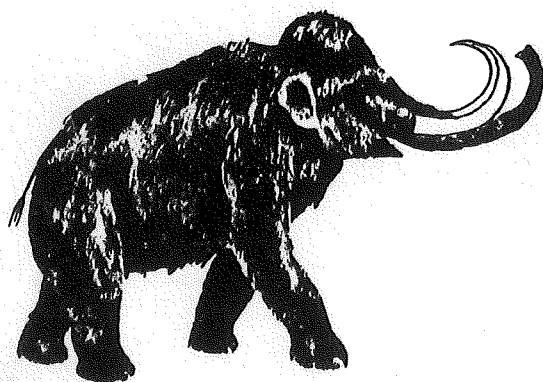


Shackleton

QUATERNARY RESEARCH ASSOCIATION

FIELD HANDBOOK



KEELE 1978

QUATERNARY RESEARCH ASSOCIATION

FIELD HANDBOOK

Annual Field Meeting 1978

by

E. A. FRANCIS

with contributions by

H. Davies, E. Derbyshire, M.P. Lee

and P. Worsley

KEELE

April 1978

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Edward A. Francis Department of Geology,
 University of Keele,
 Newcastle, Staffs. ST5 5BG.

Hilary Davies 12, Whitegates Crescent,
 Willaston, Wirral,
 Merseyside. L64 2UX.

Edward Derbyshire Department of Geography,
Martin P. Lee University of Keele,
 Newcastle, Staffs. ST5 5BG.

Peter Worsley Department of Geography,
 University of Reading,
 Reading, Berks. RG6 2AU.

PREFACE

This handbook has been prepared for the 1978 Annual Meeting of the Quaternary Research Association at Keele. Most of the contributions are directly concerned with sites and localities to be visited during the field excursions, but reference is made to additional localities where relevant. Routes can be followed on the appropriate Ordnance Survey 1:50,000 sheets, and boundaries of these are included on Fig. 1 which is a general map of the area.

I thank the other contributors for submitting material, and wish to express special appreciation to Edward Derbyshire for overseeing the preparation of figures, and for liaising on the printing of the handbook.

Grateful thanks are expressed to the following staff of the Department of Geography at Keele: Geoffrey Barber who re-drew the maps and some of the diagrams, Muriel Patrick who re-drew the other diagrams, and Janet Fairclough for photographic reproduction of the figures. Thanks are also due to Peter Tudor and Clarice Lea of the University Library who supervised and carried out the printing of the handbook respectively. I should like to acknowledge my particular indebtedness to Rosemarie Bradshaw, who coped cheerfully with the onerous task of typing the manuscript.

Partial support for my research in the Wrexham area was supplied in the form of grants from the Research Fund of the University of Keele towards the cost of travel for which I am glad to be able to express my gratitude.

Edward A. Francis

Programme

Friday, 7th April

- 8 p.m. Introductory lecture by E. A. Francis
Department of Physics, Lecture Theatre No.1.

Saturday, 8th April

- 9 a.m. Excursion: S. Staffordshire & S.E. Shropshire
Four Ashes, Eardington, Iron Bridge, Buildwas,
Cound.

Sunday, 9th April

- 9 a.m. Excursion: E. Clwyd
Wrexham area: Singret, Llay, Gwersyllt Park,
Marford, Llan-y-pwll, Bangor-is-y-coed.
- 8 p.m. Annual General Meeting of the Quaternary
Research Association.
Department of Physics, Lecture Theatre No.1.

Monday, 10th April

- 9 a.m. Excursion: N. Shropshire
Shrewsbury, Ellesmere.

Tuesday, 11th April

- 9 a.m. Excursion: N. Staffordshire and adjacent
Cheshire border.
Rudyard, Langley, Cleulow Cross, Gradbach,
Ramshaw.

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INTRODUCTION

Keele is the focus of activity for the 1978 meeting of the Quaternary Research Association. It also lies close to a topographical focus, in that surface drainage from nearby may find its way either to the North Sea via the R. Trent, or to the Bristol Channel via the R. Tern and R. Severn, or to the Irish Sea via a tributary of the R. Weaver (Fig. 1).

In geological terms, Keele is situated on a salient from the S.W. Pennines of Upper Carboniferous rocks which also form a chain of separate outcrops farther south-westwards to Shrewsbury. The Cheshire Basin to the W. is thereby separated from the Needwood Basin to the E., and each of these is filled with considerable thicknesses of Triassic strata including important beds of rock-salt, and each is covered by extensive Quaternary sediments. The Cheshire Basin, which extends into N. Shropshire, is thought to contain up to at least 2,600 m of Triassic rocks, with at least 170 m of Jurassic strata S. of Whitchurch. Locally, the bedrock is overlain by as much as 90 m of Quaternary sediments which are mostly glacial.

The meeting at Keele has been planned so that important sections in Quaternary sediments around the borders of the Cheshire Basin can be examined and discussed, and their significance assessed in a connected manner. All the deposits to be examined are referred to the Devonian, and most of them were laid down during the dissolution of the last ice-sheet, which extended over the

area between about 25,000 and 13,500 years ago, although some, e.g. the Four Ashes Gravel, are somewhat older.

The subject matter of the meeting is predominantly sedimentological, and the aim of the three main excursions is to establish comparisons and contrasts between different localities and different modes of deposition along an arc extending for some 100 km from Four Ashes near Cannock to Wrexham. The arc passes through the R. Severn valley from near Bridgnorth to Shrewsbury, and continues through Ellesmere and Bangor-is-y-coed, which overlooks the R. Dee. Keele is thus the focus of the meeting in still another sense, for all the localities to be visited on these days lie close to this arc between 35 and 55 km from the University.

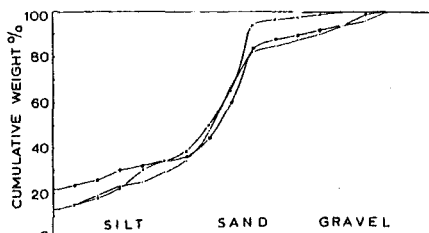
On the fourth optional day, an informal excursion will visit localities beyond the margin of the plain. It will be concerned particularly with morphology and the striking results of periglacial activity, and no itinerary is included in this handbook.

It is expected that the success of the meeting will be indicated by the amount of discussion stimulated by the excursions. It is clear that many problems remain unsolved, and it is undoubtedly true that a number of problems now thought to have been solved will be resurrected in the future. It is to be hoped that study of exposures and features in the field during these excursions will help to clarify our understanding of the processes and materials involved in glacial sedimentation. If so, valuable

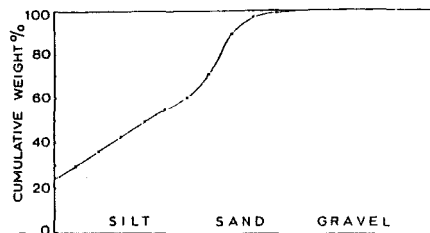
implications for the stratigraphy and chronology of these complex sequences should be forthcoming.

The order of the itineraries in this handbook corresponds with that to be followed on the excursions. An important locality not to be visited is Acre Nook (Oakwood) Quarry near Chelford, where the quality of the section has recently deteriorated, but an account of the site is included. Contributions on various techniques used in investigating the properties of the sediments and their constituents are included in a section following the itineraries.

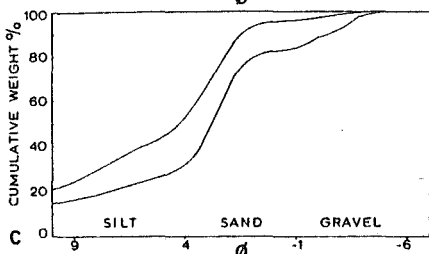
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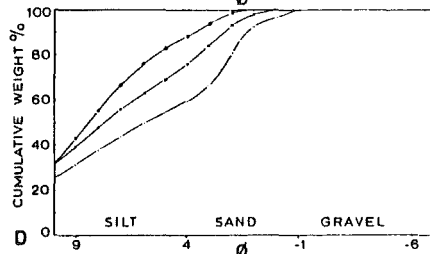
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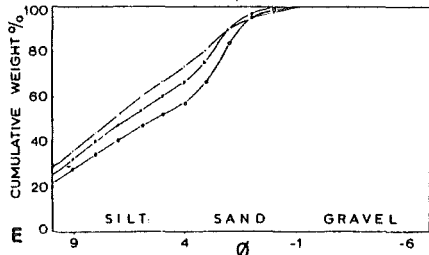
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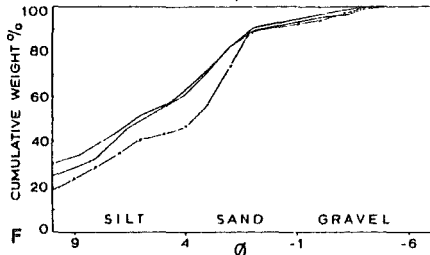
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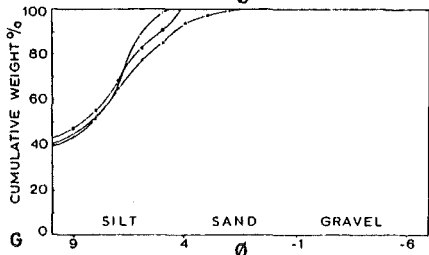
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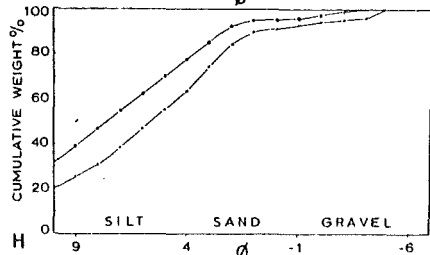
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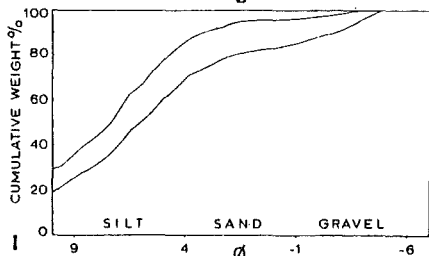
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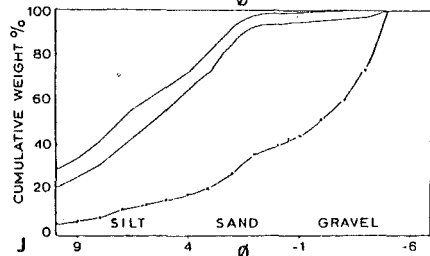
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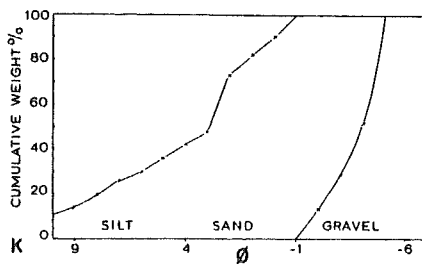


Fig. 2. Particle size distribution curves.

- (A) Till from Four Ashes (circles), Eardington (dots) and Oakwood Till, Chalford (crosses).
- (B) Till from Singret.
- (C) Envelope for four samples from the complex exposed at Rackery.
- (D) Three samples from Pant Farm.
- (E) Three samples from Marford.
- (F) Envelope for three samples of the upper till at Dawpool Cliffs, near Thurstaston, with a curve for one sample of the lower till (crosses).
- (G) Three samples from road cutting at Bangor-is-y-coed, including lower clay-silt (circles and dots) and upper clay-silt (crosses).
- (H) Two samples (R3,R4) from the till underlying the upper gravel at Radbrook Quarry, Shrewsbury.
- (I) Envelope for four samples (R1, R2, R5, R6) of the uppermost till from Radbrook Quarry.
- (J) Envelope of six samples of till from three till sheets, plus a curve for one sample from the uppermost till (crosses) from Wood Lane, Ellesmere.
- (K) The uppermost till at Wood Lane, split at -1ϕ into two equal parts.

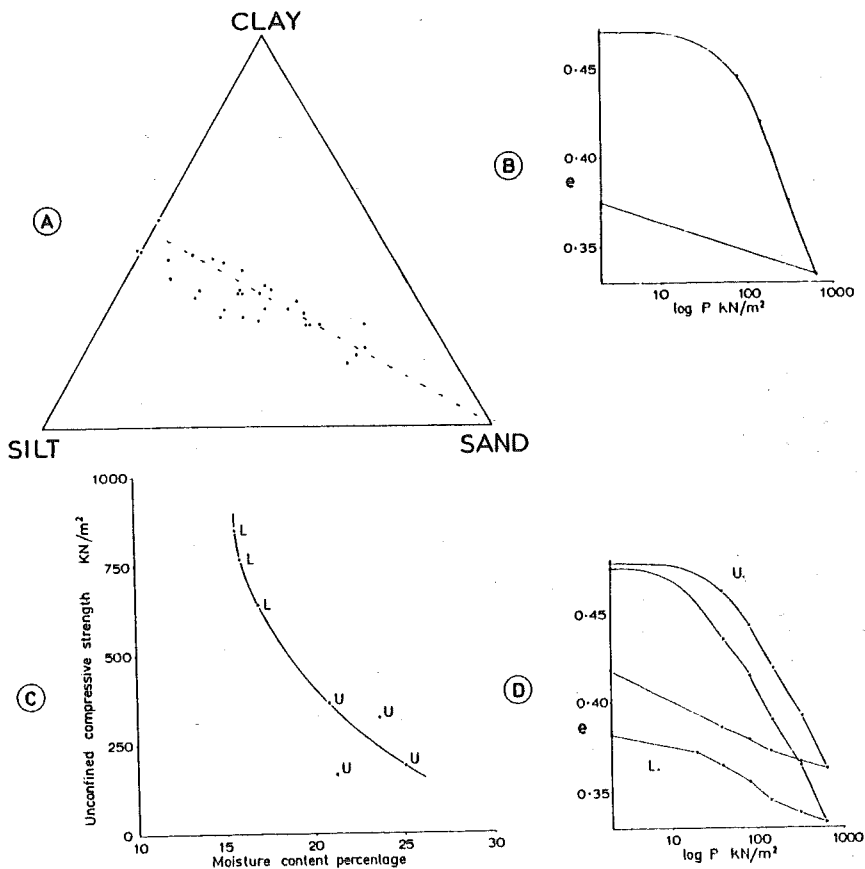


Fig. 3A. Triangular diagram showing proportions of clay, silt and sand (finer than $+1 \phi$) in 32 samples from the Cheshire Basin.

Fig. 3B. Plot of void ratio against logarithm of pressure for a sample of till from Four Ashes.

Fig. 3C. Plot of maximum unconfined compressive strength against moisture content for seven samples of clay-silt from Bangor-is-y-coed. L - lower, U - upper clay-silt.

Fig. 3D. Plot of void ratio against logarithm of pressure for two samples from Bangor-is-y-coed. U - upper, L - lower clay-silt.

KEELE to FOUR ASHES

The University of Keele campus lies on Upper Carboniferous strata: red sandstones form a prominent ridge to the south of the library, and purple mudstones have been proved in excavations for foundations at Barnes Hall. Workable coal seams extend under the site and extraction is planned in due course, though a pillar will be left under Keele Hall. The valley which falls south-eastwards through the campus is asymmetrical with a long gentle slope rising north-eastwards to Observatory Hill (206 m). This slope is mantled by heavy clay with north-western erratics, here interpreted as largely geliflucted till, but also including substantial quantities of the bedrock material. Sandstone has been quarried from the crest of the shorter steeper slope to the south-west, and is exposed along the drive to Clock House and near Keele Hall. Clays and sands have been proved by bores to underlie the valley floor between Keele Hall and Horwood Hall, but to the south-east, the gradient increases and a chain of artificially dammed lakes occupies a more symmetrical and clearly marked valley eventually joining the Trent.

The M6 motorway south of Junction 15 passes through cuttings exposing Triassic pebbly sandstones and red sandstones, and many of the fills around the southern periphery of the North Staffordshire Coalfield are composed of these materials. To the south, the country

/h

is of gentler relief. Immediately south-west of Junction 14 (SJ 900250), the M6 crosses an alluvial tract bounded by the 76 m contour. The River Sow flows along the south-western margin of this tract to join the Penn beyond Stafford. The alluvium is underlain by glaciofluvial gravels at least 45 m thick, covering a bedrock surface with channels whose floors fall below 29.4 m O.D. (Morgan, in Shotton 1977). A multidisciplinary investigation (Morgan et al. 1977) records that the gravels are overlain by a sequence of clays, silts, gyttjas and peats, and the basal organic silt has been dated as $13,490 \pm 375$ years B.P. The results so far indicate that an open lacustrine system, probably in a tundra environment, was succeeded by a completely eutrophic bog, and further research on the fauna and flora should throw light on the time at which periglacial conditions ceased, as well as providing important data on late-glacial and post-glacial events.

