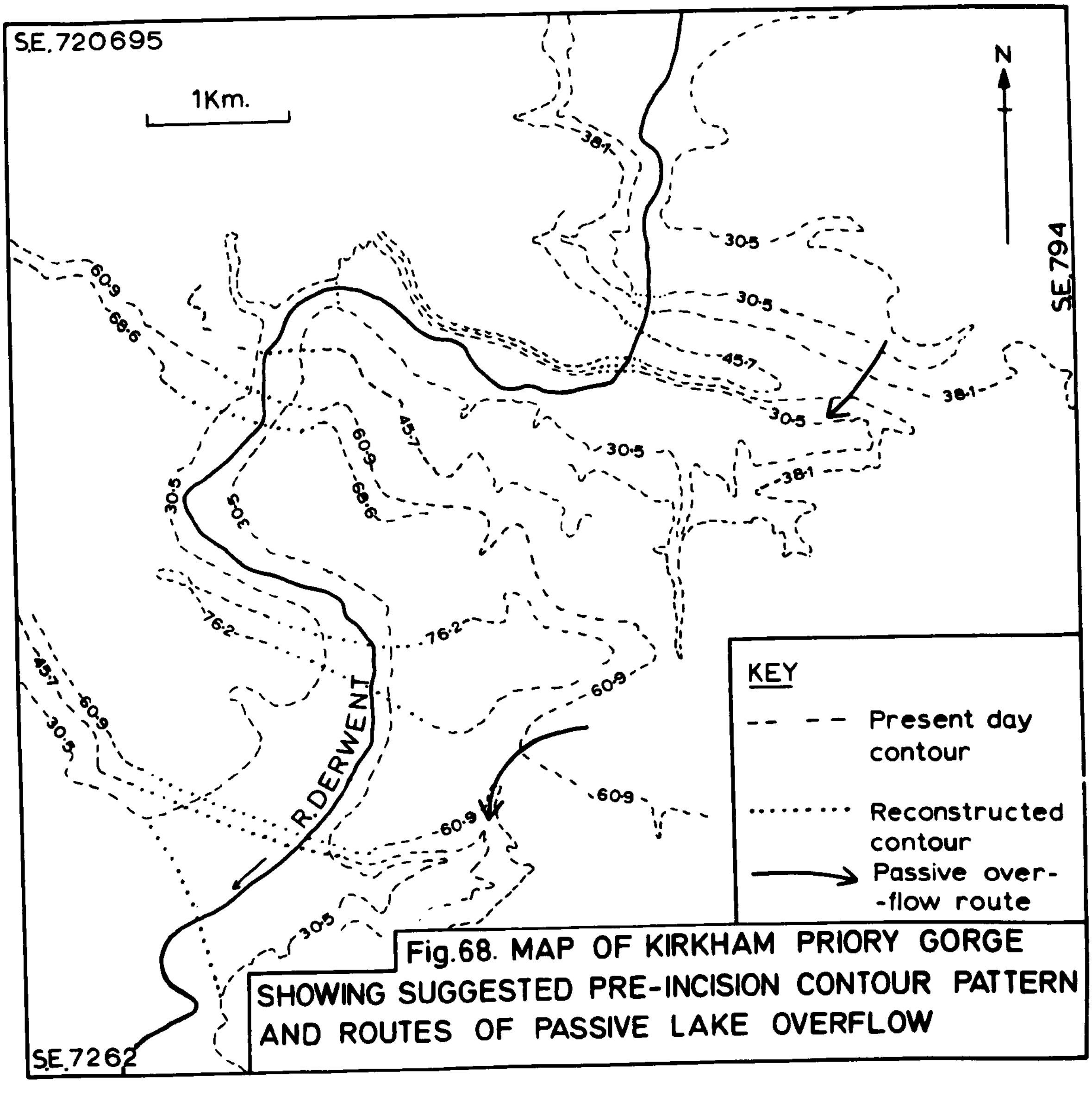


Fig.68. MAP OF KIRKHAM PRIORY GORGE SHOWING SUGGESTED PRE-INCISION CONTOUR PATTERN AND ROUTES OF PASSIVE LAKE OVERFLOW

The absence of any evidence for a deep lake in Harwood Dale confirms this degree of incision. Forge valley was probably incised by slightly more than 35m as it carried water from Harwood Dale and the Hackness ice lobe.

Kirkham Priory meltwater channel, described by Kendall as the overflow from 'Lake Pickering' is difficult to fit into a late-Devensian scheme of events. Extrapolation of the contours on either side of the channel suggest that it cut land which rose in excess of 75m O.D. However, 1.5km south of Westow (SE 755 653), the highest point of the divide between the Vales of York and Pickering is slightly over 61m O.D. If, as Kendall suggested, the Kirkham channel was cut by the passive overflow of the impounded waters of 'Lake Pickering', then this is the point at which the overflow would have occurred. Fig. 68 illustrates the degree of control imposed by ice on the initial route chosen by water crossing the divide. The route is clearly shown to be one which would not be chosen by the passive overflow of a lake. As with Newtondale, it is difficult to envisage how such a large feature could have been cut in a short space of time, taking into account that, according to Kendall, the Coxwold-Gilling gap was blocked by ice during its formation. The necessity for the continued existence of this ice dam over a protracted period of time, plus the absence of any evidence for a late-Devensian lake standing at 75m. O.D., indicate that the Kirkham Priory Channel was already in existence in the late-Devensian in more or less its present form and that its positioning across the watershed has been influenced by the presence of ice.

All four channels under discussion are much larger than those which can, without doubt, be assigned to the marginal drainage phase of the late-Devensian. All were in existence before the advent of the Devensian and may well be sub-glacial features originating during the Wolstonian or earlier. Kirkham Priory channel, therefore probably provided an outlet for meltwater from the Thornton Dale ice.

The intake of the Kirkham channel is just below 21m O.D. which, allowing for some Flandrian incision, corresponds quite well to the 30.5m strand line evident in the eastern Vale of Pickering. It is noteworthy that this height differential was not sufficient to drain the Vale of Pickering, which is why the River Derwent had to be artificially straightened in historical times. Borehole and auger evidence shows that water stood in the Vale during the late-Devensian and Flandrian, depositing unconsolidated alluvium associated with the 30.5m strand line visible on aerial photographs and suggesting that during the early Flandrian there existed a lake which occupied shallow interconnecting basins with a water level at around 30.5m O.D.

CHAPTER X

THE SPEETON SHELL BED

(1) HISTORICAL EXPOSURES

For some years, the Speeton Shell Bed has been exposed with varying degrees of clarity about 500m. south-east of The Gill at TA 1475 7585. It has been described by Phillips (1836), Lamplugh (1881a, 1881b), Stather (1907), Melmore (1935) and Versey (1938b). More recently it has been investigated by Catt (1963), and described by Catt and Penny (1966), Penny (1974) and West (1969b)who investigated its pollen content. Lamplugh (1881a) describes how the deposit, which consists of a silty warp akin to that being deposited in the Humber estuary at the present day, can be traced across New Closes Cliff to beach level near The Gill where it occurs as a re-arranged form of Speeton Clay. In May 1879, he recorded traces of the deposit on the beach nearly opposite Reighton Village (TA 144764). More recent investigation of this site by Catt (1963) proved Lower Till Series surrounding a small mass of Basement till and he suggests that Lamplugh may have seen a small streak of Bridlington Crag. The situation concerning the north-westward extension of the Speeton Shell Bed is unclear, the present author having seen no evidence of its existence other than at TA 1475 7585.

The rare past exposures of the suspected Speeton Shell Bed near Reighton have provoked much discussion about the relationship between this exposure and that at New Closes Cliff, where it lies at 32m. O.D. and is 3m thick at present. The two occurrences show some similarities in lithology and fauna (Lamplugh, 1881a) and have been generally accepted as being of the same deposit despite the marked difference in altitude. This difference in altitude has been variously interpreted as :-

(i) the original slope of the estuary floor on which the Speeton Shell Bed was deposited.

(ii) the result of ice pushing the New Closes Cliff exposure to its present position from a former lower level.

(iii) the two exposures of the Speeton Shell Bed are not lateral equivalents of one another.

(2) PRESENT EXPOSURES

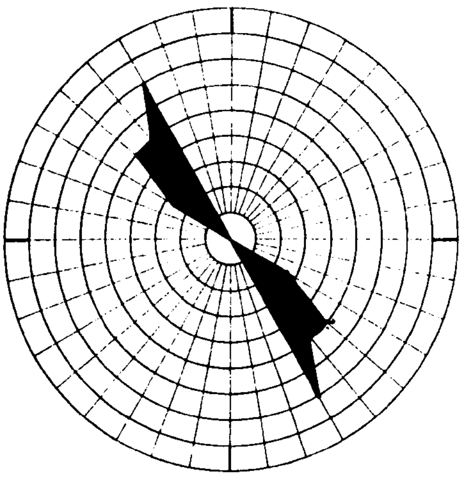
(A) SITE DESCRIPTIONS : LITHOLOGY AND TECTONICS

At present, the New Closes Cliff exposure (TA 14707585) is clearly visible to the north-west and south-east of a marked landslip. It consists of 3m of fossiliferous, silty sand and clay. The lower 1m. is composed of blue-black silty clay and the upper 1m of brownish silt and fine sand. Between the two there lies 1m of blue-brown, silty clay which forms a transitional zone between the lower and upper zones. The deposit is underlain by 0.6m of angular, chalk gravel, containing some well-rounded quartzite erratics, and which at the north western exposure (Site 1) rests on 0.3m of Speeton Clay 'D' beds (black, laminated clay-shale) over lying 'C' beds (blue-grey soft clay, B.N.S.). At the south eastern exposure (Site 2), the gravel rests on Speeton Clay 'C' beds (B.N.S.). The Speeton Shell Bed is overlain by 0.6m of soliflucted chalk gravel which lies beneath Devensian Lower Till Series which contained a streak of re-worked Wolstonian till.

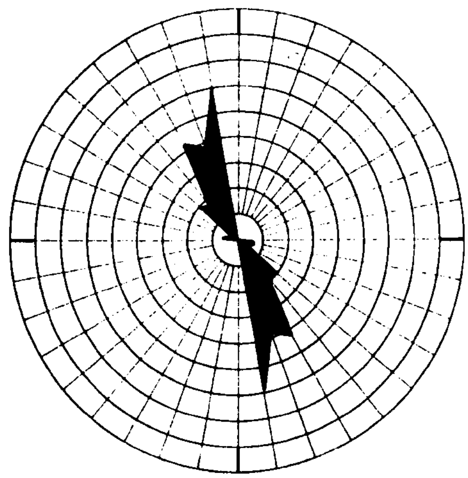
Site 1 reveals that the Speeton Clay 'D' beds and basal soliflucted chalk gravel are isoclinally folded. The trend of the folding (fig.69.1) is clearly exhibited by the shaly, laminose nature of the deposit.

The lower zone of the Speeton Shell Bed exhibits current bedding and is quite closely faulted. Each fault slice shows the remains of the original bedding which ranges from planar laminations to ripple drift bedding with occasional overfolded laminae of tectonic origin. The fault planes are marked by very thin blue-grey clay layers (see fig. 70).

Site 2 has been completely exposed for some years and is normally better exposed than Site 1. Here, folding is more apparent, affecting the lower



69·1



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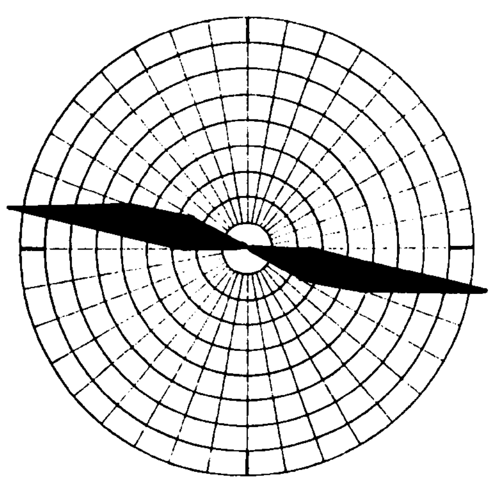

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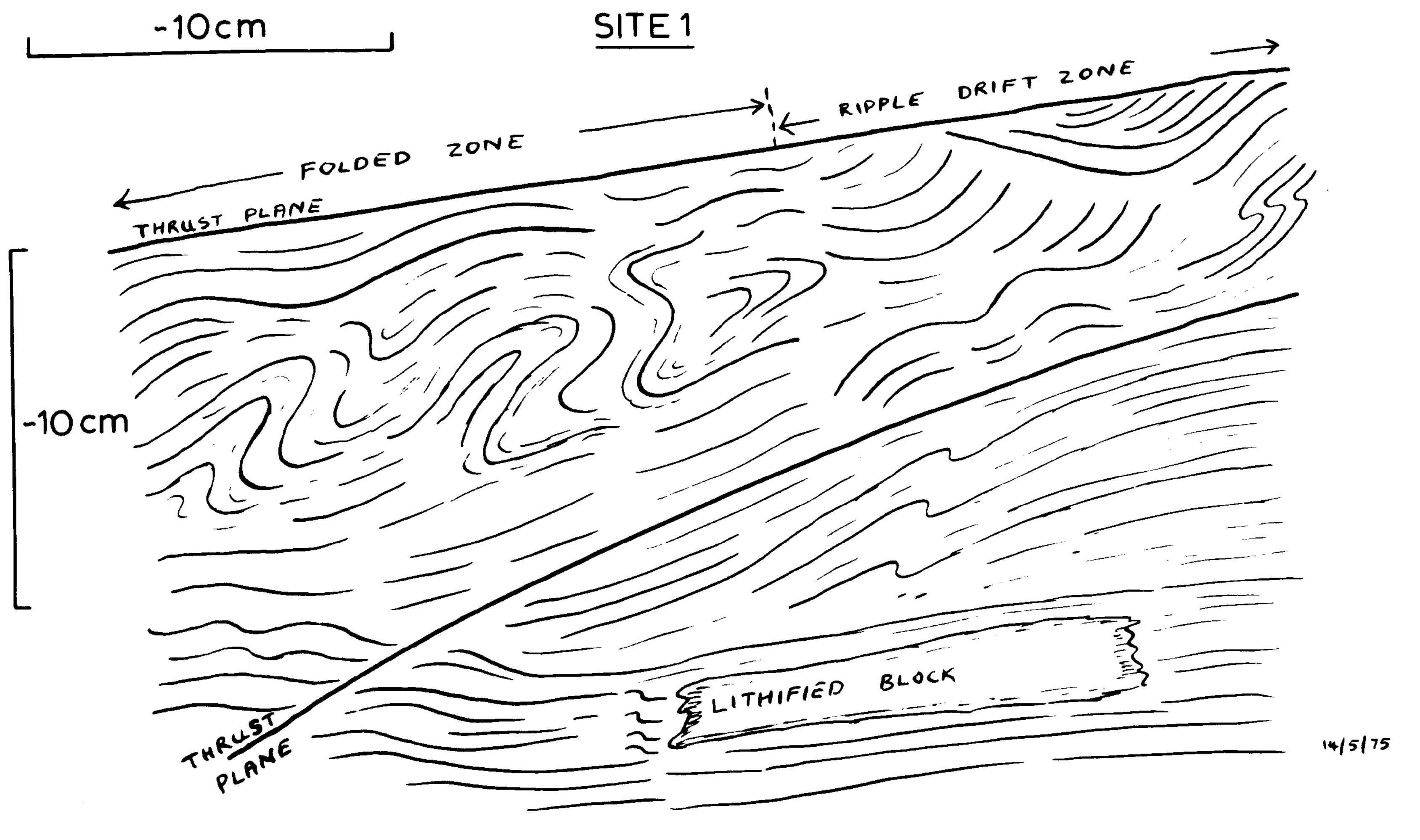

