THE PLEISTOCENE GEOLOGY OF THE AREA NORTH AND WEST OF WOLVERHAMPTON, STAFFORDSHIRE, ENGLAND

By A. V. MORGAN*

Department of Geology, University of Birmingham

(*Communicated by F. W. Shotton, F.R.S. – Received* 20 *July* 1972)

[Plates 32 to 34]

CONTENTS

* Present address: Department of Man Environment Studies and Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada.

Two hundred and fifty-two square kilometres of land north and west of Wolverhampton have been mapped on a scale of 1:10 560. This area includes a sequence at Four Ashes which has been designated the type section for the Devensian stage of the British Pleistocene.

The last glacial advance into the West Midlands occurred during the Upper Devensian, some time after 30500 years B.P., terminating along the 'Wolverhampton Line' marked by a pronounced thickening of the till sheet and a concentration of large erratics. The till at Four Ashes overlies a thin series of gravels which had at its base a restricted deposit of Ipswichian date and included many lenses of peat or organic silt ranging in age from *ca.* 70000 B.P. to later than 30500 B.P. (Lower and Middle Devensian) representing a period of fluctuating climate ranging from cool temperate to arctic continental in severity. During this period there was a considerable amount of erosion, resulting in the formation of the 'modern' landscape which has only been modified by glacial deposition and post-till periglacial activity.

The earliest Pleistocene deposits found in the region are believed to be glacial outwash gravels, probably of late Anglian age which are overlain by Hoxnian Interglacial silts and clays. These early deposits occur beneath the till sheet of the last ice and extend for at least 10 km south of the Wolverhampton Line as eroded relics of a deep channel filling.

Glacio-fluvial gravel sequences post-date the retreat of the Late Devensian ice and are concentrated along the principal drainage lines. Late-Glacial organic deposits indicate that the ice had retreated prior to 13490 years B.P. in the Stafford region.

A periglacial environment followed the retreat of the last ice (as evidenced by ice-wedge casts and ice-wedge polygons) and this is thought to have lasted until the climatic amelioration which started around 12500 years B.P.

1. INTRODUCTION

(a) *The present study*

During the period 1967–70 the Pleistocene deposits were mapped in the area adjacent to the north and west sides of Wolverhampton (figure 1). Because of the development of the urban fringe of Wolverhampton and Stafford, as well as the expansion of many of the outlying villages, numerous temporary sections were observed in the cutting of sewerage and drainage lines. Services, such as new electricity power lines, flood-prevention schemes and the construction of new roads, have led to further exposures, while the arrival of North Sea gas in the West Midlands and associated trenching for gas pipe-lines provided continuous sections to a depth of almost 2 m for many kilometres. Numerous sections were examined in clay pits and gravel pits in the north and south of the area respectively, while approximately 800 borehole logs were recorded in drift sequences which varied from less than 1 to over 46 m.

This study started as an attempt to define drift boundaries by means of an analysis of the lithology of pebbles within the drift sequences. Because of organic deposits in many areas of the study region it became possible to determine a stratigraphic sequence based upon absolute chronology within the limitations of ^{14}C dating, that is, in the case of the Birmingham University Laboratory up to approximately 47000 years B.P. Once aided by a framework of dates which preceded and post-dated the last ice advance over the area it became possible to analyse the drift sequence in the area north and west of Wolverhampton in a new light. Consequently, the objectives of the study were enlarged to include the mapping of the Late Devensian (Shotton & West 1969) glacial deposits to their southern limits and to ascertain the distribution of associated deposits of non-glacial origin which pre-dated or post-dated the forementioned ice advance.

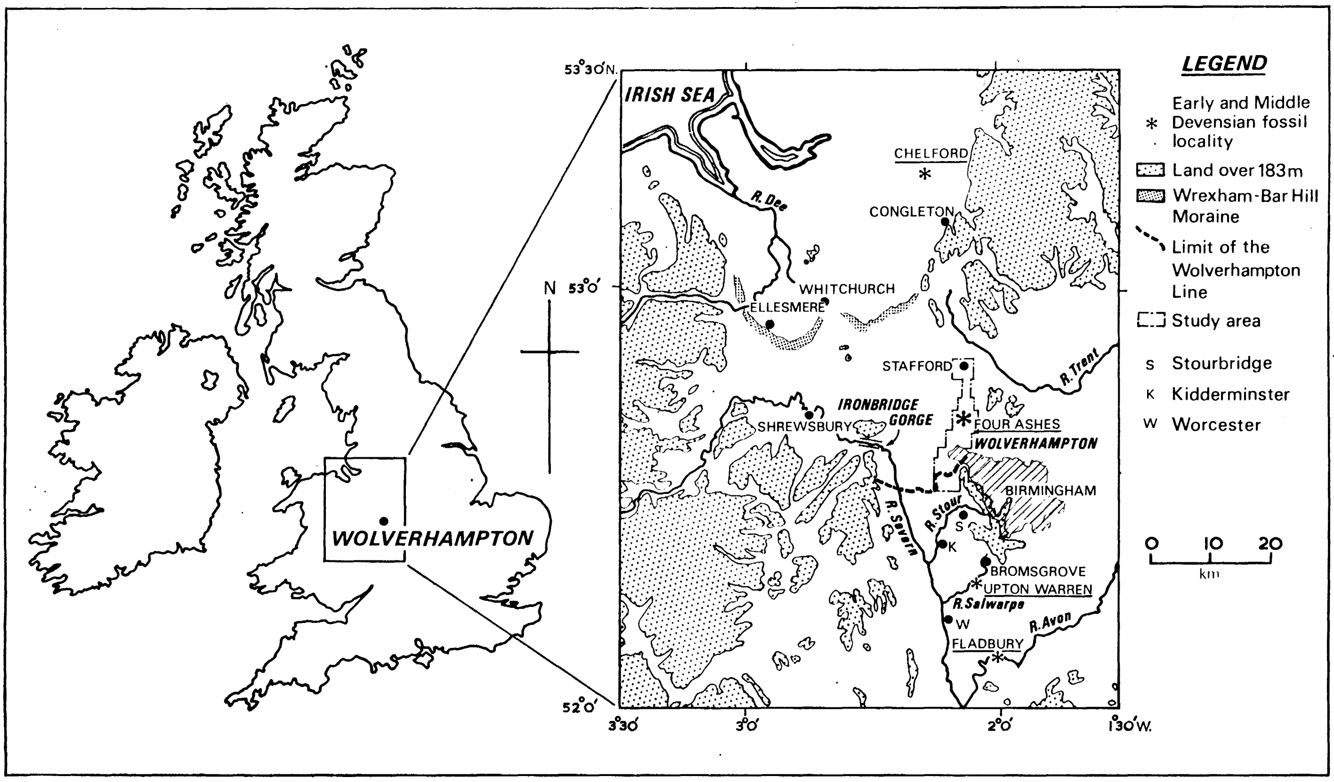


FIGURE 1. Location of the map area with sites referred to in the text.

The occurrence of faunas and floras at various levels within the Devensian deposits and the stratigraphic and geographic distribution of periglacial phenomena have also permitted a tentative analysis of the palaeo-environment over certain parts of the study area. This in turn has aided in the analysis and interpretation of the late Pleistocene succession in the region both north and south of the Wolverhampton Line.

(b) *Historical*

The initial description of the Pleistocene deposits within the area studied were made well over a century ago by geologists invoking marine incursions to explain the presence of erratic blocks and marine shells within the drift sequences (Trimmer 1835; Murchison 1836; Allies 1840;

Lister 1862). A systematic mapping of erratic blocks was suggested by Woodward (1870), and numerous reports on the erratics of the region were made to the 'Erratics Committee' of the British Association between 1873 and 1893.

After the end of the nineteenth century the output of literature on the glacial deposits of the West Midlands dwindled to sporadic reports, the most important being by Boulton (1916, 1917) on the gravels of the Kingswinford Esker and the mammalian remains in the gravels near Stourbridge. In 1924 Wills produced his first paper on the development of the Severn Valley, followed by Tomlinson (1925) on the terraces of the Warwickshire Avon. By this time the 'older drift' sequences of Worcestershire and Warwickshire were being examined and described by Pocock (1922), Shotton (1929), Tomlinson (1929, 1935) and Wills (1937, 1938). During the same period the Geological Survey was actively mapping the drift sequences, and the interpretation and results of this work may be seen in the Survey Memoirs for the Birmingham area (Eastwood, Whitehead & Robertson 1925), Stafford and Market Drayton (Whitehead *et al.* 1927), Wolverhampton and Oakengates (Whitehead, Robertson, Pocock & Dixon 1928) and Dudley and Bridgnorth (Whitehead & Pocock 1947).

A number of papers have been written within the last two decades on glacial deposits around or within the study area. Generally they tend to emphasize a specific aspect of Pleistocene research, especially those concerned with the interpretation of the palaeo-environment. The drift region south and east of Coventry was described by Shotton (1953), while Pickering (1957), Barton (1960) and Kelly (1964) examined drift sequences on the south, southwest and north sides of Birmingham respectively. Interpretations of the Devensian environment from the examination of floras and faunas in organic material at sites in Cheshire, Staffordshire, Worcestershire and Warwickshire have been made by Simpson & West (1958), Shotton & Strachan (1959), Coope (1959, 1962), Coope, Shotton & Strachan (1961), Coope & Sands (1966) and Ashworth (1969). Climatic interpretations of parts of the Devensian succession have also been made by Shotton (1960), Worsley (1966*a*, *b*) and Thompson & Worsley (1967), using the presence and distribution of patterned ground, frost-wedge structures, and the location of ventifacts.

Finally, with the development and more frequent use of radiocarbon dates, the question of correlation of late Pleistocene deposits in the forementioned counties has been subject to a certain amount of controversy. The most recent papers discussing the extent and age of the drift in Cheshire, Staffordshire and Worcestershire have been published by Simpson (1959), Poole & Whiteman (1961), Boulton & Worsley (1965), Poole (1966), Yates & Moseley (1967) and Boulton (1967). Some of the stratigraphic results mentioned in this paper have been published in a review by Shotton (1967) and commented upon by Poole (1968). The most recent works describe the morphology and probable age of glacio-fluvial features associated with the last ice advance in the area west of Wolverhampton (Morgan 1970*a*) and periglacial phenomena associated with ice retreat (Morgan 1971 *a*, *b*).

(*c*) *Physiography*

The area is in a region of medium relief which lies along and on both sides of the watershed between the River Severn, draining to the southwest and the River Trent flowing toward the northeast. The southern part of the region lies northwest of the Birmingham Plateau, whilst the northwestern and north central parts of the area occupy a relatively flat plain of low rolling topography. The land rises abruptly on the eastern side of the region where resistant rock types are brought to the surface by faults, resulting in the conspicuous ridge of Cannock Chase, the hills at Saredon, Bushbury and Essington, and the high relief area east of Lower Penn and Himley. Landforms appear to have been affected more by glacial deposition, and the subsequent modification of the drift morphology by periglacial activity, than by glacial erosion.

(*d*) *Solid geology*

The largest part of the region mapped is underlain by Triassic rocks which form a broad shallow syncline plunging to the north. The syncline is faulted by a number of north–south faults which downthrow the Keuper marls and sandstone and Bunter sandstone against Bunter Pebble Beds and Carboniferous strata. The last two formations have an important effect on topography and the land rises appreciably where these more resistant rock types outcrop.

The Productive Measures of the Middle Carboniferous occupy the extreme southeast of the map region extending northeastward across Wolverhampton toward Cannock. These beds are in turn overlain by the barren cover of the Upper Coal Measures which extend west and north from the forementioned coalfield area.

The central part of the map region is underlain by Lower Keuper Sandstone which forms a prominent escarpment along the north side of the Smestow Valley as it turns eastwards into the Tettenhall Gap. The sandstones form the rim of a shallow syncline plunging northward at a low angle and the valley of the River Penk follows the strike of the eastern limb as far as Acton Trussell in the northeast of the area. The synclinal core is occupied by a wide belt of Keuper Marl. Two large north–south trending faults are present on the east side of the central and northern sections of the area. Both downthrow to the west truncating the eastern section of the syncline, and the Bunter Pebble Beds outcropping to the east form the high land of Cannock Chase and the hills mentioned in the previous section.

The outcrop pattern of solid formations has an important influence on the distribution and lithology of the overlying drift areas, as will be mentioned later.

2. The Devensian succession at Four Ashes

(*a*) *Introduction*

The key to the Late Pleistocene succession in the Wolverhampton area was found in the stratigraphic sequence exposed in a sand and gravel pit at Four Ashes (figure 2). At Four Ashes the Redland Group has excavated considerable quantities of sand and gravel from a terrace-like feature on the north side of the Saredon Brook between Hatherton Junction (9349.0854) and the A449 (9130.0810).

In the period 1967 to 1970 the working faces of the pit generally exposed a threefold descending sequence of red clay with erratics derived from Scotland and the Lake District, overlying water-deposited sands and gravels, which in turn rest unconformably on Upper Mottled Sandstone or Lower Keuper Sandstone. The gravels and sands have within them, and at their base, deposits containing plant debris which have provided a number of radiocarbon dates, the youngest of which is 30500 ± 400 years B.P. (Birm. 195). From this it follows that the overlying till is Late Devensian (Shotton & West 1969) in age.

(*b*) *The Four Ashes sand and gravel deposit*

The sand and gravel revealed in the working faces varies in thickness, the maximum and minimum figures recorded between 1967 and 1970 being 4.6 m and 45 cm respectively.

Although the deposit consists almost exclusively of Bunter-derived quartzite pebbles, some still showing pressure marks, rare erratics, usually of flint, tuffs, rhyolite and andesite can be found. All erratics are small, generally less than 3 cm, and no granites have been seen, although dubious granitic quartz-felspar fragments (2 to 7 mm in size) can be found. The sand and gravel sequence is extremely complex, with signs of water erosion and deposition. Wash-out gullies, minor stratigraphic breaks, and current and graded bedding sequences occur throughout the deposit. At least two levels of intraformational ice-wedge casts have been seen in the gravels at Four Ashes and the top 2.5 m of the gravel sequence is frequently strongly involuted. As both the top and base of the Four Ashes gravel represent erosional surfaces, the height of the gravel unit is of little value; however, the top of the gravel is usually between 97.5 m (320 ft) at the A449 and 106.7 m (350 ft) O.D. at Hatherton Junction.

The most significant features of the Four Ashes deposit are the lenses of sandy detritus peat and grey organic clays, which commonly occur at different stratigraphic levels within the sands and gravels. These are occasionally found on bedrock, involved in the lowest few centimetres of gravel, or found higher in the sequence. The higher organic lenses have sometimes been incorporated into post-till cryoturbation, as explained later (§9). A number of ^{14}C dates have been obtained from different organic lenses and these are as follows:

locality	sample number	age (years B.P.)
3	(Birm. 24)	36343 + 767 − 706
2	(Birm. 25)	30655 + 765 − 700
4	(Birm. 56)	42530 + 1345 − 1115
20	(Birm. 74)	in excess of 43 500
12	(Birm. 170)	38500 + 1200 − 1050
44	(Birm. 171)	in excess of 45 000
45	(Birm. 195)	30500 ± 440
34	(Birm. 196)	40000 + 1400 − 1200

Large numbers of beetle fragments were obtained from the organic deposits and at least two deposits of peat, resting directly on bedrock can be matched on faunal evidence with the organic band at Chelford (figure 1) dated to 61000 years B.P. by differentially fractionated ^{14}C (Coope 1959). The comparison of the forementioned Four Ashes sites with the Chelford site also appears to be substantiated on pollen evidence. One other site at the bottom of the Four Ashes gravel sequence (Locality 44) has a poorly preserved fauna, but well-preserved macroscopic plant debris and pollen, indicating a temperate deciduous woodland cover at the time of deposition. In most of the sites examined at Four Ashes the environment was colder and more continental than today, but there appears to have been a temperate episode around 40000 years B.P. The faunas and their environmental implications are discussed at greater length elsewhere (Anne Morgan 1970).

(c) *Ice-wedge casts within the Four Ashes gravel sequence*

These were only found in the gravel pit at Four Ashes (9160.0820) and in the abandoned pit faces within the same gravel sequence on the north side of the Saredon Brook. The wedge structures in the abandoned pit were poorly preserved and largely obscured by talus, and will not be discussed further.

At Four Ashes five intraformational wedges have been personally observed, and a sixth recorded by Professor F. W. Shotton (pers. comm. 1967). All are within a sequence of coarse sand, alternating with gravel and cobbles, although the end of one wedge penetrates the bedrock. Unfortunately only two were well preserved, showing the full length of the structure. In the third example the top was complete, but the wedge form disappeared below talus. This was dug out and allowed to weather, but further slumping of the gravel and sand obscured the whole structure completely. The others appear to have been truncated and unconformably overlain by coarse gravel and cobbles, and the base of one of these enters the underlying Upper Mottled Sandstone. The final example was badly contorted, but did show slightly downturned edges at the margin of the wedge. This structure was partially obscured by tipped debris at the time of discovery, and was completely buried before it could be excavated.

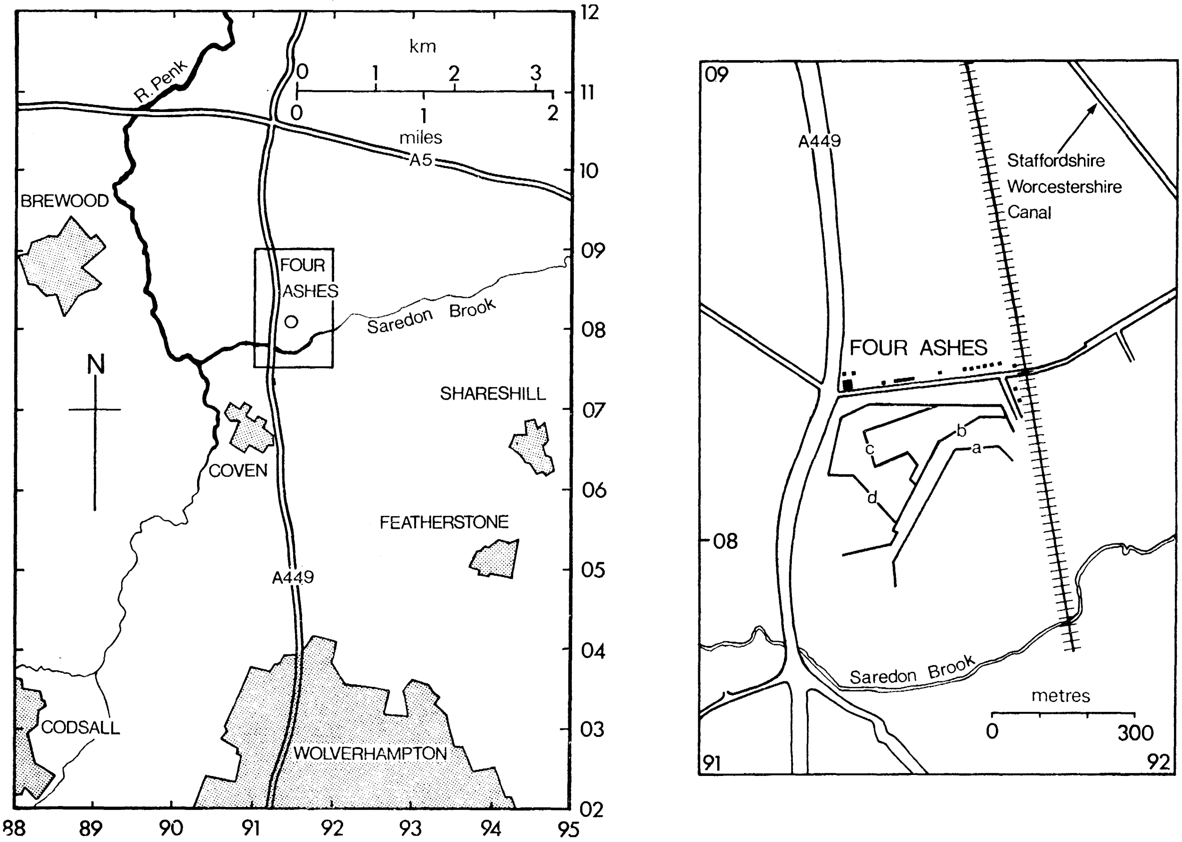


FIGURE 2. (*left*) Location of the Four Ashes site: (*right*) *a*, position of the working face in March 1967; *b*, position of the working face in March 1968; *c*, position of the working face in March 1969; *d*, position of the working face in March 1970.

All the wedge-shaped structures observed tapered gradually to a fine point, and calculations on the complete wedges indicate length:width ratios in excess of 7.5:1. The wedges varied in depth from in excess of 2.15 m to 71 cm, with widths ranging from 51 to 6 cm (figure 3). Because of the stratigraphic position of the wedges it was impossible to excavate some laterally, but three wedges were excavated and showed lateral continuation distances of 1.75 m, 1 m, and 50 cm, respectively.

In all examples the debris infilling the wedge consisted of coarse sand or fine to medium gravel. In the pre-till wedges edge effects were pronounced in all but two, the exceptions being the large wedge penetrating the sandstone and the example noted by Shotton. Edge effects consisted of downturned strata and pebbles with oriented long axes.

(d) *The Irish Sea till*

The red clay (Munsell colour, moist, 2.5 YR 3/4) with erratics overlying the sand and gravel sequence at Four Ashes is a distinct stratigraphic unit, varying in thickness from 5 cm to 2.75 m, post-dating the cessation of gravel deposition. White granite erratics (attributed to S.W. Scotland) were frequently encountered in the till, the largest being approximately 1 m^3. Other erratics found within the till unit consisted of striated volcanics and slates, probably from the Lake District and/or Scotland, Eskdale granite, Ennerdale granophyres (usually less than 5 cm in size), occasional limestones of both Carboniferous and Liassic age and Cretaceous flints. The most unusual erratic found at the base of the till sheet and probably derived from the Four Ashes gravel was a single lamellar plate of a mammoth tooth.

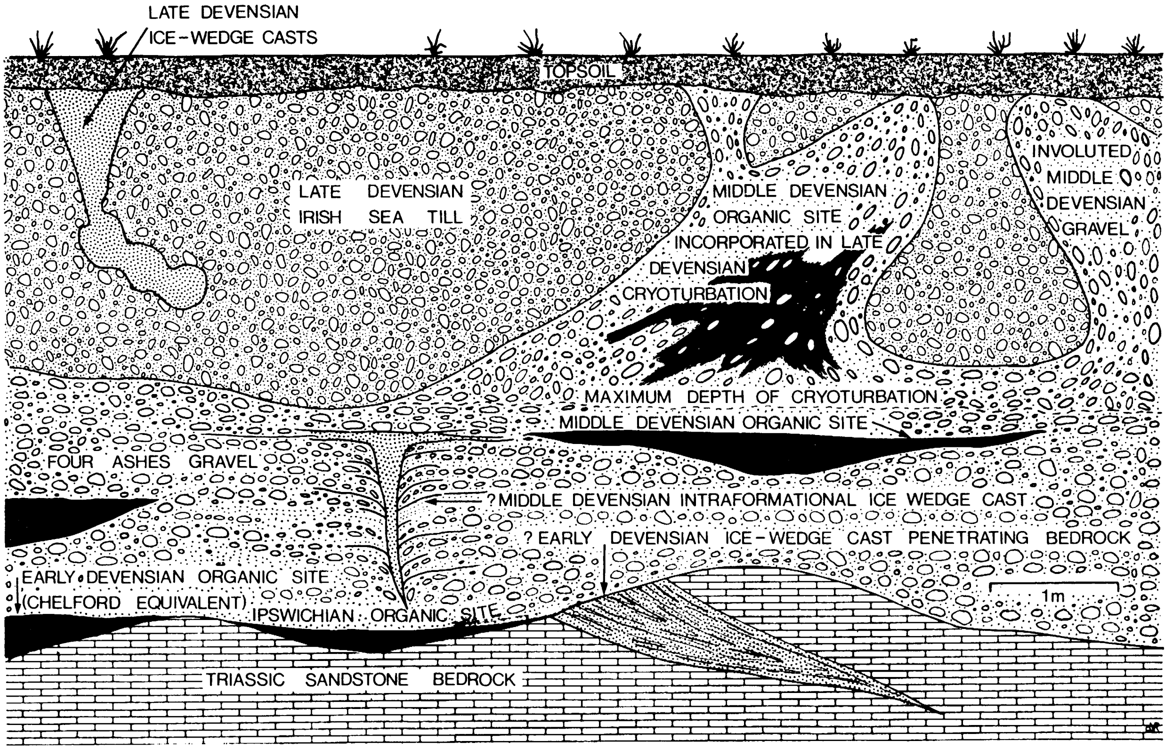


FIGURE 3. General stratigraphy of the Four Ashes pit illustrating features seen between 1967 and 1970.

(e) *Ice-wedge casts at Four Ashes post-dating the gravel deposition*

The Irish Sea till capping the gravel sequence at Four Ashes is penetrated by a number of ice-wedge casts. These will be mentioned at greater length later in this paper but they have been mentioned here to facilitate a more complete description of the Four Ashes sequence.

(f) *The significance of the Four Ashes stratigraphic sequence*

The evidence for climatic change during the Early and Middle Devensian within the study area has been derived from a number of organic lenses and intraformational ice-wedge casts in the gravel sequence at Four Ashes. This deposit is unique among the Devensian sites so far described in Britain in that it spans probably the whole of the Lower and Middle Devensian. When the Irish Sea till and the periglacial features affecting this till are taken into consideration, it appears that the Upper Devensian is also well represented. In addition, there is a strong probability that the deposit at the base of the gravels (Locality 44) is Ipswichian. At first sight it appears unusual that about 40 000 years, or more, can be represented in a gravel unit between 45 cm and 4.6 m thick. However, several facts may account for this anomalous deposit. These may be described as position, supply and source.

The position of the Four Ashes gravel on a relatively small stream system probably largely explains the lack of any effective water scour during this period. The amount of water available for the stream at this point in its thalweg was probably quite limited and when the stream was active a lot of energy was probably lost in transportation. The supply of gravel is locally derived from the Bunter Pebble Beds which outcrop approximately 3 km east of the (1970) Four Ashes Pit. The Four Ashes gravel can be traced into the gap in the Bunter Pebble Beds and it also forms an extensive spread across the Saredon Valley, reaching a maximum known width of about 800 m, at 9240.0810 to 9240.8090. In this way the streams transporting the Four Ashes gravel must have been choked with large quantities of gravel and sand, probably changing direction frequently, anastomosing over the underlying gravels and sands. Lastly, the source of material was probably directly related to the climate.

The periglacial, continental environment which typified the larger part of this period would result in severe solifluction activity, and the Bunter Pebble Beds with large water-storage capacity would probably be very susceptible to freeze/thaw action. With increased continentality the amount of water falling in the area would be less than at present and with reduced stream flow in an attenuated catchment area the streams carrying the Four Ashes gravel would probably tend to have restricted power. It is also interesting to observe that in all the sites examined at Four Ashes the only beetles indicative of actively running water are confined to the sites deposited during the Ipswichian and the Chelford episode of the Lower Devensian. Although running water undoubtedly existed throughout the gravel deposition, the braided nature of the Four Ashes sequence indicates continuous oscillation between deposition and erosion through the Devensian.

The presence of occasional far-travelled stones found within the Four Ashes gravel deposit must indicate an earlier ice advance into the area. Although the paucity of erratics may be due to dilution with numerous locally derived Bunter pebbles, it might also suggest that the erratics were derived from an older pre-Ipswichian ice advance. There is no suggestion from the 51 organic sites examined by Anne Morgan that the Four Ashes gravel is of glacio-fluvial origin.

There is, however, good evidence for climatic deterioration on at least two occasions during the deposition of the Four Ashes gravel. Evidence for climatic change within the Four Ashes gravel comes from faunal evidence and is described in considerable detail elsewhere (Anne Morgan 1970) and by the presence of two horizons of ice-wedge casts in the sequence. These are indicated by one massive wedge penetrating the bedrock and being truncated by the basal gravel, and an upper sequence of wedges originating in the gravels at least 150 cm above bedrock. This double phase of periglacial activity probably matches the major twin cold episodes indicated by beetle evidence from the gravels, and substantiated by ^{14}C dates and floral evidence.

The earliest cold period pre-dates the limit of normal ^{14}C dating, but is believed to post-date deposits of the same age as those at Chelford. The Chelford deposits were dated by differentially fractionated ^{14}C to 61 000 B.P. (Vogel & Zagwijn 1967), while the first cold phase at Four Ashes is shown to be pre-43 500 B.P. (Birm. 74). The second cold phase, probably indicated by the upper horizon of ice-wedge casts is almost certainly post 38500 B.P. (Birm. 170) for faunal reasons stated elsewhere (Anne Morgan 1970).

In conclusion, the sequence in the Four Ashes pit indicates a commencement of deposition during the Ipswichian Interglacial with representative lenses of Lower Devensian (Chelfordian) age indicative of a coniferous forest cover. This was followed by a periglacial episode which was severe enough to rupture the bedrock at the base of the gravel unit. The Middle Devensian is well represented with a number of organic sites indicating a climatic amelioration in the period between 42 000 and 38 000 years B.P. This amelioration was shortlived and the climate gradually deteriorated, periglacial conditions ensuing once again in the period prior to the youngest ^{14}C date at Four Ashes.

Some time after 30500 years B.P. but before 13500 years B.P. the Upper Devensian Irish Sea ice sheet advanced over the Four Ashes gravel and eventually halted at the Wolverhampton Line. A periglacial environment followed the retreat of this ice sheet causing the ice-wedge casts, polygonal patterned ground and involutions which penetrate the till above the Four Ashes gravel.