South of Junction 13, the M6 runs close to the River Penn for some 3 km, following a valley train of thick sands and gravels with its base 15-20 m below the present alluvium. Farther S., numerous depressions in the surface of these sands and gravels contain peat, and at Pillaton Hall (941130) 1 km E. of the M6, and at Rodbaston (928110) immediately W. of the M6, basal ^{14}C dates of $1,660 \pm 250$ and $10,670 \pm 130$ years B.P. respectively have been obtained (Morgan, in Shotton 1977).

(EAF)

The important site at Four Ashes was previously visited by the Quaternary Research Association during the summer of 1968. Between about 1967 and 1970, the stratigraphical sequence and periglacial phenomena were studied by Alan Morgan (1973), and the beetle fauna by Anne Morgan (1973). Much of the detail in the following account derives from their work.

The sequence at Four Ashes superseded that at Chelford as the stratotype of the Devensian (Shotton 1973). Although the deposits do not provide a continuous record, this is the only site at present known in Britain which covers the entire Devensian, and it is therefore particularly unfortunate that it has been impracticable to conserve a section of the sequence for posterity. About ten years ago, the workings were located around 916082, but the present exposures lie at about 930087, and a good section is not available. However, in view of the importance of the site, the locality will be visited so that the situation of the deposits can be appreciated.

The sequence has been worked for gravel in a belt some 2km long and 0.4km wide along the northern side of a small stream, the Saredon Brook, which flows W.S.W. to join the River Penk. The Quaternary beds rest upon Triassic sandstone, whose upper surface hereabouts apparently falls overall gently towards the west.

The deposits comprise the Four Ashes Gravel

overlain by the Irish Sea Till. The gravel in the area reaches up to about 4.6 m in thickness and is largely composed of Bunter quartzites together with a few erratics of flint, rhyolite and andesite, which are generally less than 3 cm. The bedding is complex with minor breaks and erosional channels, and includes both cross and graded bedding sequences. It is probable that the deposits represent sedimentation in a braided stream complex, which derived its supply largely from the Bunter Pebble Beds a few km to the east and spread a sheet of gravel and sand up to about 800m wide across the Saredon valley. Accumulation is thought to have been periodic during the Early and Middle Devensian, and the supply of sediment would have been enhanced by freeze and thaw affecting the permeable Bunter Pebble Beds. However, more continental conditions would have resulted in reduced water flow and the streams would therefore probably not have been particularly powerful.

Within the Four Ashes Gravel, over 50 lenses of sandy detritus peat and grey organic clays have been recorded, though none is exposed at the time of writing. The lenses were found at various horizons: in bedrock hollows, where the deposits usually rested on a few cm of sand and gravel, and at different levels up to just below the overlying till. Apparently, deposition began during the Ipswichian Interglacial, and remains from this period are believed to be represented by wood of alder and yew, large numbers of alder cones, and leaves and fruit stones of holly.

Pollen included predominant alder and oak, together with some pine and birch.

Also near the base of the gravel, at another place within the site, were found remains of beetles which were very similar to those recorded from Chelford and correlated with the Brørup Interstadial deposits (Simpson and West 1958; Vogel and Zagwijn 1967), when forests of pine, spruce and birch were the dominant vegetation. The beetles found in a lens formed somewhat later suggest that a continental climate with moderately cool summers ensued, and this period was followed by one between 42,500 and 38,500 years B.P. in which the climate became less continental with somewhat warmer summers, though trees were apparently absent. A similar fauna dated to about 42,000 years B.P. has been found at Upton Warren. Following this, conditions again became more continental and these continued up to at least about 30,500 B.P., the age of the youngest lens dated. The absence of derived or redeposited faunas, and the fact that each lens contains an ecologically distinct fauna suggests that the sedimentary regime was predominantly aggradational, and this is consistent with the sedimentary structures.

Two horizons of ice-wedge casts have been recorded from the Four Ashes Gravel. The earlier is represented by a wedge which penetrates the underlying sandstone but is truncated by the basal gravel, and is thought to be later in age than the deposits regarded as contemporan-

eous with the Chelford Interstadial. The later, higher within the gravels, is regarded as belonging to the second of the two more continental periods referred to above and would thus lie between the dates of 38,500 and 30,500 years B.P.

The Irish Sea Till (named the Wolverhampton Till in Shotton 1973, Table 3) is a red clay, 5 cm to 2.75 m thick, overlying the Four Ashes Gravel. It contains erratics such as white granite (up to 1 m³) attributed to S.W. Scotland, volcanic rocks and slate probably from the Lake District and/or Scotland, Eskdale granite, Ennerdale granophyre (generally less than 5 cm) Carboniferous and Liassic limestones, and flints. Part of a mammoth tooth has also been found. An involuted zone about 2.5 m thick overlying undisturbed gravels and sands may indicate permanent frost below this depth, and this is apparently supported by the sagging of masses of till into the gravels to a similar depth, with formerly semi-fluid gravels rising between these masses. Ice-wedge casts cut down into the till and consequently postdate the glacial retreat, but active ice-wedge structures probably no longer formed in the area after about 12,500 years B.P.

(EAF, with acknowledgements to
AVM and MAM)

The analysis (Fig. 2) of a bulk sample of the Wolverhampton Till from the eastern end of the workings (930087) shows that it is a red sandy till with few clasts. The fraction finer than ϕ comprises 59% sand, 15% silt and

26% clay, and is similar in composition to the till analysed at Eardington, and also to the Oakwood Till at Chelford.

A sample was compressed in an oedometer. The resulting plot of void ratio against the logarithm of the pressure (Fig. 3) shows the typical curve of an overconsolidated till which has undergone approximately 100 kN/m^2 of preconsolidation pressure, whereas the present overburden pressure is only about 20 kN/m^2 . This suggests that the till was deposited by lodgement.

(MPL)

FOUR ASHES to EARDINGTON

In the area between Cannock and Bridgnorth, the Wolverhampton Till, though locally absent, is generally a red clay, sandy in places and normally less than 3 m thick. Clasts within the till are commonly realigned by periglacial activity to at least 2 m depth and the top 20 - 30 cm are usually leached. In Wolverhampton, the till thickens and exceptionally reaches over 9 m. The border of the till is lobate S. and S.W. of Wolverhampton, with small lobes extending into the Penn Brook valley (SO 900943) and the Smestow Brook valley near Woodford Grange (858936). Beyond this, the till extends farther S. in the area drained by tributaries of the Worfe, where it partly overlies sands and gravels. Extending to the S.S.E. from pits (843955) near Seisdon through Trysull to Kingswinford is a narrow belt of sands and gravels which lie in a rock-walled channel

locally up to 34 m in depth. They are ascribed to melt-water from Anglian ice, and are overlain disconformably at Trysull by silts and clays thought to represent an early stage of the Hoxhian Interglacial (Morgan, 1973). The A454 road passes onto the alluvium of the Worfe 1 km S. of Worfield where the river turns from a meandering N. - S. course westwards to join the Severn N. of Bridgnorth. The ground immediately W. of Worfield and its continuation northwards to Cranmere Farm lies between about 62 and 70 m and was mapped by Wills (1924) as "Fluvio-Glacial Gravels". An area nearby to the west extending from near Allscott to beyond Merecot was mapped by Wills as boulder clay, while a little to the E. of the A442 S.E. of Stockton (730997) is a narrow belt designated "Glacial Gravels (Kames and Moraines)". (See also p.20)

(EAF)

The area to the E. and S.E. of the village of Eardington has been worked extensively for gravel. A section was visited in 1964 during the first meeting of the Quaternary Field Study Group, the youthful form of the Q.R.A.

Wills (1924) divided these gravels into two: the Main Terrace Gravel, and the Eardington Gravel, and he referred to them both as "fluvioglacial terrace-gravels". The former gravel lies in flat spreads and the latter forms somewhat undulating areas.

Main Terrace Gravel

The sediments are gravel and sand, in which the erratics comprise the bulk of the pebbles, including Scottish granites, Eskdale granite, ?granophyre, mica-schist, analcite-basalt, ?Precambrian grits, conglomerates and felsite, Ordovician sandstone, Silurian slates and limestones, Carboniferous limestone, chert, ironstone and coal, and Wrekin rhyolite. At other localities, Wills notes that the deposits are "fairly horizontally-bedded" or "almost devoid of bedding". They lie between 26 and 37 m above the present Severn flood plain and have a surface level of about 61 m, a little above the height of the base of the older Eardington Gravel, according to Wills.

Sections currently available are in workings to the S.W. of the road running S.E. from the village. A face examined in late 1977 exposed some 4.5 m of gravel and sand, with still lower deposits obscured by talus. The

exposed sequence could be resolved into three sedimentary units. The lowest, about 2.5 m thick, was made up of a lower part, at least 1 m thick, of sand in parallel laminae of low dip passing up into either bedded sand with abundant coal lumps and small amounts of gravel, or sandy gravel with fewer coal lumps, the dip increasing upwards so that bedding was gently concave upwards, overlain by poorly sorted sandy gravel. The middle unit, about 1.5 m thick, had a similar structure, but the basal sand included only small coal fragments and had a maximum thickness of 0.82 m wedging out laterally. The upper unit, whose full thickness could not be seen, was again composed of a lower sand and an upper gravel. The sequence is interpreted as having been formed during aggradation in a braided river complex, with the sands being deposited at the downstream ends of gravel bars which then migrated over them.

Eardington Gravel

Wills (1924) mapped this deposit as a belt between 250 and 500 m wide on the W. side of the Main Terrace Gravel, itself some 500 m wide. Near the village, in the railway cutting, he noted that the gravel was "predominantly composed of Welsh and local material" but "occasional northern erratics were found", while south of the village at a height of 64 m, "northern erratics are common". Farther N. in the railway cutting and at Knowlesands cliff (722913), Wills recorded the following sequence:

32 p.m.

over PP

+ railway

? Also Tell

Boulder-clay, reddish sandy, with common small northern erratics	to 1.8 m
Sand, brownish, coarse, with a few stones, and fairly numerous coal fragments	to 6.0 m
Gravel, coarse, angular, with plentiful Welsh erratics, but no northern erratics;	to 1.5 m
base at 58 m O.D.	

The conclusion which Wills favoured was that "by some accident, northern boulders have not been incorporated or detected" in these gravels, although at other places where mixed, the northern elements could have been introduced following the erosion of the boulder clay or as the result of overlap of the Main Terrace Gravel, which generally contains a much higher proportion of northern erratics. Although the Eardington and Main terraces were mapped as separate units, it was noted that at Eardington, they were nearly at the same level. There was a possibility that the Eardington Gravel may have derived its erratics from an earlier (Welsh?) glaciation, but the presence of occasional northern boulders suggested that it was "laid down during the advance of the north-western ice, but before the supply of northern erratics was abundant". The Main Terrace Gravel, in contrast, was formed of material derived from north-western ice during retreat.

Wills' interpretation of the "reddish sandy boulder-clay" was that it formed in a temporary lake and was probably not a ground-moraine. Recently, Coope (in Shotton 1977 p.41) has referred to a face in the Main Terrace

gravels near Eardington which has revealed a layer of interbedded flow till. The locality is at about 726908 and lies in the area mapped by Wills as Eardington Gravel. Shotton (1977 p.14), in discussion of the significance of the Main Terrace, suggested that this flow till formed from dead ice on the west side of the terrace. Wills, however, visualized the withdrawal of the ice towards the E.N.E.

The face, though disused, is still exposed, and is oriented N.E. - S.W. A preliminary examination of the sandy clay at this locality has shown that it is about 0.7 m thick and is underlain and overlain by poorly sorted sandy gravel. Fabric studies and stone-counts have yet to be carried out, but the clay apparently contains a mixture of erratid material. The upper and lower contacts are generally planar, with no disturbance of the underlying gravel. However, at one point, the base of the clay is in the form of an arch about 0.6 m wide. The depth of the arch relative to the base on the N.E. side is about 12 cm and on the S.W. side about 18 cm. The highest point of the arch is underlain by about 10 cm of sand which wedges out at the N.E. side. About halfway down the S.W. flank, the sand is 8 - 9 cm thick and then is divided into two by a thin wedge of clay which increases in thickness as it dips to the S.W. side where it is about 1.5 cm thick and underlain by about 3 cm of sand and overlain by about 2 cm of sand. This thin clay band is indistinguishable from the matrix of the overlying clay, and the sand is in situ and undisturbed. These structures are consistent with the clay

having been deposited as flow till, and it is possible that local flow took place from a northerly point, though evidence from fabric studies may modify this opinion.

(EAF)

The analysis of a bulk sample of the sandy clay at Eardington shows that it is an extremely poorly sorted sandy till (Fig. 2) with many clasts (12% coarser than - 1 ϕ) set in a red-brown matrix. The fraction finer than - 1 ϕ is made up of 61% sand, 21% silt and 18% clay.

(MPL)

EARDINGTON to BUILDWAS

Patches of gravel similar to the Eardington Gravel were mapped by Wills (1924) under the centre of Bridgnorth and at Hoards Park a short distance to the N., the name of Hoards Park - Eardington Terrace being applied to them jointly. The eastern part of Bridgnorth on the left bank of the R. Severn is built largely on the Main Terrace, but the ridge extending northwards to Stockton is free of drift. The R. Worfe is crossed 3 km N.N.E. of Bridgnorth. The area between the A442, Brockton (SJ 722035), Shifnal, Ryton (761028) and the Worfe includes stretches of sandy clay generally overlying gravel composed of slaty pebbles and northern erratics, together with fragments of marine shells, and these were interpreted as "fluvio-

glacial". It is significant that Wills previously regarded the overlying clays as "ground-moraine", thus implying that the outwash was deposited before advance of the ice. He noted, however, that "the distribution of the clays and of the gravels seems to suggest that the two deposits are intimately connected, and probably deposited in part contemporaneously". Wills (1924, p.286) concluded that the clays might be "floodplain deposits of the waters that laid down the gravels in the actual river-channel". However, it is probable that such gravels, like others in similar situations, e.g. at Four Ashes and Eardington, would be laid down by braided streams, with which deposition of floodplain clays is not consistent. The situation is indeed strongly reminiscent of that on a much smaller scale in the Eardington Gravel, and the sandy clay may be flow till laid down progressively as "great flat spreads of featureless clay" at the periphery of the lobe of ice lying across the Worfe valley as it receded to the N.N.E. Its western margin as this phase of retreat began would be marked by the lines of kames near Merecot (745981), near Echoes Hill, 0.75 km S.E. of Stockton Church, and N.E. of Norton. The bedding dipping westwards near Echoes Hill is consistent with this reconstruction.

The roundabout (709038) S. of Cuckoo Oak lies on the W. side of a valley falling to the Mad Brook, a tributary of the Worfe. At Cuckoo Oak, Wills (1924, p.283) described

a sand-pit showing 2.5 m of till with north-western and possibly Welsh erratics overlying gravel resting in turn on sand, while at its S. end, the till overlay about 3.7 m of sand like the Buildwas Sands. He also recorded a section (686055) to the W.N.W. at a height of about 134 m:

Boulder-clay, reddish, stony, with northern erratics	0.92 m	
Boulder-clay, grey, with boulders of Coal Measure sandstone and shale, but no far-travelled erratics	1.53 m	
Sand, red, loamy	1.53 m	
Silts, fine, laminated	0.76 m	
Sand, with coal-pebbles, and fine gravel	0.92 m	5.66 m
Base at about 128 m		
Sand, reddish, sharp, with bits of coal and slate, like the Buildwas Sands	+ 2.75 m	

These sections were interpreted as showing outwash over-ridden by ice, and they lie on or close to a through valley, the Lightmoor Gap, excavated as an overflow channel.

Between Madeley and Iron-Bridge, a plateau rises to about 152 m and is partly covered by till. It is in effect now an outlier of an originally continuous plateau which rises to above this height to the S. on the opposite side of the Iron-Bridge gorge. Thus, the gorge is incised across and deeply into a spur, a classic situation for an overflow channel. It was first suggested by Lapworth (in Watts

1898) that this gorge resulted from the overflow of a lake impounded by ice lying across the Shropshire plain and the details of this interpretation were worked out by Wills (1924). These details are somewhat complex, but it is important that they should be understood, and consequently a summary is included here:

1. The plateau rising to 152 m had a low "preglacial" col at about 143 m at the site of the present gorge.
2. During ice advance from the N.W., a small lake formed against the spur, and probably overflowed by way of the Lightmoor Gap via Cuckoo Oak to the R. Worfe.
3. The area was covered by ice.
4. The ice retreated and separated into two lobes:
 - a) ice retreated up the Worfe valley, and the valley floor was eroded proglacially so that it was graded continuously past Bridgnorth into the present Severn valley, where deposition of the Main Terrace possibly began farther downstream.
 - b) ice retreated over the plateau, and to the west it impounded Lake Coalbrookdale which drained along the margin of the Worfe valley ice to Coalport Brook via Lightmoor Gap which was lowered from 137 m to about 113 m. Some of the Buildwas Sands were deposited in L. Coalbrookdale.
5. The Worfe valley ice advanced slightly to close Lightmoor Gap and the surface of L. Coalbrookdale was raised from 113 m to 143 m, so that its waters overflowed through the col at the site of the present Iron-Bridge gorge, the

outlet being lowered from 143 m to below 111 m.