Fig.70. FIELD SKETCH OF TECTONIC STRUCTURES IN LOWER SPEETON SHELL BED

1m of the Shell Bed and the basal chalk gravel. The strikes of fold planes are shown in fig. 69.2. Several of the folds show re-orientation of their fold planes through up to 90°. The folding of the Speeton Shell Bed is isoclinal though in the lower, blue-black silty clay facies, monoclinal folds with thrust planes have developed. Above the zone of intense folding, the Shell Bed is composed of brown silty sand which does not reveal large scale folding though a small amount of minor flexuring and faulting occurs (see fig. 71).

Close examination of the macrofauna at Site 2 revealed that in the lower blue-black silty clay, the valves of Cardium edule are not fixed in apposition and are filled with material derived from higher beds. This suggests the valves have been moved by folding after deposition. In the upper brown, silty sand horizon, valves of Cardium edule gape, being fixed at the umbo. The infilling material is lithologically identical to that which encloses them suggesting that here the shells are in-situ. The folding in the upper brown bed is not as marked as in the lower blue-black one hence the shells are virtually undisturbed. The lithology does not reveal folding as readily as does the lower laminated blue-black silty clay, though shells in apposition suggest that very little folding has occurred. Between the lower and upper zones, there occurs a blue-brown transitional zone which shows an intermediate degree of faulting and folding, some current bedding and valves of C. edule in-situ. 0.6m of angular chalk gravel which exhibits undisturbed planar bedding overlies the estuarine beds. (see fig. 72)

(B) SPEETON CLAY TECTONICS

The Speeton Clay, which is exposed to the south-east of the Shell Bed sites, displays very clear isoclinal folding along the full length of its outcrop. The nature of the folding is shown by the presence of occasional phosphatic marker bands. The one shown in fig. 73 reveals that the

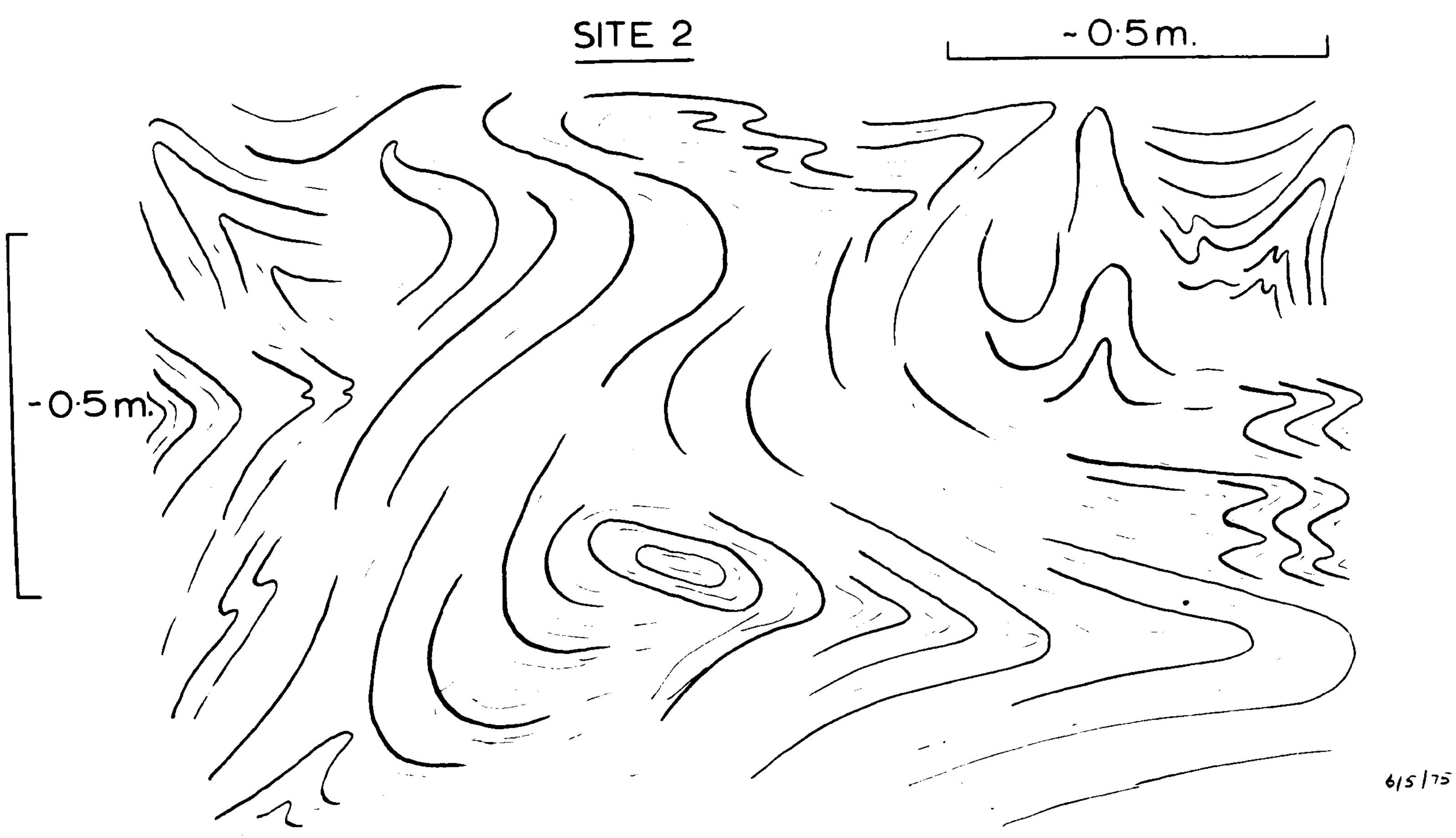

Fig.71. FIELD SKETCH OF FOLDED LOWER SPEETON SHELL BED

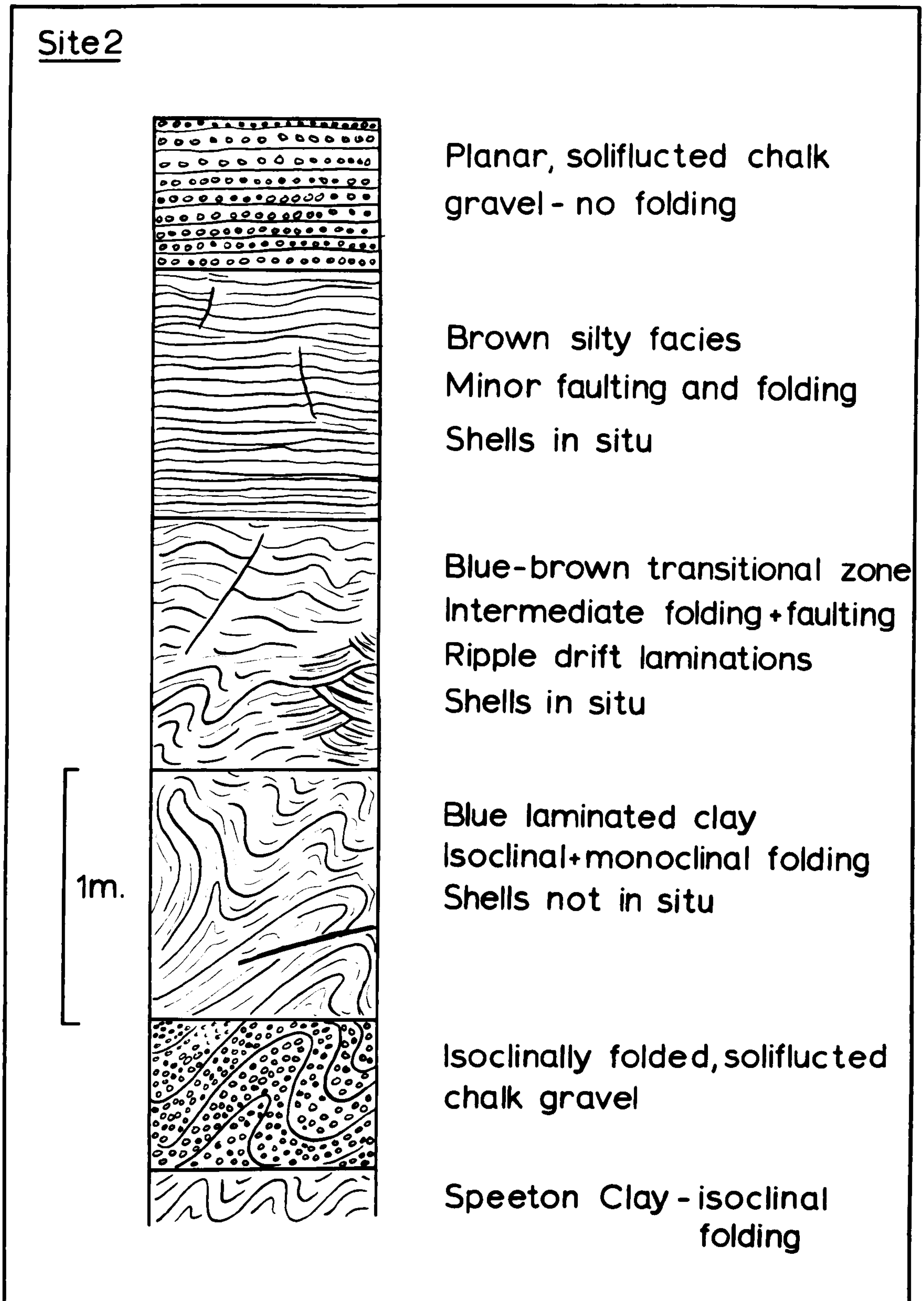

Fig. 72. TECTONIC & STRATIGRAPHIC FEATURES OF THE SPEETON SHELL BED

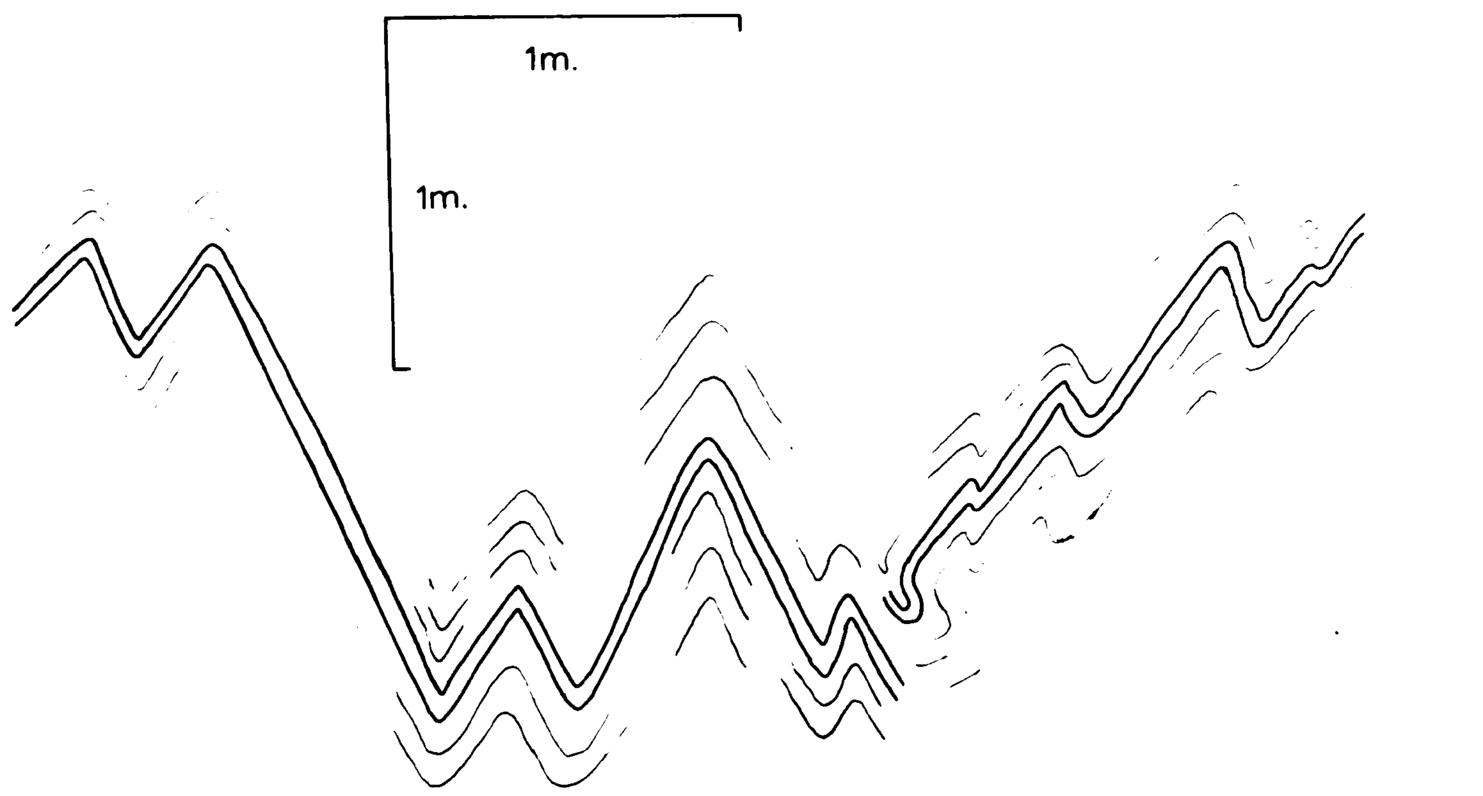

Fig. 73. FOLDING IN SPEETON CLAY 'C' BEDS

outcrop compression due to folding is in the order of 2:1. Fig. 69.3 illustrates the trend of the folding and indicates that the beds were compressed by pressure from a northerly direction consistent with ice invading the area from the present North Sea basin during the Wolstonian. Several folds in the lower part of the Shell Bed indicate rotation of the fault planes through up to 90° which makes the recorded strikes compatible with those of the underlying Speeton Clay. Reasons for the rotation are not readily apparent though it is most probably due to renewed disturbance of the basal zone of the frozen Shell Bed by the overriding influence of Devensian ice.