3. Upper Devensian till

(a) *Introduction*

The till sheet covering most of the central part of the map area is easily identifiable in the field because of the nature of the erratics which are found above or within it. The till consists of a red clay (when fresh, 2.5 YR 3/4) sandy in parts, often streaked with grey-green veinlets (5Y6/3) and quite plastic when fresh and damp. Upon exposure to air the deposit lightens in colour and becomes exceptionally hard, and if struck with a hammer tends to shatter irregularly. The till is often leached (5 Y 6/2), usually in the top 20 to 30 cm, and is frequently overlain by a deposit of coarse, brown, sand and gravel. The pebbles within the till are commonly re-alined by periglacial activity. Re-alined pebbles were encountered to a depth of at least 2 m in many exposures and, for this reason, pebble orientation measurements were useless for determining the direction of ice-flow. The till was revealed in hundreds of individual exposures throughout the field area, and at least 35 km of pipe-line trenches (gas and sewerage) provided sections through the till unit, often to bedrock.

(b) *Nature and extent of the till sheet*

The reddish or red-brown clay deposit which covers about 165 km^2 of the area mapped has been identified as a till sheet by the presence within it of numerous pebbles derived from Scotland, the Lake District and the Irish Sea Basin. A number of these erratics are facetted and striated, indicating a glacial origin, while some attain dimensions approaching 1 m^3.

The distribution and thickness of till in the map region is shown in figure 4. This map was compiled from 2422 records in the till sequence, of which 1225 boreholes and sections penetrated the complete till sequence to bedrock. The remaining 1197 records were used to give a minimum estimate of till thickness at that point. The following facts emerge:

(1) The till sheet thickens from north to south across the area.
(2) The till isopachytes trend from northeast to southwest.
(3) The till ends in the southern third of the area in small, lobate bulges.

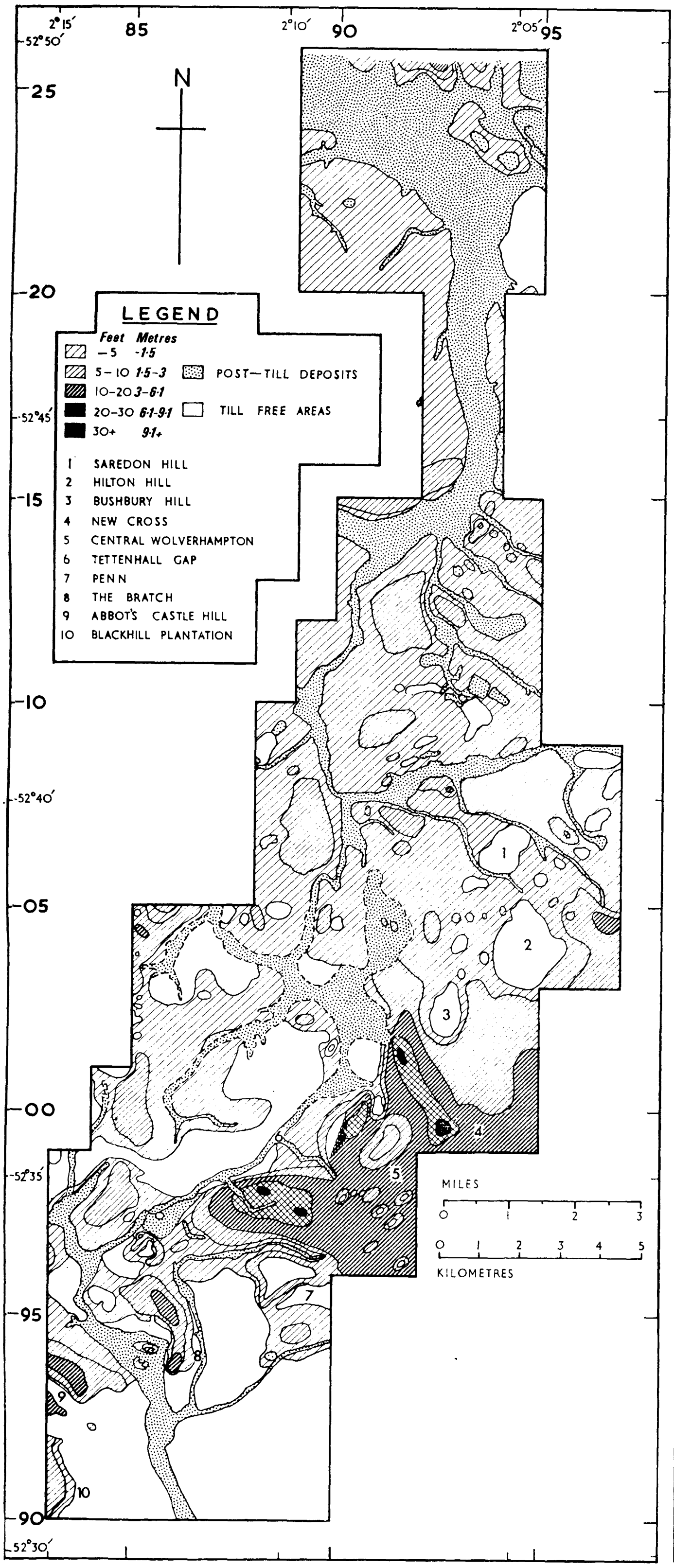


FIGURE 4. Distribution and thickness of till in the map area.

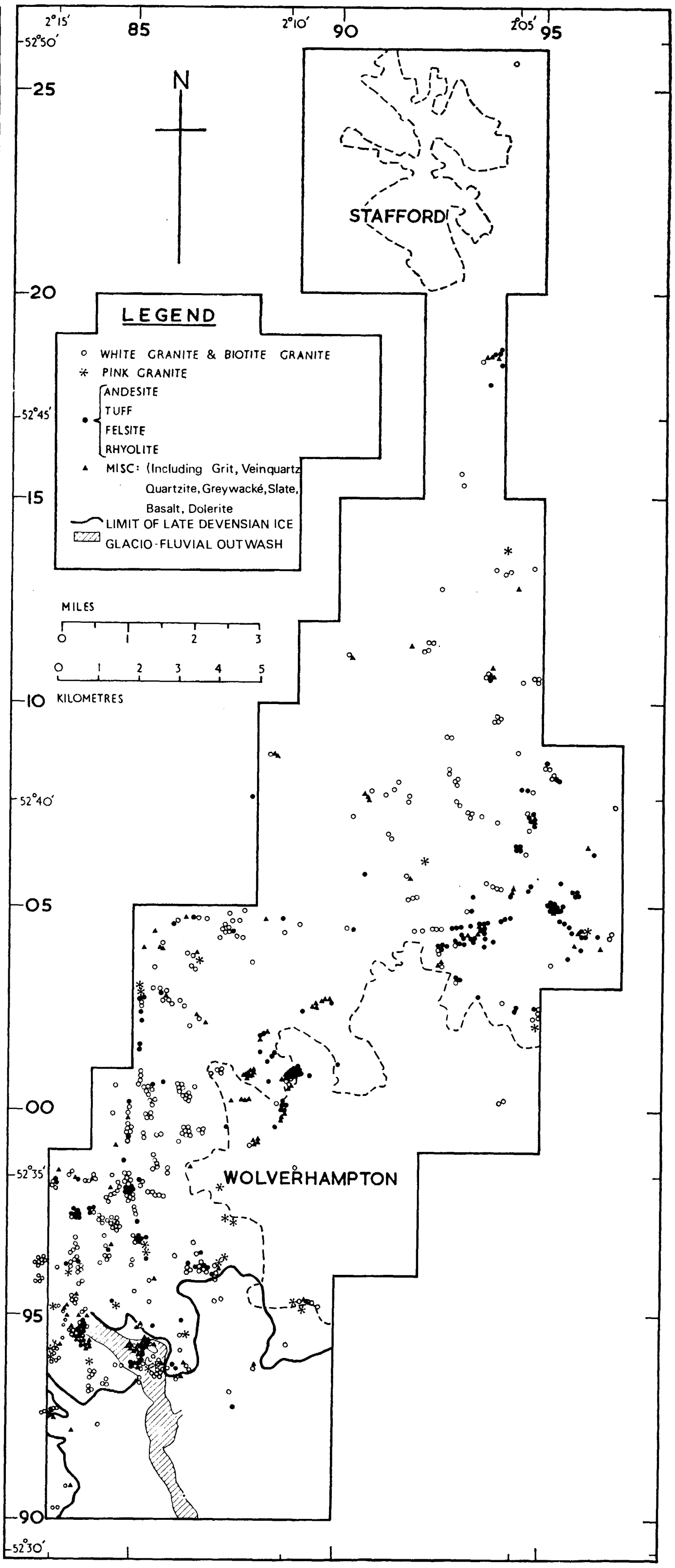


FIGURE 5. Distribution of mega-erratics in the map area.

(4) Till is absent in areas of high ground in the centre of the map.

(5) The till sheet extends farther south in the Worfe Valley than it does in the Smestow Valley.

The till sheet in the extreme north of the region is very thin, usually less than 1 m, and practically indistinguishable from Keuper Marl in many exposures. In this way areas of land mapped as Keuper Marl are frequently covered with a thin veneer of till. This can usually be detected by frequent Bunter pebbles, with occasional Scottish and Lake District erratics, in a mélange of reworked Keuper Marl overlying undisturbed Keuper Marl. Many of the erratics are striated and the altitudinal distribution of this deposit over a wide geographical area means that it is likely to be a till which has been principally derived from the local bedrock.

In the central part of the map area the till is generally less than 1.5 m, but localized areas of thicker till (usually up to 3 m) do occur. In this region the underlying bedrock consists of sandstones of Keuper and Bunter age, and this frequently results in an increase of sand in the till. In several deep exposures in the Penkridge area the till was seen to overlie about 50 cm to 1 m of fine reddish brown sand containing numerous angular fragments of sandstone, in turn resting upon Keuper sandstone. In the gas pipe-line trenches farther south the till was seen to rest either directly on bedrock or upon coarse sands and gravels containing erratics associated with the till.

In the east-central part of the map area the till thins around the Bunter Pebble Bed hills at Saredon, Hilton and Bushbury; although the present altitudinal distribution of till probably does not represent the 'strand line' of the ice surface, as erratics are found higher than the till limit on each of these hills. South of Bushbury Hill (figure 4) the till thickens steadily to an average depth in excess of 4 m, and this belt of thicker till extends from northeast to southwest approximately paralleling the limit of the till sheet. Local sub-till topography has influenced till thicknesses to a considerable extent and, whilst in the central Wolverhampton area till may be less than 1.5 m, or even absent, in the New Cross Region and in the area southwest of Bushbury Hill and south of the Tettenhall Gap thicknesses in excess of 10 m have been recorded. In the thicker areas of till the borehole records frequently show sand between boulder clay units. Although this sequence is difficult to interpret correctly unless samples are available, it has been assumed that only one till is present and that the sand and gravel units within the clays represent intra-till deposits, and not deposits which have originated extra-glacially, as, for example, during an interstadial or an interglacial episode.

The southern limit of the till sheet is not a uniform front, but appears to be modified by the local topography. In this way the high land west of Penn (figure 4) splits the till sheet into an eastern and western lobe. The eastern lobe terminates along the line of the Penn Brook south of Penn, and the western lobe ends along a line running from The Bratch to Abbot's Castle Hill. This western lobe is divided into two areas separated by the glacio-fluvial outwash of the Smestow Brook. North of the Smestow Valley the till sheet is quite clayey, thickening rapidly under localized conditions (Morgan 1970*a*, p. 126). As the till sheet passes over the Trysull sands and gravels north of Trysull and Seisdon, it becomes quite sandy and loses most of its clay, becoming difficult to differentiate from outwash. The till again thickens along the northeastern side of Abbot's Castle Hill, but disappears before reaching Park Farm (8430.9285). The area of till immediately west of The Bratch terminates at 8585.9360, approximately 250 m east–northeast of Woodford Grange Farm. The slightly undulating topography does not indicate any appreciable thickness of till. However, excavations and boreholes by the Redland Group have proved up to 6 m of till in parts of this area. Immediately east of Trysull at 8543.9412 borehole records reveal at least 3 m of till on Upper Mottled Sandstone, an interpretation later substantiated by excavations for a gas pipe-line. Other patches of till between 1 and 2 m thick have been seen in other parts of the same pipe-line and in auger holes immediately south of Trysull at 8532.9377 and 8517.9395. These till patches are situated on areas of high relief within a wide area of glacio-fluvial outwash gravels and sands, and are probably remnants of a once larger portion of the till sheet.

The till sheet is again present along the eastern edge of the River Worfe catchment basin immediately to the west of the Abbot's Castle–Blackhill Plantation ridge. In this area the till sheet in part overlies a current-bedded sand and gravel sequence which is discussed later. The till was proved to extend at least as far south as the extreme southwestern corner of the map area (figure 4), thus indicating that ice was present farther south in the Worfe Valley than it was in the upper Smestow Valley.

(c) *Erratic content of the till*

As mentioned earlier, the first descriptions of Pleistocene deposits in the West Midlands concerned the presence of numerous erratic blocks in different parts of the region. Specific concentrations of erratics have been described from the flanks of Bushbury Hill, the Tettenhall Gap, and the country around Trysull and Seisdon (Woodward 1870). One hundred years later these areas still provide large numbers of erratics; although it is difficult to find the 'thousands' referred to by earlier authors (Mackintosh 1879, p. 437). Undoubtedly numerous erratics have been removed, destroyed, or simply re-buried, and the resultant distribution map (figure 5) must be regarded as representing a minimum number of the large erratics.

The erratics have been divided into two categories; erratics which have a minimum side measurement of 30 cm, and erratics smaller than this. The size boundary is purely arbitrary and has no geological significance. The first category includes erratics frequently encountered in walls or farm buildings, but usually excavated by farmers and left near the field boundaries. These have been termed mega-erratics. The second group consists of erratics found in exposures in the till sheet. Essentially these are of the same lithological types as the mega-erratics, but certain additional lithologies have been identified which are not present in the mega-erratic group.

(i) *Mega-erratics*

Generally these exceed one half of a cubic metre and are often in excess of 1 m^3. They have been found in many parts of the field area, concentrated in regions described by earlier authors. A number of distinctive lithologies were recognized and the most common include grey-white granite (Criffel type), red-pink granite (Eskdale type), Ennerdale granophyre, felsites, andesites and tuffs. More uncommon mega-erratics include greywacke, slate, basalt, quartzites and vein quartz boulders. An examination of the mega-erratic distribution (figure 5) reveals:

(1) An apparent lack of mega-erratics in the northern one third of the map area.

(2) Concentrations of mega-erratics along the southwest, northwest and north sides of Wolverhampton.

(3) A belt of white granite mega-erratics running northeast to southwest across the map.

(4) A local concentration of volcanic mega-erratics in the hilly region around Hilton.

(5) Mixing of the different mega-erratic types in the area southwest of Wolverhampton.

(6) A small concentration of mega-erratics in the glacio-fluvial outwash at Trysull.

(7) An absence of mega-erratics in the area outside the limit of the till sheet, except for the mega-erratics in the Late Devensian outwash gravels.

The lack of mega-erratics within the limits of Wolverhampton is almost certainly purely artificial since large erratics have been described from this area in the past. Their absence is attributed to removal or re-burial during building operations. Verification of the concentration of mega-erratics in certain areas, and particularly of distinctive lithologic groups, was demonstrated during gas pipe-line trenching operations as seen in table 1.

TABLE 1. DISTRIBUTION AND LITHOLOGY OF MEGA-ERRATICS IN PIPE-LINE TRENCHES

pipe-line length (km)	locality	trench width (m)	trench depth (m)	number of erratics	lithology: grey-white granite	pink granite	andesite	tuff	felsite	slate	grey-wacke
2.7	9281.0459 – 9580.0460	1.5	2.0	16	—	—	12	2	1	1	—
2.7	8510.0050 – 8510.9754	1.5	2.0	36	29	2	2	—	1	1	1
2.7	9321.1440 – 9530.1330	1.5	2.5	2	1	1	—	—	—	—	—

There does appear to be a close similarity between the lithology of the mega-erratics found on the surface with those excavated from the surrounding till within certain geographical areas, whilst in other areas the absence of surficial mega-erratics appears to reflect a general absence of large erratics within the till sheet.

Numerous mega-erratics have been found in the glacio-fluvial gravel sequence at Woodford Grange, probably representing a lag deposit from the re-washed till lobe between Trysull and The Bratch. This is suggested because of the general lack of mega-erratics in the same terrace sequence farther to the south. If ice-rafting had been a major form of transport, these mega-erratics should be found in greater concentrations elsewhere in the glacio-fluvial terraces.

(ii) *Smaller erratics*

These consist of foreign lithologies, as well as more locally derived fragments, and fall into a size category smaller than that defined for the mega-erratics. The highest percentage of erratics in any exposure in the till is always represented by the ubiquitous Bunter pebbles with smaller numbers (up to 20 % or 25 %) of northern erratics. Dismissing the Bunter pebbles and miscellaneous Triassic sandstones and conglomerates, the remaining erratics usually consist of lithological types which are represented in the mega-erratic groups quoted above. A number of erratics can be frequently found, however, which are not represented in the mega-erratic category. These include banded rhyolites, ignimbrites, various pyroclastic volcanics, Carboniferous limestone (usually dolomitized), Lower Liassic limestones, Cretaceous flints and Pleistocene marine shells. Likely source areas can be suggested for several of these groups. In addition, the proportion of Eskdale granite fragments exceeds that of similar mega-erratics. One erratic of Cumberland haematite was also found in outwash at Woodford Grange.

The general absence of large Eskdale granites in comparison with the number of small fragments of this lithology in the till was commented on by Mackintosh (1897, p. 436) and Dewey (in Whitehead *et al.* 1928, p. 185). Similarly, the presence of Jurassic fossils and Pleistocene marine shells was described by Lister as early as 1862 (Lister 1862).

(*d*) *Ice-flow direction indicators*

A careful search was made for large-scale fluting features on the air photographs and on flights over the area, but none was observed. This might be due to a genuine absence of these landforms or lighting angles during the photographic runs, or possibly because a number of these features may have been mantled by the long history of agricultural land usage in the region. Small-scale features were similarly of little use. The bedrock over most of the area (Keuper marls and sandstone, and soft Bunter sandstones and Pebble Beds) does not retain striations, and neither grooves nor gouges were observed. Pebble orientation, microfabric and magnetic anisotropy analyses are invalidated by post-till movement caused by periglacial activity, and although a number of localities were ideal for the formation of linear sole markings, none was found. The only characteristic useful in the diagnosis of ice movement in the area was the presence of indicator erratics in the till. Because of the geological complexity of the source areas of the ice in the Highlands of Scotland, the Lake District and Wales, and because of the knowledge of at least one earlier ice advance into the region, the usefulness of indicator erratics is somewhat diminished.

The presence of Eskdale granite, Ennerdale granophyre and grey-white granite, probably from Criffel or Dalbeattie, clearly points to a northwestern derivation for a large number of the more prominent erratic types. Similarly, the presence of yellow Cretaceous flints (some with *Inoceramus* fragments) and Pleistocene marine shells points to ice movement from the Irish Sea Basin. The haematite erratic ($12 \times 6 \times 6$ cm) was almost certainly derived from the western part of Cumberland, while the Lower Liassic limestones and fossils (*Pentacrinus* ossicles, *Gryphaea* and other lamellibranchs) probably originated in outcrops in north Cheshire. In summary, there is good evidence to show that many erratics found in the Wolverhampton area were derived from Scotland, the Lake District, northwest England and the Irish Sea Basin, and must therefore have been transported by an 'Irish Sea' ice sheet.

(*e*) *Age of the till sheet*

Unlike North American tills, which contain wood fragments thought to have been incorporated when the Wisconsinan ice sheet advanced over forested areas, the British tills are devoid of vegetable debris believed to be contemporaneous with ice advance. This means that the age of the glacial advance can only be estimated by relating it to deposits which have been ^{14}C dated above and below the till sheet. The till sheet covering the area has been bracketed in this way at several sites in the region. The youngest deposits ante-dating the till were a silt with wood fragments from Four Ashes, dated at 30500 (Birm. 195) and a peaty silt also from Four Ashes dated at 30655 years B.P. (Birm. 25). Deposits overlying the till at distances north of Four Ashes of 3, 6, 5 and 15 km have provided progressively older ^{14}C dates of 10670 (Y. 464), 11580 (Birm. 118), 11660 (Birm. 131), and 13490 years B. P. (Birm. 150). In this way the ice advance which deposited the till over most of the area is known to have arrived after 30500 years B.P. and had receded prior to 13490 years B.P.

(*f*) *General discussion*

The evidence presented in the previous sections indicates that an Irish Sea ice sheet advanced into the area some time after 30500 years B.P. and stopped in the position indicated in figure 4; the area adjacent to the terminus being marked by a pronounced thickening of the till sheet.

However, this is not obvious from the topographic expression of the area, as the till infills depressions in an undulating bedrock surface rather than leaving a more obvious terminal moraine projecting above the general till plain. The terminal position of the ice sheet is also marked by large numbers of Irish Sea mega-erratics, especially in the Seisdon and Trysull areas. The ice sheet is believed to have covered all the hills in the area even though some are now free of till. This is attributed to the post-till periglacial environment and the till is believed to have moved downslope under solifluction activity. The presence of occasional Irish Sea mega-erratics on the summits of these hills indicates that the ice had formerly over-ridden them.

Distinct areas of mega-erratics of different lithological types indicate segregation of discrete masses of ice from certain source areas which have retained their identity within the composite Irish Sea ice sheet. A similar phenomenon has also been observed and described in western Alberta, where three distinct ice-masses were identified on the lithology of erratics within the till sheet (Morgan 1969*b*). Mantle (1896), describing the large erratics in the region adjoining the eastern boundary of the present map area, also noticed that the erratics appeared to be differentiated into distinct lithological groups. Specific examples of these lithological groups in the area mapped are the andesitic and tuff mega-erratics of the Hilton area, and the concentrations of Rhaetic and Lias material, together with Pleistocene marine shells found in the drift in the area immediately north and northwest of Lower Penn (Whitehead & Pocock 1947, p. 156; Morgan 1970*a*, p. 129).

The age of the Irish Sea ice advance which brought the mega-erratics and the red clay till into the region and which terminated at the Wolverhampton Line has been previously described as Saalian (Wolstonian), Early Würm (Lower Devensian) or Late Würm (Upper Devensian). In 1959 E. G. Poole suggested that the Upper Boulder clay of the Cheshire Basin was deposited at the maximum of the Riss (Saale) glaciation (discussion, p. 120, in Simpson 1959). In this same paper Simpson (1959, p. 117) stated that the Upper Boulder Clay was post 57000 (a date obtained by De Vries on wood samples from Chelford) and '...clearly must belong to the Last Glaciation'. He did not define the period which he envisaged as the 'Last Glaciation' but it would (at that time) presumably have been placed in the Middle or Upper Devensian. In a paper presented by Shotton & Strachan (1959), the authors believed that the maximum Irish Sea ice advance was slightly before 42000 years B.P. during the Middle Devensian. This view was again expressed in later papers by Mitchell (1960), Coope *et al.* (1961), Coope (1962) and Penny (1964). The age approximation of ice advance was inferred by the dating of two separate samples of peat from within a terrace of the River Salwarpe at Upton Warren to 41500 ± 1200 (GrN 595) and 41900 ± 800 years B.P. (GrN 1245). The Salwarpe terrace had been correlated with the Main (glacio-fluvial) Terrace of the Severn, and the Main Terrace was believed to have been formed by outwash from the retreating Main Irish Sea ice sheet (Coope *et al.* 1961). This correlation was apparently substantiated by a date from Fladbury of 38000 ± 700 years B.P. (GrN 1269) on a peat deposit from the base of Avon No. 2 terrace, also believed to be the equivalent of the Main Terrace (Coope 1962).

In 1961 a paper by Poole & Whiteman again postulated a tripartite division for the drifts of the Cheshire–Shropshire basin, using the Upper Boulder Clay, Middle Sands and Lower Boulder Clay of previous authors. No chronology was given, but the Main Irish Sea advance, on their interpretation, was represented by the Upper Boulder Clay. As mentioned above, Poole had suggested in 1959 that this till was Saalian (Wolstonian) and in the 1961 paper he and Whiteman extended the Upper Boulder Clay to the Birmingham district, well south of the Wolverhampton Line. This correlation was based on the assumption that the large erratics of the Wolverhampton Line did not mark the limit of the Main Irish Sea glaciation, but merely represented the limit of the northern erratics in the ice sheet. South of the Wolverhampton Line the Welsh erratics of the Birmingham district (ascribed to the 'Older Drift'; Wills 1937) were believed to be contemporaneous with the northern erratics north of the line, on the premise that a belt of Welsh ice had been pushed south of the northern ice as originally postulated by Eastwood *et al.* (1925, p. 106). Thus the 'Older Drift' Upper Boulder Clay of the Birmingham district was stated to be contemporaneous with the 'Newer Drift' Upper Boulder Clay of the Cheshire–Shropshire basin. Since the 'Older Drift' Upper Boulder Clay of the Birmingham area (Pickering 1957, pp. 223–239) is believed to be of Saale (Wolstonian) age then the Upper Boulder Clay of the Cheshire area was also believed (by Poole and Whiteman) to be Saale, and the Lower Boulder Clay probably Elsterian.

In 1963, Taylor, Price & Trotter equated the Lower Boulder Clay of the Stockport district to the Main Irish Sea glaciation of Wills, and correlated the Upper Boulder Clay to a re-advance of the same ice sheet. Both of these glaciations were then suggested to belong to the first two cold episodes of the last glaciation in Western Europe (Weichsel/Würm 1 and 2), thus making the Main Irish Sea glaciation Lower and Middle Devensian.

An analysis of the depth of leaching by Boulton & Worsley (1965) in the till sheet both north and south of the Wrexham–Whitchurch–Bar Hill moraine led them to postulate:

> '...that the drifts to the south are considerably older than those to the north. It would, therefore, appear that the ice sheet which was responsible for the deposition of an Upper Boulder Clay in the northern part of the area advanced to a line extending from Bar Hill to Whitchurch and Wrexham, in which position an end-moraine accumulated. The ice then retreated and did not afterwards override this moraine.'

Shells obtained from a sand unit beneath a till/sand complex of Upper Boulder Clay age, north of the forementioned moraine at Sandiway, were radiocarbon dated to $28\,000^{+1800}_{-1500}$ years B.P. In this way the Upper Boulder Clay north of the moraine became equated with the Late (Main) Weichselian advance, whilst the 'upper' boulder clay south of the moraine was older, and presumably Early Weichselian (Lower–Middle Devensian). This line of reasoning was also accepted by Yates & Moseley (1967).

In the survey memoir for the Nantwich–Whitchurch area, Poole & Whiteman (1966, p. 65) finally recognized that there was a conflict between their proposed Saalian age of the Upper Boulder Clay and the evidence presented by Simpson & West (1958). They then suggested that '...the Upper Boulder Clay in both the Shropshire–Cheshire Basin and the Birmingham area is Würm II in age with the further possibility that the Lower Boulder Clay is Würm I in age'.

At the outset of this mapping project in March 1967, it was evident that Irish Sea till, in the Four Ashes area, was resting on top of a gravel sequence containing peat lenses. Subsequent examination of the organic deposits suggested a Middle Devensian age for the contained faunas and two radiocarbon dates of $30\,655^{+765}_{-700}$ years B.P. (Birm. 25) and $36\,340^{+767}_{-706}$ years B.P. (Birm. 24) substantiated this idea. In this way the Irish Sea till just north of the Wolverhampton Line was evidently of Late Weichselian (Upper Devensian) age and was described as such by Shotton (1967).

In a reply to this paper, Poole (1968) reiterates that '...the Upper Boulder Clay is a viable time-stratigraphic unit within the Shropshire–Cheshire Basin...', and that the Upper Boulder

Clay is Würm II with the Lower Boulder Clay inferred as probably of Würm I age. He also re-states that:

> 'The so-called "Wolverhampton Line" is merely an approximate limit of large "Irish Sea" erratics in the Upper Boulder Clay and as such is not absolute evidence of the maximum limit reached by ice-sheets in the Würm II period of glaciation.'

W. B. Evans (Evans, Wilson, Taylor & Price 1968) gives a concise account of the problems of correlation between radiocarbon dates and the different deposits in the Cheshire–Shropshire Basin and Staffordshire, and suggests that the Main Irish Sea ice advance is most likely to represent the Main Weichselian (Upper Devensian) glaciation. Furthermore, he states that:

> '...the residual nature of the patches of Lower Boulder Clay suggest that a major period of erosion separates its deposition from that of Chelford Sand. Consequently no more can be said than that the Lower Boulder Clay is the product of one or more pre-Brørup glaciations, and there is no support for the concept of a major glaciation in this (Macclesfield-Congleton) district in the early Weichselian.'

In summary, considerable confusion has existed over the age and the extent of the glaciation which deposited the Irish Sea till over the western and northwestern Midlands. From the results presented in this paper it would appear that the maximum limit of the Irish Sea ice in the west Wolverhampton area was reached during the Upper Devensian. This final boundary is marked by a tenfold thickening of the till sheet in a belt 4 to 5 km wide. The terminal position is also marked by a concentration of Irish Sea mega-erratics referred to by earlier writers as the Wolverhampton Line. The presence of indicator erratics from Scotland and northwest England infers the movement of this ice-sheet from these source areas, whilst the indicator erratics from the Irish Sea Basin and north Cheshire suggest a general ice movement into the area from northwest to southeast. This direction of ice movement is at right angles to the general trend of thickened till in the Wolverhampton area. Although distinct lithological groups of mega-erratics occur in the region mapped, there is no indication, either from mega-erratics or smaller erratics, that a zone of Welsh ice, contemporaneous with the Main Irish Sea ice sheet, lay to the south of the latter. Where the till sheet ends, it ends as a typical Irish Sea till and there is no evidence south of the Wolverhampton Line (within the area mapped) of any till of Welsh origin of Upper Devensian age. There is also no evidence in the region for the tripartite division of the Pleistocene deposits as described in parts of the area to the northwest. Only one till is recognized over the map area, although glacio-fluvial outwash deposits of an earlier ice advance (believed to be Late Anglian and described in § 6) have been found beneath the Upper Devensian till. The erratic content of this outwash is also, significantly, characterized by a moderate percentage of Irish Sea erratics, but an assemblage different from that of the latter till.