6. The ice impounding L. Coalbrookdale withdrew westwards and the lake enlarged to form Lake Buildwas in which marginal and deltaic Buildwas Sands were deposited up to about 91 m by a river draining the Wenlock valley from the S.W. At the same time, a river flowed from the eastern lobe via the Mad Brook valley and the Worfe valley into the Severn valley near Bridgnorth. After erosion and grading, aggradation of the Main Terrace near Bridgnorth took place. Grading was also present in the valley below Iron-Bridge, so there was then a phase of equilibrium with the maintenance of the level of L. Buildwas and sufficient time for the processes of grading and aggradation to be accomplished.

7. The ice retreated from near the Wrekin, and Lake Newport to the N.E. united with L. Buildwas to form Lake Lapworth, which overflowed at 94 m at Gosall (8321) and eventually into the R. Trent valley, and also through the Iron-Bridge gorge at about the same level. Finally, the latter took the whole flow, and as a result there was further incision of the gorge and rejuvenation farther downstream, so that the course of the Severn drainage was fixed along this route.

Near Buildwas, the R. Severn now meanders on a broad flood-plain with a gradient of about 1 m in 3.2 km. From Iron-Bridge to Bridgnorth through the gorge, the gradient is 1 m in 1.6 km, and below Bridgnorth, it is 1 m in 2.6 km.

(EAF)

BUILDWAS

SJ 646040

The Buildwas Sands were regarded by Wills (1924) as having been largely deposited as marginal and deltaic sands in a lake which was overflowing through the Iron-Bridge gorge at a little over 91 m. Part of the deposit was regarded as having been laid down in Lake Coalbrookdale at a somewhat earlier stage, and a section in this at about 663039 formerly showed two masses of clean sand and gravel separated by about 18 m of clayey gravel and clay. This deposit rises to about 91 m and the sands may be followed to the bottom of the valley, so that the overall thickness should be about 40 m.

Wills figured a section from Buildwas Sand Quarry which showed nearly 15 m of sands containing "small chips of slate, shell-crums and occasional small seams of shingle". These were generally overlain by coarse gravel with blocks up to 0.76 m diameter and then by grey silts and sands. Towards the W. end of the section, the Buildwas Sands and the gravel were separated by a wedge of various relatively steeply dipping sediments including gravel, sand and silts, and also masses of boulder-clay with shell fragments and boulders, one of which was 14 m x 1.5 m. Wills explained the boulder-clay as due to deposition from floating ice.

At the time of a visit by the Quaternary Field Study Group in 1964, the sands were overlain by a grey stony clay with planar base, apparently a till. The sands were then seen to be characterized by trough cross-stratification,

and evidently fluvial in origin, rather than deltaic. Shaw (1972a) figured a 4 m section in fluvial dune cross-stratified sands overlain by a thin till and noted that the palaeocurrent direction trended directly towards the Iron-Bridge gorge, i.e. due E. Coope (in Shotton 1977) stated that the numerous cut and fill structures were probably the result of braided stream deposition, but braided streams especially in a glacio-fluvial environment commonly deposit extremely coarse sediments, as exemplified by the section in the Main Terrace Gravel near Eardington. The general absence of gravels in the Buildwas Sands may support a somewhat different sedimentary origin. Coope also refers to a former section immediately W. of the present quarry which exposed an ice-contact slope with sands, gravels and flow tills, an association reminiscent of the section figured by Wills.

The model proposed by Shaw (1972a) for other sequences in the Shrewsbury area involves a central linear zone of gravels and sands passing laterally outwards into a zone dominated by sands followed by a further zone in which silts appear. Shaw implies that the sands with large scale trough cross-stratification at Buildwas lie in one of these outer lateral zones, which would suggest that a gravel zone would have been deposited in the central part of the valley. The "occasional small seams of shingle" in the Buildwas Sands would then be the outer traces of the axial zone. Shaw also suggests that the streams depositing these sediments were laterally constrained by ice

walls, and this is consistent with a strong preferred orientation of palaeocurrents which also suggests low sinuosity meandering streams. Sedimentation in the finer zones became increasingly variable, and if this took place in an ice-contact environment, the formation of flow tills intimately associated with the gravels and sands could be accommodated by the model. The disappearance of this limiting ice could result in the association of marginal kettle holes.

Watts (in discussion of Wills 1924) noted that the base of the Buildwas Sands was "not shown (at 46 m) at Buildwas Station, and a record probably still exists of a considerable sinking into it below this level". Coope (in Shotton 1977) records that the sands have been proved by bores at the Electricity Generating Station between the quarry and the gorge to lie below the level of the bottom of the gorge. These considerations, together with the evidence of the mode of deposition, suggest that not only was flow through the gorge possible at the time, but that incision to at least the present level (and probably below this) took place before and not after the deposition of the Buildwas Sands. Shaw (1972a) argued that there was no evidence for the existence of a 91 m Lake Lapworth during the wasting of the Irish Sea ice, but that the gorge was filled to about 91 m by sediment which would have been rapidly eroded at a somewhat later stage. This conclusion, of course, raises further problems about the origin and chronology of other deposits and features in the area around and downstream of the gorge.

The Iron-Bridge gorge and the deposits down-stream and upstream of it have been considered at some length in this handbook, because there is evidently scope for discussion and some revision of accepted views. It is worth noting, however, that Wille mapped the deposits with great care, but in his paper, he was concerned to give "an attempt to explain the data", and fully realized "that parts of the record deserve further attention, and may be modified by subsequent work."

(EAF)

VENUSBANK, COUND

SJ 554057

The quarry at Venusbank exposes gravel and sand, which have also been proved in bores nearby. Shaw (1972a, b) has described the sedimentary association and structure in detail, and parts of the sequence can still be examined at the present time.

An axial zone of gravels lies through the centre of the locality. Though the basal sequence was not fully exposed, the upper 2 m of this comprised beds of alternating coarse and fine gravel which dipped at 30° towards 170° . Above an erosional surface were two fining-upwards units each with lower gravels and upper sands, the lower unit about 1.5 m thick, and the upper about 3.5 m. Up to about 22 m of gravels and sands were proved in this zone, the lower unit being interpreted as deltaic, and the sediments above this as fluvial, probably deposited here in low sinuosity braided channels. To the N.E., of the axial zone, the marginal deposits were proved in

bores to be largely silts and clays up to about 13 m in thickness, while to the S.W. the marginal deposits were proved to be largely sands, up to a thickness of about 35 m. These sands were faulted in places, and both normal and reverse faults were observed.

The present workings expose about 12 - 15 m of glacio-fluvial sandy gravels in a hole towards the N.W. end of the site, and gravels inclined southwards were recently visible just above water level in the disused part of the quarry. The marginal sands are seen in good sections which expose the upper part of the thick sequence.

Thus, in contrast to Buildwas, where the full association is as yet unproven, the sedimentary distribution at Venusbank clearly accords with Shaw's (1972a) model. The site lies approximately halfway between Buildwas and Radbrook Quarry near Shrewsbury, being about 10 km from each.

(EAF)

COUND to KEELE

The route passes close to the Wrekin (407 m) and The Ercall (265 m), and continues through Telford to Newport. From the road between Forton and Sutton, 2 - 3 km N.E. of Newport, the wooded ridges of the eskers near Aqualate Mere can be seen to the S.E. These eskers were described by Whitehead et al. 1927 and used with other deposits to infer former ice margins. The features have been discussed more recently by Worsley (1975).

(EAF)

The quarry currently in use in the Chelford area lies near Oakwood some 2 km SE of the Farm Wood Quarry (Simpson and West 1958, Coope 1959, Boulton and Worsley 1965, and Evans *et al* 1968), which is now landscaped and dedicated as a nature reserve. However, at Oakwood, the full succession down to bedrock is revealed. Fig.4 represents the stratigraphy based upon observations made over the five years of working up to late 1977.

(PW)

This quarry was referred to as Oakwood Quarry by Worsley (in Bowen 1977) and as Oakwood Sand Pit by Coope (in Shotton 1977). However, the owners designate it Acre Nook Quarry.

(EAF)

The sequence comprises (i) the Oakwood Till overlying Keuper Marl bedrock, (ii) the Chelford Sands Formation, (iii) the Stockport Formation.

(i) Oakwood Till

Debris brought up from below standing water during the excavation of the drainage sump consisted of unweathered Keuper Marl (Mercian Mudstone Formation) with typical salt pseudomorphs. No clean contact between the bedrock and the overlying till has been seen but the till is certainly at least 1 m in thickness and probably extends for a few metres below the quarry floor. The term 'Oakwood Till' is adopted here for informal use.

(PW)

The analysis of a bulk sample of the Oakwood Till shows that it is a very poorly sorted sandy till with few

clasts set in a deep red matrix. The fraction finer than - 1 ϕ comprises 60% sand, 24% silt and 16% clay. The till is mainly composed of the Keuper Marl on which it rests.

(MPL)

The till is commonly mantled by a layer of clasts, larger than pebbles and showing wind polishing and faceting, with glacial striations on some undersides. No palaeosol has been recognised at this horizon, which seems to represent a strongly eroded surface. The age of this till is not clear for it could be early Devensian or date from before the Ipswichian Interglacial.

(PW)

(ii) Chelford Sands Formation

The overlying sands are pebble-rich and generally reddish brown (5YR 5/4), probably being derived by fluvial erosion of till lying higher up slope. In marked contrast to the white sands above, they contain pebbles which are predominantly northern in origin and identical to those in the till below. These basal sands are a few metres thick at most but are persistent through sections in the quarry.

The reddish brown sands pass upwards into white (10.5YR 8/2) and pink (7.5YR 7/4) sands which are much better sorted and include clasts which are generally much smaller and less numerous. Sporadic pockets of clasts, when found, often lie in the bottoms of channels.

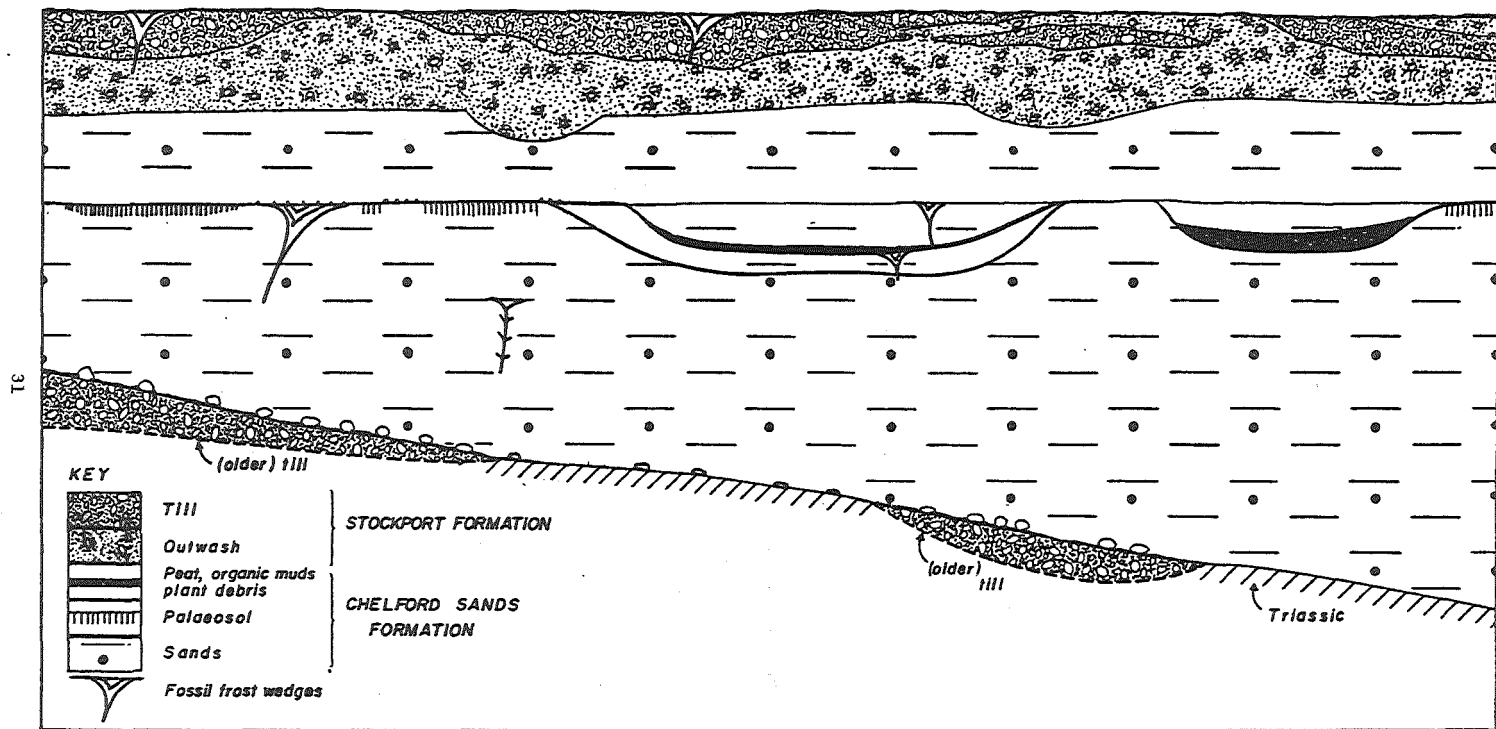


Fig. 4. Diagrammatic section of the succession in Acre Nook (Oakwood) Quarry.
The thickness varies from 7 m (left: S.W.) to some 20 m (right: N.E.).

Dispersed clasts are wind-faceted or polished. Up to a major break in sedimentation marked by a palaeosol and channels in the northern part of the quarry, the sands display dominantly horizontal stratification together with planar and trough cross-bedded sets. Above the disconformity and channel fill, clear cross-stratification diminishes and there are commonly only extensive planar bedding surfaces across the entire exposure.

The cross-bedding indicates a consistent westward transport direction and this is complemented by the clasts which are almost entirely sandstones and quartzites with only rare erratic material from sources to the north. Thus the sand was transported from the east and incorporated local material from the Permo-Triassic and Carboniferous outcrops. Possibly the sand was also derived from these sources but not necessarily at the same time.

It is now clear that the break in sedimentation was associated with marked erosion of the underlying sands and recently the face has provided a section almost perpendicular to the channel trend which showed the peat to be part of the fill of the channels. This is clearly important for palaeoecological interpretations inferred from the flora and fauna extracted from the organic materials. Only a single palaeochannel could be demonstrated up to August 1977, but then two separate channels became apparent with signs of a third. Although these channels were not in contact, the evidence suggests that they relate to separate incision events, with the southern example being the most recent. The channel fills, espec-

ially the youngest, reveal some complexity, for bedding indicates several phases of sediment infill. Along the SW margin, sediment appears to have moved into the channel from off the adjacent land surface but this is uncertain and lateral accretion within the channel is an alternative explanation. The main peat bed lies at a break between two of the phases of sediment fill and trees grew both in the channel bottom and on the side. The second channel seems to have been filled more catastrophically, for it is mainly occupied by an unbedded sand with dispersed wood and peat debris. This could result from a flood either climatically influenced (e.g. exceptional spring melt) or due to the breaking of a beaver dam. The latter has to be considered because occasionally tree stumps are found with pointed tops possibly from beaver gnawing.

Away from the channels, the corresponding land surface can be traced throughout most of the quarry and is represented either by a thin deflation-type pebble lag or a very thin organic mat with associated rootlets in situ and occasionally what seem to be burrow casts. When the channels had been filled, uniform sedimentation ensued without any significant erosion of the disconformity. The upper part of the Chelford Sands comprises parallel bedded sands with virtually no cross-bedding. Much of this material may be aeolian in origin.

(iii) Stockport Formation

The upper Chelford Sands are eroded by shallow fluvial channels which are filled with cross-bedded sands containing clasts of northern derivation. At the base, they are largely reworked Chelford Sands material but the degree of sorting and the percentage of exotic components decrease upwards finally culminating in till. Despite complex till/sand relationships this formation maintains a remarkable uniformity in thickness throughout the quarry. Though interfingering of till with sand suggests emplacement in part as flow till, this origin does not seem likely for all the till present. At one locality in the southern part of the quarry (now restored) a large clast was found at the till/sand interface under a 3 m thick till. Upon extraction the clast showed wind facets on the underside and glacial striations on the upper part where it had projected into the till, suggesting that the till had been deposited by lodgement from sliding ice.

Periglacial structures

Structures thought to relate to thermal contraction events and subsequent infill are seen at some places in the sections. Most appear to be former ice wedges but some of the thin examples in the Chelford Sands probably only represent minor cracking with little accumulation of ice. Below the disconformity within the Chelford Sands, crack structures are rare and no convincing ice wedge casts have been observed. A well-developed wedge

has been seen within a channel just below the main peat bed indicating a subaerial phase of some magnitude shortly after the channel had been cut. The deepest wedges lie at the horizon of the land surface contemporary with the channels. Since a wedge of similar size has been seen to penetrate the channels from the infill top it is possible that all the large features date from a period when the channels had become totally obliterated. This is supported by the fact that in no instance has the palaeosol been seen to extend across the top of a wedge infill. Above this horizon no wedges have been located until the present surface is reached. At the latter, wedge infills and involutions are locally present. Thus four separate phases of periglacial activity within the Devensian sequence can currently be identified, each of which probably necessitates the presence of permafrost.