Fig. 74 shows the altitudinal variation of the base of the chalk as indicated by the Chalk-Speeton Clay contact along the Chalk Wolds scarp between SE 904 753 and Dulcey Dock (TA 165750). The folded coastal outcrop of Speeton Clay forms an anomaly as it rises 28m. above the projected base of the chalk, providing further evidence of the uplift of the Speeton Clay and overlying Shell Bed.

(3) SPEETON SHELL BED FAUNA

(A) MACROFAUNA

The commonest species are Cardium edule, Macoma balthica and Scrobicula piperata. Lamplugh (1881a) has also recorded Utriculus obtusus, Hydrobia ulvae, Littorina littorea, L. rudis and Mytilus edulis. These molluscs indicate deposition near the mouth of a tidal estuary which existed at the seaward end of the Vale of Pickering. The fauna has no age significance, ranging from the Coralline Crag to the present though it clearly represents an inter glacial climate, being similar to the faunal and lithological environment of the present day Humber mud flats.

(B) MICROFAUNA

Bag samples taken from the lower blue, transitional and upper brown

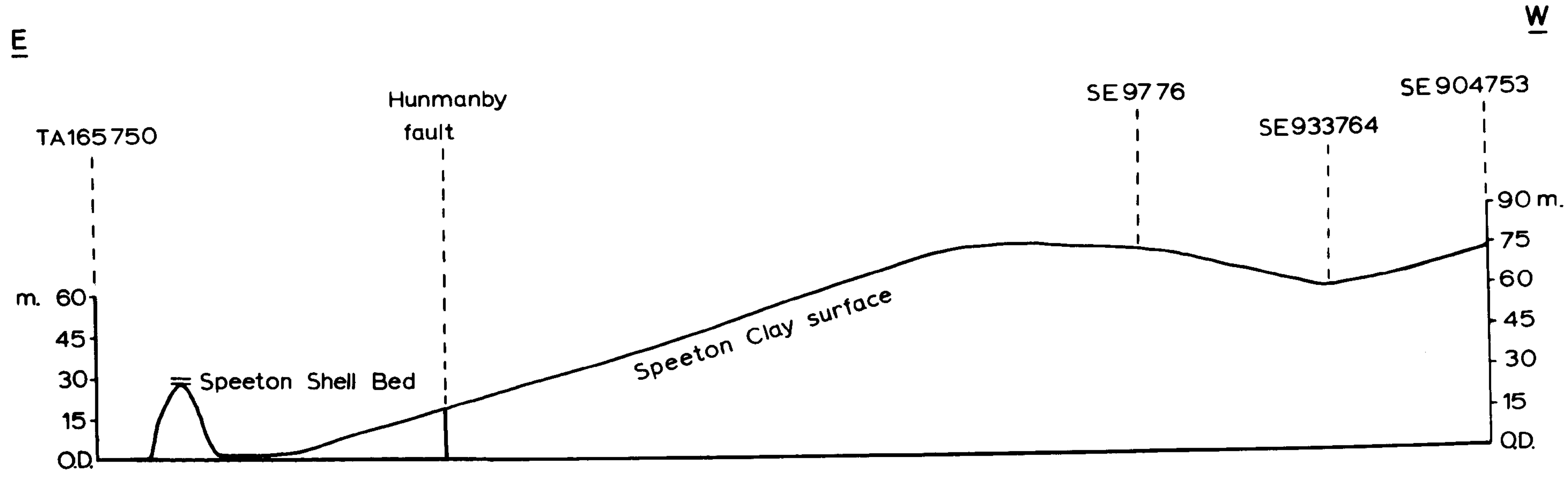

Fig. 74. VARIATION IN HEIGHT OF THE SPEETON CLAY ALONG THE SCARP OF THE CHALK WOLDS

horizons were gently dispersed in water and the suspension passed through a B.S. 100 mesh wet sieve. The residue was dried and examined for microfossils. All three horizons were found to have abundant Ostracods and Foraminifera though those in the upper brown horizon were weathered and frequently fragmentary, indicating oxidation.

(i) OSTRACODS

The lower blue horizon was found to contain the following Ostracods :- Leptocythere sp., Cytheropteron sp., Hemicytherura sp., Hemicythere villosa, Semicytherura sella, Robertsonites tuberculata, Finmarchinella angulata(Sars), Cytherolloidea sp and Eucytheridia punctillata.

The middle transitional zone was found to contain the following Ostracods:- Leptocythere sp, Hirschmannia sp, Finmarchinella angulata, Hemicytherura clathrata, Cytheropteron sp., Semicytherura undata (Sars), Semicytherura (Sars) cf. Fulva Semicytherura sella (Sars).

The upper brown horizon was found to contain the following Ostracods :- Hemicytherura clathrata, H. cellulosa, H. villosa, Semicytherura (Sars) cf. Fulva, S.(Sars) cf. undata, S. (Sars) cf. striata, Finmarchinella angulata, Robertsonites tuberculata, Cytheropteron nodosum, Hirschmannia viridis, Leptocythere sp., Aurila sp. and Eucytheridea punctillata.

(ii) FORAMINIFERA

The lower blue horizon was found to contain the following Foraminifera :- Elphidium articulatum, Protoelphidium anglicum, Nodosaria affinis, Robulus sp., Nonion sp. and Dentalina sp plus several species derived from the Speeton Clay. These include Cytherina sp., Epistomena sp., Marginulina sp. and Globigerina (d'Orbigny) cf. bulloides.

The transitional zone was found to contain the following Foraminifera :- Elphidium articulatum, Protoelphidium anglicum, Cibicides sp., Robulus sp.

and Nodosaria affinis plus several derived Cretaceous species.

The upper brown zone was found to contain the following Foraminifera:- Elphidium articulatum, Protoelphidium anglicum, Nodosaria sp., Robulus sp., Nodosaria affinis and Lagena sp.

(iii) PALAEOECOLOGICAL IMPLICATIONS

The macrofaunal content of the Speeton Shell Bed indicates a cool temperate climate and comparisons based on lithology and macrofauna have been made with the present day Humber mudflats (Versey, 1938a Catt and Penny, 1966).

The microfauna, particularly the Ostracods, indicates deposition in shallow brackish cold water in keeping with a tidal estuarine environment. The Ostracods indicate that the water was not too cold, i.e. Arctic, as Leptocythere sp. are abundant. They are not found in high Arctic areas. Conversely the fauna indicates conditions colder than the central or southern present day North Sea, suggesting an environment similar to the present day Norwegian Skaggerak. The fauna has Arctic affinities which has been established by the presence of Finmarchinella angulata and the genus Cytheropteron, Robertsonites tuberculata (Sars), Semicytherura undata and Eucytheridea punctillata.

Robertsonites tuberculata (Sars) is a well known trachyleberidinid component of shallow water boreal and Arctic faunas and prefers the sublittoral, reaching its maximum abundance at depths of less than 50 fathoms. It has been found in recent Celtic Sea deposits on the Cockburn Bank at ca. 49°45'N, 9°20'W where it is interpreted as being at the southern limit of its range. It has also been found further south in the Bay of Biscay by Peypouquet (1971) where it is indicative of a colder Quaternary environment.

Semicytherura undata has a distribution very similar to Robertsonites tuberculata as does Eucytheridea punctillata, having been found off Franz Joseph Land (Scott 1899). Cytheropteron nodosum which is present in the Speeton Shell Bed has been recorded by Klie (1942) off Spitzbergen.

Hemicytherura clathrata (Sars) has been found at 35 fathoms on the Spitzbergen Shelf (Neale and Howe, 1973).

The microfauna, however, does not indicate a true Arctic environment as described from Russian Harbour, Novaya Zemlya by Neale and Howe (1973). The presence of Leptocytheridae and Semicytherura sella (Sars) suggest that temperature conditions were similar to those of the present day Norwegian province which extends from the Shetlands via the Faroes to the Iceland Rise. The presence of Eucytheridea punctillata (Brady) suggests euryhaline and brackish water conditions indicative of the reduced salinity of an estuarine region which is compatible with the lithology of the Speeton Shell Bed.

The Foraminifera found in the Speeton Shell Bed are diagnostic of euryhaline brackish water conditions colder than those found in the central and southern North Sea at present. Many of the forms are found at present in shallow water of the Norwegian Skaggerak, thus they support the conclusions drawn from the Ostracod population.

The above conclusions have been drawn by applying the qualitative presence/absence method to the obtained fauna. The author recognises that this method has disadvantages, in that it applies equal weight to rare and common species. However, in the available time and considering the difficulty of identifying many of the oxidised and fragmentary Ostracods it was considered that this was the best approach. An investigation of the quantitative composition of the fauna would be a worthwhile future study.

(4) CONCLUSIONS

The Speeton Shell Bed is an estuarine deposit comprising clay, silt and find sand and containing a variety of macro and micro fossils. The macro fossils indicate a cool temperate estuarine environment though they have no age significance. The microfossils indicate a cold, sub-arctic euryhaline-brackish, shallow environment though they too have no definite age significance.

Lamplugh (1881a) implied that the Speeton Shell Bed may be equivalent to the Bridlington Crag and thus of Hoxnian age (Catt and Penny, 1966). Investigation of the Ostracode population of the Bridlington Crag (Neale and Howe, 1973) indicates that the fauna agrees in many aspects with the Russian Harbour fauna, particularly in the presence of a fauna characteristic of waters colder than those found in the area at the present day. Comparison of the Dimlington fauna with the Speeton one suggests that the Speeton Shell Bed was deposited further south in warmer waters than the Bridlington Crag as the Shell Bed contains Leptocytheridae which are absent at Dimlington. This marked difference is in keeping with the post-depositional histories of both lithologies. The Bridlington Crag has been transported south after deposition, whereas the Speeton Shell Bed was deposited in the estuarine area which is now the Vale of Pickering. It is possible, therefore that the faunal dissimilarity of the two deposits does not indicate that they are of differing age.

The Bridlington Crag is accepted as being of Hoxnian age and the Speeton Shell Bed has also been attributed to this interglacial period (Melmore, 1935, Catt and Penny 1966) and heavy mineral data (Versey, 1938a) indicates that the deposit was derived at least in part from a pre-Basement till. West (1969) considers the pollen assemblage to be Ipswichian zone II(f) though his conclusions have not been supported.

The tectonic disturbance of the Speeton Shell Bed described in this chapter suggests that it is of Hoxnian age. The predominant fold orientation is not compatible with the known direction of Devensian ice advance into the Filey Bay area. Instead, the compatible folding of both the Speeton Shell Bed and Speeton Clay are attributed to the more southerly flow of the Wolstonian ice and the re-orientation of the Wolstonian folds within the Shell Bed has been brought about by the overriding advance of the Devensian ice. On this evidence, the Speeton Shell Bed is considered to pre-date the Wolstonian glacial period and is therefore of Hoxnian age, or older.

The isoclinal folding within the deposit indicates that the Shell Bed has been ice rafted to its present altimetric position and the anomalous height of the Speeton Clay along the length of its outcrop, plus the isoclinal folds and subsequent compression of the outcrop length testifies to its extensive glacial disturbance. This evidence removes the necessity to consider the height differential between the present Shell Bed exposure and the one which has been recorded near Reighton. The difference in altitude and gradient of 1 in 20 or thereabouts, which has been favourably compared with gradients in the present day Humber estuary, is simply a reflection of the dip of the underlying topography and glacial beds towards the north-west.

It is not possible to make any firm correlations with the Kirmington interglacial deposit which is considered to be Hoxnian and in-situ at 30 m. O.D. If the Kirmington deposit is in-situ and is Hoxnian, then it indicates that Hoxnian sea level stood higher than 30 m. O.D. This is still compatible with the Speeton Shell Bed which may have been deposited at some depth below Hoxnian O.D. before being pushed up to its present position.

As with the Kirmington interglacial deposit, it is curious as to how such a poorly consolidated lithology has survived the Wolstonian glaciation and Ipswichian erosion. The vertical distribution of tectonic features within the deposit shows that it did indeed survive glacial rafting and one can only assume that it was transported in a frozen state. It is possible that the weathered surface and consequent discolouration and oxidised microfaunal content may be due to sub-tropical Ipswichian weathering. The presence of an undisturbed early Devensian soliflucted chalk gravel overlying the Shell Bed indicates that it was in its present position during the Ipswichian and therefore must have been transported by an earlier glacial period.

CHAPTER XI CONCLUSIONS AND SYNTHESIS

The oldest glacial deposit in the area is the 0.6m of angular chalk gravel underlying the Speeton Shell Bed in Filey Bay. It is composed of soliflucted chalk from the Flamborough peninsula during periglacial conditions preceding the interglacial deposition of the Speeton Shell Bed. Detailed qualitative investigation of the microfauna of the Speeton Shell Bed indicates that it is a shallow, brackish to saline, estuarine deposit with water temperatures similar to those of southern Norway at present. The fauna indicates quite clearly that conditions were warmer than present day high Arctic and Colder than present day North Sea.