4. Glacial outwash deposits – Trysull sands and gravels

(a) *Introduction*

Field mapping in the vicinity of Trysull and Seisdon has revealed an area of sand and gravel which is well exposed in a number of deep pits (figure 6). An extension of field mapping south of Kingswinford shows that deposits of the Trysull–Seisdon complex are a continuation of the so called 'Kingswinford Esker' (Boulton 1916). Certain broad generalizations can be made for the

Kingswinford–Trysull–Seisdon complex (henceforth referred to as the Trysull sands and gravels). The lithology of this deposit within each of its constituent outcrops is quite characteristic, consisting of coarse yellowish red (dry, Munsell code: 5 YR 5/7) sharp sand or sandy gravel with pebbles of Bunter origin usually dominant, but also with numerous large rounded erratic blocks of sandstone and frequent northern erratics. The sandstones are so large (up to 100 cm) and yet so well rounded and soft that they cannot be derived from a great distance. They are ascribed to the Upper (Barren) Coal Measures such as occur on the west side of the South Staffordshire Coalfield. The distant erratics consist of rotten white and pink granites and pink-orange felsites. Occasional rare, but well preserved, andesites are also present. The Trysull

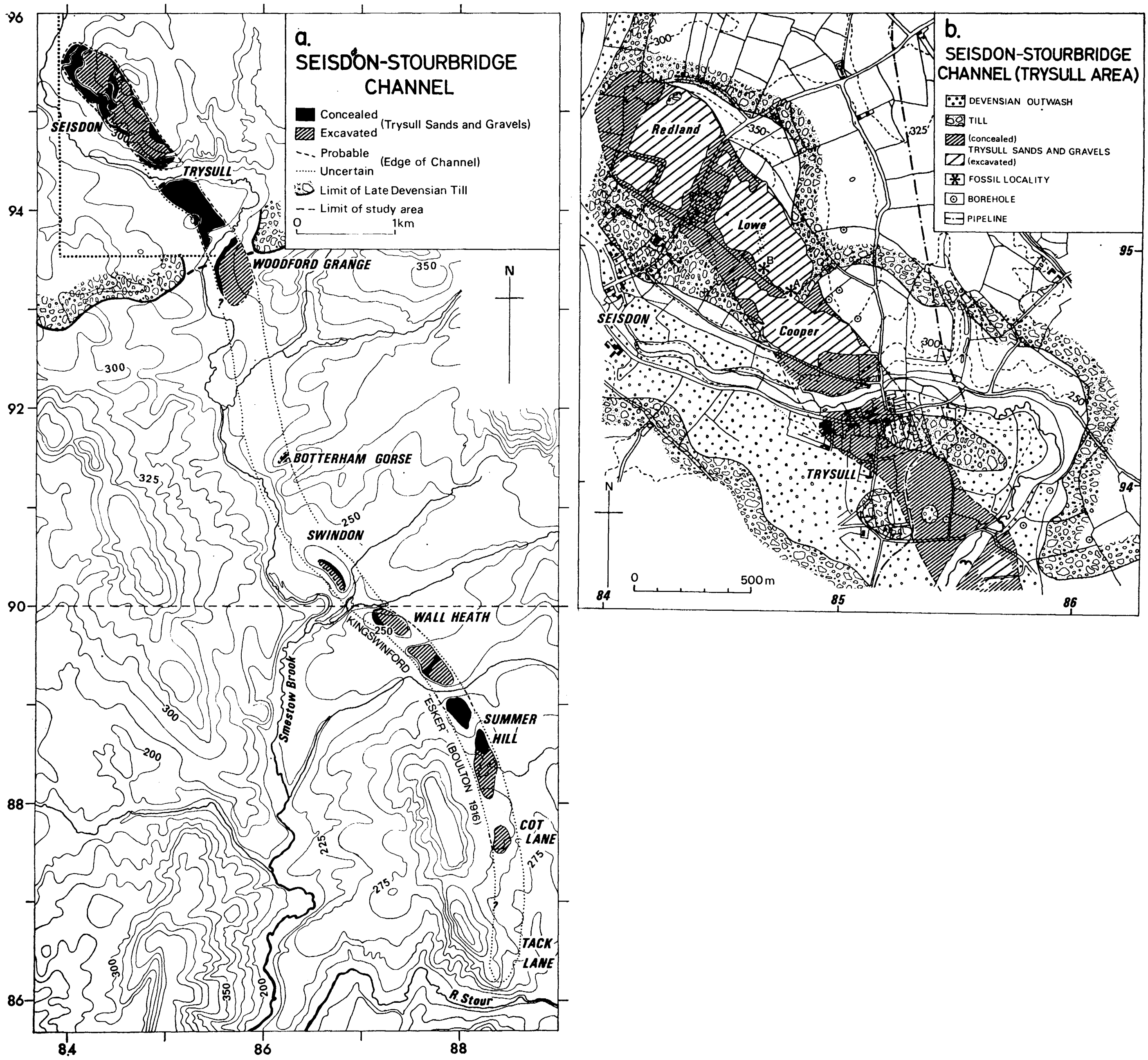


FIGURE 6. (*a*) Seisdon–Stourbridge Channel. (*b*) Seisdon–Stourbridge Channel (Trysull area).

sands and gravels are further characterised by signs of tumultuous water deposition and numerous collapse structures, some of which reach considerable dimensions. The deposits also frequently fill a deep channel-shaped depression in the sandstone bedrock.

The height above ordnance datum of the sand and gravel contact with the bedrock at the bottom of the channel is uncertain at many points, since most of the pits have been abandoned and subsequently infilled. The following figures are either field estimated observations of this contact, or taken from Boulton (1916, p. 10). These are placed on record because tipping in old pits will only further obscure the 1969 exposures.

locality	metres	(feet) O.D.
Seisdon (Redland Pit)	74.7	(245)
Seisdon (Lowe's Pit)	73.1	(240)
Trysull (Cooper's Pit)	73.1	(240)
Trysull (8547.9383)	68.6	(225)†
Woodford Grange (8555.9345)	68.6	(225)
Swindon (9673.9032)	74.7	(245)
Kingswinford (Cot Lane Pit)	83.8	(275)‡
Kingswinford (Tack Lane)	79.2	(260)‡

† Borehole data only. ‡ W. S. Boulton (1916).

The complexity of the stratigraphy prevents a detailed description of each exposure; however, certain features are worthy of mention from each of the outcrops of the Trysull sand and gravel unit and these are described in the following section.

(*b*) *Exposures examined*

(i) *Seisdon* (*Redland Pit*)

The bedrock sandstone along the northern edge of this pit can be seen in a number of shallow excavations and it has also been exposed at various levels during quarrying operations. Usually the bedrock contact is obscured by drift sand, or broken by dragline working, but in a few places it has weathered out and shows flutings and swirl marks. The reconstructed bedrock form indicates a steep sandstone wall on the north side of the pit, dipping toward the southwest. The limit of quarrying operations indicates that the bedrock floor is flat to undulating. No southern bedrock wall was observed. The maximum thickness of drift sand has been estimated at 24.5 m.

(ii) *Seisdon* (*Lowe's Pit*)

Lowe's Pit will be described in detail since it shows all the features only partially represented in other outcrops of the Trysull sand and gravel sequence, and because fossiliferous deposits were found at two localities overlying the sand and gravel. These will be discussed later.

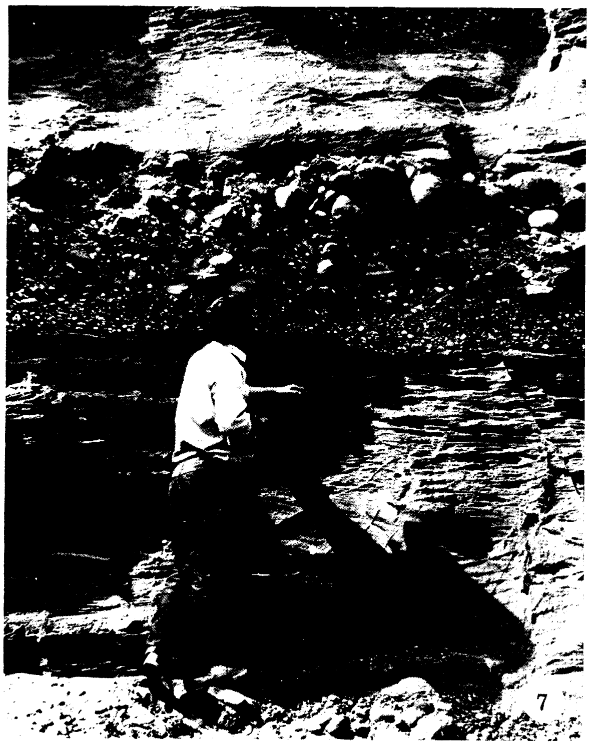
Description of plate 32

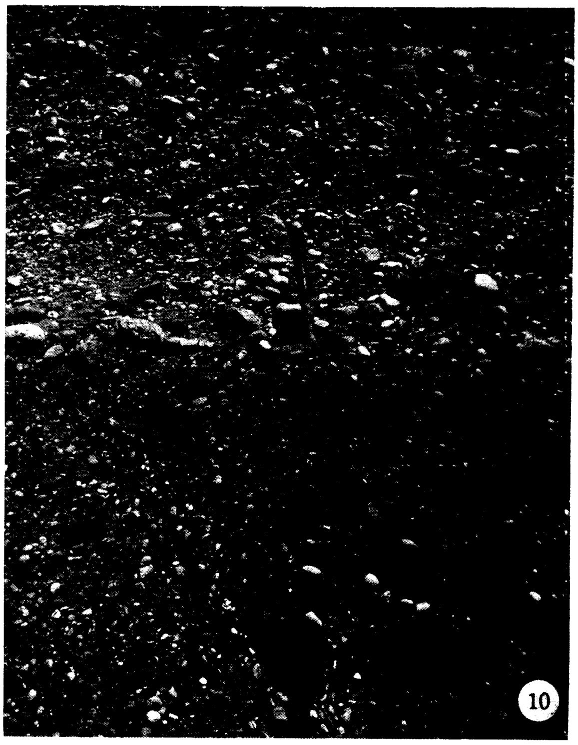
Figure 7. Alternating fine and coarse Trysull sands and gravels, Cooper's Pit, Trysull.

Figure 8. Thrust fault (2 m displacement) due to ice block ablation and subsequent collapse in the Trysull sands and gravels; Lowe's Pit, Seisdon.

Figure 9. Late Devensian till overlying Trysull sands and gravels at 8532.9377. Note rounded sandstone boulders.

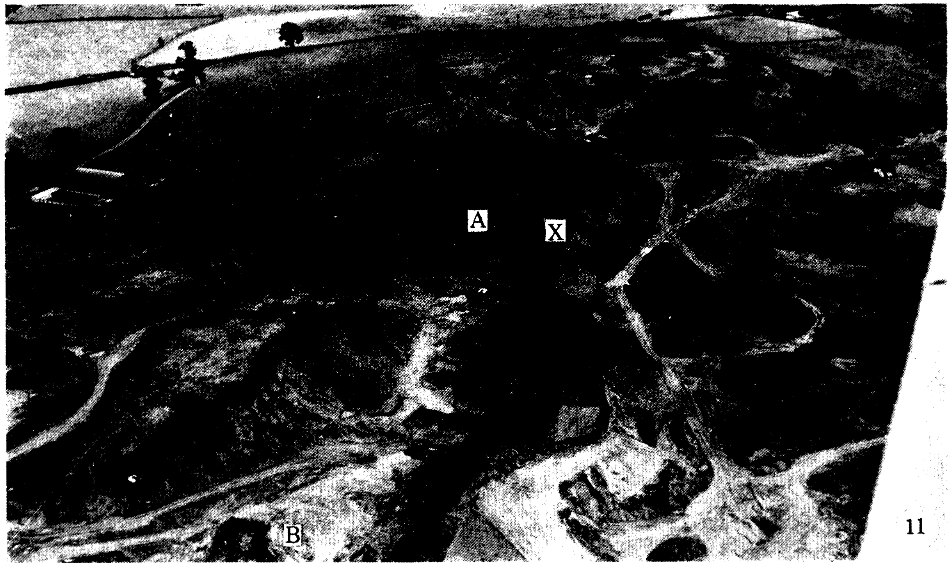
Figure 10. Late Devensian glacio-fluvial outwash on Trysull sands and gravels at Woodford Grange (8555.9345). The involuted nature and darker colour of the lower sequence and high percentage of rounded sandstone boulders can be clearly seen.





FIGURES 7 TO 10. For legends see facing page

(*Facing p.* 252)



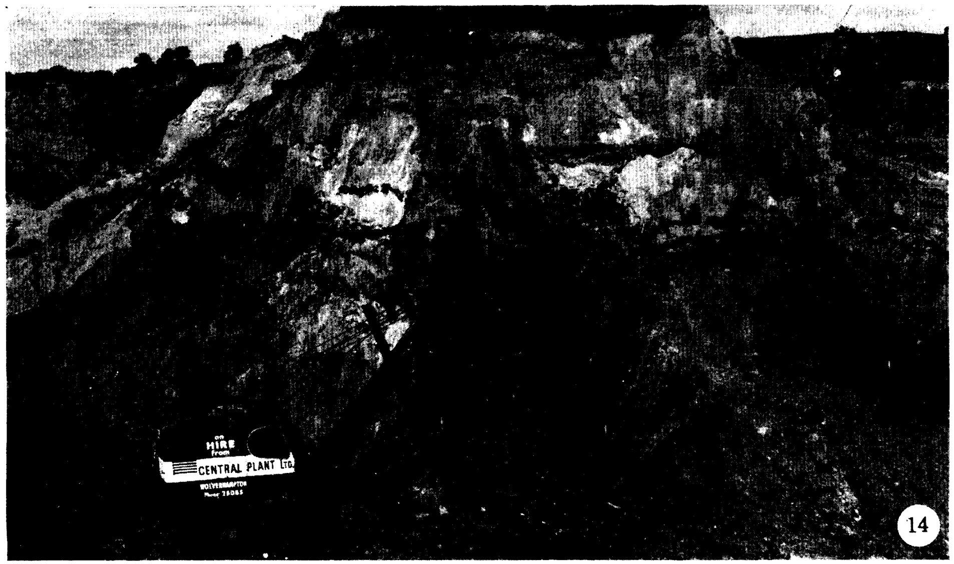


FIGURE 11. View east toward Trysull. Approximate position of northern edge of Seisdon–Stourbridge Channel lined in black. Sections A and B marked (see figures 12 and 13, and 14 and 15, this plate). Corner X at the junction of Lowe's Pit and Cooper's Pit is also marked. August 1969.

FIGURE 14. Section B, Lowe's Pit, showing the relationship between the interglacial deposits and the underlying Trysull sands and gravels, view looking north; July 1969.

FIGURE 15. Section B, Lowe's Pit, illustrating the collapsed nature of the Trysull sands and gravels underlying the interglacial organic sequence. View toward the south-west, February 1970.

Sandstone bedrock has been revealed by the removal of drift sand and gravel at many localities in abandoned sections at the west end of this pit. Unfortunately a number of the outcrops have now been obscured by the tipping of waste material or slumping of debris into the excavations. Extraction of the gravels in the centre of Lowe's Pit was eventually stopped by outcropping sandstone. The maximum thickness of drift in this pit has been estimated at 34 m.

The erratic content of the deposit consists primarily of rounded sandstone boulders (up to 50 × 100 cm) with frequent northern erratics. The most obvious feature is the apparent lack of stratigraphic order in the sequence; although more detailed analysis reveals alternating coarse and fine debris (figure 7, plate 32) which has been considerably dissected by wash-outs. The whole sequence has later been subjected to tilting and collapse with contemporaneous faulting (figure 8, plate 32). Resting unconformably on the Trysull sands and gravels are two deposits containing a moderately rich fauna and flora. These deposits in turn have been affected by post-depositional disturbance and are overlain by a sequence of coarse clayey sands. The deposits of Lowe's Pit are capped by an intermittent sandy clay with fresh Irish Sea erratics.

(iii) *Trysull (Cooper's Pit)*

This pit provides confirmation of the northern sandstone wall eastward toward Trysull Holloway, and, as in the forementioned pits, the bedrock falls towards the southwest. The erratic content of the sand and gravel sequence, the depositional environment, and the general stratigraphy are the same as in Lowe's Pit. One feature of interest was a sequence of top set, fore set and bottom set beds picked out in coarse and fine sand which had been tilted *en masse* approximately 40° from the horizontal.

(iv) *Trysull* (8510.9460) *and abandoned pit* (8465.9465)

Two other smaller workings expose the walls of the bedrock channel containing the Trysull sand and gravels. East of Cooper's Pit excavations at 8510.9460 have revealed the northern bedrock wall beneath 1.5 m of sandy soil and pebbly sand. Only 100 m to the west bedrock has not yet (1970) been reached, although 8 m of sand and gravel have been extracted. The bedrock north of this pit outcrops along Trysull Holloway and has been encountered at shallow depths in four boreholes, and in many auger holes north of the sand and gravel complex.

A small abandoned working, partially overgrown, immediately southwest of Cooper's Pit at 8465.9465 has revealed bedrock sandstone outcropping on the south side of the sand and gravel deposits. In this pit the drift sequence is banked against a bedrock wall which plunges toward the northeast. The Trysull sands and gravels and the bedrock are capped by 1.5 to 2 m of sandy till with fresh Irish Sea erratics.

(v) *Trysull (southeast of the church)*

Trench excavations for the Kidderminster–Essington gas pipe-line cut through 1.5 m of red clay till with Irish Sea erratics overlying at least 2 m of coarse, sharp, yellowish brown sands with rounded sandstone erratics (figure 9, plate 32) at 8532.9377. Approximately 250 m to the north the same pipe-line revealed at least 2.25 m of lithologically identical sands and gravels. In addition, a number of boreholes and trial pits by Redland have shown a northwest–southeast trending depression in the bedrock, which is infilled with sharp sand, and gravel, to a maximum recorded depth of 12.3 m at 8547.9383. The sands and gravels are overlain by till or coarse gravel. Although deep sections have yet to be excavated, the pipe-line sections and exposures in one face of an abandoned pit at 8548.9368 show that the sand and gravel southeast of Trysull is part of the same complex which outcrops northwest of the village.

(vi) *Woodford Grange*

Gravel excavation at the north end of this pit (1969) revealed a threefold descending sequence of crudely stratified, almost horizontal, coarse gravels and sands resting unconformably on sandy gravels with rounded sandstone boulders (figure 10, plate 32), which in turn rest upon bedrock. The uppermost gravel unit is lithologically different from the lower sandy gravel, consisting predominantly of Bunter quartzites with a few pieces of broken sandstone of local derivation and a moderately high percentage (20 to 25 %) of fresh Irish Sea erratics, grey-white and pink granites being the most obvious. This upper light-grey gravel unit also contains dozens of large (up to 1 m^3) fresh granites, granophyres, and biotite-hornblende gneisses. The lower sandy gravel is of the same lithology as other exposures of the Trysull sands and gravels, being largely composed of Bunter pebbles (approximately 55 %) with a high proportion (40 %) of locally derived sandstone boulders and a smaller (about 5 %) quantity of Irish Sea erratics. The higher percentage of yellowish red-brown sand in the lower unit presents a striking colour contrast with the upper gravel. Three points are of significance in this exposure.

(1) The granites and sandstones in the lower gravel are badly decomposed and weathered when compared with the relatively fresh appearance of the erratics in the upper gravel.

(2) Between 1968 and 1970 only one moderately large (approximately $30 \times 30 \times 30$ cm) granitic erratic has been observed in the lower sandy gravel unit. This was *in situ* but consisted of a 'ghost' of rotten felspar and biotite flakes, with quartz granules. No large fresh granites have been found, and this is in striking contrast to the frequency with which they are encountered in the overlying gravel.

(3) The lower gravel is severely cryoturbated in places whereas the overlying gravel does not show any sign of frost disturbance.

(vii) *Botterham Gorse* (8620.9145)

A small sandpit 200 m northeast of Botterham Lock (Staffordshire and Worcestershire Canal) has revealed approximately 3 m of current-bedded, coarse, yellow-brown sharp sand, with occasional Bunter pebbles and a few Irish Sea erratics, the base of the gravels being between 85 and 87 m (280–285 ft) O.D.

(viii) *Swindon* (*southeast*)

An abandoned sand pit at 8673.9032, 250 m northeast of Hinksford Lock (Staffordshire and Worcestershire Canal) exposes several sections through a gravel sequence resting in deep hollows in the bedrock. The gravels may be divided into two units on an altitudinal basis. The lowest deposits at approximately 74.7 to 79.2 m (245 to 260 ft) above O.D. consist of large, rounded sandstone boulders and angular sandstone blocks in a mélange of smaller sandstone fragments with Bunter pebbles, coarse sand, and occasional small Irish Sea erratics. These deposits rest within a narrow channel cut into the sandstone. The maximum thickness observed in the lower unit is approximately 4 m, but this is a minimum figure since quarrying has removed the overlying drift. The upper gravel unit is possibly an erosional remnant of the lower unit and the two were probably continuous. The upper deposit (82.3 to over 86.9 m; 270 to 285 ft O.D.) consists of much finer gravel, crudely horizontally stratified, at least 4.5 m thick, consisting primarily of small Bunter pebbles with occasional small sandstone pebbles and Irish Sea erratics. This sandpit is the northernmost outcrop of the 'Kingswinford Esker' as described by Boulton (1916, p. 8).

(ix) *Wall Heath* (8730.8980)

Bedrock sandstone outcrops along the eastern side of this pit, but because of waste debris it is difficult to see the true relationship between the sands and gravels and the solid geology. The lithology of the drift is identical with that of the pits already described, consisting of Bunter quartzite pebbles, rounded sandstone boulders and occasional Irish Sea erratics. The working faces (about 10 m high) regularly expose large collapse features with the strata frequently faulted and inclined 60° to 80° from the horizontal.

(x) *Wall Heath* (8780.8930)

This pit, now abandoned and overgrown, was fortunately described in great detail by Boulton (1916, p. 5–8), and he reported within it all the features seen in the exposures mentioned above.

To the southwest of Boulton's section at Wall Heath, a small outcrop of the Trysull sands and gravels is revealed in an abandoned working face at 8765.8925. At least 5 m of sand and gravel with Bunter pebbles, numerous rounded sandstone boulders and occasional Irish Sea erratics can be seen. No collapse structures are visible and bedrock sandstone was not observed, although this is present on the north side of the Dawley Brook 100 m south and east of the exposure.

(xi) *Summer Hill* (8810.8905)

Boulton (1916, p. 3) recognized that the 'Kingswinford Esker' ran across Summer Hill, but he had no exposures to substantiate this fact. In the summer of 1969 a new housing estate was constructed on the crest of this hill and numerous sections were cut to depths of up to 3 m. These revealed up to 1 m of coarse yellow-brown sand laminated with red-brown sandy silts and overlying 2 m of yellow-brown sandy gravel. The pebble content of the latter consisted predominantly of Bunter pebbles with rounded sandstone boulders and occasional rare Irish Sea erratics, some of the granites being badly decomposed. Bedrock was exposed on the southwest side of the housing estate.

(xii) *Summer Hill to the River Stour*

This section of the 'Kingswinford Esker', lying south and east of Ridge Hill, is now largely obscured by housing estates. Fortunately this region was described in some detail by Boulton (1916, pp. 1–3), while the Geological Survey (Whitehead & Pocock 1947) obtained photographs of the Cot Lane sand pit while it was still being worked. The Cot Lane Pit is now (1970) practically filled with rubbish but exposures on the north side revealed sharp sand with Bunter pebbles and rounded sandstone boulders.

(*c*) *Fossils found in the Trysull sands and gravels*

A fragment of elephant tooth was found on a waste tip in Lowe's Pit at Trysull in 1969. Specific identification was difficult as the specimen was incomplete; however, the narrowness of the tooth, the spacing of the lamellae and the enamel thickness suggest that it belongs to either *Elephas antiquus* or an early mammoth, rather than *Mammuthus primigenius* (A. J. Sutcliffe, pers.

comm. 1970). Since the specimen lacks the median protrusion in the centre of the lamellae characteristic of *E. antiquus*, it seems more probable that the tooth fragment is from an early mammoth.

The only other fossil believed to have been found in the sand and gravel sequence was in the Cot Lane Pit, where Boulton (1916, p. 5) states: 'I have been told that a Mr Richardson, of Kingswinford, found an elephant's tooth in this sand pit, but so far I have been unable to trace it'.

5. Interglacial deposits at Trysull

(*a*) *Introduction*

As mentioned earlier, fossiliferous deposits have been found resting unconformably on the Trysull sands and gravels at two localities in Lowe's Pit at Trysull. One of these deposits continues eastward to outcrop in Cooper's Pit. Both deposits are in similar stratigraphic positions but they differ in lithological content, one consisting of calcareous silts and inorganic clays, whilst the second deposit consists of organic clays with occasional layers of sand interspersed. Each will be described separately, the former being referred to as Section A, and the latter as Section B.

(*b*) *Section A – Stratigraphy*

The location of the site is shown in figure 6*b* and figure 11, plate 33, whilst the general stratigraphy of this site is illustrated in figures 12 and 13. The stratigraphy is mainly described from Lowe's Pit, where a large portion of an old working face was cleared, but since the section in Cooper's Pit is a continuation of the same sedimentary sequence, this has also been used in the analysis of the depositional environment.

Section A lies within a depression in the Trysull sands and gravels which strikes NNW–SSE. The lowest unit in the sequence largely parallels the depositional slope in the underlying sands and gravels, the junction being almost conformable. A deep (10 m) excavation below the base of Section A revealed the top of high angle collapse structures commencing approximately 4 to 5 m below bed 1. No collapse structures were observed in the 4 m below the base of Section A and the basal silt and clay of bed 1 has not been disturbed or faulted in the sections excavated.

Bed 1 consists of a fine red silt, rarely exceeding 62 cm, which contains thin (up to 3 cm) layers of red to grey-green clay and red sand. The clay bands were sampled for pollen but no grains were found.

The stratigraphy of the units above bed 1 is complex. Generally the overlying beds can be seen to overlap older deposits. The central portion of Section A is composed of up to 3 m of coarse-medium orange-brown sands with scattered Bunter pebbles which appear to be concentrated into small lenses. The most noticeable feature is the presence of numerous angular blocks and slightly rounded balls of red silty and stiff clay, the largest observed being approximately 60 cm long and 15 cm thick. The bed also contains small pieces of clay which are curved at one or both ends.

The sands described above (bed 2) are overlain by a discontinuous dark red clay band, about 8 cm thick, which can be traced from Lowe's Pit into Cooper's Pit. In the latter pit the clay (bed 3) has risen into a diapir which penetrates overlying sands (bed 4). Bed 4 consists of 1 to 1.25 m of light grey, fine-medium sand, resting upon bed 3 and hollows in bed 2.

Apparently deposited contemporaneously with bed 4 is a sequence of grey to chalky-white calcareous silts (bed 4a) largely consisting of a mass of small plant stems replaced by calcium

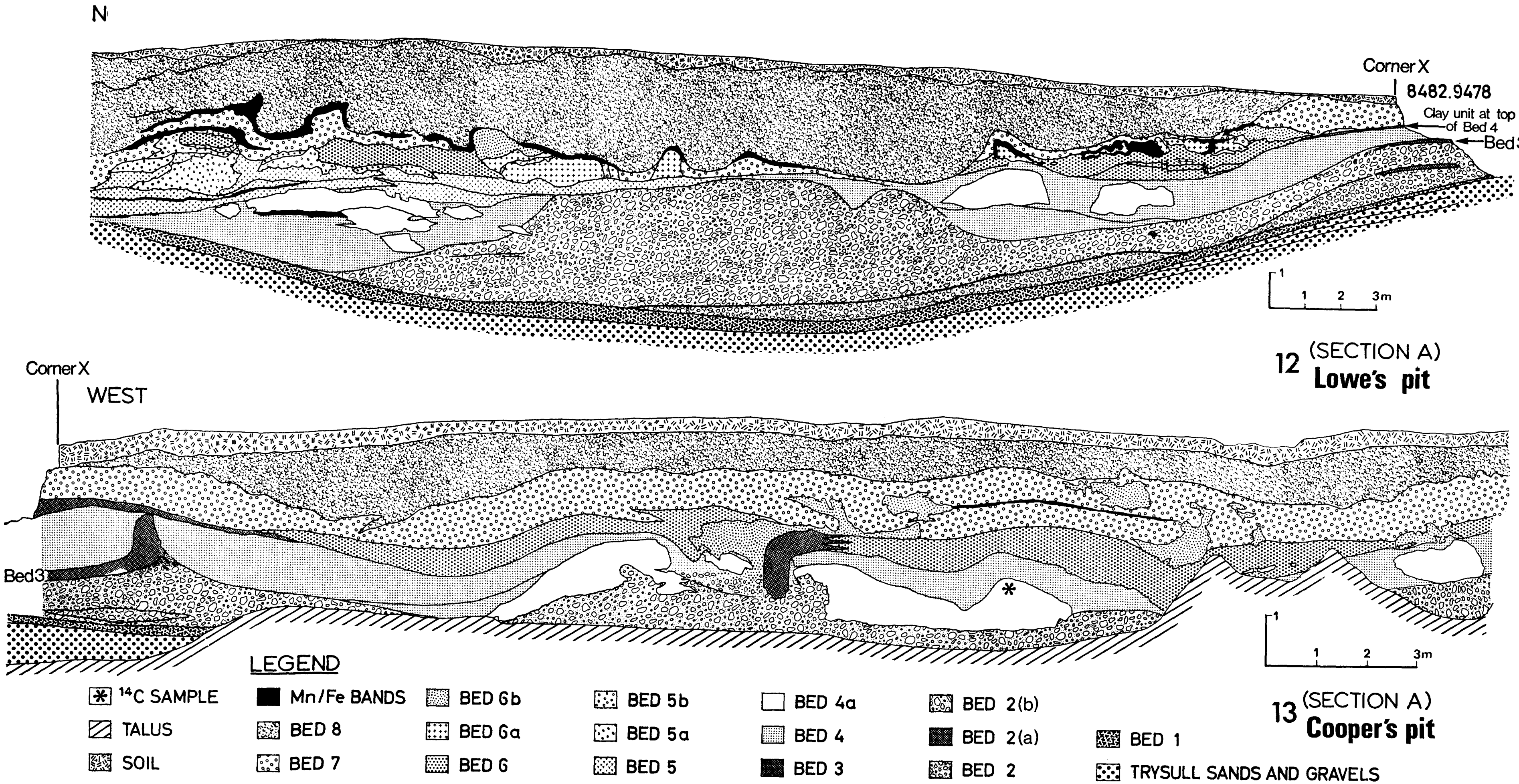


FIGURE 12. Section A. Generalized stratigraphy of the interglacial deposits in Lowe's Pit.