Age of the organic materials

From palaeobotanical studies at Farm Wood, West (in Simpson and West, 1958) concluded that the most probable correlation was with the Brørup Interstadial of Denmark and suggested that the boreal forest of south Finland could provide a suitable analogue. Work on the fossil Coleoptera by Coope (1959) supported this, and also suggested that pools were present locally. Preliminary analysis of the Oakwood Coleoptera has revealed an identical fauna to that at Farm Wood (Coope, personal communication) and, together with the striking similarity of the Farm Wood sequence, suggests that the Oakwood

organic materials are of the same age. Both may lie within the same channel system since precise levelling data indicate that the two exposures are consistent with a single system falling to the NW. The radiocarbon age determination at Farm Wood therefore seems applicable to Oakwood and as such the Groningen assay of 61 ka (GrN - 1475) remains the best estimate of the true age.

(PW)

KEELE to WREXHAM AREA

Shortly after passing under the M6 at Little Madeley, a valley is crossed which meltwater reputedly occupied as the N. part of Lake Madeley, apparently held up by an ice margin which continued to the S.S.W. to lie against the Bar Hill-Woore Moraine (Yates and Moseley 1958). At Wrinshill, the hummocky Wrinshill Moraine, a slightly later stage, lies to the W. of the A531, and the morainic mounds consist of "complex sand and clay digitations".

In Nantwich, a bore (1883) proved 43 m of drift, and about 5 km W.N.W. of the centre, the Geological Survey's Burland Bore (6018.5333), which was drilled close to the A534, proved the following Quaternary sequence (Poole and Whiteman 1966):

	m
Boulder clay, brown sandy	3.7
Sand, very clayey	2.7
Boulder clay, brown and red	10.1
Sand, red-brown, with small pebbles	0.9
Boulder clay, red, stony	2.7
Sand, red, clayey	3.7
Contd. over	

	m	m
Gravel	0.9	
Boulder clay, grey and red	<u>2.7</u>	27.5
Clay, grey to black, silty, with plant remains, fragments of beetles, and stones	10.1	
Clay, red to brown, with stones (resting on brecciated Triassic mudstone)	0.6	<u>10.7</u>
		38.2

The age of the silty clay with organic remains is unknown, and though Shotton (1977) has acknowledged the possibility that it might be Hoxnian, there seems to be no reason why it should not be Ipswichian.

Around Faddiley and Ridley, Poole and Whiteman (1966) distinguish drumlines or drumlin-like features which appear to trend N.N.W. - S.S.E. To the W., the A534 passes between the Peckforton and Bickerton Hills, composed of Triassic rocks and forming part of the mid-Cheshire ridge. A further Triassic ridge is crossed at Clutton, and Triassic rocks are exposed by the R. Dee at Farndon. From Holt, the B5102 to Rossett passes farms such as Lodge Farm, Hem House and Ithells Bridge Farm, where bores prove the level of the bedrock surface to be at about -24 to -26 m O.D. apparently on the floor of the R. Dee buried valley. The N.E. margin of the feature known as the Wrexham Delta-terrace rises 2.5 km to the W.

(EAF)

WREXHAM AREA

According to the Wrexham Memoir (Wedd et al. 1928), the Irish Sea ice-sheet occupied the Carboniferous and Triassic ground to the E., while the Welsh ice-sheet spread over the Lower Palaeozoic upland to the W. so that the two met almost at right-angles along a line passing through Minera some 6 km W. of the centre of Wrexham. Later, the Irish Sea ice retreated to the N. and dammed drainage to the Irish Sea thus forming a lake (Harmer 1907), while the Welsh ice formed valley glaciers.

Wedd et al. distinguished thick drift associated with an Upper Boulder-Clay plain along the valley of the R. Dee and the gently rising plateau to the W. Although locally stony, the Upper Boulder-Clay was said to be generally free of stones, but contained wisps and thin beds of sand and sporadic fragments of marine shells. Clays ascribed to the Upper Boulder-Clay were thought to be largely lacustrine and deposited in the lake formed during the retreat of the Irish Sea ice northwards. The Lower Boulder-Clay, in contrast, was described as a hard red or grey till with numerous stones, commonly local, but including erratics from the Lake District (abundant Eskdale granite) and S. Scotland, together with fragments of marine shells. Between these two clays lay a variable thickness of sand and silt, also with shell fragments (Middle Sands of other authors). Large spreads of gravel and sand,

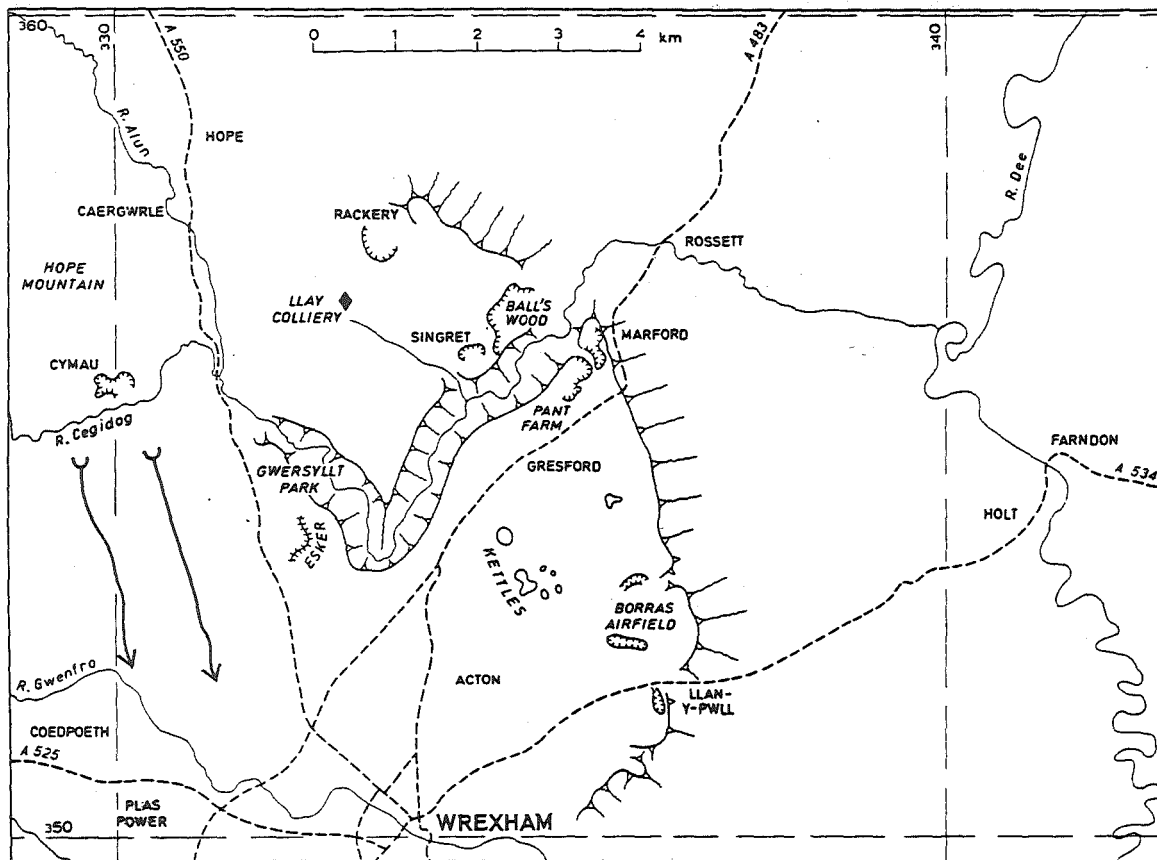


Fig. 5 Map of the area north of Wrexham.

commonly in the form of "rough terraces", such as that near Wrexham, were thought to be probably more or less contemporary with the Upper Boulder-Clay, and the fact that they included large quantities of Welsh material indicated that deposition was largely carried out by meltwaters from the Welsh ice-sheet, though it was noted that there was an admixture of northern material.

The concept of Lower Boulder-Clay, Middle Sands and Upper Boulder-Clay was presented by Hull (1864), although Binney (1848) had previously described the same area around Manchester in terms of a much more variable sequence. The Manchester Memoir (Tonks et al. 1931) noted later that a tripartite division was rarely recognizable there, and that "the variable series of sands and clays recorded can usually be correlated in several different ways, all of which may appear equally rational". Nevertheless, Poole and Whiteman (1961) stated that Tonks et al. (1931) "confirmed the presence of the threefold sequence reported by Hull (1864)", and applied the concept throughout S. Lancashire, Cheshire, Shropshire and beyond.

Whereas Wedd et al. (1928) considered that the deposits could be referred to a single advance and retreat of the ice, Poole and Whiteman (1961) concluded that the Middle Sands represented the retreat of Lower Boulder-Clay ice, that the "terraces" (interpreted by them as moraines) were not contemporary with the Upper-

Boulder-Clay, but were actually Middle Sands, and that the Upper Boulder-Clay represented a new advance of the ice from a maximum limit of retreat beyond the Carlisle plain and the margin of the Lake District. This Upper Boulder-clay ice filled the Shropshire-Cheshire basin, having overridden the Middle Sands features with only slight modification, presumably because these were deeply frozen at the time. During its retreat, this ice impounded lakes including Lake Lapworth, though the possibility was recognized that initiation of the Iron-Bridge gorge may have taken place during the retreat of the Lower Boulder-clay ice with the formation of a lake standing at about 91 m, as L. Lapworth did at the later stage. For Poole and Whiteman, there was no doubt that the Upper Boulder-clay of the Wrexham district rested upon the sands and gravels of the feature referred to by Wedd et al. (1928) as the Wrexham Delta-terrace (e.g. Poole, in discussion of Peake (1961), refers to this as "a geological fact").

Wedd et al. (1928) used the name Wrexham Delta-terrace to refer to a large spread of gravel and sand with a surface diversified by kettle-holes and by mounds resembling kames or eskers. The Wrexham Memoir, although published in 1928, had references to exposures of glacial deposits seen in 1910, and much of the survey of the delta-terrace was apparently carried out by Wills himself at that time. There is an implication

in the memoir that the feature was associated with the lake covering much of Shropshire and Cheshire and impounded by the Irish Sea ice-sheet to stand at about 91 m with an overflow through the Iron-Bridge gorge - L. Lapworth of Wills (1924). The term "delta-terrace" is not explained in the memoir, but the conception seems to be composite: it is referred to as an outwash terrace, which would imply subaerial glaciofluvial processes; it retains glacial features such as kames, kettles and an esker on its irregular plateau-like surface, which would imply deposition in contact with ice; sections show intercalation of boulder-clay with its sands and gravels, and because these upper clays were thought to have been probably deposited in a lake, the feature has lacustrine associations; the surface level approximates to the inferred level of the lake, which also suggests a lacustrine association; the extreme eastern edge is referred to as the escarpment of the delta, i.e. the delta-front, which implies progradation into standing water, again consistent with the inferred existence of a lake. It has already been noted that the meltwaters chiefly responsible for deposition were attributed to the Welsh ice-sheet during its retreat westwards.

Peake (1961) concluded that the delta-terrace was built up in a marginal lake, rather than in association with the much more extensive body of water accepted by the authors of the Wrexham memoir. She visualized the withdrawal eastwards of the Irish Sea ice from Hope

Mountain (Fig. 5) so that water drained southwards via Caergwrle and transported outwash to deposit deltaic gravels in a narrow lake. This lake was dammed by the melting Irish Sea ice whose W. margin at this stage is marked by a line of mounds through Gwersyllt Park, including a ridge described by Lamplugh (in Wadd et al. 1928) as an esker. The ice withdrew further to the E. to a line marked by Kettles (Fig. 5), drainage continuing towards the S. along the ice margin though at a somewhat lower level. The third stage inferred by Peake (1961) was a further withdrawal to the line of the Marford escarpment, which she interpreted, not as a delta-front, but as an ice-contact face, the marginal drainage now changing direction from southward to northward.

In a contribution to the discussion on Peake's paper, Whiteman wrote that the delta-terrace was neither typically deltaic nor terrace-like, but morainic in character. This opinion was also advanced in Poole and Whiteman (1961), the sands and gravels being referred to as "true morainic outwash deposits" at the W. end of the moraine extending across the Shropshire-Cheshire basin from Bar Hill through Woore and Whitchurch. Consequently, the E. escarpment was regarded again as a former ice-contact slope. Whereas Peake derived the bulk of the sediments from the N. and interpreted them as deltaic, Poole and Whiteman derived them from the E. and interpreted them as

moraine outwash. Worsley (1970) considered the feature to be "an excellently developed ice marginal lateral terrace", the escarpment again being interpreted as an ice-contact slope.

The descriptions by these various authors of the form taken by the delta-terrace point up some significant contrasts in the application of the concept by which each interprets the feature. According to Peake (1961), the surface slopes gently eastward from 91 - 61 m and ends in a 30 m escarpment. According to Poole and Whiteman (1961), meltwaters graded outwash to a lake at about 91 m, while Worsley (1970) refers to a generally flat upper surface at approximately 90 m, terminating in an escarpment up to 45 m high. All authors, of course, note the presence of kettle holes.

The boundaries of the Wrexham Delta-terrace are rather difficult to define to the N. and S. However, it is approximately 10 km from N. to S. and 6 km from W. to E., covering an area of some 45 - 50 sq km. Much of the surface has an average height of about 70 m with elongate low and broad ridges rising to a little over 75 m and hollows falling to a little below 69 m, exceptionally to 60 m. The W. margin rises to about 100 m and the area N.W. of Llay Colliery also rises to that level. The escarpment is at its steepest around Marford where it reaches $9 - 10^{\circ}$, while at the extremities near Borras Airfield and Rackery, it is $2 - 3^{\circ}$.

33
24

Around Llay, the gravels and sands, 27 - 40 m thick, overlie till, 10 - 17 m thick, and are in turn overlain by an upper till up to about 8 m thick. The latter is referred to as Upper Boulder-Clay by Wedd et al. (1928) and Poole and Whiteman (1961). However, Peake (1961) considered that the regional Upper Boulder-Clay underlay the sands and gravels of the Wrexham Delta-terrace, and therefore that the upper clay at Llay must be due to a resurgence of ice which she named the Llay Readvance.

There are several excellent exposures in quarries in the Wrexham area, and the character and disposition of the sediments exposed in them can be used to support or deny the validity of the varied conclusions reached by previous authors.

Singret Quarry (343559)

About 30 m of gravels, sands and stony clays are exposed. The greater part of this sequence comprises gravels and sands dipping generally towards E.N.E., with an upper layer of gravel, some 4 - 7 m thick, unconformably overlying the lower beds. The more steeply inclined beds are widely exposed, but the faces are steep and dangerous, so that it is not an easy matter to carry out comprehensive measurements of the attitude of these deposits. The general impression is that dips are commonly less than $10 - 12^{\circ}$, but rise locally to about 15° . The general inclination seems to be much more regular in sections parallel to the dip.

Sections transverse to the dip show that lateral continuity is interrupted, and therefore the sedimentary units are lenticular with long axes generally disposed parallel to the dip. Locally, stony clays are seen, and one of these has been seen to form a sheet with planar base overlying sands which have been stressed apparently by the weight of the superincumbent layer, giving rise to complex subhorizontal or gently dipping transposition structures. This quasi-solid behaviour under load is interpreted as a response to the emplacement of the overlying bed by mass movement. In another section, apparently similar stony clay filled to overflowing a steep-walled channel cut into sands and gravels so that the upper surface of the till lay at a higher level than the shoulders of the channel and the stony clay wedged out laterally on each side.

The deposits are interpreted as having been laid down by periodic or discontinuous floods on the surface of an aggrading subaerial fan. The incision of the channels, typically steep-sided, may be taken to indicate that this quarry is situated in a relatively proximal part of the fan above the intersection point, and the poorly sorted stony clays are analogous to the debris flows seen on arid-region alluvial fans (see e.g. Hooke 1967).

Following the construction of the fan, the upper surface was subject to erosion, and the overlying gravel was deposited by shallow streams on the surface

of erosion as a broad sheet, though this seems to wedge out in the extreme E. part of the quarry. The gravel in the W. part of the quarry near the processing plant has a stony clayey band at the base and this was sampled for particle size analysis (S.1).

(EAF)

The sample(S.1) from Singret Quarry is extremely poorly sorted. The fraction finer than -1ϕ is composed of 40% sand, 30% silt and 30% clay, the silt/clay ratio therefore being 1.00. The heavy minerals are tabulated on pp. 94-95.