The Shell Bed has a weathered upper surface indicating exposure to post-depositional sub aerial oxidation. Many of the Ostracods and Foraminifera in the upper horizons have been rendered extremely brittle by oxidation whereas those at the base of the deposit are much more robustly preserved. The fauna is diagnostic of the Hoxnian interglacial in that it indicates a period whose optimum conditions were cooler than the present.

The Speeton Shell Bed does not furnish any altimetric evidence as it is a transported mass. Isoclinal folds exposed in the underlying Speeton Clay pass upwards through the overlying angular chalk gravel into the lower zone of the Shell Bed. The basal 1m. of the Shell Bed is isoclinally folded though the orientation of the fold planes differs between the Speeton Clay and Shell Bed despite the folds frequently being structurally continuous. The Shell Bed was transported by ice which also transported and folded the Speeton Clay and later movement, probably due to later ice advance has rotated folds in the Shell Bed with respect to those in the Speeton Clay. The entire sequence displays the mechanism postulated by Catt (1963) for the disturbance of Basement till in Holderness which displayed more intense folding than that which occurs in the overlying Dimlington Silts.

Within the sequence exposed in Filey Bay, the scale of folding decreases with ascent and disappears altogether in the upper zone of the Shell Bed. This suggests that during transport, the Shell Bed was frozen and thus tectonically competent to withstand folding in its upper horizon. There is no evidence of displacement between the Shell Bed and the Speeton Clay. It is envisaged that both the Speeton Clay and Shell Bed were transported en masse thus preserving intact the depositional stratigraphic relationships between the two. In the lower zone of the Shell Bed evidence of tectonic disturbance is provided by the macrofauna whose valves are not infilled by material from the enclosing medium; instead the valves and their infill have been derived from higher in the sequence. Valves of the macrofauna in the upper horizon are in-situ as they contain the sand and silt within which they are enclosed. The weathered and friable microfauna in the upper 1m. of the Shell Bed may in part be due to post-depositional freezing though the slight reddening of the upper zone indicates that some oxidation has occurred.

It is most likely that the uplift of the Speeton Shell Bed was brought about by the advance of Wolstonian ice which dates the Shell Bed as Hoxnian or earlier. The microfauna suggest a cold interglacial period incompatible with the Ipswichian climatic optimum which supported the Leeds Hippopotamus (Denny 1854, Edwards et al, 1950) and the Kirkdale Cave Hyaenas (Buckland 1822, Boylan 1972). If the Shell Bed is Hoxnian then the post-depositional reddening of the upper zone may be attributable to the Ipswichian climatic optimum when strong oxidation of soils in Northern England occurred (Bullock, Carroll and Jarvis, 1973). Heavy mineral analyses (Versey, 1938a)support a Hoxnian age. The evidence strongly suggests that the Shell Bed is Hoxnian, therefore the underlying solifluucted chalk gravel is of late-Anglian age, or earlier.

The Shell Bed is overlain by 0.6m of undisturbed angular soliflucted chalk gravel which in turn is overlain by late-Devensian till. There is no Wolstonian till directly overlying the Shell Bed though a thin streak has been incorporated into the basal beds of the Devensian Lower Till Series.

If uplift of the Shell Bed had been accomplished by late Devensian ice, the early Devensian soliflucted angular chalk rubble which overlies the Shell Bed would display folding similar to that in the Shell Bed beneath. However, it is in-situ and has been deposited on the Shell Bed after uplift thus indicating that the Shell Bed was transported by pre-Ipswichian ice and is therefore probably of Hoxnian age.

During the Wolstonian glaciation, Basement till was deposited on the Flamborough peninsula leaving outliers which can be correlated with Holderness. A small exposure also occurs beneath the 'edgewise conglomerate' in Robin Hood's Bay.

On the North Yorkshire Moors, occasional spreads of gravel, mainly comprising quartzite and chert, occur. These constitute a remanie drift; the sedimentary erratics having been removed by weathering. The extreme degree of weathering suggests that the deposits are older than the Basement till of the Flamborough peninsula and Holderness. Due to the uncertainty of their age and lack of knowledge of the glacial Wolstonian and Anglian phases they are best described as 'Older Drift'. They are commonly found in patches on the moor surface to the west of Robin Hood's Bay (NZ 927 049) and on Stony Marl Moor where the erratics occur in the ice-wedge casts of tundra polygons. These particular polygons are not as distinctive as those in the Tabular Hills. It is unlikely that the polygons pre-date the 'Older Drift' as they would not survive glacial encroachment, the most feasible explanation is that they formed in the Devensian beneath a thin veneer of weathered till. The weathered till slumped into the open fissures during climatic amelioration. There is no evidence to suggest that the tundra polygons investigated in the Tabular Hills are older than the Devensian.

At some stage of the Older Drift period when ice almost certainly entirely covered the North Yorkshire Moors and Yorkshire Wolds, Newton Dale and Kirkham Priory channel were initiated as sub-glacial meltwater channels. Reconstruction of the present day contours of the Howardian Hills shows that the Kirkham Priory Channel does not cut the watershed at its lowest point therefore ruling out the possibility of it being a passive late-Devensian lake overflow (Kendall, 1902). Aerial photographs and ordnance survey map interpretation reveal a strong element of sub-glacial control and the same is true of Newton Dale which is of a similar magnitude and character to the Kirkham Priory Channel. Both have been under some form of directional control as would be the case beneath ice.

Periglacial activity is again represented by the 0.6m. of undisturbed angular chalk gravel which overlies the Speeton Shell Bed and post dates its uplift and folding. It is interpreted as early-Devensian as it has not been disturbed by the Wolstonian uplift of the Shell Bed and represents a return of colder conditions after the Ipswichian interglacial.

Inland, Knapton Gravel Pit exposes a sequence of chalk gravel which has been derived from the chalk scarp of the wolds by periglacial processes but which has subsequently undergone a degree of sorting not normally encountered in soliflucted gravels. The deposit is interpreted as having been deposited by water sub-marginally to ice lying in the Vale of Pickering. The height of the small dry valleys associated with the hummocky topography created by the chalk gravel along the flanks of the chalk scarp suggest that the gravel is not related to the Devensian ThorntonDale ice. Instead it is interpreted as being deposited submarginally to Wolstonian ice. The chalk gravel is also exposed at the northern end of Heslerton Sand Pit where it has been reworked and cryoturbated, and has been proved in many boreholes to cover parts of the floor of the Vale of Pickering (Oakley et al, 1942 and 1944).

During the Ipswichian interglacial when climatic conditions allowed Hyaenas to flourish in the area (Buckland, 1822; Boylan, 1972) the surface of the chalk gravel underwent solutional erosion and the solution hollows thus formed served as traps for leess which was deposited over north-east Yorkshire prior to the main Devensian ice advance (Catt et al 1974). These are exposed in Knapton Gravel Pit.

The Devensian ice advanced into the Vale of Pickering as far west as Thornton Dale where it halted and formed a terminal moraine composed of Thornton Dale till and gravel. The till, curiously, is almost entirely local in erratic content and stone orientation data displays a strong east-west ice movement, which is modified in the region of the terminal moraine by radial dispersion of the ice and en-glacial shearing (Galloway, 1956; Andrews and Smithson, 1966). West of the terminal moraine there is a similar shaped gravel deposit which comprises outwash gravel from the melting ice.

Whilst the ice stood at its maximum extent, intense cryogenic activity was occurring on the ice-free areas of the North Yorkshire Moors. It is probable that the majority of the tundra polygons of the Tabular Hills developed at this time. The excavation of one of the ice-wedge casts of a tundra polygon on Hazel Head Moor (SE 857 939) in April 1975 did not reveal any till within it. Consequently, there is no reason to believe that this polygon or those that comprise the extensive polygon area of Hazel Head Moor are older than the late Devensian, unlike the one excavated on Stony Marl Moor (NZ 956 008) which contained 'Older Drift'. The discovery of 'Older Drift' within the ice-wedge cast on Stony Marl Moor is in keeping with the findings of Dimbleby (1952). Whilst many of the polygon areas are of Devensian age it is possible that some are older and have undergone Devensian reactivation. On the other hand, the remanie drift may have been soliflucted into the ice wedge from the surrounding moor surface during the Devensian.

During this period of intense cryogenic activity when ice stood at the Thornton Dale line, the western Vale of Pickering was occupied by locally derived compacted snow and firn. Following climatic amelioration, and subsequent melting of the North Yorkshire Moor's perma frost, vast quantities of locally derived gravel was carried by meltwater over the firn surface. The firn began to melt and stagnate in a patchy fashion creating a series of interconnecting lakelets. The waters of these lakelets reworked the Kimmeridge Clay whereever they overlay it and produced the lacustrine clay of the western Vale of Pickering. The lake levels oscillated and periodically froze in response to seasonal climatic changes during the melting process thus spreads of gravel were occasionally let down into lacustrine clay. These spreads of coarse, well-rounded local stones with a northerly provenance within the lacustrine clay and occasional channel gravels on the crests of some of the Kimmeridge Clay hills in the western Vale suggest that material derived from the North Yorkshire Moors was frequently transported by fluvial activity; perhaps spring meltwater, across the frozen surface of the lakelets. By this mechanism, occasional flattened Birch twigs were carried into the lakelets and incorporated into the basal reworked clay. The absence of any such clay to the east of Thornton Dale indicates that the eastern Vale was occupied by ice; a conclusion which is confirmed by the overlap of the lacustrine clay onto Thornton Dale till along part of the western flank of the terminal moraine.

The areal extent of the lake is rather uncertain. The reworked lacustrine clay is more extensive than surface exposures suggest as it is now buried beneath Flandrian alluvium in the lower lying areas of the western Vale. The absence of clear cut shorelines is explained by the fact that it is by no means certain that one extensive lake existed; that the levels of the interconnecting lakelets frequently oscillated and that the lacustrine phase is older than Kendall (1902) envisaged hence shorelines may have been removed by periglacial activity during the remainder of the late-Devensian. It is considered that the Kirkham Priory Channel was already in existence by this time and that most of the lake and meltwater from the Thornton Dale ice drained through it into the Vale of York.

The date of the Thornton Dale ice adgance is rather problematical. Gaunt (1976) has identified two Devensian ice advances in the Vale of York; the earlier one of which was areally more extensive than the latter but shorter lived. At first sight the relationship of the Thornton Dale till to the Wykeham moraine and coastal tills of north-east Yorkshire appear similar to those described by Gaunt though the absence of a coastal equivalent of the Thornton Dale till does cast doubt on the suggestion that two ice advances are represented. The doubt is reinforced by the evidence provided by the radio carbon date from the Dimlington Silts (18,500 $\pm$ 400 BP., 1-3372 and 18,240$\pm$250 B.P., Birm 108) which is firmly accepted as dating the advance of Devensian ice into Holderness. At Dimlington the Devensian ice is represented by the Skipsea and Withernsea tills. Catt (1963) has shown that fold trends in the underlying Basement till compare favourably with the flow route of the overlying Skipsea ice thus precluding the possibility of an earlier ice advance. One would expect that if the areally more extensive Thornton Dale till was a separate ice advance prior to the advance of the Skipsea-Withernsea compound glacier, then some evidence of its passage would be available in Holderness. None is found.

In the coastal area of north-east Yorkshire, the lowermost till is that of the Devensian Lower Till Series which is equated with the Skipsea till of Holderness. It is overlain by the Upper Till Series which is the lateral equivalent of the Withernsea till of Holderness. Whereever the base of the Devensian till sequence is visible, Lower Till Series is present. In Robin Hood's Bay it rests on 'edgewise conglomerate' at NZ 9535 0450 and the nature of the contact between the two lithologies suggests that there has been no intervention by an earlier ice advance. The 'edgewise conglomerate' is very intimately mixed into the base of the Lower Till Series. The 'edgewise conglomerate' is considered to be of similar age and origin to the Dimlington Silts.

In other parts of Britain a two stage late Devensian glacial cycle has been identified. The earlier advance is dated at around 20,000 years B.P. and has been identified by Mitchell in Southern Ireland and the Western Midlands (Mitchell, 1972). The latter of the two ice advances is dated at around 18,000 years B.P.

In Southern Scandinavia, Morner (1969) dates the Pommeranian moraine at 14,800 years B.P., the Frankfurt moraine at 17,700 years B.P. and the Brandenburg moraine at 19,500 years B.P. Morner (1970) describes how this two stage cycle is recognised on a world wide scale and Morner and Dreimanis (1970) draw attention to its recognition in the Lake Erie vicinity. They combine the Brandenburg-Frankfurt moraine and equate it with the Cuba-Reesville moraine south of Lake Erie. The Erie interstade occurs between this glacial period and the younger one represented by the Powell-Union City moraine.

Other evidence from O^{18} cores in Greenland (Dansgaard and others, 1969) and Antarctica (Epstein and others 1970), deep sea cores (Ericson and

Wollin 1956, Emiliani 1966 and Griggs and others 1970) and sea level changes (Morner 1969) all show this late Devensian glacial cycle to be a world wide climatic change.

In north-east Yorkshire there is not enough evidence available yet to determine whether this world wide late Devensian two stage glacial cycle is represented by the Thornton Dale and coastal tills. The lack of any evidence of a two stage ice advance in complete coastal exposures suggests that the Thornton Dale till may be an inland local equivalent of either the Lower or Upper Till Series and that the Wykeham moraine is not a younger ice advance but reactivation of ice which was withdrawing from the Thornton Dale limit in much the same way that many Alpine glaciers have left terminal moraines composed of sand and gravel across their valleys during periods of standstill during a general period of retreat.

On balance therefore it is most likely that the Thornton Dale till post dates the Dimlington Silts though being some 65 km. further north than Dimlington the ice advance may be slightly older than the Dimlington Silts, the relationship between the two deposits being of a diachronous nature. Retreat of the Thornton Dale ice has not yet been dated by absolute means though the Kildale radiocarbon date (16,713$\pm$340 B.P., S.R.R. 145) does provide some indication of the time at which marginal Devensian ice in the North Yorkshire Moors began to stagnate. However the date is considered to be too old for the overall retreat of the Devensian ice and is perhaps better interpreted as Kildale's equivalent to the retreat of ice from Thornton Dale to Wykeham in the Vale of Pickering. In Holderness there is no known equivalent of this retreat.