FIGURE 13. Section A. Generalized stratigraphy of the interglacial deposits in Cooper's Pit.

carbonate with numerous archegonia of Characeae and millions of *Bithynia tentaculata* opercula. The deposition of bed 4 appears to have ended with a disturbance of the sequence. This apparently produced the small diapir mentioned above and the accompanying reverse and normal faults and jointing only present within bed 4 and clearly seen in the section in Cooper's Pit.

Bed 5 consists of an 8 cm brown clayey sand band, grading eastward and northwestward into coarse sand and fine gravel, and probably represents initial deposition on an erosional interface. In the northern section of the face in Lowe's Pit, bed 5 is believed to be represented by pink medium sand which truncates limonite bands and covers the underlying sand and calcareous silts of beds 4 and 4a. Contemporaneous with the deposition of bed 5 is 5a, a second sequence of fossiliferous calcareous white silt, overlain by a grey-white clay (bed 5b) and a grey sandy clay (bed 6). This in turn is followed by the deposition of a white silty clay (bed 6a) and a grey crumbly clay (bed 6b), all believed to be part of a more or less continuous sequence. In the southern part of Lowe's Pit and in Cooper's Pit, bed 6 rests largely upon bed 4, whilst beds 6a and 6b usually occur above bed 6. Beds 5a and 5b appear to be absent.

Overlying both sections (figures 12, 13) is a manganese and iron stained clay (bed 7) ranging in thickness from 20 cm to slightly over 1 m. This in turn is overlain by bed 8 consisting of red (locally white or brown) clayey sand with numerous small pebbles. Loading and subsequent derangement of the underlying deposits, must have occurred after the initial deposition of the lower part of bed 8 as this has been involved in the contortion of the bed 7/8 interface. Fresh Irish Sea erratics have been recovered from the top 1 m in parts of the section in Lowe's Pit, and vertically orientated pebbles can also be found near the top of the sections in both pits.

(*c*) *Section B – Stratigraphy*

This site is located in figure 6*b* and figure 11, plate 33, whilst the general stratigraphic succession can be seen in figure 14, plate 33. The base of Section B, marked by a pronounced manganese/limonite band, 3 to 15 cm thick, appears to rest conformably on the underlying sand and gravel. Approximately 1 m below the manganese/limonite layer the sands and gravels show progressive signs of collapse toward the southeast. In a 10 m deep exposure on the northeast side of the deposit a large collapse structure was observed with sand and gravel onlapping the collapsed strata. The clay sequence appeared to be one of the later stages of this infilling process (figure 15, plate 33). As section B was excavated the clay deposit was seen to be thickest over the centre of the onlapping sands and gravels. The sequence above the basal manganese/limonite stratum consists of up to 18 cm of dark brown to light grey silt overlain by clays with occasional thin (up to 10 cm) bands of silt and sand, the total thickness being approximately 1.75 m. The clays vary considerably in colour when freshly cut and change colour rapidly when exposed to air. They also range from soft almost thixotropic muds with strong traces of hydrocarbon oils to very stiff and quite hard clays with sheared and slickensided surfaces. Fossils were found in the bottom 80 cm of the deposit.

The upper boundary of the organic sequence consists of a thin (1 cm) band of manganese and limonite, resting on yellow, orange-brown iron-stained clay, and overlain by coarse red to white sands with occasional small pebbles. The clays and overlying sand at the extreme northeast corner of the deposit appear to have been disturbed after the deposition of the coarse red-white sands.

Post-depositional disturbance was not observed along the southern section of the deposit.

The coarse red sands reach a maximum thickness of slightly over 3 m, and are in turn overlain by 70 cm to 1 m of red, very clayey sands with numerous Bunter pebbles and frequent fresh Irish Sea erratics.

(d) Section A – Fossil content

PHYLUM POLYZOA

Cristatella mucedo Cuvier (statoblasts only)

PHYLUM MOLLUSCA

(identified by M. P. Kerney)

Class Gastropoda

Bithynia tentaculata (Linné)	*P. crista* (Linné)
Lymnaea stagnalis Jeffreys	*Planorbis* cf. *laevis* Alder
Lymnaea cf. *peregra* Müller	*Valvata cristata* Müller
Planorbis contortus (Linné)	*Oxychilus* or *Retinella* sp.

Class Lamellibranchiata

Pisidium lilljeborgi Clessin	*Pisidium* spp.
P. nitidum Jenyns	*Sphaerium corneum* (Linné)
P. subtruncatum Malm	

PHYLUM ARTHROPODA

(identified by P. C. Sylvester-Bradley and E. Robinson)

Class Crustacea (sub-class Ostracoda)

Candona balatonica (Daday)
C. neglecta Sars
Cyclocypris laevis Müller
Cyprinotus salinus (Brady)
Erpetocypris reptans Baird
Ilyocypris biplicata (Koch)
I. bradyi Sars
I. gibba (Ramdohr)
I. quinculminata sp.nov. (Sylvester-Bradley)
Lymnocythere cf. *stationis* Vavra

PHYLUM CHORDATA

(identified by P. H. Greenwood and K. E. Bannister)

Class Pisces

Esox lucius (Linné) (pike)
Rutilus rutilus (Linné) (roach)
Scardinius erythropthalmus (Linné) (rudd)
Gasterosteus aculeatus (Linné) (three-spined stickleback)

Class Mammalia (Order Rodentia) (identified by J. N. Carreck)

Fragments of Microtine incisor and molar teeth, probably either mouse or vole rather than lemming.

(Order Proboscidea) (suggested by G. R. Coope)

Fragment of tooth base, indeterminate.

(Order Artiodactyla) (identified by A. J. Sutcliffe)

Centrum of posterior lumbar vertebra, probably from a medium sized bovid or large cervid.

Plants

Characeae (Oogonia only)

(*e*) *Section B – Fossil content*

PHYLUM POLYZOA

Cristatella mucedo Cuvier (statoblasts only)

PHYLUM MOLLUSCA

Class Gastropoda

Bithynia tentaculata (Linné)

PHYLUM ARTHROPODA

Class Insecta (Order Coleoptera) (identified by Anne Morgan)

Acrotrichis sp.	*Hydraena* sp.
Oxytelus cf. *gibbulus* (Epp.)	Elateridae gen. indet.
Tachinus sp.	*Aphodius* sp.
Aleocharinae gen. indet.	*Apion* sp.
Larinus sp.?	

(Order Trichoptera) (identified by P. J. Osborne)

One crushed adult specimen

(Order Diptera) (identified by Anne Morgan)

Chironomidae (larval heads)

Class Crustacea (sub-class Ostracoda)

Miscellaneous crushed fragments

PHYLUM CHORDATA

Class Pisces

Perca fluviatilis (Linné) (perch)

Gasterosteus sp. (Linné) (stickleback)

Plants (Macroscopic fragments)
(identified by Mrs D. G. Wilson)

Alnus glutinosa (Linné) Gaertn.	*Najas flexilis* (Willd.)
Betula (tree sp.)	*Potamogeton* sp.
Carex sp.	*Ranunculus* subgenus *Batrachium*
Chara sp.	*Typha* cf. *angustifola* (Linné)
Cirsium sp.?	*Urtica dioica* (Linné)
Eupatorium cannabinum (Linné)	*Zannichellia palustris* (Linné)
Hippuris vulgaris (Linné)	Moss fragments
Linum catharticum (Linné)	

(Pollen analysis)

Preliminary pollen investigation of the Trysull samples at Cambridge University shows the presence of *Pinus* and *Betula* at the bottom of the sequence, as well as substantial frequencies of *Quercus* (R. G. West, pers. comm. 1970). A sample from near the top of the deposit has produced pollen of *Alnus*, *Corylus*, *Quercus*, *Ulmus*, *Salix*, *Polypodium* and Gramineae, with *Corylus* predominating (W. Zagwijn, pers. comm. 1970). The results of the analysis of the Trysull pollen sequence will be published later.

(*f*) *Radiocarbon dating*

Two independent deposits from Lowe's Pit were submitted for ^{14}C dating at the University of Birmingham Radiocarbon Laboratory. The first sample was from Section A, the second from a 20 cm band, randomly selected near the base of Section B.

(i) *Section A* (Birm. 114)

As mentioned earlier, the calcareous silts within certain parts of Section A were found to be extremely rich in opercula of the gastropod *Bithynia tentaculata*. A mass of silt (30 × 30 × 30 cm) weighing approximately 68 kg, from the position shown in figure 13 was sieved, and 150 g of opercula, representing about 34 000 individuals, extracted. The sample was dry-sieved and the opercula were picked out by hand to reduce any chance of contamination by tap water. These were submitted to the laboratory where the opercula were dissolved in dilute HCl and gas samples collected at the start, at the middle, and near the end of the reaction. These three samples represented the outer, middle, and inner fractions of Birm. 114 and gave the following dates:

Birm. 114 (a) outer fraction	in excess of 34000 years B.P.
Birm. 114 (b) middle fraction	in excess of 25000 years B.P.
Birm. 114 (c) inner fraction	$34\,250^{+1550}_{-1300}$ years B.P.

(ii) *Section B* (Birm. 162)

As can be seen from the floral list above, this deposit was quite rich in carbonaceous material consisting predominantly of *Betula* cone scales, fruits and complete leaves, with other plant debris, including flattened fragments of wood. The plant material appeared to be concentrated in the lowest 50 cm of the sequence and 18 kg of clay and silt were collected from a layer 25 to 45 cm above the top of the basal manganese/limonite band. Because of the frailty of the plant material and the size of the sample (12 g of carbon), it was given a weak alkali pretreatment. Both sample and humate extract were dated and gave the following results which will be discussed later:

Birm. 162 (a) sample	in excess of 44000 years B.P.
Birm. 162 (b) humate extract	in excess of 33000 years B.P.

(*g*) *Ventifacts*

A number of ventifacts were recovered from the Trysull sands and gravels in the pits worked by Redland, Lowe and Cooper. They largely consist of Bunter pebbles which have been faceted and sand-blasted, and these have been found within the sand and gravel unit and in the overlying deposits. One granitic erratic obtained from the sand and gravel has smooth sand-blasted surfaces and is now in the Geology Department museum at Birmingham University.

A sand-blasted Bunter pebble, whose stratigraphic horizon is unknown, but is believed to be associated with the deposits of Section A, exhibits preferred percussion flaking on one edge of the pebble. This pattern of flaking down one side is closely matched by another quartzite pebble in the departmental museum (no. 252/37) found at Brand Green near Upleadon, Gloucestershire. The possibility exists that both specimens are man-made artefacts.

6. Discussion of the relationships of the deposits at Trysull

Evidence has been presented in the preceding paragraphs to show that prior to a temperate episode, indicated by the fauna and flora of Sections A and B, water carrying large amounts of locally derived sandstone and northern erratics flowed through a bedrock-walled channel over a distance of at least 10 km between Seisdon and northwest Stourbridge. The nature of the pollen found in Section B indicates that this temperate episode attained an interglacial status because of the presence of mixed oak forest, and preliminary results of the pollen analysis of this sequence suggests that it represents an early stage of the Hoxnian Interglacial. The intimate relationship between the Trysull sands and gravels and the overlying organic silts and clays clearly indicates a short time break between the two sets of deposits, and if the organic beds are indeed Hoxnian, the Trysull sands and gravels, belonging to a glacial environment would therefore be of late Anglian age.

The presence of a channel deeply incised to at least the following depths in sandstone at a number of localities at Seisdon (24 m), Trysull (34 m), Swindon (8 m), Wall Heath (5 m), Summer Hill (2 m) and Cot Lane (21 m reported by Boulton (1916, p. 5)) indicates the existence of considerable quantities of water during the retreat of the Anglian ice. The presence of water erosion is substantiated by the nature of the bedrock surface when the drift is removed; as, for example, in the Redland Pit at Seisdon, where the sandstone shows flutings and swirl marks. Other examples occur in the bedrock of the north face of Lowe's Pit where drift sand has been forced down into fissures, and in some cases along bedding planes within the sandstone. The nature of the sand and gravel sequence, with numerous large rounded sandstone boulders, washouts, graded deposits and current bedded structures are further examples of fluctuating water activity. Boulton (1916, p. 6), in referring to the Wall Heath Pit, recognised the same features and stated:

> 'The conclusion is obvious that each marks a huge elongated lens or half-core of detrital sand, gravel and clay, flung down by a stream coming from the north. It is clear that the volume of water and strength of the current varied greatly from time to time, for the coarse, unstratified gravel, with pebbles up to 2 feet (60 cm) in size, has been thrown down in a tumultuous manner, and in thick lens-shaped masses, while thin bands of the finest glacial mud are beautifully laminated and extend for hundreds of yards.'

The presence of granites, flints, andesites and other northern erratics, occasionally with striated surfaces (Boulton 1916, p. 8) and of moderately large dimensions (up to $51 \times 46 \times 20$ cm), throughout the Trysull sands and gravels suggests that the source of the water was an ablating portion of an ice sheet or glacier which had Irish Sea erratics within it. Besides erratics, the glacier was also intermittently contributing substantial blocks of ice, which, upon melting, caused the large collapse structures within the sequence. It follows that the ice was probably intimately associated with the formation of the bedrock channel; first in providing the water for downcutting, and later for the contribution of vast quantities of sand and gravel which eventually choked it.

As seen in figure 6 the present topography shows no relationship to the course of the channel and the production of the modern landscape is thought to be largely the result of Lower and Middle Devensian erosion, for reasons discussed later (§7). Therefore, the only evidence for interpreting the palaeotopography is the heights provided within the channel itself, on the drift/bedrock interface. The figures given earlier in this paper (§4 (*a*)) indicate an undulating basal profile to the channel falling from 74.7 m (245 ft) at Seisdon to 68.6 m (225 ft) at Woodford Grange, rising to 74.7 m (245 ft) south of Swindon and reaching a maximum elevation of 83.8 m (275 ft) in the Cot Lane Pit. South of Cot Lane the base of the channel appears to fall to 79.2 m (260 ft) at Tack Lane and even lower toward the River Stour. This is not the normal profile of a sub-aerial river and indicates that in certain areas the water was apparently flowing under considerable hydrostatic pressure. Similarly, since the drift/bedrock contact is usually fairly deeply incised below even the present bedrock surface, it is less likely that the channel originated in a supra-glacial or englacial position. Therefore, the initial scouring of the channel was probably sub-glacial, possibly within a decaying ice sheet, and may well have been along a major weakness zone in the ice. At some later date the channel became englacial by roof collapse allowing the sands and gravels to be deposited under normal sub-aerial glacio-fluvial conditions.

The locally derived material which makes up the bulk of the Trysull sands and gravels cannot be matched in the underlying bedrock, but is probably largely derived from nearby outcrops of Keuper sandstone, Bunter Pebble Beds and Upper Carboniferous sandstone occurring north and east of the Seisdon area. A nearby source for these erratics is also suggested by the high degree of rounding of the soft sandstone boulders, since transportation over any excessive distance would almost certainly result in their destruction. Although all traces of the channel and associated deposits apparently disappear north of Seisdon, a likely course for the continuation of the depression would be into the Tettenhall Gap, since this feature antedates the Upper Devensian ice advance whilst the rock types outcropping in the Tettenhall area, and farther east, are similar to the local erratics in the Trysull sands and gravels. There is also a probability that the Seisdon–Stourbridge channel is of the same age as the Moxley channel (Eastwood *et al.* 1925, p. 110; Whitehead *et al.* 1928, pp. 191, 192) which is apparently overlain by a red clay till, which could be Upper Devensian or older. The Moxley channel is approximately 12 km east of the Trysull section of the Seisdon–Stourbridge channel.

The alternating sequence of sand and gravel seems to suggest that the volume of water was subject to considerable fluctuations until it finally ceased altogether, probably with the diminution of meltwater from the ablating ice. The gradual decrease in water appears to be reflected in Lowe's Pit by a sandy unit seen immediately below bed 1 of Section A and also beneath the basal manganese/limonite band in Section B. By this time all the major collapse features had been formed, and the cold period in the Trysull sequence is believed to have ended with the melting of the ice blocks within the sands and gravels.

The near conformity of the silt band at the base of Section A with the underlying sand and gravel indicates continuity of deposition with perhaps a short time break between the two deposits. In Section B the onlapping succession of Trysull sands and gravels and organic clays over the underlying collapse structures shows an intimate association between the uppermost Trysull sands and gravels and the overlying clays, infilling what must have been a collapse hollow. Although these are lithologically distinct units, the time break between the deposition of the two must have been of short duration. The presence of ventifacts concentrated at approximately the same level as the interface between Sections A and B and the underlying Trysull sands and gravels also suggests that the pebbles were exposed to sub-aerial sand-blasting about this time. Since the basal units (beds 1 to 3) of Section A are sterile these are believed to have been deposited slightly earlier than the clays of Section B.

In Section A the onlapping relationship of the thin clays in bed 2 shows that the primary hollow within bed 1 was being infilled. The presence of pull-apart structures and S- and C-shaped flaps of clay within bed 2 are typical of subaqueous slumping, probably due to an unstable initial depositional slope. Slowly moving water may have been flowing through the long axis of Section A at this period.

The deposition of bed 4 appears to indicate a more quiescent period as it lacks the slump structures found in the underlying deposits. The sands of this bed are indicative of water deposition with coarse and fine sediment lamination, and by the presence of calcareous silts at different levels in the sequence. Probably by this time through water movement had ceased and a number of large ponds had developed on the underlying sands. Since most, if not all, of the ice blocks in the sequence had melted by this time, a permafrost table is not envisaged, and the natural water-table in the Trysull and Seisdon area must have been considerably higher than at present.

The fossils in the calcareous silts give a good indication of the environment with the molluscs inferring fairly large, but not necessarily deep, bodies of clean, well-vegetated, moderately calcareous water, which were either still or only quietly moving.

M. P. Kerney (pers. comm. 1969) has stated: 'This is not the fauna of an impermanent pond, nor of an open river. *Pisidium lilljeborgi* and *Planorbis laevis* are characteristic of lakes in the north and west of the British Isles today, being more widespread in late-glacial and earliest post-glacial times. The climate is difficult to determine but it was almost certainly not of full glacial severity, the fauna being that of a late glacial facies'. The presence of the ostracods *Cyclocypris laevis* and *Herpetocypris reptans* denote temporary ponds, whilst *Ilyocypris bradyi* and *I. gibba* suggest inflows from intermittent and permanent streams. The water was probably not very deep and the presence of *Cyprinotus salinus* indicates that it may have been slightly saline at times (L. D. Delorme, E. Robinson & P. C. Sylvester-Bradley, pers. comm. 1969). The occurrence of pike, perch and stickleback infers quiet water, either a large pond or sluggish river (P. H. Greenwood, pers. comm. 1969).

The existence of *Cristatella* and *Chara* again establish the presence of a still, shallow-water, well-vegetated, environment. Bone fragments and portions of incisors and molars of small microtine mammals, probably vole or mouse (J. N. Carreck, pers. comm. 1969), and non-rounded bones of larger mammals in the sequence attest that the remains of terrestrial mammals were present on the nearby landscape and were available for deposition in the lacustrine sequence.

The small clay diapir penetrating the sands of bed 4 is probably indicative of localized loading conditions, and the repetition of the calcareous deposits in Section A may indicate a drying of the initial pond sequence, followed by a re-establishment of similar conditions after a short time interval.

It is difficult to relate the start of deposition in Section B to that of the silts and clays in Section A; however, the base of Section B is not broken by faulting and all collapse seems to have ceased by the start of clay aggradation. Faunally and lithologically it is logical to equate the basal clay of Section B with bed 4 in Section A. The fauna of the clays with ostracods, molluscs and fish is indicative of water and this is substantiated by the statoblasts of *Cristatella*, the beetle *Hydraena* and the Chironomidae and Trichoptera which spend part of their life history in water.

Mrs D. G. Wilson has stated: 'The environment indicated by all the plant remains is one of a temperate base-rich fen, with open water, swampy ground and nearby fen carr with birch and alder. *Chara*, *Najas flexilis* and *Zannichellia palustris* are of submerged habit, as are many species of *Ranunculus* sub-genus *Batrachium* and *Potamogeton*. *Typha* and many *Carex* species are more typical of swampy areas at the edge of open water. *Eupatorium cannabinum* can occur here too, or with *Urtica dioica* in the transitional belt between marshy areas and the drier fen carr. *Linum catharticum* is usually found in calcareous grassland, and could well occur in well-drained places within a fen system as can be envisaged at Trysull. *Najas flexilis* has formerly been more widespread with its maximum distribution in the hypsithermal. At present its northern limit is about 62° north' (in Europe).

The apparent anomaly of two contemporaneous sites, less than 300 m apart, with calcareous silts and clays in one, and organic clays in the other, is not unique. Mitchell (1965, pp. 373–381) has described Late-glacial deposits in the vicinity of Glen Wyllin, Isle of Man, approximately the same distance apart, consisting of similar lithologies, and ^{14}C dated to the start of Zone II.

The fossiliferous deposits in Sections A and B are capped by pyrolusite and limonite bands and overlain by sterile, red, slightly clayey sands, with the interface festooned in places. This may be due to loading or to cryoturbation after the deposition of the sand. The top of Sections A and B are both overlain by red, very sandy clay containing fresh Irish Sea erratics. This forms a continuous sheet over Section B, but is only patchily developed in Section A.

The organic sequences at Trysull therefore post-date a glacial retreat and probably indicate a cool facies early in the Hoxnian Interglacial deposited shortly after the final melting of remnant ice blocks in the underlying outwash. A finite radiocarbon date of 34250 years B.P., obtained from the opercula is in conflict with the evidence provided by the pollen which infers an older age for the sequence. However, carbonate shells are extremely difficult to date accurately, and this date must be regarded as too young (particularly since sites at Four Ashes given the same date figure have an arctic fauna – Anne Morgan 1970). It is unlikely that the two pool deposits A and B are of very different ages and the figure for Section B (> 44000) is consistent with one of the Interglacials.

Stratigraphic evidence also indicates that the Trysull sands and gravels and the organic sequences antedate the Late Devensian Irish Sea advance at two localities. At Trysull, a very sandy clay containing Irish Sea erratics overlying the red sands on top of the organic deposits can be traced laterally into more typical clayey Irish Sea till. Secondly, at Woodford Grange, Upper Devensian glacio-fluvial outwash rests unconformably on a cryoturbated sequence of Trysull sands and gravels. Both sequences are similar to deposits described by Whitehead & Pocock (1947, p. 157) in the Trysull–Seisdon area, where they encountered in a pit:

> '...450 yards (415 m) west northwest of Trysull church, sand with lenses of coarse gravel with northern erratics resting upon well bedded sand in which the only stones found were soft, rather weathered-looking pieces of sandstone of Triassic type. It seems clear that there are here two deposits between the formation of which there was an interval with some erosion, and it is possible that they represent 'newer' drift superimposed on 'older' drift; but, on the other hand, both deposits may belong to the same general phase, the upper, gravelly one, merely indicating an influx of more torrential water carrying coarser material and slightly eroding the previously deposited sand.'

The 'sand with lenses of coarse gravel with northern erratics' is probably the equivalent of the Upper Devensian till, or outwash, whilst the underlying sand is almost certainly the Trysull sand and gravel.

In summary, the stratigraphic sequence at Trysull can be described as follows:

Upper Devensian till	0–1 m
reddish brown to white sand	1–5 m
Interglacial silts and clays	5–6.8 m
Trysull sands and gravels	6.8–34 m

On stratigraphic grounds the interglacial deposits were originally presumed to be Ipswichian and the Trysull sands and gravels Wolstonian in age. However, pollen evidence suggests that the interglacial material is Hoxnian, and if this explanation is accepted then the large hiatus in the sequence is difficult to explain. Unfortunately the pollen does show signs of differential preservation and this problem cannot be satisfactorily resolved. Arguments can be presented for an Anglian age for the outwash deposits of the Trysull sands and gravels. The erratic content, for example, is dissimilar to the rock types found in the Wolstonian deposits in the Coventry area (F. W. Shotton, pers. comm. 1970) whilst they are also unlike the erratics described by Wills in his Second Welsh Glaciation. Anglian deposits are also known in relatively close geographical proximity at Nechells, Birmingham (Kelly 1964) and at Quinton, Birmingham (A. Horton, pers. comm. 1970). However, problems are created by the missing Wolstonian, Ipswichian and Lower and Middle Devensian deposits in the Trysull sequence. I have no doubt that further research into this area will help to answer some of the questions raised. At this time the available evidence does suggest that the organic deposits at Trysull are early Hoxnian whilst the underlying outwash is of late Anglian age.

7. Gravel deposits south of the Wolverhampton Line

(*a*) *Introduction*

Gravel deposits occur in several areas south of the Wolverhampton Line. They are certainly younger that the Trysull sands and gravels and apparently older than the Upper Devensian, but the relationship of the respective gravel sequences needs discussion.

(*b*) *Sand and gravel deposits at Wombourn*

A number of abandoned sand pits and sections in the old railway cuttings at Wombourn have revealed patches of clayey sands and gravels resting upon an eroded surface of Upper Mottled Sandstone. The sand and gravel unit is usually between 7.5 and 2.5 m thick and consists almost entirely of Bunter pebbles, predominantly quartzites. The sequence appears to cap a northeast to southwest trending ridge, south of the Wom Brook and running from Battlefield (8800.9300) to the area northwest of Himley Plantation (8670.9150) and appears to be confined to above 91.5 m (300 ft) O.D. The most characteristic feature is the intensely cryoturbated nature of the deposit. Festooning can be clearly seen in practically every exposure, but wedging was not observed.

(*c*) *Sand and gravel deposits west of Swindon*

Exposures in a gas pipe-line trench along Swindon Rough at 8600.0919, revealed at least 1.5 m of coarse light brown to white sand with lenses and stringers of fine to coarse gravel and occasional cobbles. The deposit rests unconformably on an eroded surface of disintegrated yellow-red flagstones. A careful search was made for Scottish or Lake District granites, but none was recognized; although some badly decomposed and kaolinized pebbles were located. Erratic pebbles that were found include flints (yellow, with weathered surfaces), banded rhyolites, tuffs, and miscellaneous cherts, one containing small crinoid segments. Most of the coarse gravel and cobbles were Bunter pebbles, and these were frequently concentrated along bedding planes in the sand. A fluviatile depositional environment is indicated by the presence of occasional current-bedding within the sands. No signs of post-depositional disturbance were observed in the 172 m of trench section exposing the deposit. The sand and gravel sequence forms a flat surface, the easternmost edge of which drops steeply into the Smestow Valley. Survey levels on the ground surface were 87.45 m above ordnance datum (286.91 ft) at the new (1969) gas governor house (8587.9036); 86.51 m (283.85 ft) at 8600.9016 and 86.11 m (282.49 ft) at the southernmost exposure of the sand and gravel deposit. The base of the drift appears to be undulating, but approximately at 86 to 86.3 m (282 to 283 ft) above O.D. Since the modern alluvium in the Smestow Valley is at 59.3 m approximately, the Swindon gravels are about 27 m above the present flood plain (figure 16).