(HD)

Rackery

The sand pit (332571) near Rackery has been known as Astbury's Sand Pit, but a geographical name is preferred here, especially as it is apparently changing hands. According to Peake (1961), it opened in 1958 and then showed 12 m of clean red sand, with bedding horizontal or dipping north-eastward at a very low angle, overlain by loamy brown till, up to 4.5 m thick, with boulders of Carboniferous Limestone and Cefn-y-fedw Sandstone and also northern erratics. This till was regarded as having been laid down by the Lley Readvance of the Irish Sea ice-sheet.

The section at present on the rear face trending N.W. - S.E. shows a similar thickness of red-brown sand, locally somewhat gravelly, but generally characterized by ripple cross-stratification or parallel bedding.

At some places, trough cross-stratification is also present, especially in the upper part of the face. In a low face in the central part of the pit, excellent climbing ripples can be seen. The sedimentary structures indicate a mean direction of current flow towards N.N.E./N.E.

Good sections of the till are seen in small re-entrants adjacent to the egress of field drains. The thickness ranges between 3.3 and 4.7 m, and includes bands or lenses of sand. An exposure at the S.E. end of the face is as follows:

	m	m
Soil (A 0.20m, B 0.05m)	0.25	0.25
Till	0.75	1.00
Gravel, sandy	0.80	1.80
Till, dark red brown	0.12	1.92
Till, dark grey, sample L1, weathered to chocolate brown on surface, largest clast seen: 9 x 7 x 6 cm	0.62	2.54
Till, dark grey, with laminae of red brown and yellow sand, with curvilinear trace giving appear- ance of shallow festoon.	0.30	2.84
Clay, sandy, gravelly, silty, becoming more sandy at base, largest clast seen: 10 x 8 x 6 cm	0.45	3.29

	m	m
Sand, brown	0.10	3.39
Gravel, with some mud balls	0.45	3.84
Gravel, brown, sandy, largest clast seen: 100 x 80 x 66 cm	1.10	4.94
on Sand, red-brown		

A section towards the N.W. end of the face demonstrates
a division into three sub-units separated by sand:

	m	m
Soil (A 0.24m, B 0.10m)	0.34	0.34
Till (sample U2) containing sandy wisps and a sand lens 12 cm long x 3 cm thick between 1 m and 1.5 m from the top	1.65	1.99
Sand in continuous band	0.09	2.08
Till (sample U3)	0.60	2.68
Sand, cross-bedded, with coal	0.25	2.93
Till (sample U4)	0.80	3.73
on Sand, brown		

(EAF)

The composition of fractions finer than -1 ϕ for
the four samples from Rackery is shown below:

	L1	L2	L3	L4
Sand%	44	46	47	62
Silt%	27	28	27	18
Clay%	29	26	26	20
Silt/Clay	0.93	1.08	1.04	0.90

(MPL)

The interpretation adopted here is that the sands with current ripples were deposited on the distal flank of an alluvial fan supplied by meltwater from ice lying to the S.S.W./S.W. Lobate sheets of flow till (debris flows) accumulated over the relatively smooth surface of the fan, and on their upper surfaces; small ephemeral streams sorted and deposited thin bands and lenses of sand or occasionally sandy gravel. The invocation of a readvance seems unnecessary.

(EAF)

Gwersyllt Park

If time permits, a detour may be made to the W. side of the area to see the ridge of gravel between 3220.5394 and 3210.5350 identified by Lamplugh (in Wadd et al. 1928) as an esker (Fig. 5) and "one of the most striking glacial features of this area". It is gently sinuous with the S. end curved to the W., and is 550 m long, between 12 and 18 m high and has a basal width of about 45 m. The 84 m contour is drawn along the foot of the entire W. flank and along the N. half of the E. flank, demonstrating that the base of the ridge pursues an essentially horizontal course. An area of sand and gravel about 850 m x 650 m has been worked immediately to the N. and some human interference with the ridge itself has taken place, but it remains a clearly marked feature.

(EAF)

Marford and Pant Farm

25
- 19

Sections of disused faces at Marford and Pant Farm quarries (Figs. 6, 7) have been drawn from photographs, followed by checking and adjustment of the drawings at the sites.

(HD)

Much of the lower part of the face at Marford is obscured by spoil, so that a maximum of about 11 m is exposed, though the face probably cut through some 30 m of deposits.

Marford Quarry (358558) lies immediately behind the eastern slope of the Wrexham "Delta-terrace". The face depicted on Fig. 6 strikes at approximately 323° in its S.E. part (Fig. 6, B-D) but to the N.W., it curves round to about due N. (Fig. 6, A-B) and then to N.E. The S.E. part is a strike section and the beds have a general dip up to a maximum of 9° towards 43° , so that the N. - S. trending part of the face is a section oblique to the dip.

At about 450 m to the S.W. (3555.5545), a face (Fig. 7) in Pant Farm Quarry, now largely obscured by landscaping, showed up to about 10 m of beds though not in full continuity. The trend of the face was about 43° , and measurements showed dips of $6 - 8^{\circ}$ towards points between 35° and 47° (mean: 40°). Thus, the quarries at Marford and Pant Farm show sections parallel to the strike and dip respectively. As at Singret, the dip section suggests greater continuity of the strata,

while the strike section emphasizes lenticularity. All beds are subject to rapid lateral change and there is great variability in grade of sediment. Medium gravel is a prominent feature of the sequence, but coarse gravels and fine sands are also present.

The units referred to as clays are particularly variable, and it must be stressed that this term is adopted merely for convenience in the field. These units are in places laminated, elsewhere cross-bedded or slumped, or even composed entirely of clay balls. Their representation on Fig. 6 is wholly diagrammatic and the clay ornament implies merely admixture, not the precise disposition of specific subunits.

(EAF)

Three samples of material were collected from bands with clay admixture at Marford Quarry:

M1: from the inclined band of mixed sand and clay towards the left side of Fig. 6 B-C,

M2: from the central part of the humped band at the top of the right side of Fig. 6 A-B,

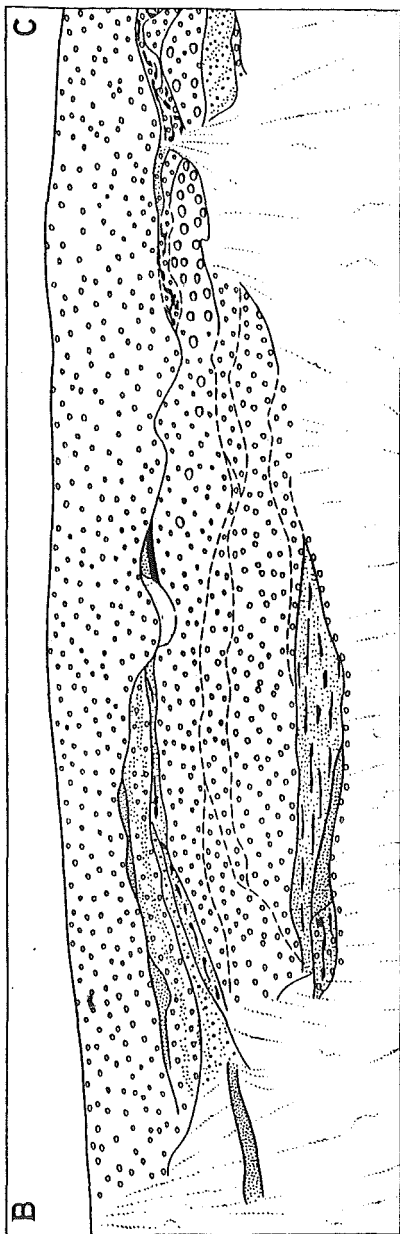
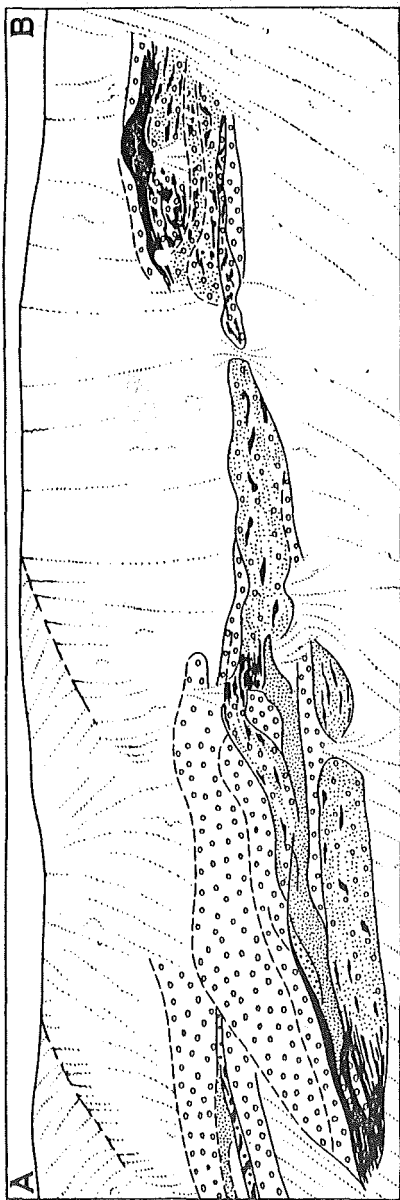
M3: from the lower left side of Fig. 6 A-B.

Analyses of the fraction finer than -1ϕ yielded the following results:

	M1	M2	M3	Silt/clay
Sand%	43	33	27	1.04
Silt%	29	34	37	1.03
Clay%	28	33	36	1.03

Details of heavy minerals are given on pp. 94-95.

(HD)



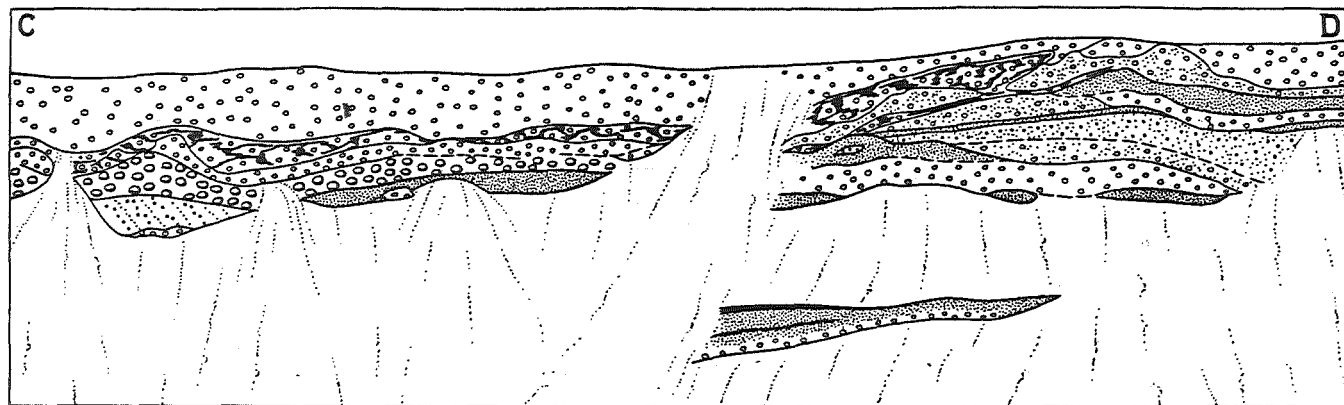
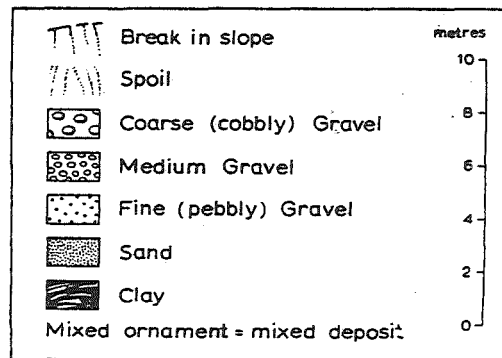


Fig. 6 Section of the face at Marford Quarry.



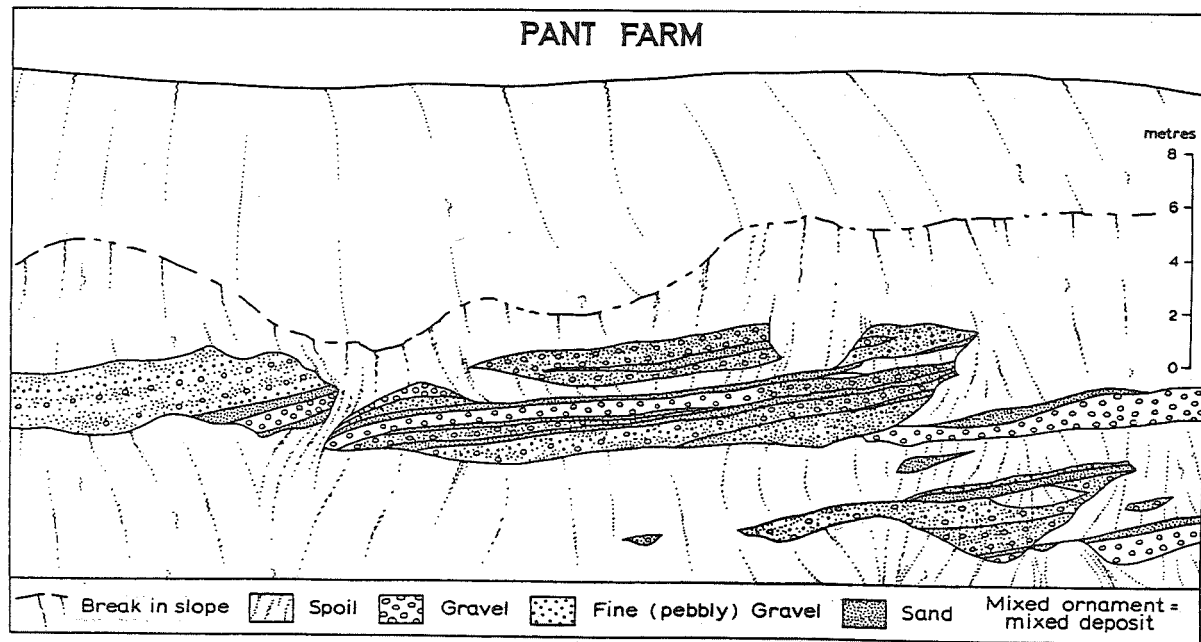


Fig.7 Section of the face at Pant Farm Quarry.

The sections at Marford and Pant Farm quarries show features which are more appropriately explained as a consequence of accumulation on a subaerial fan supplied by glacial outwash. The extreme lateral and vertical variability of the sedimentary sequence is typical of an alluvial fan, and the bands of clayey material, formerly thought to be lacustrine, can be interpreted as debris flows. The inclination of foresets on a delta-front is generally the result of avalanching and consequently dips are normally high, commonly between 15° and 30° and exceptionally up to 40° . The inclination of beds on an alluvial fan is generally less than 15° and commonly $5^{\circ} - 8^{\circ}$. Thus, the attitude of the beds in the exposures around Gresford is consistent with the interpretation advanced here and inconsistent with a deltaic origin. The maximum slope of the escarpment at Marford corresponds with that of the underlying beds seen in Marford Quarry, and can thus be explained as constructional, without resorting to deposition in contact with ice for which no evidence is available. The evidence of depositional directional structures indicates transport towards the N.E. and this does not accord with what would be expected if sediments were being derived from an adjacent ice margin to the N.E. The reconstructions of ice melting advanced by Poole and Whiteman (1961), Peake (1961) and Worsley (1970) are inadequate to explain the evidence revealed in the available exposures, whereas this is accommodated satisfactorily by the interpretation

presented here.

(EAF)

Llan-y-pwll

Flood's Sand Pit (365516) near Llan-y-pwll exposes up to about 10 m of sand with impersistent layers of clay, which Worsley (1970) regards as "indicative of deposition into a lake", and Poole and Whiteman (1961) consider to be an example in accordance with their contention that Upper Boulder-clay is proved "beyond doubt" to rest upon "Middle Sands around the margin of the Wrexham-Gresford sand-belt".

However, the sands can be interpreted as deposited on the southern flank of a subaerial fan to complement those seen on the northern flank at Rackery. The clays near the quarry entrance closely resemble those seen at Marford, and the others in the present working face are thin and impersistent and were apparently highly mobile mud flows like those seen at the present day on the distal parts of fans.

At Borrass Airfield, workings expose an upper layer of gravel some 7 m thick and resembling that seen at Singret. This overlies unconformably a sequence of sands with clay beds (proved in bores) which are evidently comparable to the similar sequences exposed elsewhere. Current flow indicators in this E. part of the Wrexham area point to transport directions of E.S.E. at Borrass and S.E. at Llan-y-pwll. There is thus a fanning

of transport directions around the feature, which is again consistent with formation as an alluvial fan. Lines of kettles and ridges across the fan mark ice-contact borders but the ice was on the W. side of these and not on the E. as supposed by other authors.