Below about 45m. O.D. on the northern flanks of the Wolds there occurs a linear belt of waterlain sand which has been excavated to a depth of 7m. in Heslerton Sand Pit. These sands indicate a northerly flow of water and the water responsible for their deposition has partially reworked the supposed Wolstonian angular gravel exposed in the northern part of the pit. They are considered to be younger than Wolstonian and as they occur only within or marginal to the limits of the Thornton Dale ice advance, they are considered to be of an early, late-Devensian age contemporaneous with the Thornton Dale till on the northern side of the Vale. They show no indication of glacial overriding and have not been extensively cryoturbated therefore most probably do not pre-date the Thornton Dale ice advance.

The limited development of slender ice wedge casts within them is attributed to late Devensian periglacial conditions. Their distribution along the southern side of the Vale of Pickering as a linear belt some distance above the lowest point of the Vale suggests that they were deposited marginal to ice. The known distribution of the Thornton Dale ice provides the 'best fit' to their distribution.

Withdrawal of ice from the Thornton Dale line was accompanied by melting of permafrost and subsequent downslope movement of the active layer resulting in accumulations of soliflucted angular chalk overriding the earlier waterlain chalk gravel at Knapton Gravel Pit. At this site, clear exposures have been observed which show the unconformable truncation of the supposed Wolstonian angular chalk gravel by the late Devensian soliflucted gravel. The soliflucted gravel contains lenses of structureless fine sand and it is considered that this is late Devensian loess blown from the outwash plain of the advancing Thornton Dale ice.

On the northern side of the Vale of Pickering an exposure in Thornton Dale quarry reveals soliflucted limestone fragments overlying loess. The sequence is interpreted in a similar manner to that at Knapton and both sites are correlated with the late Devensian loess and head sequence at Sewerby (Catt et al, 1974).

This period of solifluction which post-dates the deposition of loess was quite complex, involving several climatic fluctuations. In Knapton Gravel Pit, exposures have been observed which show that the periods of accumulation of soliflucted angular chalk gravel were interspersed with periods of accumulation of blown sand presumably from the Heslerton Sand belt with which the sand shows mineralogical affinities. Whilst this blown sand was accumulating, it was affected by cryogenic processes which produced small ice wedge casts within it. Formation of the ice wedge casts was terminated by burial due to aeolian processes followed by further accumulation of soliflucted gravel. At the same time, this brief period of cryogenic activity formed slender ice wedge casts in the Heslerton Sands and festoons and vertically orientated clasts in the chalk gravel at the northern end of Heslerton Sand Pit. A small exposure of soliflucted OOlitic limestone overlying outwash sands at Thornton Dale is correlated with this period of solifluction and cryogenic activity.

The precise stratigraphical relationships between the Thornton Dale till and coastal tills are not clearly understood, though the evidence indicates that the Thornton Dale till is probably a local equivalent of the coastal Lower Till Series. The Wykeham moraine has always been interpreted as the limit of the Devensian glaciation in the Vale of Pickering though this is no longer certain. It is probably more accurate to envisage it as being produced by a period of standstill during a general period of retreat which began initially at the Thornton Dale limit.

Coastal exposures of Devensian till reveal that the ice sheet was two-tiered, the basal layer being composed of northern Pennine ice and the upper originating in the Permo-Triassic area of north-east England. The tills deposited by the two ice sheets have been named the Lower and Upper Till Series respectively. They correlate with the Skipsea and Withernsea tills of Holderness (Madgett, 1975). He has shown that in Holderness the

Withernsea till is areally less extensive than the Skipsea and this present work indicates that the same is true in north-east Yorkshire.

For many years, visual field observations have led workers to distinguish between the Holderness tills on the basis of texture and colour; the Skipsea till being sandy and drab coloured whereas the Withernsea till is plastic and purple. This method proved adequate for fresh till in Holderness where both types are in the main undisturbed lodgement till deposited on a chalk plain some metres below present O.D. However, north of Flamborough Head, the pre-Quaternary surface presents extreme variety both lithologically and in its topographic expression. Consequently, greater textural and lithological variety occurs in the tills of north-east Yorkshire than Holderness indicating that such parameters are strongly influenced by the lithology and form of the pre-Quaternary basement in the local area of deposition.

Shearing within the ice most directly affects texture and lithology, producing narrow band tills (Glen, Donner and West, 1957) and being a direct result of the variation in pre-Quaternary topography. Wherever ice has been relatively tectonically undisturbed, thick lodgement till characteristic of Holderness occurs. This grades laterally into areas of excessive shearing where the Holderness-type characteristics have been thoroughly destroyed. The lodgement till is replaced by narrow band tills whose lithology and texture reflect changes brought about by localised shear. Thus it is possible within the Lower Till Series, whose lateral equivalent in Holderness is characteristically sandy, to find thin bands of clay-rich till especially towards the base of the succession. Similarly, within the characteristically clay-rich Upper Till Series, thin bands of sandy till occasionally occur. Wherever this variety within a lithology occurs, it is not possible to allocate a till unit to a particular series on colour or texture alone. Consequently the elucidation of the Quaternary coastal stratigraphy of north-east Yorkshire in this study has been achieved by a combination of field and laboratory techniques, namely Munsell Colour notation, mechanical analysis and the 'S ratio' derived from pipette analysis. These have been proved to be the most effective parameters for determining between Lower and Upper Till Series.

Wherever shearing has occurred near the Lower/Upper Till Series contact, thrust slices of Lower Till Series occasionally lie above the contact indicating that the shearing was upward. Shearing invariably occurs in the vicinity of pre-Quaternary basal obstructions such as the rising land which flanked the Flamborough peninsula. As one traverses away from these obstructions the sequences of narrow band tills are replaced by sequences of undisturbed Holderness-type lodgement till. Much of the lateral variation in Filey Bay, which has rendered the identification of a type locality for both till series impossible, is attributed to this shearing process. The presence of Mesozoic Clay rafts and folded gravel lenses within the Filey Bay Lower Till Series are also indicators of extensive en-glacial shearing. Despite the difficulties of readily determining the Lower/Upper Till Series contact wherever shearing has occurred, it is possible to find it by carefully measuring the section with a tape and Paulin aneroid altimeter, sampling each till unit and determining their Munsell colour notation, particle size parameters and S ratio value. Thus the boundary can be traced through these shear zones and linked to more obvious contacts where there is undisturbed lodgement till.

At such lodgement till sites, the boundary is frequently marked by sands and gravel. It is not unusual that such sands and gravels are found wherever a two-tier ice sheet existed as they are simply an expression of meltwater flowing between the two major ice layers, being unable to penetrate to any marked extent into the tectonically undisturbed ice from which the lodgement till was produced. Conversely, within the shear zones, thick sequences of sand and gravel may occur at any horizon. This is an indication of tectonically disturbed ice allowing water to penetrate into the ice wherever weaknesses in the form of shear planes allowed. Thus at Site 1 (Filey Bay) sands and gravel occur within the Lower Till Series and again at the contact of the Lower/Upper Till Series. Due to the lateral impersistence of the shear planes, the sands and gravels deposited in the sheared zones are extremely local in nature and do not constitute reliable marker horizons. The same is true of narrow band tills, some of which are characteristically coloured (e.g. Red Band of Holderness, Bisat 1939), A similar red narrow band till occurs in Filey Bay at Site 6 where it is considered to represent a streak of Permo-Triassic material. They may occur at any horizon within the Lower Till Series.

In this work, stone orientations have been used primarily to indicate the mode of deposition of the various tills rather than the direction of movement of ice within the area. Previous work (Lamplugh 1891, Stather 1897, Catt 1963, Andrews and Smith 1970) plus knowledge gained from observations made over a protracted period of time by the Erratic Blocks Committee (1873 to 1915) provides a reliable indication of the provenance of both till series. The great variation in till lithology, both laterally and vertically, and the mechanism of ice diversion around headlands (Catt, 1963; Andrews and Smith 1970) are more worthy of investigation than the overall pattern of regional ice movement. The dip of the pre-Quaternary basement to the north west across Filey Bay is indicated by the regional dip of the glacial beds in coastal exposures and by quantitative data obtained from the till. Thus the vertical sequence of stone orientation data obtained from Site 1 (Filey Bay) repeats itself at neighbouring sites to the north-west and gradually dips below beach level.

Stone orientation data has proved useful for lateral correlation over short distances within each till series though the great within-site variation renders it alone useless as a tool for distinction between till series. The degree of topographical control of ice movement and resultant shearing has created overlap of data which makes the two till series indistinguishable on stone orientations alone. However, when coupled with other quantitative data and viewed within the regional picture, the information is quite meaningful and provides an insight into the degree of shearing and mode of deposition of each till unit. Within-site variation illustrates the degree of shear that individual till units have undergone. Those which display strong longitudinal maxima are true lodgement tills and have undergone very little shearing. Those which have been extensively sheared show no obvious longitudinal maxima; instead the data are well dispersed around the compass rose. Sense of dip has been recorded and proved invaluable as an indicator of imbrication which in itself is a useful indicator of lodgement till when coupled with a strong longitudinal maximum.

The mechanism of ice pivoting around headlands, first described from Flamborough Head by Catt (1963) and confirmed in Robin Hood's Bay by Andrews and Smith (1970) has been discovered to the south of Carr Naze. To the north west of Carr Naze, ice was diverted to the south east by highland and then pivoted around Carr Naze and into the western Vale of Pickering once the obstruction had been by passed. Inland, the direction of ice movement is indicated by the orientation of the drumlin long axes in the southern half of the Filey embayment. Their orientation is a reflection of the direction of movement of the upper layers of the Upper Till Series ice as coastal exposures and occasional roadside ones reveal these drumlins to be composed of the Upper Till Series. Ice movement was being controlled by the high land of the Flamborough peninsula to the south and the Yorkshire Wolds to the west of the Hunmanby fault scarp. The slow rate of movement resulting from the obstructions to the south and south west plus the deflection of the main Devensian ice stream around Carr Naze by high land to the north may have been important factors in the development of the drumlins.

Carbonate analyses performed at certain sites reveal that no weathering occurred within the till sequences. Thus the two tier sequence is a composite one with the Upper Till Series ice occurring as an overrider on the Lower Till Series ice. It is this composite structure which is responsible for the differences in particle size distribution between the two till series. The Lower Till Series ice eroded the floor of the present North Sea basin and was constantly incorporating erratics and coarse material into its matrix. There was a continual supply of this material, much of which did not achieve its terminal mode, thus the Lower Till Series is sandy by nature. The Upper Till Series ice was erosionally less active and was not constantly incorporating new material from the terrain it traversed. Consequently, the till retains properties such as its reddish colour which were established in the Permo-Triassic source area of north-east England. Material enclosed within the ice has also been reduced almost to its terminal mode thus the Upper Till Series tends to be clay rich and have a characteristically lower S ratio value than the Lower Till Series.

Carbonate analyses do reveal Flandrian weathering at the present surface. This weathering has frequently totally obliterated the characteristics by which fresh till is distinguished hence recognition of the weathered till is to a certain extent dependent upon the presence of fresh till beneath. Wherever the two-tier till system is present, no problems occur. However, wherever only one till is present and has been thoroughly weathered as on the high cliffs between coastal bays, it becomes difficult to determine the origin of the till. There are several factors which are responsible for masking the true identity of such a till. Firstly, it is not always obvious how incorporation of the underlying bed rock into the till alters the particle size distribution if no fresh till is available, though the problem can be partly overcome by recognising that if the till is locally derived as it is most likely to be if it is thin enough to be weathered throughout its entire profile, then it is most likely that only the coarser fraction of the till will be modified, assuming that the bedrock is resistant to glacial abrasion, e.g. Deltaic Sandstones. In this case, weathering tends to break down the locally incorporated and therefore fairly large sandstone clasts into individual grains which increases the sand content of the till. This is reflected as an increase in the S value. Thus if highly weathered sand-rich till has an S value marginally above the critical value of 49% then it is assumed that the S value has been raised by the incorporation of sand and that the till is weathered Upper Till Series. Similarly, if the locally modified till has incorporated Oxford Clay into its matrix thus enriching the clay and silt content, a lowering of the S value may result in Lower Till Series appearing as Upper Till Series. Tills distinguished on this basis are done so tentatively, except where they overlie fresh till. Because of the difficulties encountered in recognising weathered till, partly due to the coating of the majority of heavy mineral grains in iron oxide, it was not attempted to map the variation in areal extent of the two till series inland. However, the surface limit of the late-Devensian tills has been mapped by aerial photographs supported by field augering. The break of slope between the till surface and the Flandrian deposits is clearly visible on aerial photographs and provides the means to accurately delimit the surface extent of the tills plus the areal extent of Flandrian peat and alluvium in low lying areas. Borehole evidence suggests that the till extends beneath the Flandrian deposits about as far as the Wykeham moraine, though the original borehole logs do not identify the till.

Ice retreat during the late Devensian was by a process of stagnation and downwasting and not by active withdrawal of the ice front (Kendall 1902). This stagnation began in Kildale at around 16,713 years B.P. (SRR-145) and though the date is considered to be too early for the melting of the main mass of the late-Devensian ice, it may correlate with melting of ice between Thornton Dale and Wykeham in the Vale of Pickering. This melting phase is considered to have occurred before melting of ice to the east of the Wykeham line which is more likely to have melted at about the same time as the Holderness ice. The short time period, in the order of 1,500 years between the Dimlington and Kildale dates does not allow sufficient time for the ice to invade Holderness on such a large scale and then melt though the Kildale date becomes more acceptable if it is interpreted as an indicator of early peripheral stagnation of ice as is known to have occurred at the Thornton Dale limit.

The complex system of glacial drainage channels in north-east Yorkshire reflect the manner in which the ice dispersed and are best described as 'meltwater' channels rather than 'over flow' channels (Kendall 1902). Gregory (1962) showed that much of the glacial drainage in Esk Dale was of a sub-glacial nature towards the north-east, in accordance with ice stagnation in-situ and not active ice withdrawal. Consequently much of the water which Kendall (1902) envisaged flowing southwards and eroding Newton Dale flowed subglacially to the north-east. It is noteworthy that the sum of the cross sectional areas of the marginal channels which Kendall considered supplied water to Newton Dale doesnot equate with the cross sectional area of Newton Dale. Newton Dale may have been supplied by meltwater from a melting ice front in the Fen Bog area though the volume of water required would have necessitated ice standing so high above Fen Bog that it would have flowed much further south than is the case, as the flow of ice depends on its surface gradient and not on topographic gradients. It is considered that Newton Dale existed prior to the late-Devensian and that it was trimmed by a small amount of late-Devensian meltwater, witnessed by the small alluvial fan on which Pickering now stands.