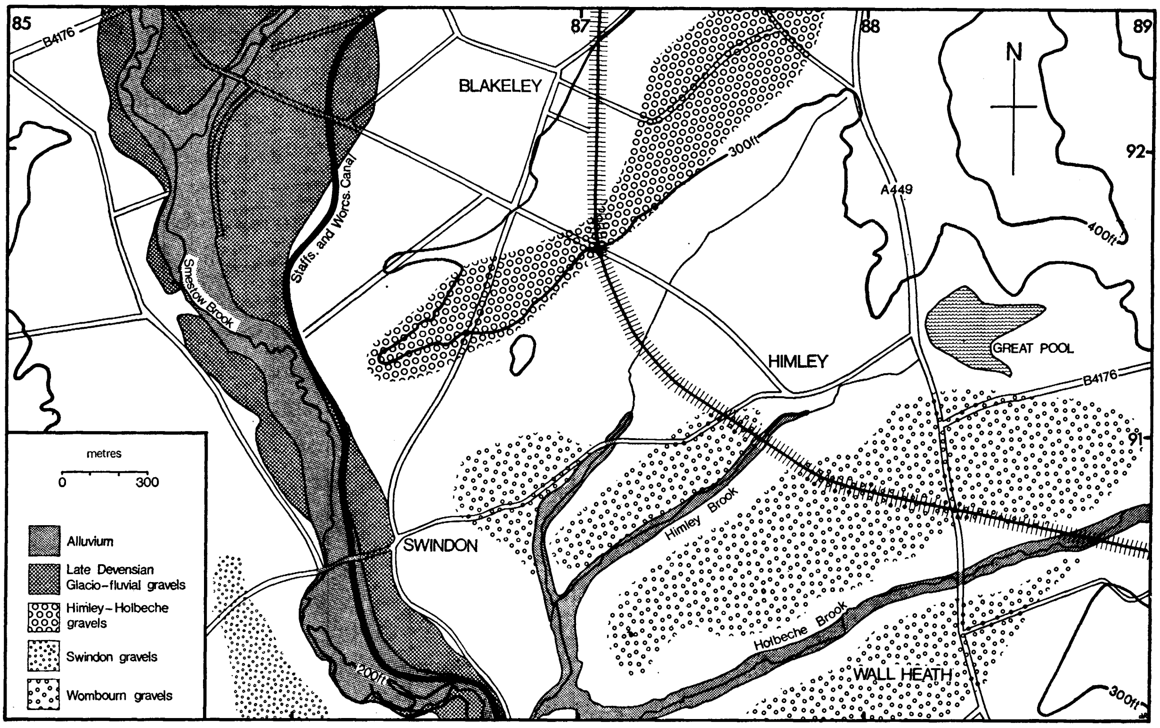


FIGURE 16. Distribution of gravels in the area south of the Wolverhampton Line.

(*d*) *Sand and gravel deposits in the Himley area*

Exposures in several sections of a gas pipe-line trench north of Wall Heath revealed thin deposits of light brown sand with occasional pebbles resting in hollows in an undulating surface of Upper Mottled Sandstone. The sand and gravel deposits were rarely more than 50 cm thick and the pebbles found within the deposit were entirely of local derivation. These include Bunter quartzites, coarse grits and sandstones and coal pebbles, and not uncommonly, fragments of basalt. All the pebbles, with the exception of the quartzites, have probably been derived from the coalfield area immediately to the east. No indication of the depositional environment can be deduced from the deposit. The sands and gravels appear to lie between 73.1 and 79.2 m (240 to 260 ft) O.D. between spot heights on the A 449 and between 73.4 and 79.2 m (241 and 260 ft)

O.D surveyed along the pipe-line, although similar gravels occur at heights up to 83.8 m (275 ft) O.D. at 8850.9090. In view of the height consistency on either side of the Himley Brook and the Holbeche Brook, it is probable that the gravels were derived as a single unit, and later down-cutting along the streams has left them perched on the interfluves. No fossils have been found in the deposit.

(e) General discussion of the age and provenance of the gravel deposits

The absence of fossils in any of the gravel deposits examined south of the Wolverhampton Line creates a difficult problem in age determination. Because of erratic content, depositional characteristics, and more significantly, altitudinal position, some broad generalisations can be made.

The Wombourn gravels are very similar lithologically to the Swindon gravels, with a preponderance of Bunter derived pebbles, few erratics and no visible granites. The clayey sands and gravels at Wombourn have been severely cryoturbated which suggests that even if they were not deposited in a cold environment they have been affected by post-depositional periglacial activity. Furthermore, when comparing the severity of the involutions with the Upper Devensian involutions (§ 9 (*c*)) the Wombourn gravels appear to have been contorted to a greater degree, possibly due to exposure to a longer period of periglacial action. Finally the altitudinal position of these gravels, above 91.5 m (300 ft) O.D. places them well above the Upper Devensian deposits ending a few kilometres to the north at the Wolverhampton Line.

The fluviatile deposits near Swindon have been described by Wills (1938) and Whitehead & Pocock (1947) who assigned them to the northernmost outcrop along the gradient curve of the Kidderminster terrace; the equivalent of Avon No. 4 terrace (Tomlinson 1925). According to Wills (1938) the Kidderminster terrace deposits were laid down along a wide open valley during a cold phase in which there was strong wind action. The gravels which make up the terrace are largely Bunter derived but with volcanic erratics of Welsh and northern origin.

The age of the gravels west of Swindon is difficult to determine because of their paucity and the absence of fossiliferous material; however, the Swindon gravels are high above the glacio-fluvial outwash of the Upper Devensian ice. At Hinksford the respective levels on the top and base of the highest Upper Devensian outwash are about 69.8 m (229 ft) and 66.5 m (218 ft) above O.D., compared with the base of the feather edge of the higher gravel unit at approximately 86 m (282 ft). Therefore the base of the uppermost (Swindon) gravel and the top of the lower (Upper Devensian) gravel are separated by a minimum vertical distance of 16 m, and consequently the Swindon gravels must be considerably older than the Upper Devensian outwash (figure 17).

The presence of involutions within the Kidderminster terrace suggests that this deposit was laid down in a cold environment, whilst the involuted Wombourn gravels were either deposited in, or followed by, a periglacial episode. At least one cold period is known in the area prior to the Upper Devensian. This was during the Lower and Middle Devensian (Anne Morgan 1970). Two other cold periods may be postulated, one following the retreat of the Anglian ice (§ 6) and one during the Wolstonian stadial.

Since the lithology of the Wombourn and Swindon gravels are so dissimilar to the Trysull sands and gravels, it is unlikely that they belong to the same episode, thus eliminating a Late Anglian age for the Wombourn and Swindon deposits.

The similarity of erratics in the red clayey gravels at Wombourn and in the fluviatile terrace deposits at Swindon suggests that the latter may be derived from the former.

There is a probability that the Wombourn gravels may represent a reworked Wolstonian till, since the erratic content of the Wolstonian till in the Birmingham area is similar to the Wombourn gravels but unlike that from the Trysull sands and gravels. The Swindon gravels could be a lag deposit washed from the same till. The absence of Wolstonian and Ipswichian deposits in the map region has to be explained since glacial deposits of the Wolstonian are found in the Birmingham area, south and east of the Wombourn region.

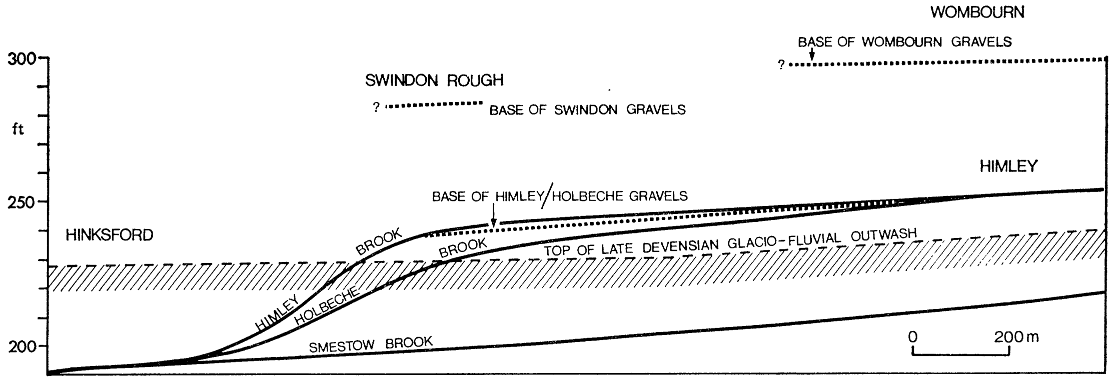


FIGURE 17. Attitudinal relationships of Upper Devensian outwash and earlier gravel deposits.

From the above hypothesis it would follow that the gravels in the area of the Himley and Holbeche Brooks are younger than the Swindon and Wombourn gravels since they are, on average, 6 to 12 m lower altitudinally; but they are also older than the Upper Devensian outwash, as they are approximately 3 to 9 m above it. The intimate relationship between the gravels and courses of the Himley and Holbeche Brooks makes it likely that the gravels were derived either as a terrace gravel or a solifluction gravel spread. In view of the complete absence of signs of water activity, the latter seems more likely. This was also the origin given to these gravels by Wills (1938, pp. 203–205), who called them 'taele gravels'. The relationship of these gravels to the high level deposits at Swindon and Wombourn would suggest a Middle Devensian age for the deposits along the Himley and Holbeche Brooks. This would conform with the interpretation of a climate largely cooler than the present given to the Middle Devensian gravels of Four Ashes (Anne Morgan 1970).

8. Upper Devensian glacio-fluvial deposits

(a) *Introduction*

Glacio-fluvial erosional phenomena, together with ablation deposits are frequently found in association with the Late Devensian till. Since glacio-fluvial deposits usually rest within erosional features caused by melt-water, it is difficult to separate the erosional and depositional phases involved. The products of melt-water can, however, be divided into somewhat arbitrary categories depending on the processes involved in their formation. These are, sub-glacial or latero-glacial phenomena which include erosional features believed to have been formed beneath, or immediately beside the ice sheet, and extra-glacial features. The extra-glacial features include deposits which are a direct product of melt-water from the ice, but which may be seen many kilometres from the terminal position of the ice-sheet. In the area studied only glacio-fluvial terrace deposits fall into this category.

(b) *Sub-glacial or latero-glacial features*

Excavations through the Irish Sea till in many parts of the map area frequently revealed extensive deposits of sand and gravel, rarely more than 1 m thick, interposed between the base of the till sheet and the bedrock. Usually there is no obvious sign of water erosion on the underlying bedrock, nevertheless, the erratic content of the gravel indicates a clear association with the overlying till, and 'northern' erratics often comprise between 15 and 35 % of the pebble content.

It is perhaps necessary to re-emphasize that the Four Ashes gravel sequence (§ 2), whilst situated beneath the Upper Devensian till, is not a glacio-fluvial outwash deposit. Very occasionally, small rhyolites and flints can be found in the gravel unit, but these Irish Sea erratics always represent considerably less than 1 % of the total pebble content. Apart from this, the faunal evidence indicated by the Coleoptera extracted from the organic deposits precludes a glacio-fluvial environment for this sequence.

(i) *Potholes*

Three potholes and a narrow water-eroded channel were revealed beneath the Upper Devensian till in a deep gas pipe-line trench at 8523.9669 in June 1969. These features have been fully described elsewhere (Morgan 1970*a*). A number of marine shells found in the potholes were identified by J. Cooper as:

Acanthocardia sp.	*Turritella communis* Risso
Cerastoderma edule (Linné)	*Littorina littorea* (Linné)
Macoma balthica (Linné)	*Bela* or *Lora* sp.

All species are extant in British waters today.

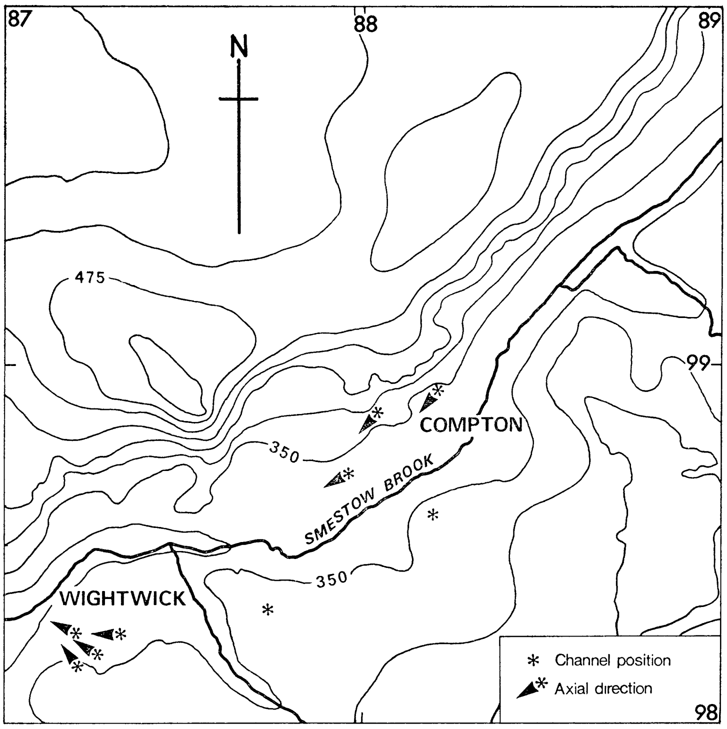


FIGURE 18. Location of drift-infilled channels in the Tettenhall Gap.

(ii) *Drift-infilled channels*

A number of channels incised in the sandstone bedrock were observed in different localities along both sides of the Tettenhall Gap (figure 18). The channels are filled with either till or sand and gravel, and they occasionally contain large erratics. They are well exposed in different sand pits, particularly at Compton (8820.9895) (Lister 1862, p. 161; Dewey 1916, p. 17) and at Wightwick (8725.9823). In the latter pit the channels have been left as sinuous ridges due to the quarrying of the adjoining sandstone. A summary of the location and altitude of the drift-infilled channels in the Tettenhall Gap is given in table 2.

TABLE 2. LOCATION AND ALTITUDE OF THE DRIFT INFILLED CHANNELS IN THE TETTENHALL GAP

locality	altitude m	altitude (ft)	minimum depth of channel m	infill
1 8820·9895	105.2	(345)	1.5	clayey sand and gravel
2 8804.9887	112.2	(368)	1.8	sandy till
3 8850.9882	106.7	(350)	1.5	sand and gravel
4 8820.9859	107.2	(355)	?	pebbly drift†
5 8795.9870	106.1	(348)	?	sand and gravel†
6 8775.9835	107.2	(355)	?	pebbly drift†
7 8732.9825	103.6	(340)	2.4	sandy, gravelly, till
8 8725.9824	103.6	(340)	3.0	sand and gravel
9 8726.9819	103.6	(340)	2.4	sandy till
10 8721.9816	106.7	(350)	6.1	sandy till, gravel at base

† Geological Survey; Whitehead *et al.* (1928, p. 191).

The longest drift-infilled channel found was example 8, approximately 100 m in length. Although most of the channels are separated from the general drift sequence, example 10 was deeply incised into the sandstone bedrock and infilled with a sandy till. At the top of the channel, the sandy till infill merged with the Upper Devensian till sheet.

(iii) *Other glacio-fluvial gravels*

A flat-topped layer of till at 8340.9255 west of Upper Whittimere Farm conceals a thick sequence of glacio-fluvial sands and gravels, originally described by Whitehead & Pocock (1947, p. 158), showing deltaic depositional structures which dip towards the east. The sands and gravels are approximately 6.1 m thick and rest upon at least 1 m of brown stoneless clay. The brown clay overlies a 3 cm band of coarse gravel and cobbles which in turn rests directly upon bedrock. Irish Sea erratics are commonly found in the sands and in the overlying till which caps the sequence. The till is usually between 2 and 3 m thick.

Several relatively flat areas of land were observed at the north end of the Tettenhall Gap at Dunstall (9040.0070), Pendeford (9010.0270) and Ford Houses (9140.0410). Excavations for building extensions and gas pipe-line trenches in the last two areas have revealed relatively thick (up to 6.1 m) sequences of glacial sand and gravel underlying and overlying clay deposits, or resting directly on bedrock. Deposits of till resting on glacial sand and gravel on bedrock were also observed at the Goodyear Tyre plant at Oxley (9130.0180). The relative altitudes of ground level and the bedrock contact beneath the glacial sequences at selected localities in the fore-mentioned areas are given in table 3.

As mentioned above the glacial sands and gravels are frequently overlain by till, and this relationship was clearly seen in a gas pipe-line trench (figure 19*a*) and nearby borehole records (figure 19*b*).

Similarly, in the borehole records at Pendeford, till was observed overlying the sands or was present beneath sands and gravels (figure 19*c* and *d*). Pebble samples recovered from gravels in these boreholes also included typical Irish Sea erratics.

North of Coven Heath sand sequences in excess of 2 m, with occasional gravel lenses, were revealed in a number of auger holes, but till was not recorded. Finally, north of Brewood at 8850.0923 approximately 6 m of fine sand with clay intercalations, overlain in parts by till, was observed resting on sandstone.

(iv) *Gravel ridges*

A ridge of sand and gravel approximately 850 m long, 50 m wide and 4 to 6 m high was observed 800 m north of Lower Penn between 8688.9685 and 8626.9725. Several auger holes put down in the crest of the ridge revealed up to 1 m of coarse brown sands with occasional gravels, whilst auger holes on either side of the ridge penetrated till. One auger hole on the top of the ridge at 8639.9703 entered bedrock (Upper Mottled Sandstone) immediately below the soil. However, the drift thickness appears to be quite variable since 4.5 m of gravel are exposed in a small abandoned pit north of Langley Farm at 8665.9685. The erratic content of the gravels in this pit clearly indicates an association with the Irish Sea ice and many granite pebbles, Lake District volcanics and Cretaceous flints were seen in the abandoned pit.

Similar small gravel ridges have been described by the Geological Survey near Cranmoor Lodge (8530.0048), Long Birch Farm (8790.0576) (Whitehead *et al.* 1928, pp. 188, 189), and near Pendeford at 0590.0420 to 9108.0378 and 8955.0287 (unpublished data). Auger holes at 8821.0649 and 8821.0640 encountered 1 and 1.5 m of coarse to medium brown sand with occasional gravel resting upon sandstone in a 500 m long ridge approximately 600 m north-northeast of the Long Birch Farm ridge. Irish Sea erratics were found among the gravels extracted from the auger holes.

(v) *Melt-water channels near Penkridge*

Two channels were observed in the area immediately east and southeast of Penkridge and a third in the region southeast of the Staffordshire Farm Institute at Rodbaston. The first two channels vary from shallow troughs to steep-sided depressions. Inside the map area the courses run parallel to each other, the northeastern channel running from Broom Bridge (9325.1475) passing the north side of Pillaton Farm and leaving the map area at 9500.9360. The southwestern channel runs from near Penkridge Bridge (9282.1403) in a southeasterly direction leaving the map area at 9500.1240. The two channels are generally between 600 and 900 m apart over a distance of slightly over 2 km within the map area. Outside the area mapped the northeastern channel was traced eastward on stereo air photographs as far as 9620.1368 and the southwestern channel continued southward to near Hatherton Hall (9560.1110).

The northeastern channel cuts through bedrock at Quarry Heath (9429.1375) and north of Wolgarston Farm (9363.1442). This channel is floored with sand and gravels in different localities. Up to 1.25 m of coarse gravels and cobbles were encountered in an auger hole at

Table 3. Location and altitude of glacio-fluvial sequences northeast of the Tettenhall Gap

locality	general ground level (O.D.) m	(ft)	bedrock contact (O.D.) m	(ft)	gravel and sand thickness m
Oxley					
(9134.0183)†	116.1	(380.78)	107.6	(353.0)	6.2
(9135.0186)	115.4	(378.50)	108.9	(357.2)	6.0
Ford Houses					
(9152.0420)†	109.4	(*c* 359)	100.9	(*ca.* 331)	6·6
(9130.0416)†	104.2	(*c* 342)	100	(*ca.* 328)	2.7
Pendeford					
(9051.0295)	103.6	(*c* 340)	98.1	(*ca.* 322)	5.5
(8980.0244)	104.2	(*c* 342)	99.7	(*ca.* 327)	4.4
(9023.0205)	104.5	(*c* 343)	98.4	(*ca.* 323)	5.9
Dunstall					
(9017.0158)	107.2	(351.76)	102.1	(334.8)	5.2
(8963.0035)	106.1	(*c* 348)	100.6	(*ca.* 330)	5.5

† Gravels and sands overlain by till.

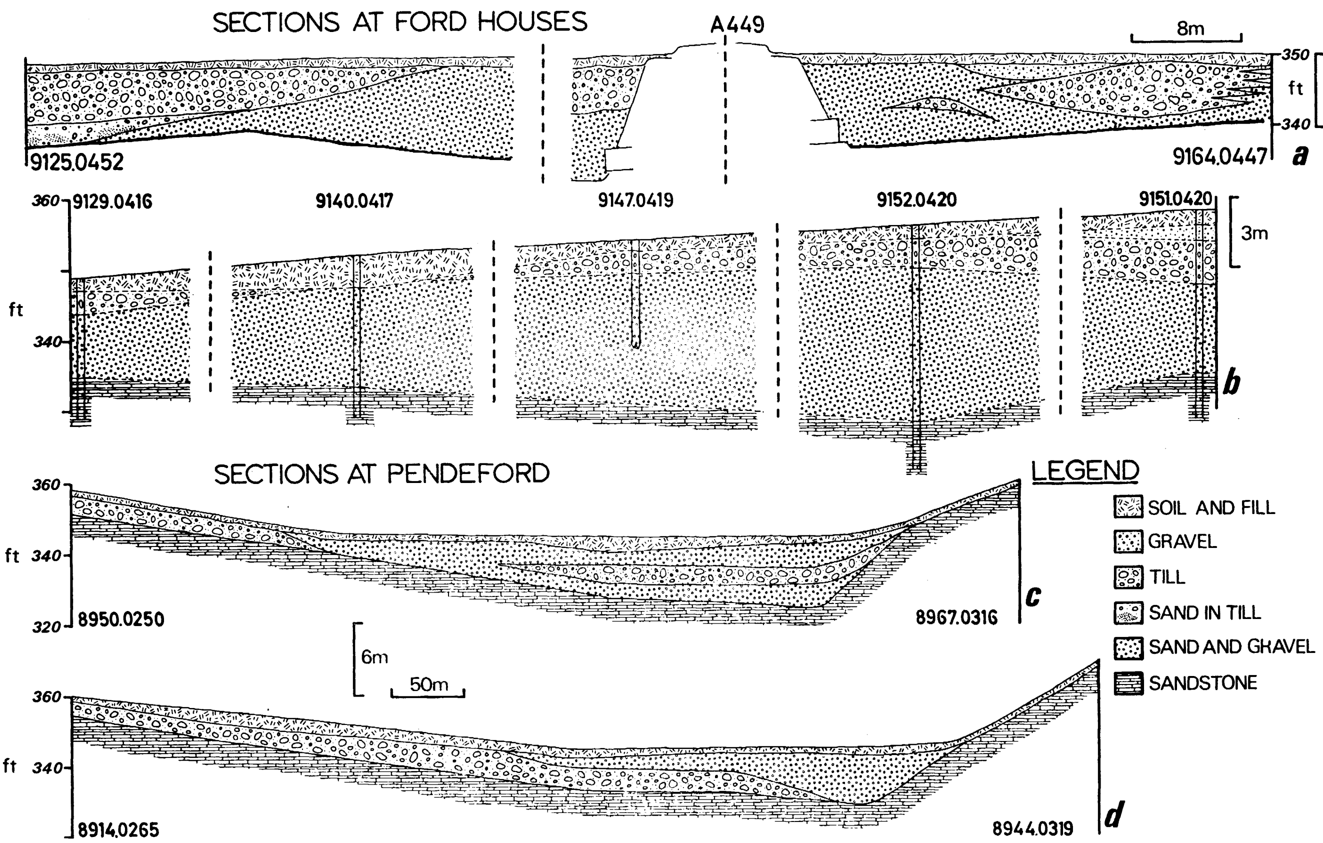


Figure 19. Sections through Late Devensian deposits at Ford Houses and Pendeford.

9463.1366, whilst the boreholes associated with the construction of the M. 6 motorway revealed the following (simplified) succession in the northern end of this channel:

M. 6 Borehole no.		
25	9325.1484	9.1 m of brown sand, medium to coarse gravel and cobbles
26	9329.1482	9.6 m of brown sand, medium to coarse gravel and cobbles on 2 m marl and sandstone
27	9340.1466	1.5 m of brown sand, medium to coarse gravel and cobbles on 4.6 m sand, gravel and cobbles on 4.6 m sandstone with bands of marl

The southeastern channel appears to be incised in drift near the northern end of its course, but southwest of Pillaton Old Hall (9428.1295) the channel sides steepen considerably and there is a possibility that the side walls may be bedrock. This channel is of interest as peat deposits were found within it, southwest of Pillaton Hall Farm. These deposits will be discussed later, but a sample of vegetable debris from a depth of 2.6 m, immediately overlying sterile fine sand was ^{14}C dated to 11 660 years B.P. (Birm. 131). The deposits elsewhere in the channel usually consist of coarse sands and gravels as, for example, in another M. 6 borehole at 9324.1358 where a succession of black peat (46 cm), on gravel and sand (5.2 m), on red marl (2 m) was recorded.

The third channel in the region occurs between Rodbaston Hall (9220.1163) and the Gailey Reservoirs (9350.1040). This was first described by Shotton & Strachan (1959), but field mapping has revealed peat infilling the drainage channel running from Rodbaston toward Penkridge. Sections of the channel at Rodbaston have been infilled with organic debris to a depth of at least 2.9 m and the lowest dateable horizon (at 2.4 m) has provided a radiometric age of 10 670 years B.P. (Y. 464).

Spreads of coarse gravel and sand were also observed east of Rodbaston along the stream south of Fullmoor Wood and in the area between Otherton Farm (9306.1238) and Horsemoor Wood.

(c) *River terraces*

Terrace deposits composed of Upper Devensian glaciofluvial silts, sands and gravels can be seen bordering the principal drainage lines in the map area. The three largest streams exhibiting terrace deposits are the Smestow Brook and the Rivers Penk and Sow, while terrace deposits can also be found along the Moat Brook and the Whiston Brook, both tributaries to the Penk (figure 20). With the northerly trend of the retreat of the ice sheet the glacio-fluvial outwash sequences are believed to be oldest in the south. Consequently it is proposed to discuss the deposits along each of the stream systems, starting with the Smestow Brook.

(i) *Smestow Brook*

The distribution of Upper Devensian glacio-fluvial outwash on the sides of the Smestow Valley is shown in figure 21. The gravels and cobbles which make up the terrace are predominantly derived from local bedrock outcrops of Bunter quartzite pebbles and Triassic sandstones. A large proportion of the pebbles, usually between 20 and 25 %, are derived from Scotland and the Lake District. The granite erratics are quite fresh and some attain considerable dimensions, as for example, at Woodford Grange (8555.9348) where a $121 \times 61 \times 61$ cm white granite erratic was excavated from the terrace deposits. The glacio-fluvial terrace of the Smestow is only slightly above the alluvium between Seisdon and Trysull, rising to nearly 11 m above the alluvium at Hinksford.

The top of the terrace deposit varies between 90 m (295 ft) at Trescott (8510.9740) to 71.6 m (235 ft) immediately north of Swindon (8579.9115). Less than 100 m south of the map area at 8654.8996, the top of the outwash was revealed in a surveyed gas pipe-line trench at 68 m (223.1 ft) above O.D., although this is almost certainly a minimum figure. The base of the terrace deposits in the pipe-line trench varied between 66 m (216.6 ft) and 59.1 m (194 ft) above O.D. In this exposure the bedrock was 'stepped' in a series of benches separated by small steep bluffs. Similar benches were observed under the terrace deposits in another gas pipe-line trench south of Trysull between 8551.9425 and 8554.9430. In a third gas pipe-line transect across the outwash deposits of the Smestow Brook east of Trescott (8510.9704) the Upper Devensian glacio-fluvial gravels were observed resting upon Irish Sea till.

Coarse brown sands and gravels with frequent Irish Sea erratics were also observed resting upon till in a drainage cut excavated along the line of the Black Brook from 8361.9650 to 8372.9770. The sands and gravels were usually less than 1.4 m thick and occurred beneath 60 cm to 1 m of peaty silt and alluvial clay. Low mounds of gravel at 8360.9782 and 8345.9743 probably represent remnants of a thicker gravel unit. The northernmost gravels along the Black Brook appear to the west of Freehold Wood (8410.9840) and the easternmost gravels recorded along the Smestow Brook occur west of Castlecroft Farm at 8665.9778.

Collapse structures were seen in the terrace gravels at 8572.9356 and involutions were observed in the top 65 cm of the gravel sequence at Woodford Grange. The only fossils found in the terrace deposits have been occasional fragments of Pleistocene marine shells, which are in fact erratics of the Irish Sea Glacier.

(ii) *Moat Brook*

Moat Brook is an eastward flowing tributary to the River Penk, joining the main stream at 8903.0370 (figure 20). Gravel with many Irish Sea erratics can be seen forming an undulating deposit along the north side of the stream. Exploratory holes made by the Redland Group near Gunstone Hall (8724.0457) revealed 5.2 m of sand and gravels without encountering bedrock. Generally the deposits were between 2.7 and 3.4 m thick in the centre of the belt of gravel. The top of the glacio-fluvial sequence at Gunstone Hall is at approximately 108.2 (355 ft), approximately 3 m above alluvium, and the base is below 102.4 m (336 ft) O.D. Trial boreholes 1.5 km to the east at Codsall sewerage works (8834.0364) revealed 1.1 m of sandy peat overlying 4 m of sand and gravel. At this locality the top of the deposit is at approximately 105.2 m (345 ft) and the base below 98.4 m (323 ft) O.D. The Essington–Trysull gas pipe-line trench crossed the Moat Brook 180 m north of Gunstone Hall, and although excavation depth was only about 2.1 m, the gravels were seen to rest directly upon bedrock or on red silt and clay (? reworked till). Thick gravel deposits were absent on the sides of the stream, although they form pronounced features barely 100 m to the south. No fossils have yet been found in this gravel sequence.