(EAF)

BANGOR-IS-Y-COED

A road-cutting (393451) to by-pass Bangor-is-y-coed and provide a new crossing of the R. Dee exposed an upper sheet of clay-silt with very few clasts, 3 - 4 m thick, overlying a layer of silt, 0.60 - 1.00 m thick, showing convolute lamination, resting in turn upon 1 m of clay-silt with very few clasts, underlain by sand to at least 0.31 m. These clay-silts are undoubtedly glacial but their classification as tills is a matter for discussion,

(EAF)

Analysis of samples of the upper clay-silt revealed a silt content of 54% and clay content of 46%, while the lower clay-silt was composed of 7% sand, 50% silt and 43% clay.

Samples of each clay-silt were compressed in an oedometer. The resulting plot of void ratio (a measure of porosity) against the logarithm of the pressure (Fig. 3) shows that the two layers have similar initial void ratios, but that the lower is less compressible under a given load. The curves are roughly parallel indicating similar relative response to pressure increments. The upper layer has a preconsolidation value of about 36 kN/m^2 whereas the lower has a value of 72 kN/m^2 , both values corres-

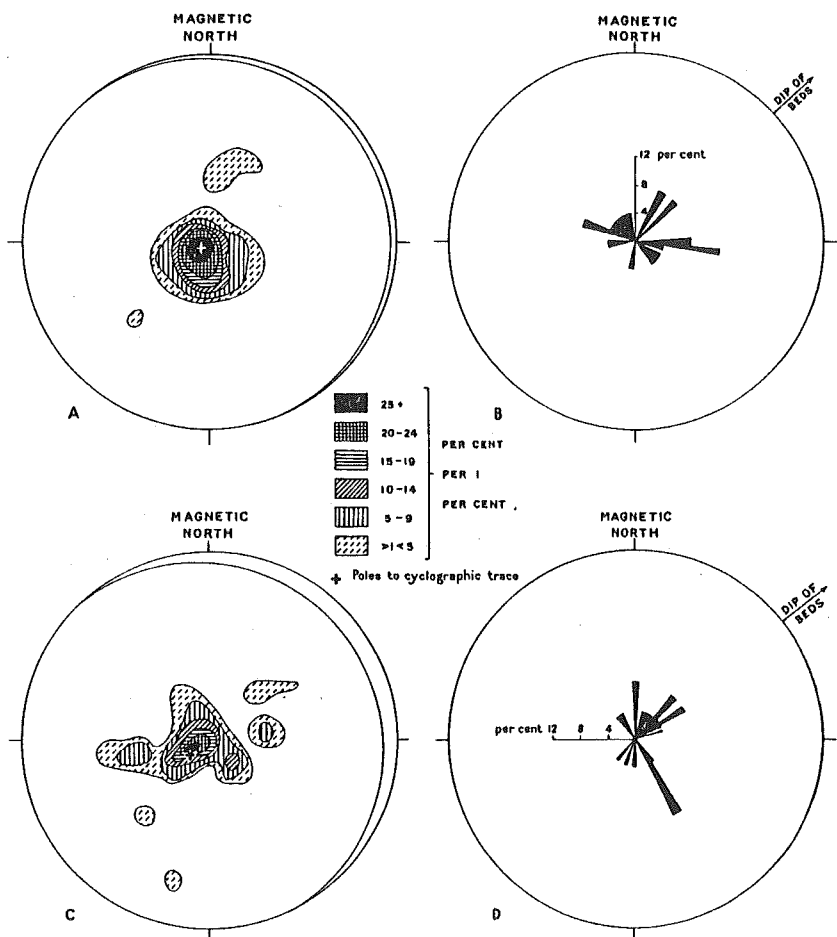


Fig. 8 Selected fabric parameters from the road cutting at Bangor-is-y-coed. A- poles to a/b planes of clasts; B- long axis azimuths of clasts; C- principal joint sets, lower clay-silt; D- principal joint sets, upper clay-silt.

ponding to the present overburden pressure. Hence neither layer is overconsolidated. This, together with the frequent occurrence of silt lenses in the upper layer and sand lenses in the lower, suggests that these silts may not be lodgement tills at all.

Seven cylindrical samples, $1\frac{1}{2}$ in in diameter and 3 in long, were compressed in a portable unconfined compression machine. A plot of peak unconfined compressive strength against field moisture content (Fig. 3) shows the normal inverse relationship.

(MPL)

The Bangor deposits are clay-silts with some sand and sporadic clasts, amongst which quartzite and coal are prominent. The clay-silts are massive in hand specimen but freshly broken samples appear to be very finely laminated (laminae 0.2 - 1 mm) when viewed at $\times 40$ - $\times 80$. Contortions of some laminae may be seen and also minute flame structures. Confirmation of the general presence of very fine lamination in these silts must await examination by thin-section and scanning electron microscope.

The clast fabric of the lower stony clay-silt is very diffuse (Fig. 8B). There is no clearly preferred long axis orientation, two-dimensional vector magnitudes being extremely low (3.7 in a range where 0 is totally dispersed and 100 is totally clustered). The two-dimensional vector magnitude of the a/b plane fabric (Fig. 8A) is rather higher (26.7: mean direction 120°). This may be compared with vector magnitudes of 31 - 37 in freshly-deposited subglacial meltout tills in Norway. However,

the three-dimensional fabric strength is very low indeed and of an order (12%) comparable to the lowest fabric strengths found in subglacial meltout tills and glacially remoulded (dilated) tills.

Taken together, the sedimentological properties of these stony clay-silts cast doubt on their classification as tills. However, they display a well-developed joint or fissure fabric of a type found in drumlinized tills and glaciallacustrine clay-silts elsewhere in Britain. The principal fissures, shown in simplified form (Figs. 8C and 8D), consist of a subhorizontal set (H1) and a conjugate pair of subvertical sets (V1, V2). The sub-vertical sets are commonly coated with translocated clays ('clay skins') but these are rare on the subhorizontal fissures. The subhorizontal fissure sets broadly conform with the surface slope of the feature (here interpreted as a drumlin) at the sample sites (203° for the upper, 293° for the lower clay-silt: Figs. 8D and 8C respectively), and they are interpreted as unloading joints. Subvertical fissure sets in matrix-dominated till and lacustrine sediments have been shown to lie conjugately about the former ice movement direction as determined from independent evidence. At Bangor-is-y-coed, the bisector of the subvertical fissures in the lower clay (Fig. 8C) is $143^{\circ}/323^{\circ}$ and in the upper clay (Fig. 8D) is $153^{\circ}/333^{\circ}$. These azimuths closely parallel the drumlin axis at Bangor. Accordingly, it appears that the clay-silts have been overridden from W. of N., perhaps following initial deposition, though without evident overconsolidation.

(ED)

BANGOR to KEELE

The route returns via Whitchurch and Audlem and traverses a gently undulating plain upon which Poole and Whiteman (1961) have mapped linear moraines. The tracing of these may involve the joining of discrete features, and there are often various ways of accomplishing this. However, at Woore, the route joins the more prominent and continuous ridge between Woore and Bar Hill. The area around this has been studied in detail by Yates and Moseley (1967), who interpreted the ridge as marking the terminal position of an ice advance, probably about 20,000 years ago. Boulton and Worsley (1965) had previously stated that the ridge extending from Bar Hill through Whitchurch to Wrexham must belong to the maximum of the last glaciation, though Poole (1966) in reply wrote that it had been clearly demonstrated that this "moraine suite is considerably older than 40,000 years and cannot be a product of the last or late Weichselian Glaciation". We now know, of course, that neither of these conclusions is correct.

Boulton and Worsley (1965) distinguished different depths of leaching to the N. and S. of the ridge, concluding that greater depths to the S. implied a considerably greater age, and consequently that the drifts to the N. and S. did not belong to the same drift sheet.

(EAF)

A trend surface analysis of the eleven data points given by Boulton and Worsley (1965) does indicate greater depths of decalcification in the surface till to the S., but a simple linear surface sloping southwards accounts for over 65% of the variance of the data. An F test indicates that this result is significant at the 95% level. Since more than one measurement was made by Boulton and Worsley at some of the localities, another trend surface was computed with each locality weighted according to the number of readings made there. These 63 observations also gave a first order surface which explained 65% of the variance of the data. An F test indicates that this result is significant at the 99% level. Hence, as a first approximation, it can be argued that the depth of decalcification varies fairly evenly across the ridge, a result that may be due to factors such as systematic parent material variation.

A plot of residuals from the simple linear surface indicates that 4 out of the 6 locations north of the ridge, while only 1 out of 5 to the south, show positive anomalies. This result is analogous to that found by Rodda (1970). Hence, as a second approximation, the possibility of a threshold existing must be borne in mind. Assuming that depth of decalcification does accurately reflect the age of a till sheet, the only means by which this problem may be resolved is the collection of more data.

(MPL)

At Bar Hill, the ridge is seen to be founded on Triassic sandstone. At Madeley, to the E., the route crosses the Madeley Basin which lies at the northern end of the Whitmore Trough.

(EAF)

KEELE to SHREWSBURY

At Baldwin's Gate (795403), the A53 crosses the S. end of the Whitmore Trough (Yates and Moseley 1958). This has a surface cover of peat locally overlying plastic clay, which rests in turn upon sand, the total fill being of the order of 46 m in depth. It has been suggested that this and other similar troughs represent former valleys which existed before the last glaciation, and were then utilized by meltwater during deglaciation.

After passing the Maer Hills composed of Triassic rocks, the A53 crosses (769387) a headwater of the R. Tern, about 3 km W. of the watershed between the Severn and Trent drainage systems. Though this is a broad flat-bottomed valley superficially somewhat resembling that at Baldwin's Gate, it is cut in bedrock (Gibson and Wedd 1925). Between the Triassic hills at Loggerheads and Hodnet, the road passes close to the R. Tern around Market Drayton, and the R. Roden is crossed at Shawbury.

In Shrewsbury, between Ditherington and the centre, the axial line of a deep buried valley is crossed and the floor has been proved to lie at -28 m O.D. at least. The buried valley continues through this area from near Cound close to the course of the R. Severn and then is thought to trend N.N.W. to join the buried valley of the R. Dee near Ellesmere.

(EAF)

SHREWSBURY

The Quaternary deposits around Shrewsbury were described by Pocock et al. (1938), and correlations over a wide region including this were advanced by Poole and Whiteman (1961). More recently, a detailed study of the area between Ellesmere and Iron-Bridge has been carried out by Shaw (1971, 1972a, 1972b).

An important section (476110) lies 2.5 km S.W. of the centre of Shrewsbury. Recent publications have referred to this as Mousecroft Lane (Worsley 1970, Shaw 1971, 1972b), but the correct name is Radbrook Quarry. Poole and Whiteman (1961) give a section measured in 1957:

	m	m
(6) Soil, brown, clayey	0.3	0.3
(5) Boulder-clay, yellow-brown, abundant small stones, Welsh erratics; contorted at base	2.7	3.0
(4) Silts, light yellow-brown, occasionally banded and lenticular; top contorted	0.3-0.6	3.6
(3) Gravel, grey, coarse, with large boulders in a sandy clay matrix, numerous Irish Sea erratics	3.7	7.3
(2) Clay, red-brown, stiff, gravelly, occasional sand pockets, roughly laminated, passes laterally into bedded gravels in S.E. corner of pit.	7.6	14.9
(1) Sand and gravel, red-brown and grey, coarse bands of gravel and thin laminated brown clay, markedly current-bedded on a large scale	8.5	23.4

Units (1) to (4) were interpreted by these authors as due to the melting of an ice-sheet carrying predominantly Irish Sea erratics, and the overlying boulder-clay (5) was regarded as due to Welsh ice contemporaneous and confluent with a later Irish Sea glacier. Worsley (1970) referred to Welsh tills and outwash gravels exposed in this quarry, and Shaw (1971) stated that the "upper till and sands and gravels are primarily of Welsh origin". In spite of the presence of northern erratics in the gravels (3), Shaw considered that these "were almost certainly deposited in a pro-glacial braided stream complex by melt waters from the advancing Welsh ice". It is interesting to note that different observers concluded that a particular deposit had an almost totally different provenance as a result of their different assessment of the erratic content as being "predominantly Irish Sea" or "primarily of Welsh origin".

Shaw's conclusions (1971, 1972a, 1972b) were that up to 21 m of gravel and sand were deposited in a central sequence, which passed laterally into sands with dominant trough cross-stratification, passing in turn into alternating sediments with horizontal stratification, small scale ripple cross-stratification, and parallel stratified silts and clays. The latter were proved to a thickness of 20 m in the Conduit Head bore (Shotton 1962), which was drilled at a waterworks pumping station (472111) about 200 m W. of the W. extremity of the present quarry. The association is in accordance with Shaw's (1972b) model of accumulation in a channel walled by ice which prohibited

the lateral migration generally regarded as a feature of normal non-glacial streams. As the ice-walls melted back, ablation till would be released and would form flows on to the glaciofluvial deposits. These flow tills would also be subject to burial as a result of continued glaciofluvial sedimentation. Some of the ice was also buried and did not melt until after the later Welsh ice had begun to waste away, so that the whole of the upper part of the sequence was subject to subsidence which produced the marginal kettle holes. According to Shaw (1971), the stratified silts (4) are lacustrine sediments and he concludes that the overlying till was deposited into a lake either by flow or by squeezing of saturated basal till. However, some laminae were observed to overlie a till lens and to dip at 50° , and Shaw therefore invoked incorporation of lacustrine sediments into the base of the advancing ice which transported them as a debris band. From this, he inferred that the overriding Welsh glacier was of the polar type.

The present exposures lie on a relatively shallow face extending for 100 m in a S.W. - N.E. direction, and on an adjacent face some 300 m long extending in a N.W. - S.E. direction, which are referred to here as the N.W. and N.E. faces respectively. At a point (4743.1117) on the N.W. face, two sections of the upper till 3.75 m apart were measured:

(i) Soil (A_1 0.08 - 0.10 m, A_2 0.20 m, B 0.30 m)	^m 0.60	^m 0.60
Till, pinkish brown, (Sample R1)	3.65	4.25
Gravel		

	m	m
(ii) Soil (A_1 0.10m, A_2 0.30m, B 0.30 m)	0.70	0.70
Till, pinkish brown (Sample R2)	3.30	4.00
Gravel		

Samples (R1 and R2) were taken from 0.50 m and 1.9 m respectively above the base of the till. At a point (4756.1109) on the N.E. face about 180 m S.E. of the intersection of the two faces, the upper part of the section was measured as:

Till, pinkish grey with soil at top	m 2.3 - 2.5
Gravel, grey	2.5
Till, brownish red, with 20 cm purple band between 1.55 and 1.75 m from top	+ 3.5
Samples were taken from the purple band (R4) and from the 20 cm (R3) immediately below it.	

At a point (4761.1103) about 75 m farther S.E. at the top of the face, a gently curved re-entrant provides an exposure of the deposits overlying the grey gravel. The structure of these upper deposits is complex, but a brownish-red band about 0.55 m thick slopes across the face with an apparent dip of about 5° towards the S.E. A sample (R6) was taken from this band. An overlying reddish-brown till forms a wedge thickening from 0 to 0.75 m towards the S.E. under the soil (A_1 0.12 m, A_2 0.15 m, B 0.35 m, total 0.62 m). Below the sloping band, the basal sequence of the deposits is composed of parallel bedded and laminated sediments which are transected by the lower surface of the band and consequently wedge out out apparently towards the S.E. from a maximum thickness in this exposure of about 1 m. Between these sediments and the lower surface of the band, a layer of till, up to 0.30 m thick, wedges in towards the N.W., and a sample (R5) was taken from this.

(EAF)

The six samples are all extremely poorly sorted tills with few clasts set in a red-brown matrix. The composition of the fraction finer than $\sim 1 \phi$ is as follows:

	Till below gravel (Mean of 2)	Till above gravel (Mean of 4)
Sand %	25.5	18.0
Silt %	39.5	48.5
Clay %	35.0	33.5

There is thus little difference in particle size distribution between the deposits above and below the gravel, though the upper is generally more silty. Of the four samples from the upper till, three were virtually identical, while the other closely resembled a sample from the lower. (See also p. 21).

(MPL)

Shaw (1972 fig. 5) plots sand/silt-matrix ratios for tills, and the range for the upper till at Radbrook is about 0.16 - 0.44. For the analyses above, the ratios are 0.64 and 0.37 for the samples below and above the gravel respectively.