The Kirkham Priory channel is of a similar magnitude to Newton Dale and it is most likely that the two are related both in time and mode of origin. As with Newton Dale, there does not appear to be a mechanism by which the Kirkham Priory channel could have been cut during the late-Devensian. The passive overflow of a lake impounded by ice would have cut a channel across the lowest part of the Howardian Hills, yet reconstruction of the contour pattern by air photograph investigation indicates that this is not the case. The route taken by Kirkham Priory channel indicates that it has been controlled by the presence of ice on the Howardian Hills and consequently it is suggested that both Newton Dale and Kirkham Priory channel are older than Kendall realised.

Referring now to the obviously late-Devensian meltwater channels of the eastern North Yorkshire Moors, two types can be distinguished; namely those that drained directly away from the ice front and those which drained roughly parallel to it. Those which drained directly away from the ice front are the oldest and were superceded by channels which drained along the ice margin and into the ice as it began to stagnate and disintegrate, coupled with a withdrawal to the east of the position of the present A171 Scarborough-Whitby Road. The two types of drainage channel are a direct result of topographic control of meltwater discharge. When ice stood at its maximum extent it was able to discharge meltwater into the lowland to the north of Harwood Dale in much the same way that melting ice in Goathland discharged some meltwater away from the ice down Newton

Dale. With ice retreat and stagnation a subglacial drainage system evolved and water which could no longer cross the watershed followed by the A171 began draining southwards along the easterly facing slope and developed a series of assymmetrical marginal channels.

The channels which drained directly away from the ice fronts either drained down the south westerly facing dip slope or flowed along the margins of ice lobes producing one sided channels which eventually coalesced into channels free of directional control by ice. This situation existed in the Kirk Moor Gate area along the margins of the Robin Hood's Bay ice lobe.

As the ice stagnated and the margins melted, meltwater ceased to cross the watershed and began flowing in a series of ice-marginal and sub-glacial channels according to sub-glacial topographic gradients. Thus most of the water flowed southwards, in a series of sub-parallel ice-marginal channels, towards Cloughton. These channels are occasionally two-sided and therefore free of directional control by ice but more frequently they are one sided and obviously of an ice-marginal nature.

In Robin Hood's Bay, the only channels which carried water out of the area are those which breach the western watershed and which operated when the ice stood at its maximum. With down wasting, these became inoperative and the lack of southerly watershed breaches show that meltwater in Robin Hood's Bay must have drained down the sub-glacial gradient towards the north-east. The lack of sub-glacial depositional and erosional features in Robin Hood's Bay suggest that drainage was chiefly en-glacial.

The early breaching of the watersheds by ice and later by meltwater provided a supply of meltwater which cut Jugger and Biller Howe Dales. These were partially supplied by ice melt from Iburn Dale which breached the watershed for a short period before draining sub-glacially.northwards into Esk Dale. In their early stages the erosion of the Dales was partially controlled by a lobe of ice at around SE 952 975 which had travelled northwards from Harwood Dale. Thus at this point, Jugger Howe meltwater was prevented from following the lowest line of the valley in which it was flowing. Meltwater from Jugger and Biller Howe Dales plus that derived from the later sub-marginal phase to the east of the A171 entered Harwood Dale from where it flowed into Hackness via Lang Dale. There is no evidence of lacustrine deposits in Harwood Dale though it was occupied by ice which controlled drainage and deposition by meltwater.

Aerial photographs indicate that the head of Lang Dale was incised by about 30m., akin to Biller Howe and Jugger Howe Dales and that this incision resulted in diversion of the headwaters of the River Derwent from a course which previously took the river to the North Sea along Harwood Dale.

In Hackness there is no evidence of a lake of the proportions suggested by Kendall. Forge Valley is considered to have existed as a watershed breach prior to the late Devensian ice advance though it was incised to a considerable degree by the late Devensian meltwater phase. The meltwater flowing through Forge Valley came from a very large northern catchment at a time when the outlet to Forge Valley was blocked by ice. This ice extended as far west as Wykeham and meltwater issuing from Forge Valley flowed westwards parallel to it, depositing the Hutton Buscel Kame terrace. However, the continuation of the Kame Terrace into the Wykeham moraine, which is largely composed of sand and gravel indicates that a large proportion of the clastic debris was derived from ice melt in-situ.

Following deposition of the kame terrace, the Seamer valley became an active area of meltwater discharge. Initially, meltwater flowed sub-glacially down dip on Irton and Seamer Moor; the channels showing a certain degree of directional control by ice in that they frequently traverse the dip at about 45°. This indicates that ice stood between Seamer and Wykeham at this stage. However, when the Seamer valley discharge was at its peak, the valley exit was ice-free as the gravel deposits show no depositional control as does the Hutton Buscel Kame Terrace. Instead, the Seamer gravel has been deposited as an unrestricted fan and it is shown from bore hole evidence that it was this discharge which was responsible for removal of the southern part of the Wykeham moraine and distribution of much of the fine grained sand and gravel in the central Vale of Pickering. The Seamer valley stage was the last large scale meltwater phase and from field evidence the presence of Upper Till Series in the valley indicates that it was a watershed breach prior to the late-Devensian ice advance.

The outwash deposits of this period in the eastern Vale of Pickering reflect the close proximity of melting ice and show a gradual change from torrential clastic material proximal to the melting ice front to fine grained silts and sands at the distal end of the outwash plain in the western vale. Consequently the eastern vale was a braided outwash plain during the melting of ice to the east of the Wykeham line and the western vale occupied by shallow pools of standing water within which the poorly consolidated blue-grey silty alluvium accumulated. The hills covered by the earlier lacustrine clay were not covered by alluvium, instead it occurs around the flanks of the hills, the contact between the two usually forming a marked break of slope identifiable on aerial photographs.

During the early Flandrian period, shallow pools existed on the till surface in the eastern Vale of Pickering in which alluvium and peat accumulated. The same occurred on the outwash plain surface of the central Vale though in the west peat formation was replaced by the accumulation of silty alluvium, perhaps indicating that drainage in the western Vale was better than in the east due to the proximity of the Kirkham Priory Channel through which the present drainage flows. In the eastern Vale, several peat accumulations have been revealed by coastal erosion. In addition to those noted by Phillips (1836) and Cole (1891) the stratigraphy at two previously unknown sites suggests they are of Allerød age and this has been confirmed by radio carbon date.

The extensive surface peat formation in the eastern Vale is younger than this as the coastal Allerød peats are covered by younger soliflucted material.

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APPENDIX A. MECHANICAL ANALYSIS DATA FOR COASTAL SITES
(% WT. HELD ON EACH SIEVE)

SITE 1 TA 1470 7585

SAMPLE	Ø INTERVALS -1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT. (grams)
J	5.85	1.18	1.01	1.16	1.36	1.61	2.12	3.43	5.28	5.57	5.75	153.85
H	7.71	1.76	1.48	1.76	2.09	2.58	1.22	3.77	5.46	5.05	6.22	147.07
G	3.62	1.05	0.85	0.98	1.22	1.54	1.96	2.79	4.01	4.71	5.61	149.68
F	6.24	1.18	0.95	1.21	1.71	2.59	3.60	5.29	7.24	5.96	6.54	148.96
E	2.54	0.78	0.70	0.87	1.32	2.11	3.14	5.03	6.34	5.96	4.83	140.30
D	12.68	0.85	0.72	0.95	1.53	2.59	4.02	6.11	8.21	6.69	5.83	150.17
C	3.02	1.46	0	0.81	1.22	2.05	3.37	4.30	5.75	5.04	3.89	146.90
B	6.78	1.55	1.30	1.47	1.99	2.87	3.89	5.22	6.53	4.80	4.97	149.60
A	5.03	0.66	0.59	0.66	0.95	1.67	2.31	3.38	5.12	2.92	2.90	146.60

SITE 2 TA 1460 7585

C	6.11	0.59	0.44	0.56	0.88	1.55	2.16	3.70	4.33	3.31	2.77	148.43
B	7.13	1.04	0.87	1.10	1.62	2.56	3.96	5.90	8.13	6.95	6.67	145.60
A	7.50	1.45	1.23	1.44	1.83	2.77	3.91	5.42	6.83	5.59	4.85	151.13

SITE 3 TA 145 761

D	2.49	0.58	0.50	0.56	0.65	0.83	1.03	1.42	1.94	2.28	2.35	152.29
C	7.32	0.97	0.76	0.99	1.45	2.40	3.69	5.82	8.13	7.11	5.44	153.40
B	4.17	0.70	0.57	0.76	1.02	1.64	2.53	3.94	5.07	4.05	3.12	155.63
A	8.37	0.83	0.63	0.59	0.78	1.26	1.93	2.92	3.49	2.78	2.36	151.54

SITE 4 TA 144 762

D	2.46	0.68	0.60	0.83	1.21	2.16	2.81	4.34	5.99	5.12	4.28	146.00
C	10.45	0.53	0.58	0.74	1.14	1.81	2.84	4.29	5.70	5.21	3.73	147.50
B	6.17	1.03	1.04	1.12	1.40	2.08	2.99	4.05	4.68	3.99	3.62	148.64
A	0.09	0.12	0.24	0.45	0.89	1.92	3.30	6.68	10.27	9.63	6.94	153.34

SITE 5 TA 1403 7650

	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT
C	5.03	0.88	0.92	1.06	1.63	2.53	3.73	5.88	8.43	7.27	6.54	140.22
B	2.45	0.68	0.67	0.88	1.24	1.98	3.19	4.23	6.17	4.80	4.27	134.85
A	3.69	1.00	0.89	1.00	1.37	1.89	2.51	3.89	6.06	6.59	5.72	149.08

SITE 6 TA 131 773

D	4.85	1.28	1.14	1.22	1.42	1.67	2.04	2.79	4.26	4.94	6.78	143.96
C	5.40	0.86	0.92	1.18	1.56	2.39	3.44	5.00	7.15	6.26	5.91	152.88
B	3.56	0.62	0.57	0.67	1.04	1.71	2.75	4.46	6.35	5.35	4.79	158.38
A	3.77	0.91	0.75	0.90	1.14	1.64	2.30	3.93	6.65	7.42	6.72	158.85

SITE 7 TA 1305 7740

C	8.17	1.89	1.49	1.61	1.99	2.78	3.61	5.33	7.55	6.52	4.87	150.16
B	6.72	0.86	0.79	1.03	1.33	2.45	3.62	5.53	7.44	5.85	4.17	152.64
A	4.37	1.12	1.06	1.22	1.53	2.03	2.65	3.93	6.19	6.86	5.38	152.59

SITE 8 TA 1298 7749

E	4.05	1.03	1.01	1.08	1.33	1.76	2.37	3.64	5.59	5.76	5.92	136.37
D	5.90	1.53	1.34	1.41	1.53	1.81	1.97	2.87	4.26	4.77	5.69	139.48
C	5.69	0.85	0.77	0.93	1.47	2.43	3.47	5.52	7.38	5.91	5.03	138.98
B	2.16	0.56	0.51	0.71	1.03	1.74	2.67	4.46	6.23	5.25	4.07	152.61
A	3.91	1.04	0.93	1.06	1.32	1.91	2.50	4.07	6.70	6.70	6.64	137.91

SITE 9 TA 1275 7775 No Data

SITE 10 TA 1258 7805

A	3.33	0.56	0.51	0.70	0.90	1.37	1.99	3.31	5.72	6.81	6.45	158.14

SITE 11 TA 1246 7824

B	9.06	1.81	1.51	1.63	1.79	1.99	2.38	3.27	5.25	5.97	5.20	155.20

SITE 12 TA 123 786 No Data

SITE 13 TA 1223 7868

	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT.
E	28.25	2.29	1.75	2.05	2.86	3.92	4.90	6.40	7.75	5.35	3.87	143.98
D	3.22	0.64	0.60	0.75	1.16	1.90	3.12	5.55	7.38	5.59	4.42	142.20
C	3.97	0.85	0.85	1.05	1.46	2.20	2.99	4.78	6.74	6.32	4.69	154.65

SITE 14 TA 1215 7888

B	5.04	0.94	0.92	1.16	1.61	2.53	3.67	5.45	7.51	6.14	5.14	143.31
A	4.98	0.90	0.81	0.97	1.43	2.09	2.89	4.70	6.80	5.56	4.47	148.23

SITE 15 TA 1196 7949 No data

SITE 16 TA 1192 7978

D	5.44	1.13	1.11	1.23	1.62	2.43	3.25	4.93	7.04	6.21	5.85	151.16
C	4.01	1.11	1.02	1.29	1.88	2.83	3.83	5.80	8.04	6.61	5.56	154.09

SITE 17 TA 121 810)
) No data
SITE 18 TA 122 812)

SITE 19 TA 1250 8165

D	1.25	0.44	0.43	0.64	1.00	1.24	1.80	3.46	6.23	6.31	6.35	141.64
C	7.08	1.30	1.01	1.17	1.41	1.81	2.27	3.43	5.16	5.29	5.23	155.66
B	8.10	1.09	0.95	1.11	1.41	1.98	2.80	4.06	6.06	5.65	5.27	159.78
A	20.12	1.90	1.60	1.69	2.10	2.48	2.95	3.70	6.18	6.47	5.15	152.41

SITE 20 TA 102 826

C	5.69	1.03	0.79	1.18	1.85	3.18	4.51	7.13	9.51	7.57	5.76	151.92
B	3.23	0.72	0.72	1.00	1.47	2.43	3.48	5.40	7.48	6.12	5.42	140.54
A	13.31	1.71	1.40	1.58	1.81	2.02	2.48	3.42	5.22	5.25	5.03	146.61

SITE 21 TA 0866 8370

B	3.24	0.92	0.74	0.94	1.33	1.85	2.46	3.71	5.95	6.42	6.47	156.70
A	4.75	1.12	0.99	1.19	1.63	1.41	2.60	3.57	4.62	3.98	8.92	150.34