(iii) *River Penk*

With the exception of localized patches of gravel the outwash sequences along the River Penk from the headwaters to Penkridge, are confined to narrow strips bordering, and only slightly above, the modern alluvium. The Whiston Brook brings large quantities of gravel and sand

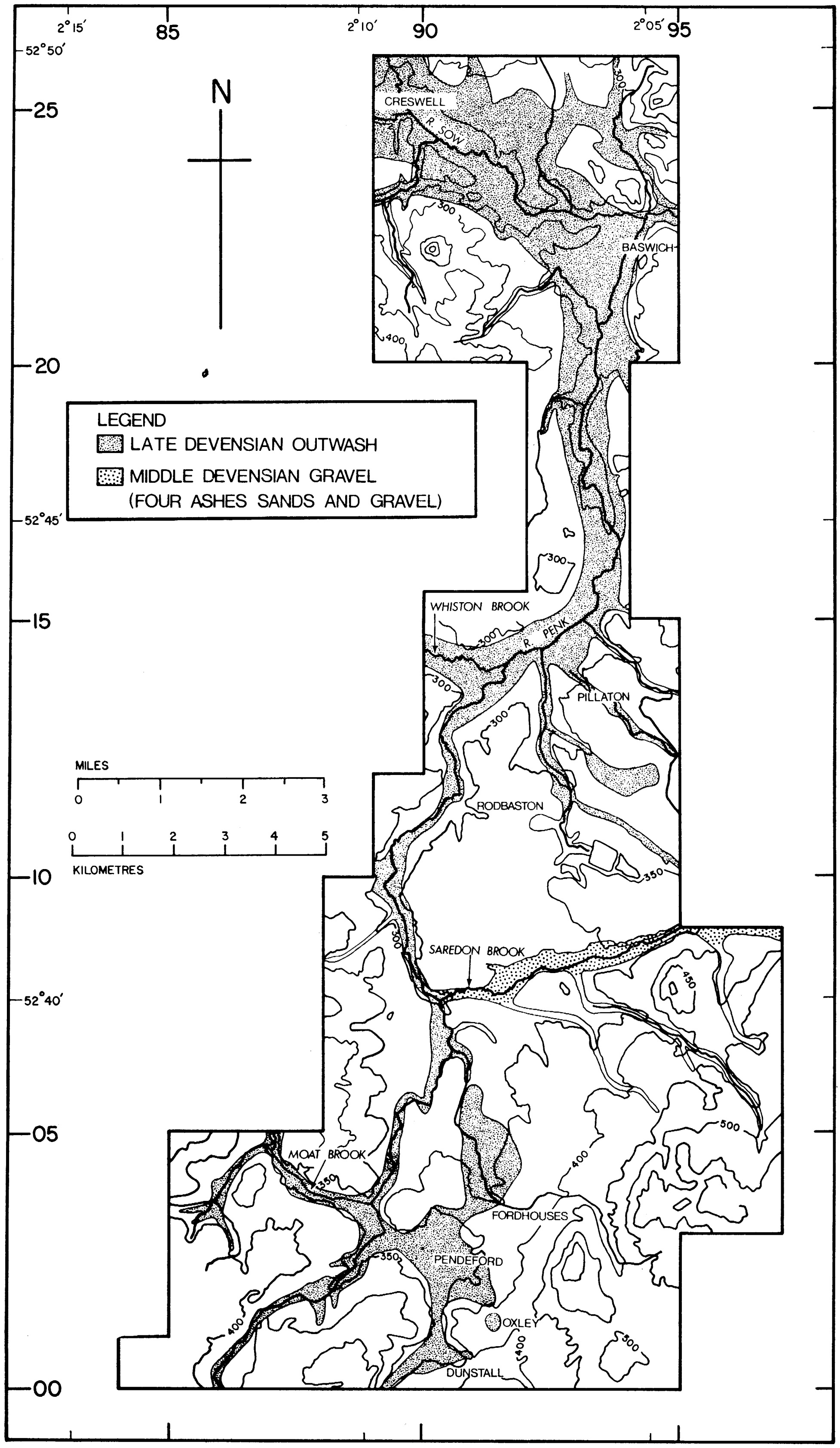


FIGURE 20. Distribution of Upper Devensian glacio-fluvial deposits between Wolverhampton and Stafford

into the Penk system, and below the confluence of the two near Penkridge there are wide areas of terrace deposits (figure 20).

The first area of glacio-fluvial gravel encountered on the River Penk is south of Codsall, bordering both sides of the stream northeast of Wergs Hall. Sandstone outcropping along Keepers Lane and south of Bedford Spinney (8730.0195) indicates that the drift forms a thin veneer over a bench cut into the bedrock. An auger hole at 8811.0173 penetrated approximately 1 m of gravels without entering bedrock. Downstream, the glacio-fluvial sequence becomes confused with the drift deposits at Pendeford, described earlier in this section. Below the Pendeford site the Moat Brook joins the Penk as a west bank tributary and the combined streams flow north through a sandstone ridge running from Upper Pendeford Farm (8970.0330) toward the Hattons Farm (8875.0465). It is interesting to observe that the top of the glacio-fluvial gravels is at 105.2 m

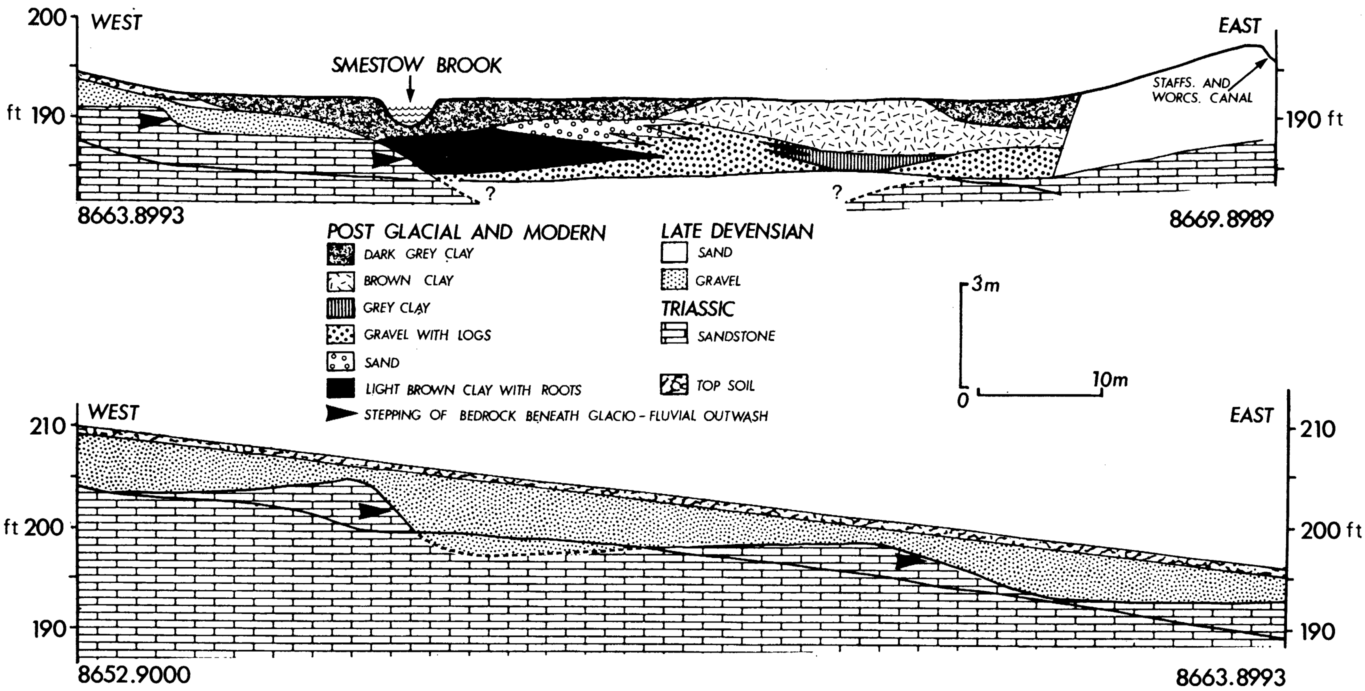


Figure 21. Section through Late Devensian Terrace deposits and post-glacial sequences at Hinksford.

(345 ft) O.D. along the Moat Brook, whereas less than 1 km to the north a gas pipe-line trench across the Penk Valley revealed the top of the outwash deposits at approximately 99.1 m (325 ft) O.D. This will be discussed later. North of the gas pipe-line crossing at 8930.0473 the glacio-fluvial gravels are confined to a narrow belt below 97.5 m (320 ft) O.D. The deposits expand southwest of Coven at 9069.0648 where a small tributary enters the Penk from the east, providing a flat area with a top surface at approximately 96 m (315 ft) O.D. Other expansions in the glacio-fluvial gravels occur at Lower Green (9044.0716), the junction with the Saredon Brook (9032.0751) and between Brewood and Somerford (8967.0832 to 8913.0969). Just below the junction with the Saredon Brook the top of the glacio-fluvial gravels reaches 91.4 m (300 ft) O.D. (approximately 2 m above the alluvium), and at the junction with the Whiston Brook, west of Penkridge the surface of the outwash deposits is at approximately 85.3 m (280 ft) O.D. (about 6 m above alluvium). Exposures are rare along the Penk Valley, but below Penkridge new sewerage schemes and the construction of the M. 6 motorway have resulted in numerous

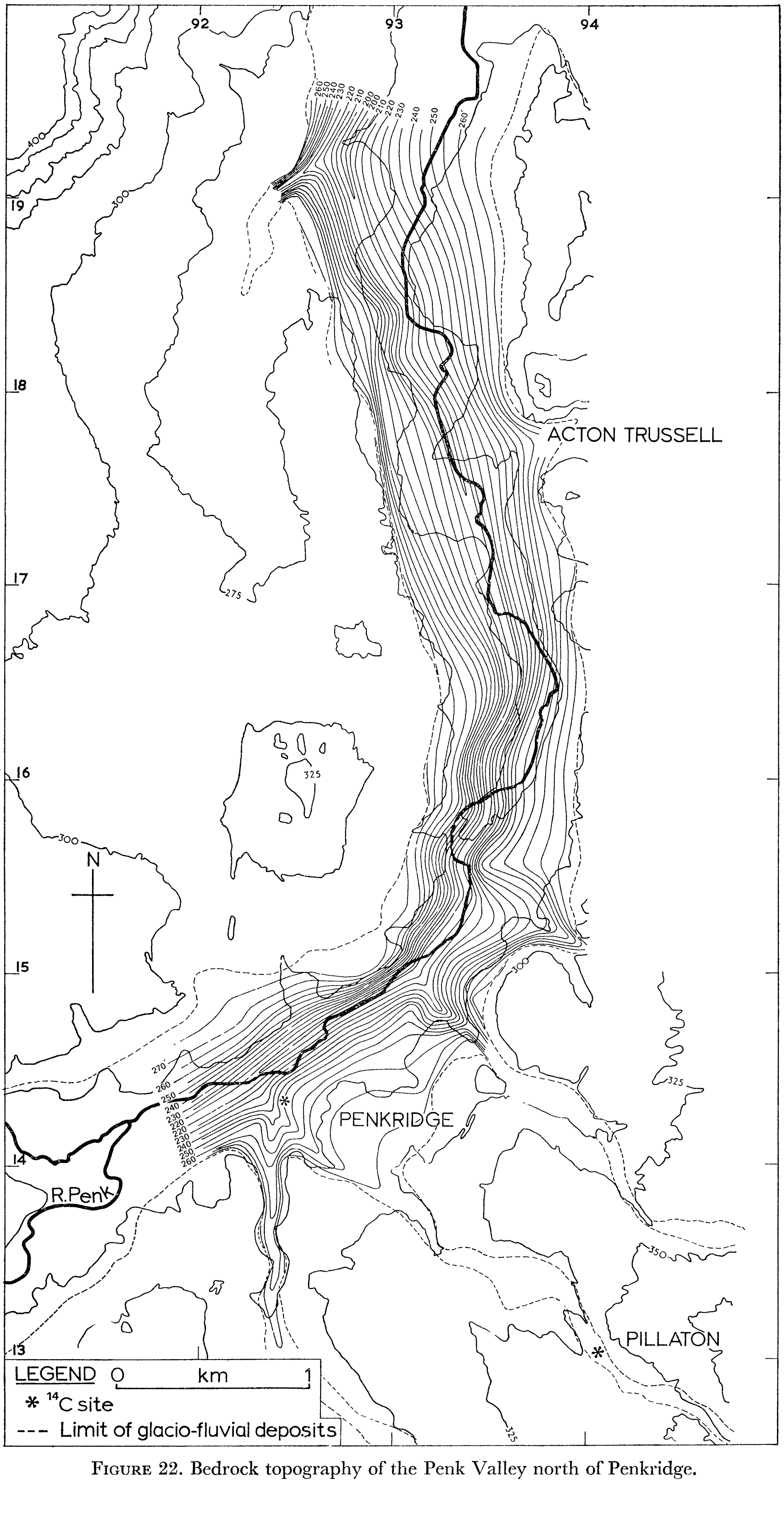


FIGURE 22. Bedrock topography of the Penk Valley north of Penkridge.

temporary excavations and trial boreholes. From these data it has been possible to determine the general bedrock morphology and an attempted reconstruction of the sub-drift surface is given in figure 22. In the Penk Valley at Penkridge three deposits can be recognised. These are from oldest to youngest; glacio-fluvial sands and gravels, Late-glacial gravels, and modern alluvium.

The glacio-fluvial deposits consist of coarse brown sand with lenses of gravels containing frequent Irish Sea erratics. The sands are commonly current-bedded and occasionally contain mega-erratics. Along the west bank of the Penk, south of Lower Drayton Farm at 9295.1534, the sands and gravels were observed resting upon red clay containing Irish Sea erratics (figure 23, plate 34) and also overlying fossil ice-wedge casts penetrating the till. The top of the glacio-fluvial deposits in the area around Penkridge is at approximately 85.3 m (280 ft) O.D., falling to 83.5 m (274 ft) O.D. near Acton Trussell. Numerous boreholes have revealed the bedrock contact beneath the drift and four selected examples give maximum recorded depths of drift along the River Penk as follows. These must be regarded as minimum figures for drift thickness in this area:

Penkridge (9270.1478)	13.1 m of gravel and sand, bedrock at 66.2 m (217.2 ft) O.D.
Lower Drayton (9345.1581)	7.5 m of alluvium, gravel and sand, bedrock at 68.9 m (255.9 ft) O.D.
Acton Trussell (9324.1759)	9.1 m of alluvium, gravel and sand, bedrock at 66.2 m (217.3 ft) O.D.
Acton Trussell (9304.1816)	11.0 m of alluvium, gravel and sand, not bottomed at 62.8 m (206.2 ft) O.D.

One of the more puzzling aspects of the glacio-fluvial deposits between Penkridge and Stafford is the presence, at different levels in the gravel and sand sequence, of layers of red clay with occasional Irish Sea erratics and frequent Bunter pebbles. The clay bands vary in thickness from 30 cm to over 2 m and occur either as discrete lenses or as continuous sheets traceable for several hundreds of metres. In 25 sites where surveyed levels were obtained the clay deposits ranged from a maximum recorded height of 84.4 m (277 ft) to a minimum height of 73.8 m (242 ft) O.D. The most laterally persistent deposits were seen in sewerage pipe-line trenches at Penkridge between 9295.1459 and 9315.1445 (300 m), approximately 1.2 to 2.4 m thick, and at Acton Trussell, where similar clay layers, approximately 1 m thick, were seen 350 m apart at 9305.1768 and 9335.1768. A particularly deep excavation on the west side of the M. 6 motorway revealed the following sequence:

Location 9335.1605; G.L. 83.2 m (272.9 ft) O.D.

0–0.76 m	topsoil
0.76–1.8 m	medium to coarse brown sand, small gravel
1.8–3.3 m	stiff red clay with numerous Bunter quartzites and occasional Irish Sea erratics
3.3–4.9 m	coarse gravels, predominantly Bunter quartzites but with occasional Irish sea erratics
4.9–7.6 m	Keuper Marl (bedrock)

Generally there does not appear to be any height constancy of the clay unit, either taken over the whole valley or in localized areas. One 'strong marly clay band' recorded as being 56 cm thick at a depth of 2 m in a borehole at the new Penkridge sewerage plant northeast of Lower Drayton, was excavated during construction work. The base of the clay band (indistinguishable in lithology from the clay bands described above, and elsewhere in the region) was rolled into clay 'balls', the maximum diameter of which was about 12 cm. The internal composition of the clay ball was identical with the overlying band of clay and the ball showed no sign of a central nucleus.

North of Acton Trussell the top of the glacio-fluvial sands and gravels along the Penk Valley drops from approximately 80.8 m (265 ft) O.D. at Rickerscote to about 79.2 m (260 ft) O.D. at the confluence of the Penk and Sow near Baswich. Along this section of the river the glacio-fluvial terrace remains about 6 m above alluvium. No fossils have been found within the glacio-fluvial gravels, but organic deposits have been found in the fluvial Late-glacial sequences which overlie them.

(iv) *River Sow*

A vast spread of glacio-fluvial gravel, frequently more than 2 km wide and with a top surface approximately 6 m above the modern alluvium, occupies the Sow Valley in the vicinity of Stafford. Because of motorway construction and the danger of salt subsidence in the Stafford region, numerous exploratory boreholes have been put down through the drift sequence. The construction of the M. 6 across the Sow Valley at Creswell between 8975.2467 and 9027.2543 has resulted in 52 closely spaced test boreholes through the drift and 19 of these reached bedrock. The resultant geological sections are given in figure 24. Similar trial boreholes at Doxey (9100.2335) have revealed an undulating bedrock surface and confirmed that the borehole recorded near the engine sheds at Stafford (Whitehead *et al.* 1927, pp. 91, 94) is not unique. Indeed the height of the bedrock contact in this borehole, 38.1 m (125 ft) above O.D., is considerably above the drift depths recorded in the deepest borehole of the Creswell Viaduct sections, which penetrated 45.1 m of glacio-fluvial deposits to 29.4 m (96.7 ft) above O.D. and still did not encounter bedrock. The fluvial and glacio-fluvial deposits along the valley of the River Sow can be divided into the following groups.:

0–18.0 m	peat and organic silts and clays (not always present)
0–9.0 m	coarse brown sand and gravel (with Irish Sea erratics)
9.0–30.0 m	brown fine sandy silt and clay
30.0–bedrock	gravel and cobbles (till in places)

This succession represents a very generalized section through the deposits and each borehole varies subtly, but usually the uppermost unit is a coarse brown sand with gravel, and this is overlain in certain areas by organic debris which can reach considerable thicknesses. The base of the sand and gravel is usually less than 9 m below ground surface and rests upon fine grained silts and clays with medium to fine sand layers, the description varying according to the drillers' logs. Occasional stiff clay bands or layers of cobbles have also been reported from this unit. The

---

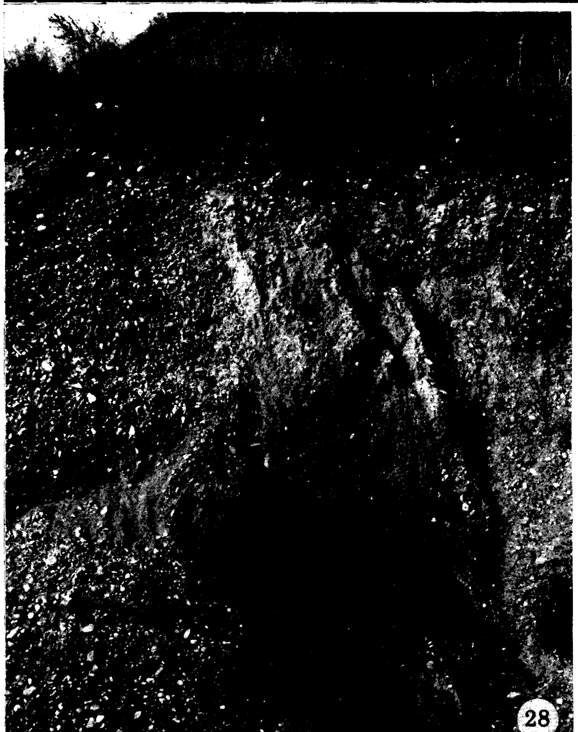
DESCRIPTION OF PLATE 34

FIGURE 23. Upper Devensian terrace deposits overlying Irish Sea till north of Penkridge (9295.1535).

FIGURE 26. View east, south of Four Ashes at 9108.0720. Note the appearance of the polygonal ground under the different crop conditions.

FIGURE 28. Lobe of Irish Sea till sagging into Middle Devensian gravels at Four Ashes.

FIGURE 31. Upper Devensian organic deposits in the fluvial gravels of the Penk Valley at Penkridge.



FIGURES 23, 26, 28 AND 31. For legends see facing page

(*Facing p.* 280)

lowest deposit occurring directly above bedrock can consist of a coarse gravel, till, or a continuation of the silt unit. I was fortunate in obtaining an undisturbed sample from a borehole at 9245.2354 at a depth of 23.01 to 23.47 m; 48.8 m (160 ft) above O.D. and only 15 cm above the Keuper Marl bedrock. The sample consisted of a red sandy plastic clay containing the following gravels and cobbles:

Marl; sub-angular to rolled fragments up to 1 cm	60 %
Bunter quartzites	30 %
Siltstone	4 %
Limestone	2 %
Granite, tuff, quartz porphyry, grit	4 %

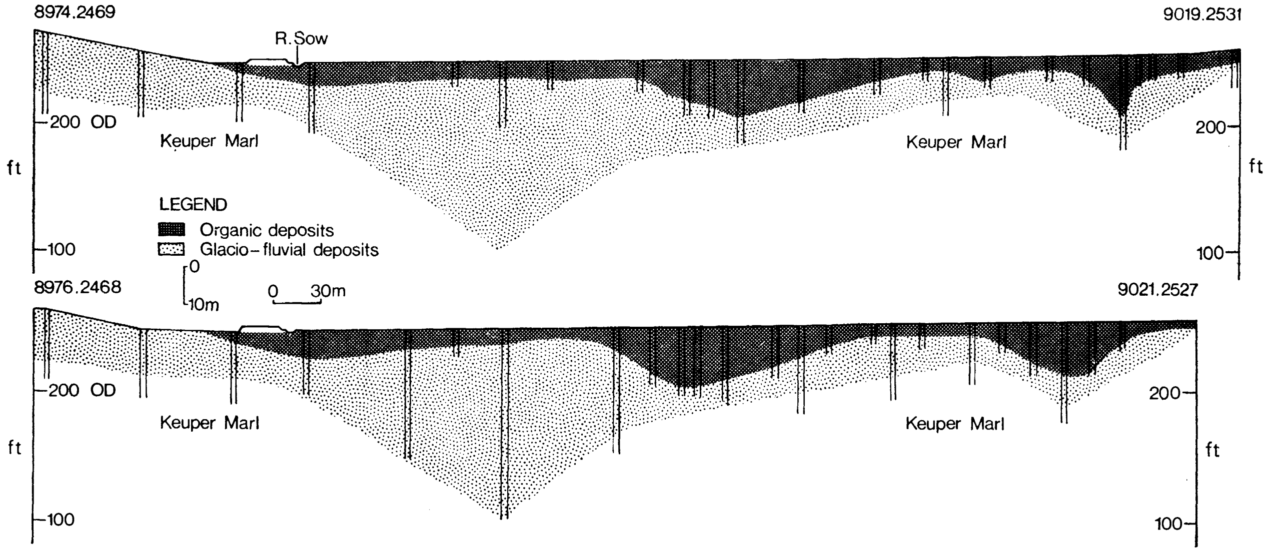


FIGURE 24. Cross-sections of the Sow Valley at Creswell, near Stafford.

Fossils have not been found in the glacio-fluvial gravels at Stafford and the overlying organic deposits will be described later. A ^{14}C sample at the contact of the overlying organic sequence and the glacio-fluvial gravels provided a minimum age for the end of glacio-fluvial deposition of 13490 years B.P. (Birm. 150).

Finally, the glacio-fluvial deposits of the Sow merge with those of the Pearl Brook and the Penk, whilst a fourth sequence joins the Sow Valley gravels from the north, entering through a gap in the sandstone now occupied by Kingston Pool (9430.2365). All these gravels meet in the area between Kingston Hill (9417.2330) and Baswich (9445.2225) and then enter a deep gorge in the Pebble Bed outcrop flowing eastward into the main valley of the River Trent at 9945.2252. Boreholes at the new Brancote Sewerage works at 9545.2252 revealed at least 10.4 m of sands, gravels and clays, sometimes resting on Bunter Pebble beds. Exposures of the drift/bedrock contact often revealed steep bluffs with vertical rock steps some of which were smoothed as though by water action (Works engineer, pers. comm. 1939)).

(*d*) *General discussion*

Because of the complexity of deposition in the environs of large ice-sheets, it is extremely difficult to ascribe specific depositional origins to the glacio-fluvial features within the area studied. Similarly, the presence of till-like deposits, either as true 'ground moraine' in secondarily derived ice-rafted blocks, or as reworked till re-deposited by melt-water streams in glacio-fluvial or glacio-lacustrine environments makes it difficult to establish a chronological framework for the deposition of the outwash. This problem is further aggravated by the lack of fossils within the glacio-fluvial deposits which means that the recognition of an *in situ* till deposit, either above or below the gravel and sand sequences, is practically the only way of determining the relative age of the deposit. Till overlying glacio-fluvial outwash does not accurately define the depositional environment or the age of the deposit, since the outwash could have been laid down in an ice marginal position and covered during the main ice advance. Similarly, it could have been deposited during ice retreat and covered by a temporary readvance. Alternatively, some features are most likely to have been initiated in sub-glacial or englacial positions, whilst the glacio-fluvial outwash terraces of the Smestow apparently lie completely outside the ice front south of Woodford Grange. Because of the reasons mentioned above, there is considerable difficulty in determining the history of the glacio-fluvial features in the region. A few of the deposits have probably originated in one specific way, within or outside the ice-sheet margin. The origin of the other deposits almost certainly may be explained in several ways. However, the presence of Irish Sea erratics in all the glacio-fluvial deposits studied indicates that the Irish Sea (Upper Devensian) ice-sheet was the principal source of the melt-water which eroded the bedrock, and later deposited the gravel and sand sequences. The glacio-fluvial sand and gravel found beneath the till over large areas has probably originated either as a thin outwash spread which the ice sheet has advanced across, or as a water deposited unit beneath the ice sheet. The potholes and the drift-infilled channels are almost certainly intimately associated with melt-water streams either immediately beside or, more likely, beneath the ice. The glacio-fluvial gravels and sands capped with till near Upper Whittimere Farm and at Oxley probably represent minor pro-glacial lacustrine areas being infilled with sand and gravel from the ice front and later covered by an ice advance. Similarly, the glacio-fluvial deposits at Pendeford, Ford Houses and Dunstall probably indicate small bodies of water receiving debris from a nearby ice front. The presence of clay layers beneath, within and above the gravel and sand sequences in these areas seems to suggest that the ice front was probably not completely inactive, but was subject to minor re-advance pulses. The gravel ridges, particularly those near Langley Farm and at Long Birch Farm, may well have originated in a sub-glacial position. Their morphology and altitudinal position in relation to the surrounding till plain strongly suggests that they were formed of eskerine ridges (as in the Langley Farm example) or possibly as crevasse infillings (Long Birch Farm area). A similar ice-controlled origin is postulated for the parallel melt-water channels near Penkridge and for the channels near Rodbaston. The glacio-fluvial terraces along the major drainage lines are the most difficult deposits to put into chronological order. The presence of till at the base of the Sow sequences at Stafford and the clay (till-like) layers within the Penk sand and gravel deposits leads to at least three possible alternatives. The glacio-fluvial sequences along these valleys could be pro-glacial outwash spreads infilling an interglacial or interstadial drainage system; the deposits may have formed in tunnel valleys beneath the ice during maximum ice advance, or the deposits might have been laid down within a stagnating ice mass which was later rejuvenated by a minor readvance.

The glacio-fluvial sequence in the Smestow Valley south of Woodford Grange was deposited contemporaneously with the maximum extent of the ice-sheet in this area, and undoubtedly also received outwash during the early stages of recession before the retreating ice crossed over the main watershed north of Tettenhall and Pendeford. During the ablation of the Upper Devensian ice it is highly probable that the upland areas at the top of the Tettenhall Gap emerged from the ice cover whilst the lower topography south of Tettenhall still retained areas of stagnant ice. Water flowing from the ice front appears to have been impounded in a series of shallow basins situated at Dunstall, Pendeford and Ford Houses. Natural drainage via the Smestow Valley (parallel with the Tettenhall escarpment) was restricted by the presence of ice, but water did escape along sub-glacial and ice-marginal channels which became incised into the sandstone at a number of locations. The fact that the channels are sometimes infilled with sand and gravel and frequently overlain and filled with till, whilst retaining quite sharp edges in the soft sandstone, seems to indicate that they were incised and infilled beneath a stagnating ice-sheet which was never rejuvenated. Although water levels in the area northeast of Tettenhall may have fluctuated considerably during the ablation of the ice it would appear that the surface level probably stood at 103.6 m (340 ft) to 106.7 m (350 ft) above O.D. for some time because of the flat glacio-fluvial deposits at this level at Dunstall, Pendeford and Ford Houses. A water level of 105.2 m (345 ft) is also suggested by the upper limit of sand and gravel deposits along the Moat Brook, as described by Dixon (Whitehead *et al.* 1928, p. 189). The differences in level between the top of the sand and gravel sequences along the Moat Brook and the River Penk, 105.2 m (345 ft) and 99.1 m (325 ft) respectively, indicates that the former did not grade into the latter during the deposition of the outwash, and this might have been due to an ice front blocking the drainage northward along the Penk Valley. In this way ablation water fed the Pendeford/ Dunstall area and then exited beneath stagnant ice occupying the Tettenhall Gap and the area south of the Gap, finally flowing into the Smestow and Severn drainage. A recession of the ice sheet north of Pendeford removed this barrier, and drainage from the Moat Brook probably rapidly cut through the sand and gravel sequences along the watershed, capturing the headwaters of the Smestow system and diverting them north into the Trent drainage. I disagree with the comments made by Dixon (Whitehead *et al.* 1928, p. 189) that: 'It is indeed possible that at this period (during ice retreat) the gap was initiated...' and Wills (1937, p. 6) who stated: '...a small lake was impounded just north of Wolverhampton which flowed out south-westwards over the watershed near Tettenhall, forming the Tettenhall Gap.' If the so-called Tettenhall Gap had been initiated by water overflow from glacial lakes impounded between the watershed and the retreating ice front, the drift-infilled channels could not have been cut and infilled with glacial drift, since the melt-water would have been excavating solid rock. Similarly, I use the term 'so-called Gap' because except for two localities, southeast of Tettenhall and at Wightwick, the southern flank of the Gap is composed of Upper Devensian till. If the drift sequences were removed the Tettenhall 'Gap' would be revealed as a continuation of the Perton escarpment with two residual outliers of sandstone near Compton and at Wightwick.