(EAF)

In the same re-entrant, two oriented block samples with horizontal upper surfaces were taken from the basal 0.20 m of bedded and laminated deposits overlying the gravel (R7, R8). Examination under a low-power binocular microscope showed alternation of thin layers of light olive brown (2.5Y 5/4) fine sandy silt with pebbles and darkish yellow brown (10YR 4/4) and reddish brown (5YR 4/4) layers of silty sand with pebbles, varying in thickness from 1 to 15 mm. In the exposure, the thicker units give an impression of great con-

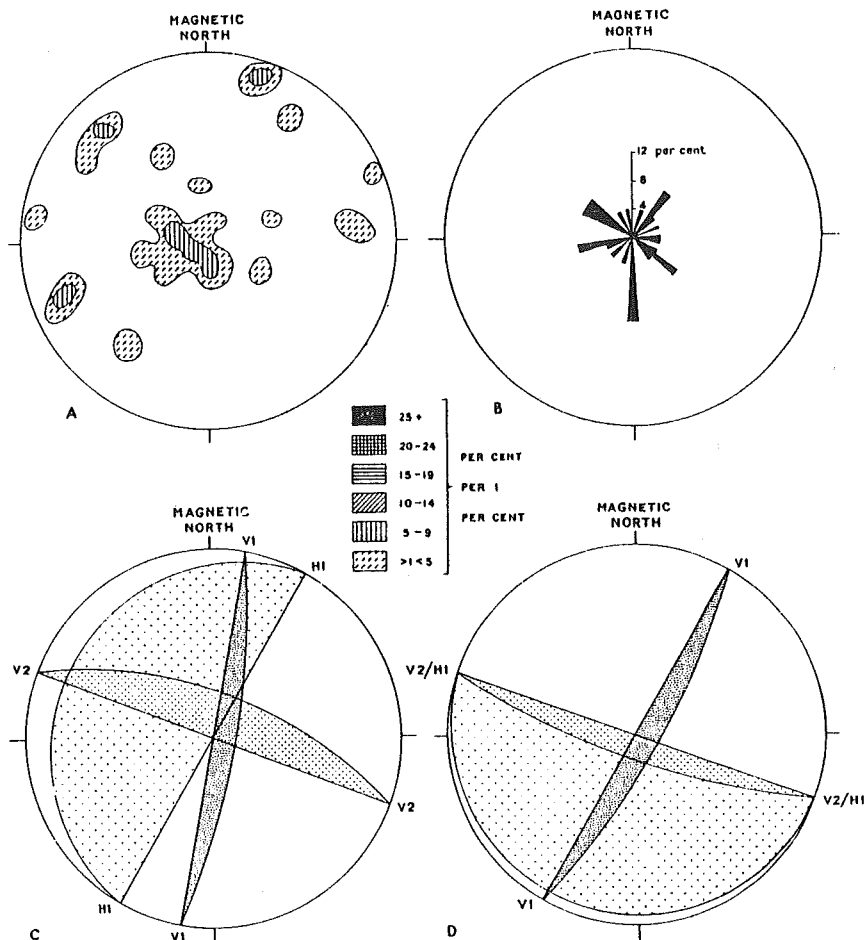


Fig. 9 Clast fabric properties, Radbrook Quarry, Shrewsbury. A- poles to clast a/b planes in sample R7; B- clast long axis azimuths in sample R7; C- poles to clast a/b planes in sample R8; clast long axis azimuths in sample R8. Cyclographic traces indicate bedding plane dips.

tinuity but there is some notable variation in thickness, continuity and local dip in the thinner laminae. Vesicles, generally fine to very fine in size (< 1 mm diam.) are common, reaching 2 - 5% per unit area in some layers. They are clearly elongated in the direction of dip of the strata. With the exception of some concentration of silt at their tops, individual laminae appear unsorted. There is no evidence of grading within laminae or of rhythmic coarse-fine alternation.

Clasts range from 2 - 100 mm, and a stone-count suggests a predominance of Lower Palaeozoic rocks of Welsh derivation ($> 60\%$) with about 10% each of Triassic sandstones, coal and quartzite. Clasts vary from sub-angular to well-rounded.

The clast fabric preferred orientations (Fig. 9) accord with the dips of the strata which are 5° towards 040° for sample R7 and 10° towards 045° for sample R8. The modes of the a/b plane clast fabrics (Figs. 9A and C) coincide precisely with the poles to the bedding planes, fabric strengths being high (R7 - 36%, R8 - 28%) and within the range typical of some modern and Pleistocene flow tills. The long axis plots (Figs. 9B and D) show a principal maximum transverse to, and a secondary maximum parallel to the direction of dip of the laminae. The abundance of Lower Palaeozoic material is reflected in the dominance of clasts of rod, tabular and thin wedge shapes, which may be a critical influence upon the clast fabric of this gravelly clay-silt because of the relatively high frequency of clast interference. The rather

more diffuse a/b plane mode in sample RB probably arises as a result of its higher percentage of equant clasts (Trias-derived).

The sedimentary structures, grain size and fabric of this deposit indicate deposition as a series of subaerial flow tills from a local source to the S.E.

(ED)

SHREWSBURY to ELLESMERE

The upper or Welsh till around Shrewsbury, exposed in Radbrook Quarry, has been interpreted widely (e.g. Pocock and Whitehead 1948, Wills 1948) as the deposit of a Welsh Readvance or Little Welsh Glaciation, which spread eastwards from the valleys of the R. Tanat and R. Vyrnwy to the west. At a somewhat earlier stage, Irish Sea ice had spread southwards across Cheshire and Shropshire during the Main Irish Sea Glaciation, and, along a line passing roughly through Mold, Wrexham, Ellesmere and Leaton (4618) as far as the N. end of The Long Mynd, had become confluent with Welsh ice. This idea dates back to Carvill Lewis (1894), who supposed that the confluence at Ellesmere had produced a medial moraine there. Peake (1961) drew this line of confluence farther W. in the area N. of Leaton to indicate that the Irish Sea ice extended W. of Oswestry, Chirk and Wrexham. She drew a second line of confluence between the Welsh Readvance (E. of Oswestry) and an Ellesmere Readvance (some 4 - 5 km S.W. of Ellesmere) along the valley of the R. Perry and thence to the N.N.W. to Ruabon and beyond. The limit of the Ellesmere Readvance diverged from that of the Welsh Readvance near Myddle (4724) and pursued a course to the N.E. round Wem to Whitchurch.

Poole and Whiteman (1961) denied the separate identity of the Welsh Readvance, and stated their view that the till carrying Welsh erratics around Shrewsbury was an extension of the upper till sheet distributed widely over Cheshire, Shropshire and beyond, which contains "Irish Sea" erratics.

The A528 road between Shrewsbury and Ellesmere crosses a deserted meander (and clearly-marked bluff) of the R. Severn 2 km N. of the centre of Shrewsbury, and then lies on till with Welsh erratics, but also the occasional northern granite. Between Albright Hussey and Preston Gubbals, there are several ridges trending N.N.W. - S.S.E. and made of gravelly material, mostly Welsh erratics (Pocock and Wray 1925). This area lies towards the E. extremity of the presumed lobate extension eastward of the Welsh Readvance, but till and gravels distributed over 10 - 15 km to the E. are recorded as containing chiefly Welsh erratics with occasional granites and flints.

To the N., Pim Hill, Harmer Hill and Myddle Hill are formed from Triassic rocks. About 9 km to the W.S.W., another ridge of these rocks lies between Ruyton-XI-Towns and Nesscliffe, and the intervening vale is thought to mark the course of the buried valley connecting similar valleys beneath the R. Severn and R. Dee. Pocock and Wray (1925) note that, although "granites, Chalk flints, and other material of distant and probably northern origin" are present in nearly every section E. of the Ruyton-Nesscliffe ridge, "the Welsh material is always largely preponderant", whereas to the N. and E. beyond Wem "the materials of northern origin correspondingly increase in proportion, and those of Welsh origin are rare".

According to Peake (1961), the ground between the R. Perry and Whixall (515345) is occupied by three crescentic terminal moraines trending N.W. - S.E. through Bagley (404273), Loppington (470293), and N. of Wem. Each of these has a marginal marshy depression, now drained by the R. Perry, Sleep Brook and R. Roden respectively, and each has outer terrace-like sandy deposits passing into outwash hummocky gravels and then into a core of boulder-clay. The road N.W. of Myddle runs close to the E. margin of the Bagley Moraine and the W. margin of the Sleep Brook depression. It is curious that Poole and Whiteman (1961) also trace "well-developed" terminal moraines in the area, and one of these is crossed by the A528 at Cockshutt. It curves to the N.E. towards Whixall and crosses Peake's Bagley and Loppington moraines almost at right-angles.

(EAF)

ELLESMERE

The best exposure in the area around Ellesmere is found in Wood Lane Quarry (422328). The appearance of the faces changes rapidly, and it is not possible to forecast the details of the section before a visit. This complicated pit has not yet been surveyed accurately and grid references cited below must be regarded as very approximate. A section measured in late 1977 showed the following sequence made up of units which were subject to marked lateral variation in thickness:

- (10) Boulder drift, sand and clay matrix, grey in lower 1.5 m, becoming pinkish or brownish grey above; abundant coarse clasts of Carboniferous Limestone together with chert, Upper Carboniferous including ganister, sandstone, and coal, and Lower Palaeozoic igneous, pyroclastic and sedimentary rocks, apparently largely Welsh; granites, presumably northern, are also present; cross-cutting base. + 4.00
- (9) Complex of brownish-red clay, thin beds of sandy gravel and sand 4.50
- (8) Silt, light brown, and sand, fine-grained. 0.45
- (7) Gravel, grey, and sand 1.90
- (6) Till, red-brown, brick-red basal layer up to 1 cm thick; sample W6 from 0.50 m above base; thickness varies markedly, probably partly as a result of structural disturbance, and boundary may be discordant 3.00
- (5) Sand, pale red, becoming darker red at top; in lens 11 m long and up to 2 m thick; generally parallel bedded, dipping at 17° to 143° , some coarser bands with sporadic pebbles; limestone pebble $5 \times 4 \times 2$ cm, imbricated at 18° to the bedding, suggested direction of current flow towards 143° ; local small-scale faulting 2.00
- (4) Gravel, with sand beds, with ?Welsh erratics; 3.90 m exposed above and 1.00 m below an estimated 1.75 m gap (due to offset from one face to another at a lower level); up to at least 10 m thick to S.E. 6.65

- m
1.25
- (3) Till, in 3 sub-units:
- (c) Brownish-red sandy clay-silt (0.44 m),
slightly lighter shade than (b) below; sample
W4 from 0.16 - 0.26 m above base
 - (b) Dark reddish-brown sandy clay-silt (0.38 m);
sample W3 from 0.11 - 0.33 m above base
 - (a) Red-brown sandy clay-silt (0.43 m); upper
boundary marked by sand lenses measured as 2 cm,
1.7 cm, 1.4 cm and 2.7 cm in length; sample W2
from 0.10 - 0.25 m above base; base sharply planar.
- (2) Sand, brown, with clasts up to 2.5 cm diam.,
especially in the upper part, and coal flecks; in
part with ripple cross-stratification (wave-length
about 47 cm); upper part coarse sand with fine gravel,
parallel bedded in fining-upwards units approx 2.5 cm
thick, some coarser clasts imbricated indicating
current flow from N.W./W. 2.25
- (1) Till, in 2 sub-units: + 0.90
- (b) Brownish-red sandy clay-silt (0.50 m), with
rounded stones up to 4 cm diam; sample W1 from
basal 0.10 m
 - (a) Reddish-brown sandy clay-silt (+ 0.40 m);
sample W5 from 0.05 - 0.15 m below top

Total = 26.90

Units (1) to (4) were measured in a lower section (about 415329)
and units (4) to (10) in the steep S.W. face (about 4210.3285).
A further sample (W7) was taken (about 4205.3270) from gravelly

material, with a few thin layers of sand apparently representing the upper part of the boulder drift (10).

(EAF)

Seven bulk samples were analysed, and of these, six (W1 - 6) were found to be extremely poorly sorted silty tills with few clasts set in a red-brown matrix. The other sample (W7) is a brown sandy gravel with 56% coarser than -1 ϕ . The results were standardized for varying clast content by recalculating the fraction finer than -1 ϕ as 100%:

<u>Samples</u>	<u>W1 - 6</u>	<u>W7</u>
	Mean	Standard Deviation
Clay%	32.00	2.77
Silt%	39.17	2.19
Sand%	28.83	3.02
		58

The small standard deviations for W1 - 6 demonstrate the similarity of these samples. The fine fraction of W7 resembles that from the sandy tills sampled at Acre Nook (Oakwood), Four Ashes and Eardington, but the heavy minerals show dissimilarities (see Table, p.92),

(MPL)

The early workings were seen by Pocock (in Pocock and Wray 1925), when a good section exposed morainic gravel at a point estimated now to be at about 422327 on a former hill rising to a little over 122 m. This coarse gravel with seams of sand contained Carboniferous limestone and chert, various granites, Ennerdale granophyre, and graptolitic slates, and was thus apparently the same deposit as that sampled for W7, about 150 m to the N.W. A little over 9 m was exposed.

The quarry was visited in 1964 during the first meeting of the Quaternary Field Study Group, and the N.E. face was then seen

to be in parallel-bedded grey gravel up to some 25 m in thickness with thin layers of brown sand in the upper part and beds of red-brown sand in the lower part. At its N.W. end, this face curved round to the point still seen at the present day where a band of reddish till stands in a near-vertical attitude. The gravels formerly showed a gentle increase in dip as they abutted against the E. side of the till. On the W. side, the high dip gradually decreased from the vertical away from the till. There were indications that a second disturbance of the same type was present a little farther W.

At present, the narrow zone of steeply dipping strata can be traced northwards from the upper part of the S.E. end of the S.W. face to the foot of the central part of this face, where vertical gravel and sand form a belt about 3 m wide. According to Worsley (1970), the uppermost layer in the whole sequence, which he refers to as a Welsh till, is "seen to overlie and be the source of complicated tectonic structures in a characteristically Irish Sea type glacial sequence". Worsley follows Peake (1961) in supposing contemporaneity of Welsh and Irish Sea ice in this area, but Peake places the line of confluence along the valley of the R. Perry S.W. of Ellesmere, to which each ice front moved forward respectively as the Ellesmere Readvance from the N. and the Welsh Readvance from the

W. Shotton (1977) is apparently in general agreement with this view but concludes that the uppermost till "would be later than the main Irish Sea till and its conveying glacier, pushing into the outwash gravels of the earlier retreat phase producing the severe glacitectonic disturbances...." He also refers to "large horizontal overfolds, moved forward on thrust planes", and to the belt with vertical strata, as evidence of this reconstruction of events.

The mechanism of deformation by advancing ice, supported by Worsley and Shotton for these sediments, can be criticised on several grounds. The uppermost till, or rather its parent ice, cannot be seen to be the direct cause of the structures, and the structures as a whole are not consistent with this mechanism. The till and associated gravel, here referred to as boulder drift (10), form a superficial cover not proved to be greater than somewhat over 4 m in thickness. Although its base is inclined and unconformable locally over the underlying beds, it is not seen to be involved directly in the deformation. The first-order structure is the narrow near-vertical belt of strata, with an inter-bedded sequence of gravels and sands to the W. having a semi-catenary form in section. As noted above, a second feature of the same kind probably lies a short distance farther W. These structures suggest that differential subsidence took place over melting buried ice and the boundary of the area of subsidence was

marked by the vertical zone. In this connexion, it is relevant to point out that a zone of kettle hollows lies to the W. of the S.W. face, and this may be interpreted as the surface expression of the subsidence, which was indeed a prominent feature of the whole area. Various writers have commented on the morphology near Ellesmere. Carvill Lewis (1894) refers to "an unusually large moraine... comparing well with the Wisconsin 'Kettle Moraine' ", and Peake (1961) writes of "outwash hummocky gravels, which have their greatest development in the remarkable kettle-drift of the Ellesmere locality".

It seems clear that prior to the final retreat of the ice, material had been transported from the W. Thus, Pocock and Wray (1925) note the presence of a mass of Llandeilo limestone, 1.8 m diam., at St. Oswald's College, about 2.5 km W.N.W. of Wood Lane Quarry, and relate it to an outcrop near Llanrhaiadr-ym-Mochnant, indicating a direction of transport from 260°. According to Poole and Whiteman (1961), retreat at Ellesmere was to the N., and Peake (1961, Fig. 6) suggests retreat to the N.E. at this point (the Loppington Moraine), later becoming due N. at the Flintshire Maelor Moraine immediately N. of Ellesmere. However, the thick undisturbed gravels lie to the E. and S.E. of the disturbed deposits at Wood Lane, and current flow indicators consistently point to transport towards the S.E. These gravels include no beds of till, which only come in towards the

W. in the vicinity of the disturbances. According to Shaw (1972a), these tills originated from debris bands in the ice and were most likely deposited by direct melt-out, although he did not discount the possibility of emplacement from flowage. They are here interpreted as flow tills, which moved as very mobile flows on to the proglacial sediments.

(EAF)

Recently, workings a short distance to the N. of the central part of the S.W. face have exposed a till dipping at about 38° towards 285° . This is a yellowish-red (5YR 4/6) sandy silt with sporadic gravel-sized clasts. It is generally massive in structure, and the sand grains and fine gravel-sized quartz and quartzite clasts are distributed randomly throughout the clay-silt matrix. However, occasional laminae (c. 1 mm) of clean, open-textured sand dip at between 30° and 40° towards the W.N.W. This till is interpreted as a subaerial flow till. The few clasts available for measurement dip slightly N. of W. However, the abundance of equant-shaped grains of quartzite within the relatively well-sorted matrix results in a rather diffuse mode with fabric strengths rather lower than in finely bedded and more stony flow tills.