SITE 22 TA 0847 8382

	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT.
C	2.33	0.84	0.76	0.97	1.49	2.87	2.95	4.40	7.76	7.77	6.10	155.47

SITE 23 TA 069 843

E	0.55	0.25	0.22	0.25	0.34	0.41	0.54	0.82	1.27	1.25	1.83	148.48
D	2.33	0.94	0.93	1.18	1.71	2.61	3.65	5.64	6.92	5.88	5.11	142.84

SITE 24 TA 068 843

E	3.15	0.67	0.45	0.54	0.80	1.38	2.26	3.90	6.32	6.08	5.64	147.84
D	7.46	0.82	0.79	0.87	1.12	1.61	2.17	3.57	5.67	5.95	5.94	145.94
C	5.72	1.12	0.92	0.95	1.26	1.78	2.69	4.70	7.91	8.15	8.42	146.24
B	2.09	0.41	0.43	0.47	0.64	0.77	1.03	1.53	2.38	2.89	3.77	153.26
A	5.91	1.70	1.54	1.56	1.85	2.55	3.49	5.24	7.80	6.99	6.28	156.91

SITE 25 TA 064 854

B	3.43	0.85	0.67	0.82	1.28	1.96	2.76	4.31	6.20	5.64	4.98	156.97
A	2.85	0.58	0.43	0.56	0.76	1.22	2.03	3.71	6.83	7.79	6.60	157.52

SITE 26 TA 061 854 No data

SITE 27 TA 061 857

D	5.43	0.71	0.64	0.81	1.10	1.74	2.79	4.92	8.04	8.55	6.84	146.92
C	3.04	0.82	0.75	0.94	1.18	1.68	2.52	4.46	7.35	6.56	6.26	147.59

SITE 28 TA 057 864

A	10.63	0.62	0.45	0.49	0.75	1.25	2.13	3.88	6.57	6.75	6.41	145.00

SITE 29 TA 053 865 No data

SITE 30 TA 049 870

B	2.47	0.77	0.71	0.92	1.21	1.90	2.86	4.82	7.90	8.22	7.20	143.13

SITE 31 TA 037 909

	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT.
C	4.90	1.17	0.93	1.10	1.43	2.14	3.17	4.37	6.66	6.04	5.86	150.63

SITE 32 TA 035 912

D	5.77	0.88	0.67	0.73	1.01	1.51	2.28	3.78	6.02	6.12	6.17	148.96

SITE 33 TA 032 914

D	6.72	1.11	1.07	1.14	1.37	1.90	2.83	4.43	6.49	6.42	7,22	140.01
C	3.91	0.74	0.73	0.86	1.10	1.52	2.26	3.61	5.78	6.42	6.53	149.51
B	6.59	1.52	1.37	1.44	1.87	2.79	3.98	5.58	7.61	6.43	5.74	146.44
A	7.49	1.12	1.02	1.01	1.23	1.91	2.66	3.80	5.77	5.71	4.84	149.11

SITE 34 TA 029 928

A	4.49	0.82	0.90	1.19	1.78	3.17	4.69	7.26	9.59	7.70	6.56	142.40

SITE 35 TA 028 929

B	6.91	1.38	1.20	1.35	1.66	2.39	3.99	6.98	10.17	7.64	5.86	144.77

SITE 36 TA 027 931 No data

SITE 37 TA 028 937

C	8.70	0.94	0.92	1.25	1.43	1.99	2.78	4.38	7.10	7.84	6.64	144.57

SITE 38 TA 029 939 No data

SITE 39 TA 009 972

D	10.46	1.22	1.11	1.23	1.62	2.35	3.29	4.68	6.49	6,33	4.99	156.16

SITE 40 TA 010 974

E	3.42	0.27	0.17	0.13	0.16	0.37	0.99	2.26	4.37	4.24	4.26	148.72

SITE 41 SE 9970 9985 No data

SITE 42 NZ 987 013

	-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	SAMPLE WT.
A	2.66	2.18	2.31	2.84	3.24	3.49	4.27	4.21	7.97	12.93	5.56	159.11

SITE 43 NZ 9685 0260 No data

SITE 44 NZ 9590 0325

C	2.26	0.63	0.53	0.56	0.66	1.00	1.53	2.36	3.54	3.71	4.02	151.64
B	2.39	0.51	0.45	0.50	0.70	1.10	1.69	2.67	4.18	3.97	3.95	156.70

SITE 45 NZ 9570 0365 No data

SITE 46 NZ 9537 0420

E	5.70	1.22	1.00	1.10	1.29	1.60	2.18	3.25	4.56	4.33	4.13	141.60
D	8.49	1.47	1.24	1.35	1.55	2.00	2.53	3.50	4.50	4.05	3.14	141.84

SITE 47 NZ 9535 0430 No data

SITE 48 NZ 9535 0450

G	1.94	0.62	0.58	0.72	1.13	1.62	2.19	3.10	3.80	3.02	2.25	138.79
F	3.29	0.89	0.83	0.88	0.85	0.86	1.00	1.26	1.55	1.32	1.92	139.71

APPENDIX B. PIPETTE ANALYSIS DATA FOR COASTAL SITES

SITE 1 TA 1470 7585

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
J	21.7829	37.00	58.20	26.31	38.86
H	22.2714	30.96	64.95	24.19	32.28
G	21.1530	33.37	47.77	34.79	41.13
F	26.0470	45.97	42.38	31.12	52.03
E	21.8926	36.34	40.47	37.89	47.31
D	21.3800	46.00	33.59	35.82	57.79
C	20.8893	31.55	25.01	51.31	55.78
B	25.2700	44.20	38.49	34.31	53.54
A	21.500	22.00	25.84	57.83	45.98

SITE 2 TA 1460 7585

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
C	29.9519	46.90	17.18	43.97	73.18
B	21.6564	47.92	29.21	36.86	62.12
A	27.8039	46.65	30.36	37.14	60.57

SITE 3 TA 145 761

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
E	27.8818	33.70	25.70	49.22	56.73
D	24.8386	26.29	36.89	46.50	41.61
C	23.9878	39.88	34.23	39.53	53.81
C	28.6365	48.81	32.90	34.34	59.73
B	22.9554	22.98	68.55	24.22	25.10
B	22.0583	37.65	43.53	35.19	46.37
A	24.4065	14.88	31.21	58.54	32.34

SITE 4 TA 144 762

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
D	27.1064	30.13	19.64	56.13	60.53
C	21.3995	29.90	15.49	59.23	65.87
B	24.1882	51.54	17.07	40.18	75.12
A	24.2773	48.47	30.26	35.85	61.56

SITE 5 TA 1403 7650

C	27.0476	45.39	33.02	36.57	57.88
B	27.1387	44.03	33.62	37.14	56.70
A	24.7589	33.00	26.71	49.01	55.26

SITE 6 TA 131 773

D	25.6749	34.22	35.92	42.14	48.78
C	24.0214	36.97	28.08	45.32	56.83
B	27.6384	49.88	27.53	36.31	64.36
A	24.1943	39.90	32.52	40.55	55.09

SITE 7 TA 1305 7740

C	24.5682	53.62	59.27	18.88	47.49
B	25.3089	41.17	30.90	40.64	57.12
A	25.0096	35.43	32.69	43.45	52.01

SITE 8 TA 1298 7749

E	27.9870	36.44	30.70	44,03	54.27
D	27.0813	34.00	33.61	43.80	50.28
C	26.2565	39.85	31.03	41.48	56.22
B	25.9963	32.88	28.07	48.26	53.94
A	27.3879	38.78	36.85	38.65	51.27

SITE 9 TA 1275 7775 No data

SITE 10 TA 1258 7805

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
A	25.1710	35.25	35.89	41.38	49.55

SITE 11 TA 1246 7824

B	27.2003	42.89	34.68	37.29	55.29

SITE 12 TA 123 786 No data

SITE 13 TA 1223 7868

E	28.0012	67.88	45.50	14.53	59.86
D	23.4228	26.67	24.14	55.62	52.48
C	26.3451	45.94	37.90	33.52	54.79

SITE 14 TA 1215 7888

A	25.7022	35.73	36.21	40.99	49.66

SITE 15 TA 1196 7949 No data

SITE 16 TA 1192 7978

D	24.9164	45.22	46.00	29.57	49.57
C	24.6259	44.54	35.23	35.91	55.83

SITE 17 TA 121 810)
) No data
SITE 18 TA 122 812)

SITE 19 TA 1250 8165

D	25.6770	34.80	26.05	47.93	57.18
C	25.6929	36.31	28.39	45.60	56.12
B	25.4820	39.34	34.00	40.02	53.64
A	27.7099	61.02	21.61	30.54	73.84

SITE 20 TA 102 826

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
C	28.5767	55.41	38.24	27.53	59.16
B	26.5221	38.78	35.00	39.78	52.56
A	26.8630	49.46	43.51	28.61	53.19

SITE 21 TA 0866 8370

B	24.9905	41.25	40.70	34.83	50.33
A	26.2744	33.49	27.80	48.01	54.64

SITE 22 TA 0847 8382

C	26.8711	39.32	35.60	39.07	52.48

SITE 23 TA 069 843

E	27.5610	13.46	32.49	58.41	29.29
D	21.5870	46.63	27.84	38.17	62.61

SITE 24 TA 068 843

E	22.2029	29.38	30.90	46.76	48.73
D	24.2583	21.26	25.35	37.36	45.61
C	25.7849	42.04	36.12	41.98	53.78
B	24.2751	39.84	37.93	58.75	51.22
A	23.4319	43.76	30.20	39.24	59.16

SITE 25 TA 064 854

B	25.9249	36.83	24.14	47.90	60.40
A (top)	23.2675	38.30	28.83	43.91	57.05
A (base)	24.0970	29.65	23.50	53.81	55.78

SITE 26 TA 061 854 No data

SITE 27 TA 061 857

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
D	27.5345	40.46	57.18	27.48	41.43
C	29.7829	38.08	37.00	39.00	50.71

SITE 28 TA 057 864

A	27.1459	38.01	42.74	35.48	47.07

SITE 29 TA 053 865 No data

SITE 30 TA 049 870

B	25.6175	47.31	59.18	21.50	44.42

SITE 31 TA 037 909

C	26.2106	40.29	52.32	28.46	43.50

SITE 32 TA 035 912

D	27.8854	35.73	34.77	41.91	50.68

SITE 33 TA 032 914

D	25.1994	40.98	37.57	36.84	52.17
C	25.5494	34.91	30.96	44.93	52.99
B	24.6259	44.36	30.83	38.43	58.99
A	26.1971	39.86	45.81	32.58	46.52

SITE 34 TA 029 928

A	26.8986	55.69	45.69	24.06	54.93

SITE 35 TA 028 929

A	24.2035	49.95	37.62	31.22	57.04

SITE 36 TA 027 931 No data

SITE 37 TA 028 937

SAMPLE	WEIGHT	% SAND	COARSE SILT AS % TOTAL SILT + CLAY	% FINE SILT + CLAY	S RATIO
C	26.9695	44.99	48.47	28.34	48.13

SITE 38 TA 029 939 No data

SITE 39 TA 009 972

D	27.3635	40.54	44.82	32.80	47.49

SITE 40 TA 010 974

E	28.9985	20.17	29.19	57.26	40.86

SITE 41 SE 9970 9985 No data

SITE 42 NZ 987 013

A	27.8731	56.17	45.21	24.01	55.40

SITE 43 NZ 9685 0260 No data

SITE 44 NZ 9590 0325

C	26.1804	25.42	35.25	48.28	41.89
B	28.3510	29.12	26.66	51.97	52.20

SITE 45 NZ 9570 0365 No data

SITE 46 NZ 9537 0420

E	24.023	25.60	28.25	53.38	47.53
D	26.3599	35.34	34.93	42.06	50.29

SITE 47 NZ 9535 0430 No data

SITE 48 NZ 9535 0450

G	29.8690	23.34	15.04	65.12	60.81
F	29.9755	17.80	34.80	53.59	33.84

APPENDIX C. STONE ORIENTATION DATA FOR COASTAL SITES (° True)

SITE 1 TA 1470 7585

1m. above base of T1 (fig. 44.1)

017	257	328	282	046	330
257	277	325	056	037	058
012	274	280	034	355	078
359	202	048	335	293	085
040	040	011	067	040	034
281	022	319	043	348	076
046	012	063	066	300	286
319	006	045	025	045	294
081	356	068	345	328	266
337	310	036	033	288	321
359	029	282	054	089	354
310	002	350	005	007	023
334	256	034			

SITE 1 (T2, fig. 44.2)

209	185	175	233	133	156
226	118	210	174	185	130
198	170	200	208	214	227
122	270	305	197	184	139
139	139	172	199	072	154
225	160	257	199	166	196
221	175	226	200	209	214
213	143	199	195	207	218
215	177	192	203	173	237
223	197	284	233	219	191
207	166	195	191	218	141
191	170	336	193	210	166
183		192		236	

SITE 1 (T3, fig. 44.3)

242	168	264	189	246	135
226	244	234	245	165	230
170	157	243	232	207	256
184	216	231	280	241	282
					189

SITE 1 (T4A, fig. 44.4)

217	294	198	294	227	272
294	329	212	174	149	232
243	328	169	169	272	312
257	194	155	149	279	208
					214

SITE 1 (T4B, fig. 44.5

260	233	158	266	209	278
246	221	190	160	268	188
204	219	186	215	225	210
185	236	184	207	184	242
					238

SITE 1 (T5, fig. 44.6

302	250	019	300	346	329
343	308	330	046	004	341
026	212	335	358	278	058
274	201	349	280	333	345
216	198	265	318	267	341
284	356	288	253	042	335
270	199	029	057	319	333
267	276	018	005	330	359

/continued

233	236	043	241	336	021
197	213	052	326	001	329
206	352	007	347	333	004
206	349	036	323	329	318
348		034		298	

SITE 2 TA 1460 7585 (Basal T1, fig. 44.7)

199	275	234	247	231	252
319	246	220	175	246	169
244	170	195	188	238	230
201	238	232	218	193	266
					256

SITE 2 (Top of T1, fig. 44.8)

279	250	293	293	308	345
250	222	215	284	277	318
278	239	306	266	235	336
196	326	273	333	304	336
					319