The age of the glacio-fluvial terrace of the Smestow, which, according to Wills (1938, pp. 203–206) grades into the Main Terrace of the River Severn, is at conflict with the evidence provided by other tributary valleys of the Severn. As suggested above, the Smestow outwash is equivalent to the Upper Devensian maximum ice advance (Main Irish Sea glaciation) which postdates 30500 years B.P. (§3(*e*)). For reasons explained earlier (§3(*f*)) the Main Terrace (which has yet to produce Pleistocene organic material) was assumed by earlier authors to be slightly older than 42000 years B.P. The evidence presented in this section suggests that this correlation should be re-evaluated.

North of the main Severn–Trent watershed the glacio-fluvial outwash sequences along the valley of the River Penk are confined to small gravel spreads either flanking the modern alluvium or forming a low terrace at approximately 91.4 m (300 ft) above O.D. near Coven. The gravels of the Saredon Brook, joining the River Penk at 9032.0751, have been shown to be of Lower and Middle Devensian age (§ 2) and the statement made by Dixon (Whitehead *et al.* 1928, p. 187) that: 'The Saredon Brook valley appears from its narrow linear character and parallelism to ice stands elsewhere to the north-west to be a marginal channel cut by water flowing along the ice front during a stand...' is not substantiated by field relationships.

The main source of glacio-fluvial outwash joining the Penk drainage appears to have been derived from water flowing down the Whiston Brook. This is explained by Dixon as being due to tumultuous deposition along an ice front parallel to the Whiston Brook (Whitehead *et al.* 1928, p. 199); a possibility which I have not been able to verify because the Whiston Brook continues westward outside the map area. Certainly, well-developed terraces do appear to be confined to the Whiston Brook, rather than the Penk Valley, above Penkridge. Below Penkridge the terrace deposits form pronounced flats with a top surface about 6.1 m above the modern alluvium. This is also true of the Sow Valley outwash deposits and the two appear to be at grade. In the case of the Penk terrace sequences there is considerable difficulty in explaining the presence of the clay bands within the gravel and sand deposits. Irish Sea erratics found in the outwash gravels above and below the clay bands indicate deposition in association with the last Irish Sea ice, but whether the clay bands represent the main Upper Devensian till, or whether they represent either reworked till or till developed by minor re-advances during an overall retreat is difficult to say. Because of the rolled till balls at the clay bands mentioned earlier, I believe that the last two explanations are more likely, but further work is needed to substantiate this suggestion.

The deep drift deposits of the Sow Valley, discovered in the borehole logs at Creswell and beneath Stafford, are far more difficult to explain. The Geological Survey officers went to some lengths to discuss various hypotheses accounting for the deep borehole at the engine sheds at Stafford (Whitehead *et al.* 1927, pp. 91, 94, 95). The difficulty in explaining this borehole (and the others which reach similar depths, described earlier) is that the only exit for water in the Stafford area must have been the same as it is today – via the deep gorge at Baswich and into the headwaters of the Trent. As explained by Whitehead this means that:

> '...it is necessary to suppose that a channel of considerable depth is concealed by the deposits of the River Trent nearly as far as Nottingham; for it is only in that neighbourhood that 'solid' formations form a surface at a height not greater than that of the Keuper Marl in the Stafford borehole'.

When Whitehead described the borehole and the problem of grade in 1927, he only had to account for one borehole to a bedrock contact at 38.1 m (125 ft) above O.D. The problem has only become aggravated with the discovery of a yet deeper section upstream amongst the Creswell boreholes, where the bedrock contact had not been encountered at a depth of 29.4 m (96.7 ft) above O.D. The only additional information which has been revealed in this study is that the deep drift-infilled depression continues up the Sow Valley for at least 2.5 km to the west of the area described by Whitehead, and apparently also 1 km to the east.

The steep Keuper Marl sides of the depression in the Creswell area (figure 24) are unlikely to have remained stable during the environment of the Early and Middle Devensian. This fact, coupled with the presence of apparent till-like clay layers near the base of several of the deeper boreholes in the Stafford region makes it likely that the depression originated in association with the Late Devensian ice-sheet. As yet there is no evidence for a drainage reversal for the water which cut the depression either south along the Penk or westward along the Sow Valley. Similarly, there is no evidence for a deep canyon under the Trent Valley. Consequently on the basis of the evidence obtained in the field area, the deep bedrock depression infilled with drift in the Stafford area probably represents an overdeepened trough along the line of the Sow Valley which originated beneath the Late Devensian ice. Further subsurface analysis, either westward along the Sow Valley, or, more likely, in the eastern end of the Baswich Gap, at the junction with the Trent Valley, may well reveal a drift-filled gorge which will represent a continuation of the anomalous channel under the River Sow at Stafford.

9. Late Devensian periglacial features

(a) *Introduction*

Upper Devensian periglacial features have been seen in many localities within the map area. They can be divided into two major categories; ice-wedge casts which are reflected aerially as polygonal patterned ground, and involutions. Solifluction deposits, vertically orientated pebbles and ventifacts are included in this section since they are believed to have formed contemporaneously with the Upper Devensian periglacial environment.

(b) *Ice-wedge casts and polygonal patterned ground*

Wedge-shaped sand infilled structures were observed penetrating the Upper Devensian till overlying the Lower and Middle Devensian gravels at Four Ashes and in sewerage and gas pipe-line trenches north and west of Wolverhampton.

The ice-wedge casts rarely exceeded 190 cm, averaging about 156 cm, and were not observed penetrating bedrock. The shape of the ice-wedge casts varied considerably from narrow sand-infilled fractures only 5 cm wide to contorted wedges with bulbous sections expanded at depth. A typical trench section which revealed ice-wedge casts is illustrated in figure 25. Edge effects were limited to orientated pebbles and small upturned clay flaps within the sands at the edge of the ice-wedge cast.

Following the discovery of the ice-wedge casts in the section at Four Ashes in 1967, flights were made over the area in July 1967 and July and August 1969. Extensive areas of polygonal patterned ground were observed (figure 26, plate 34) which frequently coincided with the distribution of ice-wedge casts in many parts of the map region. The polygonal patterns are believed to reflect differential crop growth and ripening in fields of long-rooted cereal crops, particularly barley, oats and wheat. The average diameter of some 650 polygons from various parts of the region west and north of Wolverhampton was 4.96 m. Both the ice-wedge casts and polygonal ground have been described in more detail elsewhere (Morgan 1971 *a*, *b*).

(c) *Involutions*

Involuted or contorted strata are found in many localities in the study area and affect deposits within and outside the Upper Devensian ice limit (figure 27). Involutions were seen disturbing disintegrated bedrock (Bunter Pebble Beds), Anglian glacio-fluvial outwash, Lower and Middle Devensian gravels, and Upper Devensian till and glacio-fluvial outwash. However, the involutions probably belong to one episode contemporaneous with, and post-dating the maximum Upper Devensian ice advance.

(i) *Involutions affecting Anglian deposits*

At Woodford Grange (8570.9350) contorted Trysull sand and gravel (§4*b* (vi)) festooned to a depth of approximately 1 m was unconformably overlain by almost horizontal Upper Devensian glacio-fluvial terrace gravels.

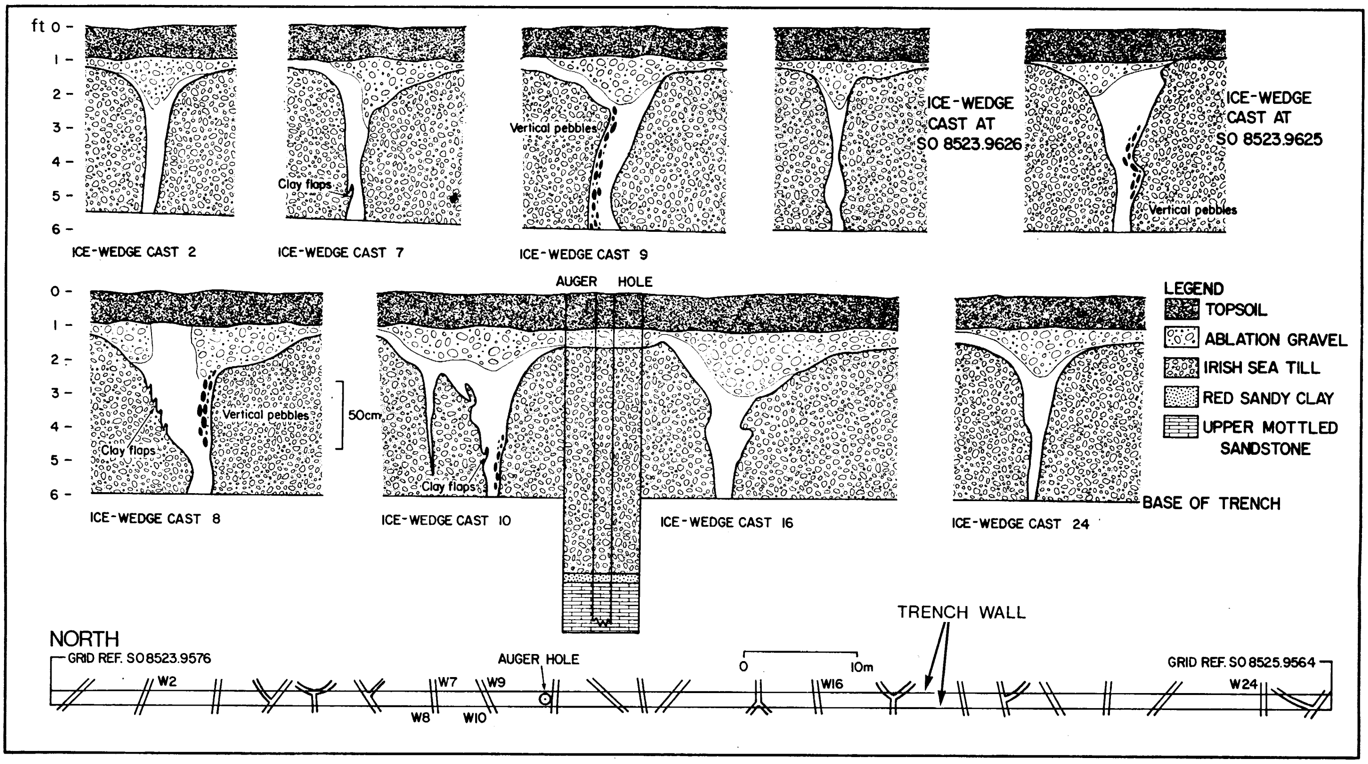


Figure 25. Ice-wedge casts revealed in a gas pipe-line trench near Trysull.

(ii) *Post-till involutions*

Nearly all the involutions are believed to be the result of disturbances post-dating the deposition of the Upper Devensian till. At Four Ashes this is clearly demonstrated by the foundering of till blocks into the underlying gravel, and the intimate association of neighbouring festoons with lineated pebbles in the gravel sequence (figure 28, plate 34). All the till masses seen within the gravels are spherical and the pebbles immediately adjacent parallel the edge of the foundered mass. The clay sag structures are represented by two forms differentiated by size. Small pear-shaped masses of till (76 × 53 cm) with stretched tops have foundered into the gravel in the proximity of fissures in the till sheet (figure 29*c*). The larger sag structures consist of till balls which have sunk partially, or almost completely, into the gravel unit to a maximum recorded depth of 2.4 m. Below this depth the original stratification in the gravel sequence is undisturbed.

The festooned gravels were frequently seen rising toward, or entering, fissures in the overlying till (figure 29), whilst the remains of an apparently once continuous organic horizon have been left in isolated patches below the base of each fissure. The maximum depth of festooning recorded at Four Ashes was approximately 2.5–2.6 m below the base of the soil. Since the

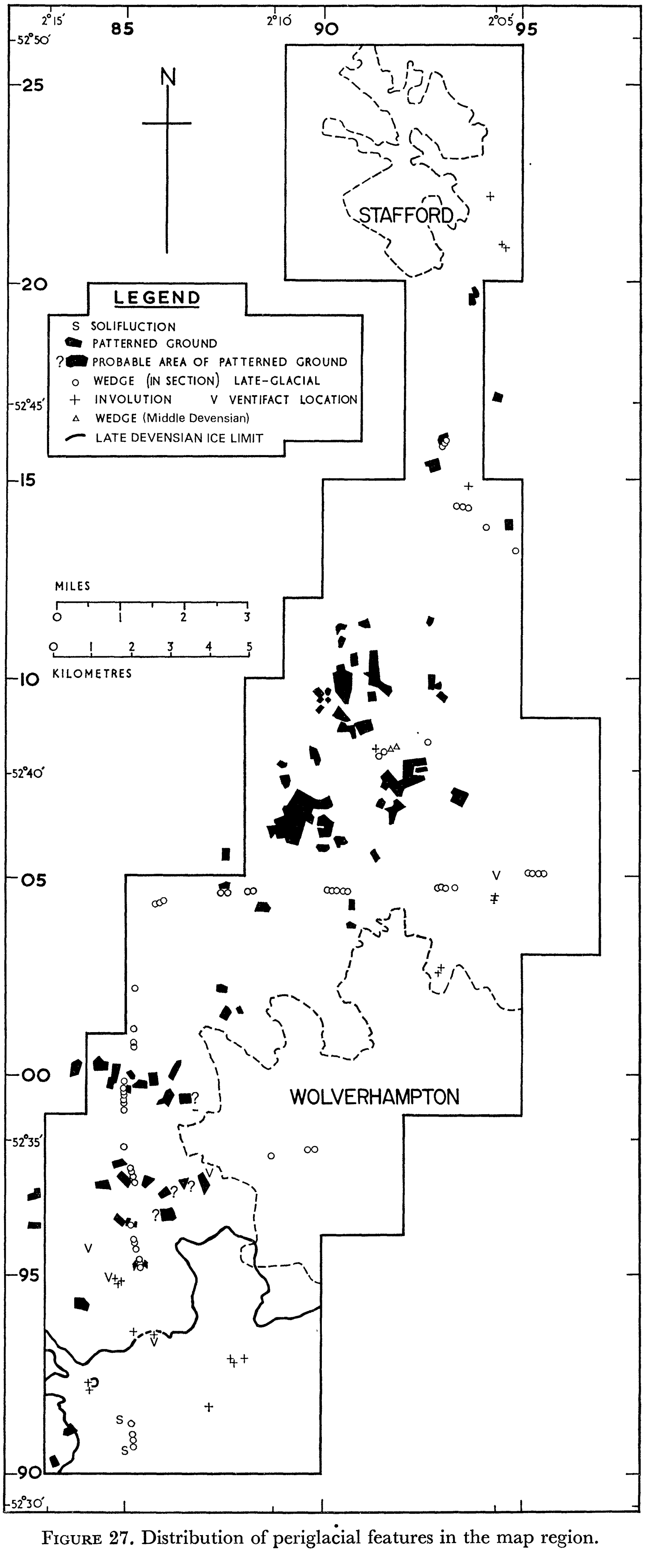


FIGURE 27. Distribution of periglacial features in the map region.

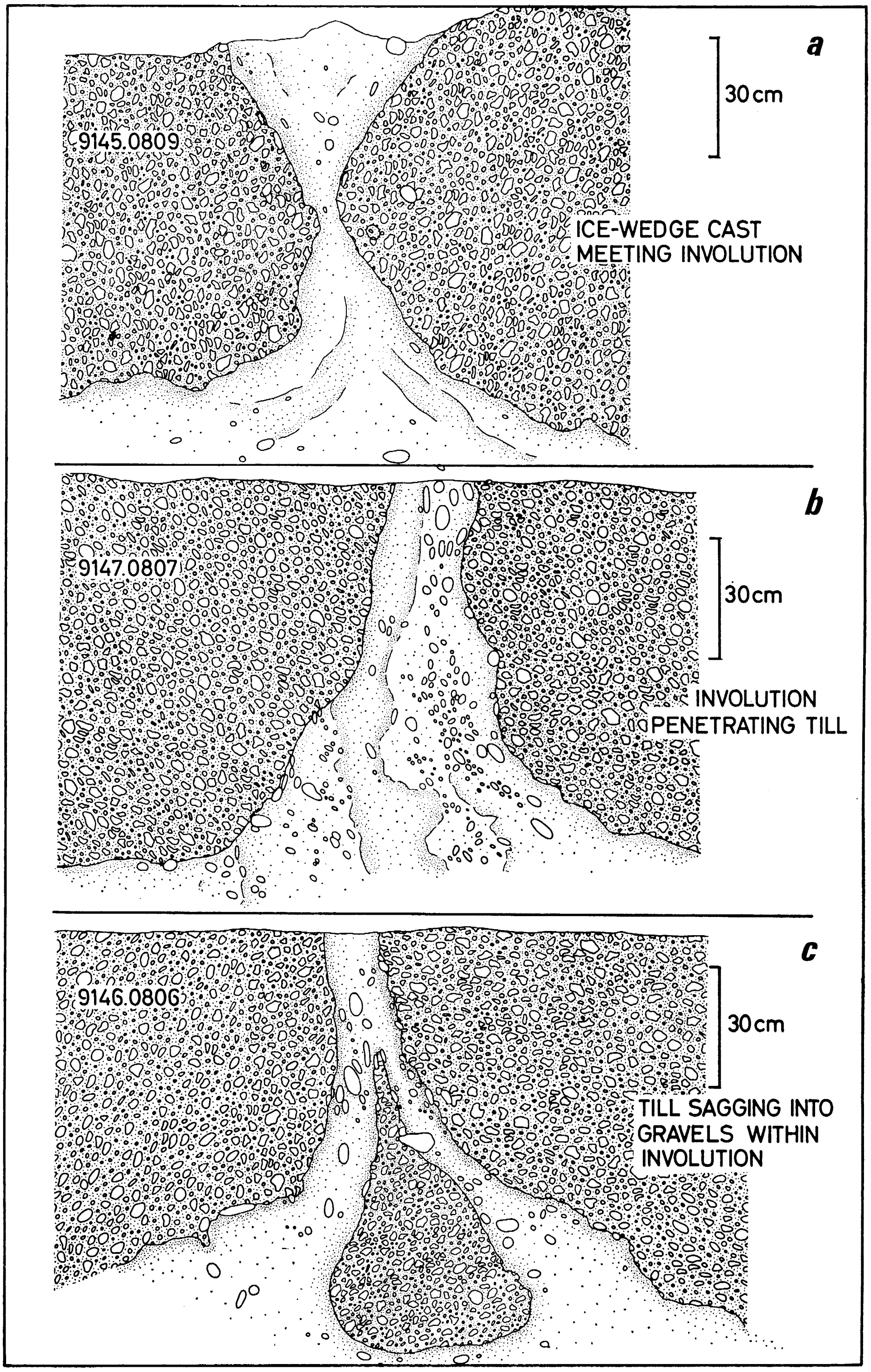


FIGURE 29. Involutions penetrating Upper Devensian till at Four Ashes.

overlying till is not continuous over the gravel but fluctuates to a greatest recorded thickness of 2.75 m, it is not possible to give depths of involution disturbance below the base of the till.

Elsewhere in the field area involutions were observed affecting Bunter Pebble Beds to a maximum depth of 3 m at Hilton (9440.0400) and Bushbury (9290.0250). A number of exposures in abandoned sand pits at Wombourn show up to 2.5 m of contorted clayey sands and gravels overlying Upper Mottled Sandstone. Finally at Woodford Grange 30 m east of the exposure which revealed involutions affecting Anglian outwash gravels the top of the Upper Devensian outwash is disturbed to a minimum depth of 65 cm, the top of the sequence having been removed by gravel excavation. South of the study area an excavation at Ashwoodfield House (8730.8820) revealed 36 to 56 cm of involuted Bunter pebbles in a sharp coarse brown sand matrix overlying 1.4 m of brick-red to purple fine sandstone.

(*d*) *Solifluction deposits*

These appear to have originated predominantly in the pre-till cold phase, with a less pronounced development following ice retreat. Pre-till deposits probably include the involuted clayey sand and gravel at Wombourn. Deposits which either coincide with the maximum advance of the Upper Devensian ice, or post-date its retreat, include the large stratified solifluction deposits along the east side of the Blackhill and Whitehouse Plantations (8500.9100) north and west of Swindon, and 'head' overlying parts of the Bunter Pebble Bed hills of Saredon, Hilton and Bushbury, north of Wolverhampton.

The Swindon area was cut through by two gas pipe-line trenches and revealed a minimum depth of 2.5 m of stratified coarse red to yellow sands with layers of fine red clayey silt and reworked Bunter pebbles. Ice-wedge casts penetrated the sequence to a depth of 1.5 m in several localities. At Saredon, Hilton and Bushbury the involuted and wedged strata described above are frequently overlain by 50 cm to 2 m of coarse sand and gravel which probably represents a solifluction deposit. The absence of till on the steeper, higher portions of these bedrock hills might also be due to solifluction.

(*e*) *Vertical pebbles*

Pebbles with vertical or highly inclined long axes were found in numerous localities throughout the map region. They occurred almost exclusively in till and other clay-rich lithologies, as, for example, at Wombourn (8772.9275 and 8710.9170), and were normally concentrated in the top 1.5 to 2 m of the deposits.

(*f*) *Ventifacts and polished pebbles*

Ventifacts were found concentrated in three localities: at Hilton (9460.0513), in the Trysull–Seisdon area, and in the Smestow Valley around Woodford Grange. Isolated ventifacts from Trysull are of two distinct ages, the earliest ante-dating the Upper Devensian (probably of late Anglian age), the other being contemporaneous with, or just post-dating, ice maximum, whilst all the remaining examples are post-till. Pebbles showing a high degree of polish were found at Seisdon (8429.9559), Woodford Grange (8570.9350) and in Wolverhampton (9130.9894). All are post-till.

(*g*) *Palaeotemperature reconstruction*

Ice-wedge casts and polygonal patterned ground are regarded as indicators of a former permafrost régime with average annual temperatures of below 0 °C, characterized by abrupt drops in temperature below this figure. Péwé (1969) regards the average annual temperature at the time of modern ice-wedge formation as being −6 to −8 °C, while Shumski (1955) suggests an average of −3 to −3.5 °C.

The term involution has been defined as the interpenetration and localized deformation of stratified materials attributed to frost action. Although involutions do not always indicate frost action (see Embleton & King 1968, pp. 471–472 for other forms of genesis) their association with ice-wedge casts in the field area is taken to indicate a periglacial origin.

The presence of permafrost is not a necessary prerequisite in solifluction. The requirements in areas without permafrost are deep and rapid frost penetration followed by thawing from the surface down, and in permafrost areas solifluction is characterized by cool summers. Large-scale solifluction is usually found in regions where the mean annual temperature is not higher than 1 °C (Embleton & King 1968, p. 512).

Ventifact formation and wind polishing is indicative of an open environment with little or no vegetation, strong winds and an adequate supply of sand. In short, during the time when ice-wedge and involution formation was active the average temperature in the Wolverhampton area must have been at least 9.5 °C (17.3 °F) below the present annual average temperature and possibly as low as 17.5 °C (31.7 °F) below the present annual average. The region must have been characterized by an open landscape, strong winds, thin snow cover and abrupt temperature falls during the winter.

(*h*) *General discussion and age of the periglacial features*

At Four Ashes the presence of an involuted zone approximately 2.5 to 2.6 m thick, overlying apparently undisturbed gravels and sands, possibly indicates the existence of permafrost below this depth during the formation of the involutions. This seems to be further substantiated by the presence of till blocks which have sagged into the underlying gravels to a similar depth, but have been prevented from entering the basal 1.5 to 2 m of gravels. The association of festoons of gravels which rise into cracks in the till probably indicates movement of a semi-fluid mass into the fissures. This may result from water, trapped between permafrost and a surficially frozen layer, being forced into fissures (perhaps initiated by ice-wedge casts) in the upper layer. Identical features in a similar stratigraphic succession in southwestern Alberta have been described by the present author (Morgan 1969*a*). These structures are generally believed to be indicative of a severe frost climate with the presence of permafrost. Similar depths of involuted strata are recorded at Bushbury and Hilton.

The solifluction deposits east of the Blackhill and Whitehouse Plantations appear to represent washes of disintegrated Bunter Pebble Bed bedrock which have moved downslope into the Smestow Valley. Similar deposits occur in the Bunter Pebble Bed outcrops at Saredon, Bushbury and Hilton, and at Hilton the solifluction debris overlies involuted and ice-wedged gravels and sands.

Wind-abraded pebbles or ventifacts are commonly found in high latitudes and altitudes today, and are also frequently encountered in Pleistocene deposits. Pleistocene ventifacts have been described from Lilleshall Hill, Shropshire, some 17 km west of the map area (Raw 1913, p. 493). They have also been found in Worcestershire (Wills 1910), Nottinghamshire (Swinnerton 1914) and Leicestershire (Raw 1934), whilst Thompson & Worsley (1967) have described Weichselian (Devensian) ventifacts from Cheshire. Nineteen ventifacts were found in the present study, although these were accidental encounters rather than the result of a deliberate search.

The composition of the substrate, although of different geological age, is similar and the ventifacts are all in fairly resistant lithologies.

The post-till ventifacts were found either on predominantly drift-free areas, the Bunter Pebble Bed hill at Hilton, or associated with gravelly outwash from the Upper Devensian ice, either as a glacio-fluvial deposit or a sandy ablation gravel overlying the till. In the drift-free area at Hilton the ventifacts are all Bunter pebbles, but on the outwash area at Woodford Grange only one ventifact in three was a Bunter quartzite, the other two being erratics. One of these erratics, a felspar porphyry, shows etching of the felspar phenocrysts, presumably by wind action, on the cut faces. Similarly, north of Lower Penn, two ventifacts found overlying the till were Bunter quartzite and flint, the latter showing wind polish. The ventifacts were also found on till at Seisdon, two lying within the overlying ablation sand, whilst the third was embedded in the till, with the ventifact top projecting into the sand. Here the first two erratics were Bunter quartzites and the third a greywacke erratic. In addition to the examples mentioned above, three other wind polished pebbles were found. All were at different localities, two were flint and the third a Bunter quartzite.

In summary, it appears that ventifacts were widely distributed over the area studied following ice-retreat. They occur on drift-free and drift-covered areas where there appears to be a supply of resistant pebbles to form the ventifact, and a source of sand to act as a cutting agent. Wind polishing is most evident on smooth silica surfaces, all examples being in either flint, quartz, or fine quartzite.

The main ice advance to the Wolverhampton Line was of Upper Devensian age. At Four Ashes it is known to post-date 30 500 years B.P. (Birm. 195) and it probably reached the maximum advance limit about 20 000 to 18 000 years B.P. The abundant signs of periglacial activity following its retreat indicate a severe environment, and this can be placed into a relative age sequence by studying the deposits affected by the ice-wedge casts. The ice-wedge casts cut the till, therefore they are post ice retreat. They are overlain and infilled by ablation gravel on the till surface and this is taken to indicate the formation of the ice-wedge casts within the till, followed by secondary infilling of the wedges by re-worked ablation gravel and sand contemporaneous with the later destruction of the permafrost table. At Penkridge the ice-wedge casts are overlain by glacio-fluvial outwash. The wedges were probably inactive at the time of deposition of the overlying sands, either because the permafrost table was depressed due to the proximity of the water carrying the outwash, or because the environment had warmed sufficiently for the wedges to become extinct. As the climate was known to be cold at the time of deposition of organic silts considerably younger than the glacio-fluvial deposits, it is presumed that permafrost was locally depressed at Penkridge whilst the terrace sands were laid down.

At Woodford Grange, involutions in deposits ante-dating the deposition of Upper Devensian glacio-fluvial outwash gravels suggests that a periglacial environment was in existence at the time of maximum ice advance. This is postulated since the underlying deposits have been truncated by Upper Devensian outwash, itself undisturbed by cryoturbation for the lowest 2 m. The Upper Devensian outwash is only cryoturbated in the uppermost 65 cm.

The relationship between the age of the wedges in the till at Four Ashes and the involutions in the underlying gravels is uncertain. All that can be said is that the permafrost table was at least 2.6 m higher during ice-wedge cast formation than it was when the involutions developed. It is likely that the ice-wedge casts developed first and the involutions took advantage of weak zones in the till for later movement. A second alternative is that both were more or less contemporaneous.

The latest age of active wedging can be postulated by analysis of faunal evidence in the field area and its environs within a framework of ^{14}C dates. A radiocarbon date at the base of an organic sequence at Stafford has given an age of 13 490 ± 375 years B.P. (Birm. 150) and the climate indicated by faunal evidence (Anne Morgan 1970) was one of arctic severity. However, by pollen zone Ic the environment had warmed sufficiently to allow the immigration of thermophilous species of Coleoptera (G. R. Coope, pers. comm. 1969) and under these conditions it is likely that permafrost would have disappeared.

Coleopterous faunas from Rodbaston and Pillaton peat moors (§ 10) indicate the presence of arctic stenotherms during pollen zone III, but although the re-introduction of periglacial conditions during this episode is known elsewhere in Britain, no periglacial features were found in the map region which relate to this period. Therefore it would appear that the periglacial features are Upper Devensian in age, probably contemporaneous with the maximum extent of the Main Irish Sea glacier, but also representing a period post-dating ice retreat from the Wolverhampton Line. The age of the start of ice retreat is unknown but active ice-wedge structures probably ceased to form in this area about 12 500 years B.P.