(ED)

The conclusion advanced here is that the ice, having flowed from the W. and having become confluent

with the Irish Sea ice, then retreated towards the W. so that distal glaciofluvial gravels and sands formed as a proglacial plain and proximal gravels, sands and flow tills were deposited over its stagnant margin. As this buried ice melted, first-order subsidence structures were formed, together with second-order folds and faults of various kinds. It is important to appreciate the topographical relationships in this area. At Wood Lane, the surface formerly reached a little over 122 m, and at Yarnest Wood, 1 km to the S.W., it rises to 130 m. The general level of the low ground nearby is 80 - 90 m, and the buried valley rock floor, thought to lie about 3 - 4 km to the W. of Wood Lane, may fall to about 45 - 50 m or below. The situation seems therefore very suitable for the development of a stagnant margin during a retreat to the W. The boulder drift (10) was presumably deposited from ablation moraine.

(EAF)

ELLESMERE to KEELE

The route from Wood Lane continues for 2 km along the A528 and then follows the A495 towards Whitchurch. In the Ellesmere area, it passes several of the large meres which are a feature of this, the Shropshire Lake District. Beyond Welshampton, Peake's (1961) Flintshire Maelor Moraine is crossed near Breadon Heath, and this was considered to have held up a meltwater lake, whose site is

now occupied by Fenn's Moss. Most of these meres and mosses lie at about or just below 91 m, and Pocock and Wray (1925) thought it likely that they were relics of Lake Lapworth which supposedly drained through the Iron-Bridge gorge at that height. Peake, however, thought it more probable that these features postdated Lake Lapworth and were individually formed during the local retreat.

(EAF)

TECHNIQUES

Particle size analysis by the Pipette method

Samples were dried and carefully ground to remove stones $> 2\text{mm}$ ($\sim 1\%$). A 30g sample of matrix $< 2\text{mm}$ was dispersed using an ultra-sonic bath. 6cm^3 5% sodium hexametaphosphate was added and the suspension made up to 1000cm^3 . After settling according to Stokes' Law, 25cm^3 samples of particles $< 20\mu\text{m}$, $< 6\mu\text{m}$ and $< 2\mu\text{m}$, were taken with a pipette at a depth of 20cm. After drying at 105°C and weighing these samples, the weights of coarse silt, fine silt and clay were calculated. The sand fraction was separated by repeated settling and siphoning to remove particles $< 20\mu\text{m}$. The sand was dried and sieved at ϕ intervals: 0, 1, 2, 3, 4. The results were plotted as a summation % curve.

The pipette method was used because of its good reproducibility, and because the samples taken at $20\mu\text{m}$, $6\mu\text{m}$ and $2\mu\text{m}$ could also be used for a preliminary study of calcium carbonate distribution in the matrix. This was done by reaction of each fraction with excess 0.1M hydrochloric acid and back titration of the residual acid with 0.1M sodium hydroxide. Most of the carbonate was in the $< 2\mu\text{m}$ fraction, with a smaller amount in the 6 - $20\mu\text{m}$ fraction. Very little was found in the 2 - $6\mu\text{m}$ range.

Samples analysed were of two types: a) from deposits recognized in the field as tills, b) from clay-rich bodies which formed part of a complex, mainly sand and gravel in composition. Both types of sample gave typical till-like particle size distribution curves,

with very little sorting. In most cases the matrix was dominated by equal proportions of clay and silt with a varying mixture of fine sand. The proportions of coarse sand were small.

(HO)

Particle size analysis by the Hydrometer method

After wet sieving the coarser fractions down to -1ϕ , the Hydrometer method (Bouyoucos 1951) was used for finer fractions down to 10ϕ . This method depends on measuring the density of a slowly sedimenting suspension with a direct reading hydrometer. After 24 hours, the suspension is also wet sieved down to 5ϕ . The two sets of results are usually plotted as cumulative weight percentage finer as ordinate and phi (ϕ) size as abscissa.

(MPL)

Interpretation of cumulative curves with reference to tills

The cumulative curve can be used to estimate various grain sizes at set percentiles. Folk and Ward (1957) suggest that the ϕ values at the 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles should be noted. These can then be used to calculate the summary statistical measures of the whole distribution: the median, the mean, the sorting coefficient (a measure of concentration or otherwise of particular sizes), the skewness (a measure of the lop-sidedness, in either direction, of the distribution) and the kurtosis (a measure of the peakedness of the distribution). Sorting is a measure of the action of running water etc., while skewness is

often the result of the breakdown of aggregates during the analysis. The values of clay content (finer than 9 ϕ), silt content (finer than 4 ϕ) and sand content (finer than -1 ϕ) can also be read off the cumulative curve. These values can be displayed in a triangular diagram (Fig. 3).

The cumulative curves of British lowland tills often plot out as two straight line segments of differing gradient. Beaumont (1971) calls the point at which these segments meet the break of slope whilst McGown and Derbyshire (1977) refer to it as the split size. The two segments represent two particle populations: the clasts and the matrix. The clasts are associated with detachment and entrainment beneath a glacier, whilst the matrix is associated with comminution. However, the parent lithology also affects the till composition, and Dreimanis and Vagners (1965), and Beaumont (1971), distinguish between rock and mineral fragments. Coarse sediments act as cohesionless soils, in engineering terms, whilst fine sediments act as cohesive soils. This means that tills of slightly differing grading can behave in very different mechanical ways. The break of slope may not always be present if, as in the case of the tills from Bangor-is-y-coed, there are very few clasts or, as in the case of the uppermost till at Wood Lane, there are far too many clasts. Samples of about 1 kg may not contain a representative sample of the clast population. Hence it is useful to standardize clay/silt/sand contents in isolation from the gravel fraction.

Some engineering tests applied to tills

Engineers have standardized tests on the physical behaviour of sediments. Such tests, applied to tills, give some indication of both composition and past history. In the oedometer, a confined disc of sediment is subjected to a one-dimensional stress, pore water is expelled and the sample is said to be consolidating. In a virgin sediment, there is an exponential reduction in porosity with load, hence a plot of porosity against the logarithm of pressure gives a straight line. Porosity is not linearly related to the change in sample thickness in the oedometer and so an alternative measure, the void(s) ratio is used. However, if the sediment has been interfered with by excess loading in its past history or by the removal of load on sampling then it is said to have been precompressed or over-consolidated. This is revealed by a lack of compression at low loads on the curve, followed by an increasing gradient until the virgin line has been reattained. This transition curve can be used to gauge the preconsolidation load: if it is greater than the overburden at the sampling site then the sediment has been stressed in its past history. Different types of tills are often differently consolidated. Lodgement till is almost invariably clearly overconsolidated, flow and meltout tills are much less so. In the unconfined compression test a cylindrical sample of cohesive sediment is subjected to a compression without any lateral con-

finement. An autographic mechanism draws a plot of compressive stress against deformation (i.e. a stress-strain curve). If the sediment deforms plastically by barrelling a gentle curve is produced, but if brittle failure occurs, a peaked curve is drawn with a distinct yield stress. Yield stress is often related to composition and moisture content.

(MPL)

Analysis of heavy minerals

Counts were carried out on heavy minerals in sand of the 3 - 4 ϕ fraction, after separation with bromoform. About 1000 grains were counted in each sample.

The mineral suites were dominated by opaque minerals, mostly limonite. Occasionally pyrite was identified, some of which may have been authigenic, as fresh cubic crystals were observed. However, there were also framboidal grains which are typically formed in sediments by microbial action.

A wide range of non-opaque minerals was observed and these are expressed in the Table as % non-opaque fraction. Samples designated as Welsh Till in the field (R 1, 2, 5, 6) had mineral suites dominated by chlorite, whereas samples referred to as Irish Sea Till were dominated by zircon. However in the case of W7 from Ellesmere, a Welsh Till, the distinction is less clear (chlorite 28.6%, zircon 17.8%). In the suites dominated by zircon, the zircon grains were of varying freshness, suggesting either more than one source, or their addition to the matrix at different times by erosion from erratics.

TABLE OF HEAVY MINERALS (3 - 4 ϕ fraction)

Sample	Four Ashes		Eardington(E)		Radbrook(R)						Ellesmere(W)					
	A	B	1		1	2	3	4	5	6	1	2	3	4	5	7
<u>Non-opaques</u> ^a																
Zircon	39.2	55.0	49.1		1.5	3.6	16.3	10.5	0.8	0.3	30.8	33.3	19.0	7.9	14.8	17.8
Sphene	-	-	-		-	-	4.1	1.0	-	-	-	-	-	-	-	-
Garnet	12.8	8.0	6.2		1.5	1.0	1.0	4.0	0.2	0.3	13.3	10.0	2.5	1.8	2.0	3.6
Staurolite	-	-	1.6		1.5	1.0	-	-	-	-	-	-	-	0.9	-	-
Epidote	1.6	1.0	-		-	1.6	2.0	-	0.8	0.7	6.7	-	2.4	0.9	4.0	3.6
Zoisite	-	1.0	-		1.5	-	-	-	-	-	0.3	-	0.2	-	-	-
Tourmaline	5.6	5.1	10.1		0.7	2.6	9.2	2.5	0.5	1.4	16.7	6.7	8.9	13.2	12.8	15.5
Augite	4.8	3.0	5.5		3.0	1.0	19.4	23.5	2.0	1.0	6.7	26.7	16.4	8.9	8.9	10.7
Hypersthene	-	-	-		3.0	1.0	2.0	4.0	2.0	1.7	0.4	-	5.1	1.8	2.0	-
Hornblende	8.1	4.2	2.3		5.2	4.7	17.0	9.0	2.0	1.0	4.3	6.7	3.8	3.5	8.9	3.6
Glaucothane	-	-	6.3		-	-	-	-	-	-	-	-	0.9	-	-	-
Tremolite	-	-	0.1		-	-	-	-	-	-	-	-	3.8	-	-	-

Non-opaques contd.

Biotite	-	-	-	-	-	0.3	-	-	-	0.2	-	-	1.8	-	-
Glauconite	1.6	2.0	-	-	-	-	1.0	-	-	-	-	-	-	-	-
Chlorite	4.0	2.2	2.3	69.4	72.0	7.1	2.0	89.2	88.7	6.7	3.3	7.6	12.4	2.0	28.6
Rutile	8.1	7.6	7.8	-	3.2	3.1	2.0	-	-	3.3	3.3	5.1	4.4	3.0	6.0
Calcite	-	-	-	11.2	3.7	5.1	40.0	1.4	1.7	10.0	-	2.5	24.8	26.7	-
Apatite	12.0	11.0	14.7	1.5	4.7	13.2	0.5	1.1	3.1	0.5	10.0	21.5	17.7	14.8	10.7
Monazite	2.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corundum	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-

Opaques

(total) ^b	78.0	79.4	84.8	64.0	70.6	80.8	81.1	65.1	64.0	90.8	90.8	85.3	79.6	75.4	86.5
Limonite ^c	71.0	69.1	82.6	64.5	75.0	47.0	84.2	95.7	95.0	83.9	82.4	84.5	88.3	85.0	84.5
Magnetite ^c	18.2	18.3	13.2	31.3	19.9	43.9	6.2	1.3	1.5	8.1	3.7	7.9	4.6	9.8	8.2
Leucoxene & Ilmenite ^c	10.8	12.6	4.2	4.2	5.2	5.8	6.1	3.0	3.5	8.0	13.9	7.6	7.1	5.2	4.3
Pyrite ^c	-	-	-	-	-	3.2	3.5	-	-	0.3	-	-	-	-	3.0

a, b, c, See footnotes on p. 95.

TABLE OF HEAVY MINERALS (3 - 4 ϕ fraction) Contd.

Sample	Singret	Rackery (L)				Pant Fm. (P)			Marford (M)			Bangor
	1	1	2	3	4	1	3	4	1	2	3	2
<u>Non-opaques</u> ^a												
Zircon	27.6	39.9	35.0	48.6	44.2	17.8	14.7	29.5	23.5	27.6	14.9	8.7
Sphene	-	-	-	-	-	0.2	-	-	-	-	-	-
Garnet	5.1	2.3	4.1	3.8	5.5	4.0	8.8	3.2	18.4	6.6	5.0	2.0
Staurolite	-	-	2.1	1.0	1.1	2.0	1.5	2.0	-	1.0	-	1.0
Epidote	5.5	-	3.1	2.9	1.7	7.2	1.5	5.2	5.1	1.0	5.7	6.3
Zoisite	0.2	-	-	-	-	0.6	-	-	0.2	-	-	0.4
Tourmaline	10.2	2.2	1.0	2.9	4.4	10.1	7.4	2.6	6.4	3.8	0.7	3.8
Augite	28.8	22.0	24.7	12.4	14.9	16.2	29.4	33.4	27.6	32.4	27.0	16.3
Hypersthene	-	1.5	-	1.9	-	1.5	1.5	1.6	-	1.0	-	-
Hornblende	8.5	19.0	14.1	7.6	2.8	14.1	8.8	3.6	7.5	3.8	7.1	16.0
Glaucophane	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	-	3.0	3.1	5.7	0.2	-	-	-	1.0	-	3.5	1.0

Non-opaques contd.

Biotite	-	0.2	0.3	-	-	0.2	-	-	-	-	-	6.2
Glauconite	-	-	-	0.8	-	-	-	-	1.0	1.9	14.2	-
Chlorite	4.2	5.8	1.0	4.8	1.8	16.0	7.4	3.8	-	5.7	2.8	19.2
Rutile	5.7	4.1	6.2	4.8	6.1	4.2	5.9	5.1	5.3	6.6	2.1	-
Calcite	-	-	-	-	-	-	2.9	6.4	-	1.0	10.0	18.3
Apatite	4.2	-	5.2	3.8	13.3	6.0	10.3	3.8	3.2	7.6	7.1	6.7
Monazite	-	-	-	-	-	-	-	-	0.2	-	-	-
Corundum	-	-	-	-	-	-	-	-	-	-	-	-

Opaques
(total)^b

(total) ^b	87.4	89.8	84.9	89.4	83.5	89.7	90.4	89.1	84.0	85.6	88.1	83.5
Limonite ^c	89.0	89.0	82.8	84.3	80.7	89.5	88.9	89.9	79.7	90.9	85.5	92.3
Magnetite ^c	5.7	5.6	10.3	9.7	11.4	4.3	7.0	6.7	16.2	5.8	11.5	4.6
Leucoxene & Ilmenite ^c	5.3	5.4	6.9	6.0	7.9	6.2	4.1	3.4	4.1	3.3	3.0	3.1
Pyrith ^c	-	-	-	-	-	-	-	-	-	-	-	-

a Expressed as per cent by number of non-opaque minerals

b Expressed as per cent by number of total heavy fraction

c Expressed as per cent by number of opaque minerals

(HD)

In some samples, calcite made up a large proportion of the fraction but the percentage was very variable, the sandiest samples having the lowest per cent calcite. The garnet content was remarkably low for such a resistant mineral; only colourless garnet was observed. Augite was a common mineral, occurring as short ragged grains. Both twinning and exsolution laminae typical of augite from tholeiitic rocks were observed. Glauconite always occurred as rounded aggregates typical of marine sediments, not as single crystals.

(HD)

Some aspects of till fabric analysis

Measurements have been made of the disposition of joints or fissures and clasts in stony clay-silts from three sites (Bangor-is-y-coed, Redbrook Quarry (Shrewsbury) and Wood Lane Quarry (Ellesmere)). In addition preliminary work has been done on size and disposition of particles using low-power binocular microscopy.

The dips and azimuths of joints and fissures were measured in the field using compass and clinometer and in the laboratory. Large oriented block samples (up to 15 x 15 x 15 cm) with marks cut into their horizontal upper surfaces were placed on a contact goniometer incorporating an enlarged universal stage.

The dip and azimuth of clasts were measured using the contact goniometer according to the procedure out-

lined by McGown and Derbyshire (1974), which makes possible the measurement of the directional properties of clasts as small as 3 mm diam. Particles of coarse sand (0.6 - 2 mm) may be measured using an illuminating magnifier. The method is essentially unselective with respect to particle shape, all clasts larger than 3 mm being measured provided an a/b plane and a long axis can be determined.

Measurement of the long axes of clasts provides a clear indication of the direction of former ice movement in the case of tills deposited by lodgement. The disposition of the a/b maximum projection planes of clasts is a sensitive indicator of stress distributions. It varies systematically with depositional mode, clast shape and degree of clast interference (a product of the particle size distribution). Dips of clast a/b planes are imbricated up-glacier in lodgement tills. They lie parallel to depositional surfaces in flowtills with occasional weak imbrication.

The long axis fabric data are expressed (Figs. 8, 9) as two-dimensional (azimuthal) diagrams. The data for a/b planes of clasts are plotted as points representing the poles to these planes on the surface of the lower hemisphere of an equal area graticule ('Schmidt net'). The degree of clustering of these points is referred to as the clast fabric strength and is expressed as the percentage of poles lying within one % of the area of the graticule. Fissure populations and bedding planes are shown on the same type of graticule as cyclographic traces.

(ED)

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