SITE 2 (T2, fig. 44.9)

210	223	233	223	210	215
207	169	242	202	247	205
203	228	208	208	189	236
200	226	208	197	236	239

SITE 3 TA 145 761 (T1, fig. 45.1)

189	245	094	217	174	168
200	300	249	178	087	200
191	214	290	176	257	200
238	257	145	179	134	188

/continued

229	185	189	159	154	254
200	256	248	155	114	211
232	236	141	198	112	110
215	245	233	275	152	184
217	296	301	205	260	260
209	300	122	179	180	196
212	205	253	150	238	203
225	239	174	208	176	164
237		161		234	

SITE 3 (T2, fig. 45.2)

199	198	208	188	224	123
230	220	205	106	203	180
189	215	212	209	188	209
182	220	194	154	199	202
					175

SITE 3 (T3, fig. 45.3 and 45.4)

	(Dip)		(Dip)		
026	+	028	-	280	No dip data
004	+	055	+	224	
091	-	065	-	278	
016	-	062	-	017	
058	-	319	-	312	
038	+	050	-	030	
069	o	033	-	248	
076	o	004	+	260	
069	o	023	+	344	
333	+	299	-	236	
058	+	059	-	339	

continued

037	+	048	-	257
008	+	042	-	014
054	o	006	o	025
061	-	297	o	019
039	+	059	o	066
058	+	072	-	073
077	+	041	o	017
064	o	088	o	357
038	+	047	o	001
101	o	071	o	034
014	+	061	o	038
355	o	051	-	006
065	o	322	+	057
063	o	066	-	328

Clast rising in stated direction shown thus +

Clast horizontal shown thus o

Clast dipping in stated direction shown thus -

SITE 4 TA 1403 7650 (T1, fig. 45.5)

192	093	188	156	189	131
275	264	186	163	197	198
259	212	224	224	184	152
135	222	173	225	195	210
146	207	227	214	199	244
221	250	220	178	215	196
235	280	209	151	191	248
174	196	214	188	101	237
234	221	188	275	182	200
247	165	171	168	196	194
194	174	219	202	244	229

/continued

177	214	181	182	191	183
164		224		164	

SITE 5 (TA 139 766 fig. 45.6)

227	195	212	207	226	227
281	212	219	212	227	239
200	196	209	177	199	214
202	192	185	175	138	205
205	222	200	223	213	229
248	222	198	175	219	202
217	202	227	232	253	212
195	177	230	215	200	197
195	142	215	212	209	195
282	227	196	201	208	186
222	219	187	206	137	202
249	200	192	202	187	224
212	207	187	214	214	232
207	123	262	220	232	232
237	230	263	210	205	262
242	227	217	228	222	232
212	195	202	225		

SITE 6 TA 131 773 (figs. 45.7 and 45.8)

196	-	205	-	201	o
246	-	224	-	180	o
180	o	197	-	218	o
197	-	250	o	201	o
180	+	226	-	240	o
202	+	296	-	108	-
254	-	216	-	173	-

/continued

270	-	187	-	193	-
241	-	233	-	114	-
283	-	126	-	277	+
179	+	205	-	226	-
214	o	266	+	123	+
301	-	219	-	184	-
261	o	226	-	169	+
290	o	232	-	173	-
246	+	224	-	253	+
229	+	256	+	244	-
194	o	262	-	171	+
119	+	228	-	190	+
129	+	232	o	245	+
228	-	293	+	139	+
226	-	230	-	220	o
202	o	249	-	107	-
297	-	228	-	132	+
188	+	262	o	119	+

+, o, - sense of dip. See Site 3

SITE 6 TA 131 773 (T2, figs 45.9 and 45.10)

305	+	035	-	123	-
251	-	099	o	135	-
194	-	056	+	130	-
302	-	165	+	124	-
333	o	079	-	135	-
310	-	081	o	132	+
165	-	038	o	046	-
164	o	045	o	137	o

/continued

258	+	067	o	038	-
344	-	024	-	117	o
278	+	078	o	125	-
202	-	074	+	116	o
256	+	013	+	128	+
274	+	045	o	071	-
285	-	008	+	161	-
276	o	010	+	129	-
239	+	026	+	128	-
325	o	078	o	015	-
268	+	060	o	129	-
240	+	068	o	106	+
207	o	096	o	126	-
266	o	015	+	222	+
326	+	164	-	117	-
226	-	043	-	094	o
278	+	047	o	158	-

+, o, - Sense of dip - see Site 3

SITE 7. TA 1245 8155 (Tl, fig. 46.2)

281	297	009	212	022	349
254	028	026	337	339	340
359	020	021	343	296	354
002	016	329	343	326	030
290	018	014	014	338	305
326	026	357	009	042	008
270	357	289	039	000	346
336	341	252	313	030	328
314	312	334	349	011	326

/continued

307	030	009	342	032	344
310	060	303	007	011	039
341	005	007	007	332	354
332		026		035	

SITE 9 TA 127 817 (T2, fig. 46.3)

104	170	155	140	252	127
175	083	153	157	172	115
168	038	087	142	072	214
115	138	155	187	132	155
067	191	142	206	132	135
103	163	133	172	117	082
130	167	080	167	189	192
131	078	096	177	139	162
136	062	162	207	154	151
209	138	146	232	150	137
155	147	187	117	140	190
112	073	142	118	108	095
119		128		124	

SITE 10 TA 087 837 (T1, fig. 46.4)

078	180	102	113	259	300
156	156	115	152	204	283
154	189	168	185	330	309
162	158	206	148	268	284
107	154	179	150	306	169
165	112	153	329	264	166
192	170	157	085	106	

/continued

SITE 11 TA 0360 8385 (fig. 46.5)

247	217	319	259	239	276
243	300	272	182	256	256
264	240	272	204	242	202
277	237	223	249	284	246
248	228	238	247	264	275
279	294	322	216	256	241
257	282	264	227	249	263
300	252	230	222	221	255
285	246				

SITE 12 TA 065 854 (T1, fig. 46.6)

222	324	316	302	308	313
255	309	274	313	312	014
312	258	277	312	331	262
337	297	202	337	291	327
317	327	322	313	272	311
337	321	256	328	306	290
292	292	312	328		

SITE 13 TA 026 949 (fig. 46.7)

289	290	225	295	285	218
342	354	267	315	312	244
265	264	335	257	275	349
237	329	240	254	179	356
357	338	310	202	020	196
277	259	296	342	314	187
341	290	320	260	244	354
241	336	342	340	230	198
268	220	326	037	276	182

/continued

253	249	296	066	206	236
323	298	042	280	301	199
301	265	017	340	319	243
341		315		260	

SITE 14 NZ 958 036 (fig. 46.8)

310	270	221	261	189	355
223	292	246	143	234	204
182	334	162	280	344	215
219	215	150	202	199	219
180	295	126	188	266	218
204	228	226	293	336	231
318	324	206	228	178	186
268	217	203	240	260	176
211	208	236	251	296	193
189	218	155	290	220	188
270	257	211	213	274	268
248	268	272	213	227	190
258		130		162	

APPENDIX D MECHANICAL ANALYSIS DATA FOR INLAND SITES (% SAMPLE WT)

THORNTONDALE

SITE 4 SE 8432 8197

Ø INTERVALS | SAMPLE WT

-1.0	-0.5	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4	
0.65	0.30	0.25	0.27	0.30	0.34	0.45	0.95	2.97	6.03	6.21	142.63

SITE 22 SE 8420 8325

12.42	1.87	1.48	1.75	2.02	2.23	2.46	3.2	6.73	7.81	5.75	137.58

STONY MARL MOOR

NZ 956 008 WEATHERED TILL

A	6.90	1.80	1.40	1.37	1.51	1.99	2.85	4.36	6.75	6.48	4.96	147.75
B	7.87	1.76	1.46	1.44	1.63	2.23	3.00	4.41	7.00	8.21	5.73	141.01

NZ 956 008 LAMINATED STONY SILT

A	9.39	0.84	1.68	0.92	1.31	2.02	3.18	5.01	7.24	6.45	5.13	138.05
B	14.92	1.23	0.98	0.98	1.22	1.83	3.17	5.26	9.21	9.01	7.08	137.86

APPENDIX E. FOLD ORIENTATION DATA FOR SPEETON CLAY AND SHELL BED

ORIENTATION OF AXIAL PLANES OF FOLDS IN SPEETON CLAY D BEDS AND CHALK GRAVEL. SITE 1 (fig. 69.1)

(° TRUE)

318	331	307	328
309	304	331	322

ORIENTATION OF AXIAL PLANES OF FOLDS IN SPEETON SHELL BED SITE 2 (fig. 69.2)

(° TRUE)

317	336	340	327	331	345
311	335	351	321	345	347
280	321	345	336	314	347
291	333	307	348	353	330
299	329	306	349	345	326
337	327	336	339	348	325

ORIENTATION OF AXIAL PLANES OF FOLDS IN SPEETON CLAY (fig. 69.3)

(° TRUE)

280	276	295	293	278	273
293	272	296	281	264	273
279	275	296	286	271	275
283	288	296	288	281	283
283	287	281	282	275	287
277	287	299	281	266	305
281	273	274	283	280	278
293	293	292	284	277	293
300	276				

APPENDIX F. STONE ORIENTATION DATA FOR INLAND SITES (^{o} TRUE)

THORNTONDALE. SITE 4 SE 8432 8197

(fig. 50.1)			(fig. 50.2)		
124	250	211	264	172	157
238	244	173	298	200	238
104	256	248	247	190	178
123	247	204	233	218	284
130	292	246	297	200	226
187	234	232	316	241	128
127	286	237	178	238	134
160	220	236	158	295	234
172	260	285	272	240	216
092	231	163	260	223	156
234	236	250	165	226	231
248	236	249	242	219	236
184	213	256	262	222	334
113	213	216	188	219	271
234	201	280	269	195	317
204	220	213	260	220	223
192	241	278	307	202	196
208	247	304	164	170	226
256	267	256	283	145	259
225	221	296	175	158	184
187	308	285	218	213	255
261	189	221	213	161	248
260	250	211	226	245	205
198	254	215	248	159	122
248	160	259	167	259	229

/continued

THORNTONDALE SITE 21 SE 840 831

(fig. 50.3)

208	276	252	307	213	196
202	210	292	206	206	176
231	258	313	271	159	178
238	248	153	229	203	178
211	257	298	194	210	173
160	165	213	191	171	260
237	236	271	206	142	181
154	177	183	204	148	233
308	270	180	248	256	318
218	251	271	156	134	213
200	299	209	206	130	198
195	307	191	189	176	199
226		223		168	

THORNTONDALE SITE 22 SE 8420 8325

(fig. 50.4)			(fig. 50.5)		
048	020	084	303	216	260
277	039	271	196	217	340
044	020	271	261	219	006
088	302	276	298	195	235
070	055	268	222	270	203
304	297	261	241	194	244
048	043	054	243	199	242
321	028	264	219	224	303
340	027	256	200	242	232
084	026	285	240	235	237
105	312	270	253	326	311
066	294	030	321	345	312

/continued

081	346	355	262	233	229
138	060	017	206	218	246
097	042	257	278	223	357
081	028	248	293	240	256
115	058	227	351	225	300
073	301	039	256	178	183
086	297	303	235	226	245
065	026	276	245	203	343
056	298	276	225	182	228
055	044	279	214	208	306
013	270	283	322	225	206
141	339	272	228	225	278
054	054	289	248	217	218

APPENDIX G CARBONATE ANALYSES FOR COASTAL TILLS

SITE 1 TA 1470 7585

SAMPLE POINT	SAMPLE WEIGHT	RESIDUE WEIGHT	% SOLUBLE
12	200.39	180.08	10.14
11	200.04	180.54	9.75
10	206.67	184.67	10.65
9	202.13	186.86	7.55
8	201.35	185.12	8.06
7	206.63	189.13	8.47
6	203.33	186.05	8.50
5	211.36	188.98	10.59
4	227.39	203.28	10.61
3	210.19	186.80	11.13
2	214.99	189.98	11.64
1	214.05	188.11	12.11

SITE 2 TA 1460 7585

SAMPLE POINT	SAMPLE WEIGHT	RESIDUE WEIGHT	% SOLUBLE
3	207.39	180.95	12.75
2	208.53	178.57	14.37
1	208.60	186.31	10.69

SITE 3 TA 1445 7610

SAMPLE POINT	SAMPLE WEIGHT	RESIDUE WEIGHT	% SOLUBLE
8	210.58	188.91	10.29
7	210.64	190.52	9.55
6	205.09	182.99	10.77
5	207.80	182.91	11.97
4	205.80	180.55	12.27
3	198.96	176.99	11.05
2	204.24	177.55	13.07
1	213.50	167.89	21.37

SITE 4 TA 144 762

SAMPLE POINT	SAMPLE WEIGHT	RESIDUE WEIGHT	% SOLUBLE
6	208.82	190.15	8.94
5	198.17	180.56	8.88
4	216.70	198.00	8.62
3	210.80	192.52	8.67
2	202.85	183.93	9.32
1	203.34	185.19	8.92

SITE 5 TA 1403 7650

5	211.67	195.71	7.54
4	197.58	183.11	7.83
3	202.17	184.86	8.56
2	196.78	176.58	10.27
1	207.62	187.56	9.66

SITE 6 TA 131 773

7	203.10	189.40	6.75
6	210.38	183.10	12.97
5	208.02	187.97	9.64
4	211.54	190.46	9.97
3	204.17	184.07	9.84
2	214.16	193.59	9.60
1	201.03	180.90	10.01

SITE 7 TA 1250 8165

8	200.54	193.69	3.42
7	204.20	184.24	9.78
6	209.36	177.20	15.36
5	209.33	183.09	12.64

/continued

4	207.37	185.98	10.31
3	203.54	179.21	11.95
2	208.31	190.46	8.57
1	201.84	180.06	10.79

THE WESTERN VALE OF PICKERING


THE EASTERN MOORS
NZ 90
TA 09
SE 99
SE 98
TA 08
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SUFFIELD-cum-EVERLEY
WYKEHAM
WYKEHAM FOREST
EAST AYTON
WEST AYTON
HUTTON BUSCEL
IRTON
SEAMER
CAYTON
Robin Hood's Bay