10. Upper Devensian organic deposits

(a) *Introduction*

A number of organic deposits which post-date the retreat of the Upper Devensian ice have been found in different parts of the map area. All are associated with drainage lines which were operational during ice retreat. Two sites have been found overlying glacio-fluvial gravels along the River Penk, and additional sites overlie the glacio-fluvial deposits in the Sow Valley at Stafford and Creswell. Two hollows, believed to be within meltwater drainage courses in the area south and east of Penkridge, contain peat moors. These hollows, together with the deposit at Stafford, provide organic sequences which are believed to have originated in the Upper Devensian and which have probably continued to accumulate through most of the Flandrian.

(b) *Organic deposits at Stafford*

Trial boreholes drilled for R. M. Douglas for a new relief road at Stafford revealed nearly 21 m of organic deposits lying within an elongate depression in glacio-fluvial gravels (figure 30). Several disturbed and undisturbed samples were obtained from different horizons in different boreholes in organic and inorganic sequences. Correlation between different boreholes was impossible but faunal (mainly insect) analyses were made from the lower sections of five boreholes and one radiocarbon sample was submitted from a basal sample at the contact of organic and inorganic deposits (depth 15.24 to 15.54 m) in borehole 12 (sample 25). The sample was only given an acid pretreatment due to the small amount of organic material recovered. The date obtained was 13 490 ± 375 years B.P. (Birm. 150). The geology and fauna of this site will be described in more detail elsewhere, but a brief synopsis of the Upper Devensian environment will be presented later in this section.

(c) Organic deposits near Pendeford Hall

Excavations for the gas pipeline crossing of the River Penk at 8930.0473 revealed the following sequence:

0–1.07 m	topsoil and sandy peat (thin sand layers in basal 23 cm)
1.07–1.83 m	white coarse sand and gravels (frequent Irish Sea erratics)
*1.83–1.98 m	slightly sandy, detritus peat
1.98–2.59 m	red silty sand, occasional small rounded gravel.

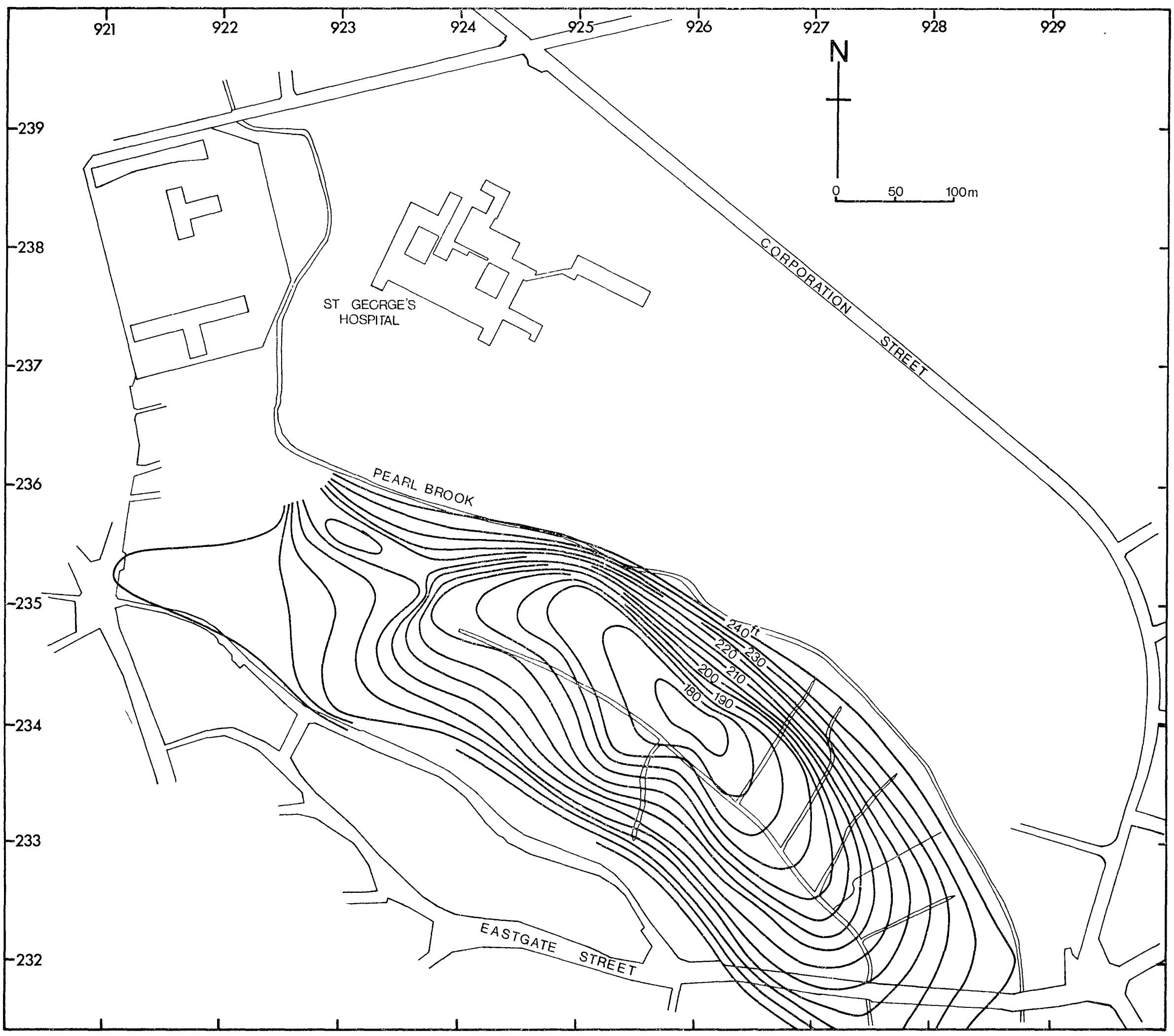


FIGURE 30. Upper Devensian and Flandrian deposits at Stafford.

The sample of peat (*) was brought back to the laboratory and the insect remains, plant fragments and pollen extracted. The insect fragments have been described by Anne Morgan (1970) and a general account of the environment will be given later in this section. The sample was not submitted for dating because of the possible contamination from rootlets from the upper peat bed.

(d) *Organic deposits at Penkridge Village*

Organic material was collected from seven separate localities within a sequence of fluviatile gravels bordering the River Penk at Penkridge. The organic material consisted of detrital peat revealed in discrete lenses in a sewerage pipeline trench between SJ 92446.14354 and 92353.14341. A radiocarbon date was obtained from one sample (locality 2) recovered at a depth of 2.44 to 2.79 m below the base of the topsoil. This sample provided a date of 11 580 ± 140 years B.P. (Birm. 118).

(e) *Organic deposits near Pillaton Hall*

In 1968 excavations for new field drains near Pillaton Farm revealed at least 1 m of peat resting upon coarse sand. In 1969 whilst mapping the same area I encountered peat in two adjacent fields. A pattern of 56 auger holes revealed a long depression trending northwest to southeast infilled in parts with approximately 3 m of peat. In July 1968 a pit was excavated at the site of maximum peat thickness and the following sequence encountered:

0– 50 cm	topsoil and peat
50–1.85 m	brown peat
1.85–2.00 m	pronounced 1–3 cm bands of medium to fine sands in peat
2.00–2.95 m	brown peat
2.95–3.00 m	fine to medium pink sand (no organic debris)

Peat samples were taken at 5 cm intervals from a depth of 50 cm. Sample 49 (depth 2.85 to 2.90 m) was submitted for ^{14}C dating and gave an age of 11 660 ± 250 years B.P. (Birm. 131).

(f) *Organic deposits near Rodbaston Hall*

In 1959 Shotton & Strachan published an account of the stratigraphy, fauna and flora of a peat moor near Rodbaston Hall approximately 2.5 km southwest of the Pillaton deposit. In 1966 peat samples were collected by P. J. Osborne and C. H. S. Sands from a pit excavated in the peat at 9229.1114. Samples were collected in 5 cm units to a depth of 2.55 m, and a bulk sample was taken from 2.55 to 2.70 m. Two samples from this deposit have been radiocarbon dated. The lowest sample with enough organic material to be dated (2.35 to 2.40 m) was submitted by Shotton & Strachan (1959, p. 4) and a date of 10 670 ± 130 years B.P. (Y 464) was obtained. A second sample (2.00 to 2.05 m) was submitted by A. C. Ashworth and gave a date of 10 300 ± 170 years B.P. (Birm. 92).

The Coleoptera extracted from this deposit are described by Ashworth (1969) and his findings will be briefly discussed in the following section.

(g) *General discussion*

The organic sequences deposited after the cessation of glacio-fluvial deposition in the Wolverhampton/Stafford area indicate that the environment was open and treeless with a somewhat cold and continental climate about 13 500 years ago. Beetle evidence from elsewhere in Britain (G. R. Coope & P. J. Osborne pers. comm. 1970) suggests a climatic amelioration starting about 1000 years later and the Coleoptera from certain sites at Penkridge and Pillaton indicate a climatic régime at 11 500 years B.P. with summer temperatures only a few degrees cooler than at present. The landscape during this Zone II episode was still fairly open although there may have been small stands of birch and willow. There is good evidence for deterioration of climate from about 10700 to 10300 years ago by the appearance of arctic stenotherms in the peat moors at Rodbaston and Pillaton, and there is a possibility that the cold fauna from Pendeford also belongs to this period. Following the Zone III cold, the environment once again warmed at the start of the Flandrian. Although organic sequences found elsewhere in the map region continue into the post-glacial, this account of the stratigraphy ends with the close of the Devensian, 10000 years ago.

I should like to express my sincere thanks to Professor F. W. Shotton, F.R.S., for suggesting and supervising this project which forms part of a thesis submitted to the Department of Geology, University of Birmingham. The research was undertaken with financial assistance from a N.E.R.C. research studentship, the Lapworth Scholarship and the Caroline Harrold Research Fund. Manuscript preparation was aided by the National Research Council of Canada. I gratefully acknowledge the help and suggestions given to me by Birmingham colleagues, particularly Dr G. R. Coope, Mr P. J. Osborne, Dr A. C. Ashworth and Mr R. E. G. Williams, and to the various authorities quoted in the text who provided identification of certain fossil groups.

This study would have been impossible without the assistance of innumerable farm owners throughout the region who have allowed, without exception, access to all requested areas. I would also like to thank all quarry owners, especially the Redland Group, L. H. Lowe and D. H. Cooper for access to numerous pits. Permission to examine gas pipe-line trenches was freely given by the West Midlands Gas Board and their contractors, Mitchell-Socea, Turiff and William Press. I am grateful to the Cannock and Seisdon Rural District Councils, Wolverhampton and Stafford Corporations, Staffordshire County Council and Staffordshire Highways Department for providing me with information from borehole records and giving permission to examine samples and visit temporary sections. Similarly, I acknowledge R. M. Douglas, W. V. Zinn, British Reinforced Concrete, the Goodyear Tyre Company and the Geological Survey for the provision of borehole data.

Finally, I thank my wife, Anne, who has examined the Coleoptera from hundreds of kilograms of organic material from different stratigraphic horizons in the area, and who has provided constant advice during the preparation of this paper.

References

Allies, J. 1840 On marine shells found in gravel at Worcester. *Br. Ass. Rep. for* 1839, p. 70.

Ashworth, A. C. 1969 The Late Quaternary coleopterous faunas from Rodbaston Hall, Staffordshire and Red Moss, Lancashire. Unpublished Ph.D. thesis, University of Birmingham.

Barton, M. E. 1960 The Pleistocene geology of the country around Bromsgrove. *Proc. geol. Ass.* **71**, pt. 2, 139–155.

Boulton, G. S. 1967 Studies of modern glacial sedimentation applied to the Pleistocene. Unpublished Ph.D. thesis, University of Birmingham.

Boulton, G. S. & Worsley, P. 1965 Late Weichselian glaciation in the Cheshire–Shropshire Basin. *Nature, Lond.* **207**, 704–706.

Boulton, W. S. 1916 An esker near Kingswinford, south Staffordshire. *Proc. Bgham nat. Hist. phil. Soc.* **14**, pt. 1. 29–39.

Boulton, W. S. 1917 Mammalian remains in the glacial gravels at Stourbridge. *Proc. Bgham nat. Hist. phil. Soc.* **14**, pt. 2, 107–112.

Coope, G. R. 1959 A Late Pleistocene insect fauna from Chelford, Cheshire. *Proc. R. Soc. Lond.* B **151**, 70–86.

Coope, G. R. 1962 A Pleistocene coleopterous fauna with arctic affinities from Fladbury, Worcestershire. *Q. Jl geol. Soc. Lond.* **118**, 103–123.

Coope, G. R. & Sands, C. H. S. 1966 Insect faunas of the Last Glaciation from the Tame Valley, Warwickshire. *Proc. R. Soc. Lond.* B **165**, 389–412.

Coope, G. R., Shotton, F. W. & Strachan, I. 1961 A Late Pleistocene fauna and flora from Upton Warren, Worcestershire. *Phil. Trans. R. Soc. Lond.* B **244**, no. 714, 379–421.

Dewey, H. 1916 Glacial, Staffordshire. In *Summary of progress of geol. surv. Great Britain* 1915, pp. 16–17.

Eastwood, T., Whitehead, T. H. & Robertson, T. 1925 The geology of the country around Birmingham. *Mem. geol. Surv. U.K.*, **168**.

Embleton, C. & King, A. M. 1968 *Glacial and periglacial geomorphology*. London: Edward Arnold.

Evans, W. B., Wilson, A. A., Taylor, B. J. & Price, D. 1968 Geology of the country around Macclesfield, Congleton, Crewe and Middlewich. *Mem. geol. Surv. U.K.* **110**.

Kelly, M. R. 1964 The Middle Pleistocene of north Birmingham. *Phil. Trans. R. Soc. Lond.* B **274**, 553–592.

Lister, W. 1862 On the drift containing recent shells, in the neighbourhood of Wolverhampton. *Q. Jl geol. Soc. Lond.* **18**, pt. 1, 159–162.

Mackintosh, D. 1879 Results of a systematic survey, in 1878, of the directions and limits of dispersion, mode of occurrence, and relation to drift-deposits of the erratic blocks or boulders of the west of England and east of Wales, including a revision of many years previous observations. *Q. Jl geol. Soc. Lond.* **35**, 425–455.

Mantle, H. G. 1896 The glacial boulders east of Cannock Chase. *Proc. Bgham nat. Hist. phil. Soc.* **10**, pt. 2, 33–72.

Mitchell, G. F. 1960 The Pleistocene history of the Irish Sea. *Advmt Sci., Lond.* **17**, 313–325.

Mitchell, G. F. 1965 The Quaternary deposits of the Ballaugh and Kirkmichael districts, Isle of Man. *Q. Jl geol. Soc. Lond.* **121**, 259–381.

Morgan, Anne 1970 Weichselian insect faunas of the English Midlands. Unpublished Ph.D. thesis, University of Birmingham.

Morgan, A. V. 1969*a* Intraformational periglacial structures in the Nose Hill gravels and sands, Calgary, Alberta, Canada. *Jl Geol.* **77**, 358–364.

Morgan, A. V. 1969*b* Lithology of the Erratics Train in the Calgary area. In *Geomorphology* (ed. J. G. Nelson and M. J. Chambers), pp. 165–182. Toronto: Methuen.

Morgan, A. V. 1970*a* Late Weichselian potholes near Wolverhampton, England. *Jl Glaciol.* **9**, 125–133.

Morgan, A. V. 1970*b* The glacial geology of the area north and west of Wolverhampton. Unpublished Ph.D. thesis, University of Birmingham.

Morgan, A. V. 1971*a* Engineering problems caused by fossil permafrost features in the English Midlands. *Q. Jl Engin. Geol.* **4**, no. 2, 111–114.

Morgan, A. V. 1971*b* Polygonal patterned ground of Late Weichselian age in the area north and west of Wolverhampton, England. *Geogr. Annlr*, **53** A, nos. 3–4, 146–156.

Murchison, R. I. 1836 On the gravel and alluvia of South Wales and Siluria, as distinguished from a northern drift covering Lancashire, Cheshire, North Salop, and parts of Worcester and Gloucester. *Proc. geol. Soc. Lond.* **2**, 230–233.

Penny, L. F. 1964 A review of the Last Glaciation in Great Britain. *Proc. Yorks. geol. Soc.* **34**, 387–411.

Péwé, T. L., Church, R. E. & Andresen, M. J. 1969 Origin and paleoclimatic significance of large-scale patterned ground in the Donelly Dome Area, Alaska. *Geol. Soc. Am. Spec. Pap.* **103**.

Pickering, R. 1957 The Pleistocene geology of the south Birmingham area. *Q. Jl geol. Soc. Lond.* **113**, 223–237.

Pocock, T. I. 1922 Terraces and glacial drifts of the Severn Valley. *Z. Gletscherk.* **12**, 123 (cited in Wills, L. J. 1938).

Poole, E. G. 1966 Late Weichselian Glaciation in the Cheshire–Shropshire basin. *Nature, Lond.* **211**, 507.

Poole, E. G. 1968 Age of the Upper Boulder Clay Glaciation in the Midlands. *Nature, Lond.* **217**, 1137–1138.

Poole, E. G. & Whiteman, A. J. 1961 The glacial drifts of the southern part of the Shropshire–Cheshire basin. *Q. Jl geol. Soc. Lond.* **117**, 91–130.

Poole, E. G. & Whiteman, A. J. 1966 Geology of the country around Nantwich and Whitchurch. *Mem. geol. Surv. U.K.* **122**.

Raw, F. 1913 On the occurrence of a wind-worn rock surface at Lilleshall Hill, Salop, and of wind-worn stones there and elsewhere. *Br. Ass. Rep. for* 1913, pp. 493–494.

Raw, F. 1934 Triassic and Pleistocene surfaces on some Leicestershire igneous rocks. *Geol. Mag.* **71**, 23–31.

Shotton, F. W. 1929 The geology of the country around Kenilworth (Warwickshire). *Q. Jl geol. Soc. Lond.* **85**, 203–220.

Shotton, F. W. 1953 The Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing upon the topographic development of the Midlands. *Phil. Trans. R. Soc. Lond.* B **237**, 209–260.

Shotton, F. W. 1960 Large scale patterned ground in the valley of the Worcestershire Avon. *Geol. Mag.* **97**, 404–408.

Shotton, F. W. 1967 Age of the Irish Sea Glaciation of the Midlands. *Nature, Lond.* **215**, 1366.

Shotton, F. W. & Strachan, I. 1959 The investigation of a peat moor at Rodbaston, Penkridge, Staffordshire. *Q. Jl geol. Soc. Lond.* **115**, 155–157.

Shotton, F. W. & West, R. G. 1969 Stratigraphical table of the British Quaternary. *Proc. geol. Soc. Lond.* no. 1656, 155–157.

Shumski, P. A. 1955 *Principles of structural geology*. Moscow.

Simpson, I. M. 1959 The Pleistocene succession in the Stockport and south Manchester area. *Q. Jl geol. Soc. Lond.* **115**, 107–121.

Simpson, I. M. & West, R. G. 1958 On the stratigraphy and palaeobotany of a Late Pleistocene organic deposit at Chelford, Cheshire. *New Phytol.* **57**, 239–250.

Swinnerton, H. H. 1914 Periods of dreikanter formation in south Notts. *Geol. Mag.* **1**, 208–211.

Taylor, B. J., Price, R. H. & Trotter, F. M. 1963 Geology of the country around Stockport and Knutsford. *Mem. Geol. Surv. U.K.* **98**.

Thompson, D. B. & Worsley, P. 1967 Periods of ventifact formation in the Permo-Triassic and Quaternary of the northeast Cheshire Basin. *Mercian Geol.* **2**, no. 3, 279–298.

Tomlinson, M. E. 1925 River terraces of the lower valley of the Warwickshire Avon. *Q. Jl geol. Soc. Lond.* **81**, 137–163.

Tomlinson, M. E. 1929 The drifts of the Stour-Evenlode Watershed. *Proc. Bgham nat. Hist. phil. Soc.* **15**, 157–196.

Tomlinson, M. E. 1935 The superficial deposits of the country north of Stratford on Avon. *Q. Jl geol. Soc. Lond.* **91**, 423–462.

Trimmer, J. 1835 On the occurrence near Shrewsbury of marine shells of existing species in transported gravel and sand resting upon a peat bog which contains embedded trees. *Proc. geol. Soc. Lond.* **2**, 200.

Vogel, J. C. & Zagwijn, W. H. 1967 Groningen radiocarbon dates VI. *Radiocarbon* **9**, 63–106.

Whitehead, T. H., Dixon, E. E. L., Pocock, R. W., Robertson, T. & Cantrill, T. C. 1927 The country between Stafford and Market Drayton. *Mem. geol. Surv. U.K.* **139**.

Whitehead, T. H., Robertson, T., Pocock, R. W. & Dixon, E. E. L. 1928 The country between Wolverhampton and Oakengates. *Mem. geol. Surv. U.K.* **153**.

Whitehead, T. H. & Pocock, R. W. 1947 Dudley and Bridgenorth. *Mem. geol. Surv. U.K.* **167**.

Wills, L. J. 1910 On the occurrence of wind-worn pebbles in high-level gravels in Worcestershire. *Geol. Mag.* **7**, 299–302.

Wills, L. J. 1924 The development of the Severn Valley in the neighbourhood of Iron Bridge and Bridgnorth. *Q. Jl geol. Soc. Lond.* **80**, 274–314.

Wills, L. J. 1937 The Pleistocene history of the West Midlands: *Rep. Br. Ass.* (*Nottingham*), pp. 71–94.

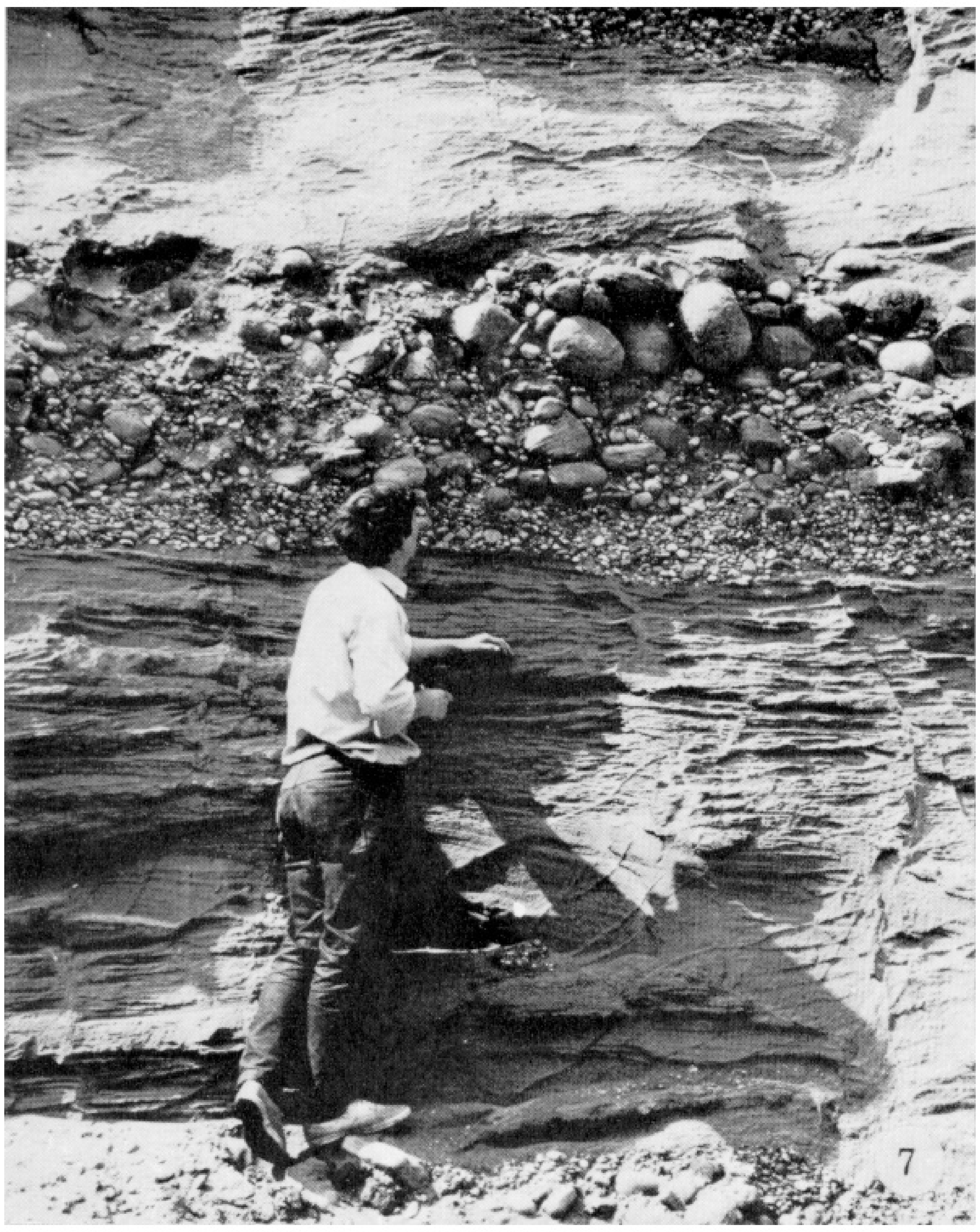
Wills, L. J. 1938 The Pleistocene development of the Severn from Bridgnorth to the sea. *Q. Jl geol. Soc. Lond.* **94**, 161–242.

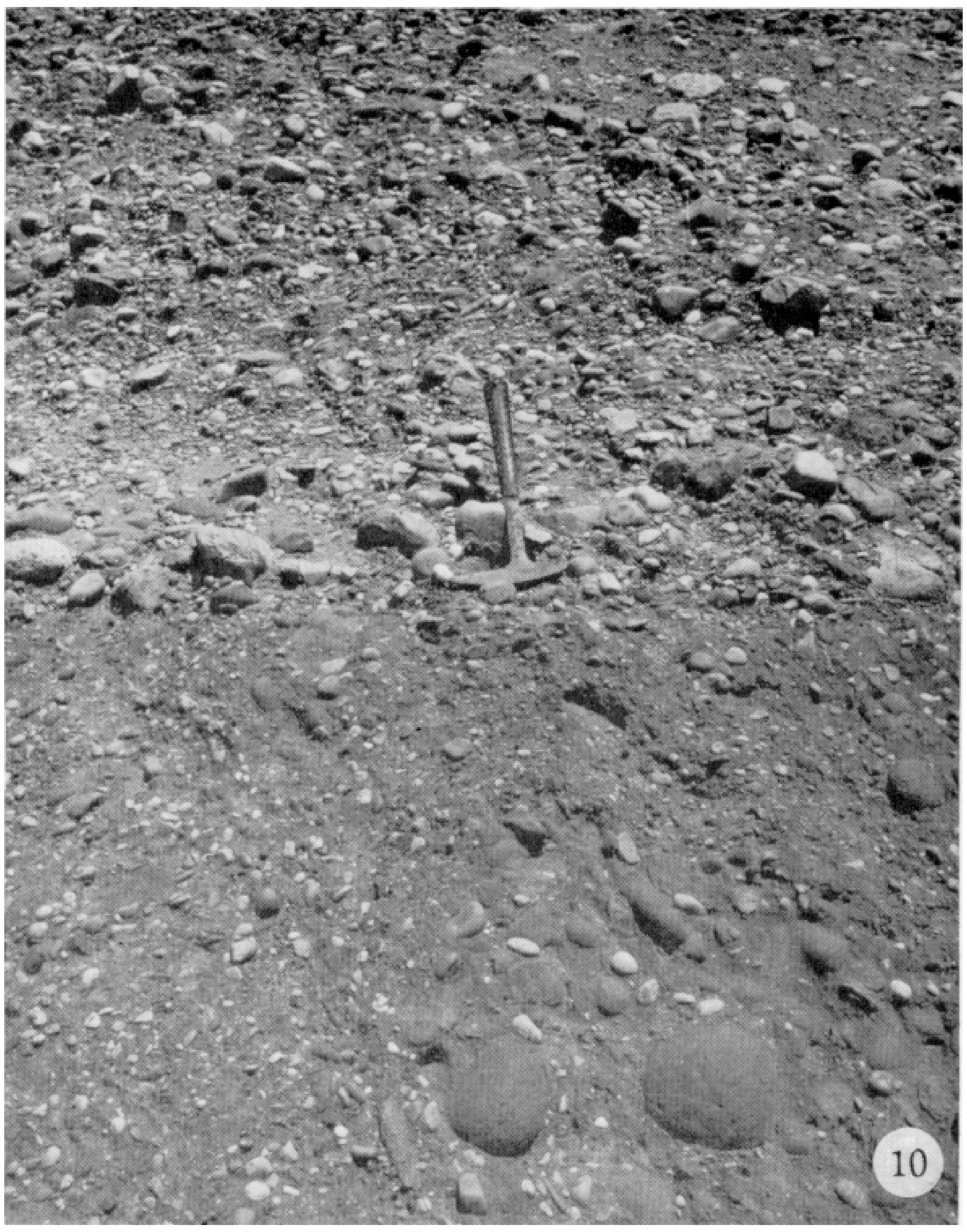
Woodward, C. J. 1870 Report of the progress made in mapping the boulders. *Proc. Bgham nat. Hist. microsc. Soc.* pt. 2, 57–58.

Worsley, P. 1966*a* Some Weichselian fossil frost wedges from East Cheshire. *Mercian Geol.* **1**, 357–365.

Worsley, P. 1966*b* Fossil frost wedge polygons at Congleton, Cheshire, England. *Geogr. Annlr*, **48**A, 211–219.

Yates, E. M. & Moseley, F. 1967 A contribution to the glacial geomorphology of the Cheshire Plain. *Inst. Br. Geog.* **42**, 107–125.





Figures 7 to 10. For legends see facing page

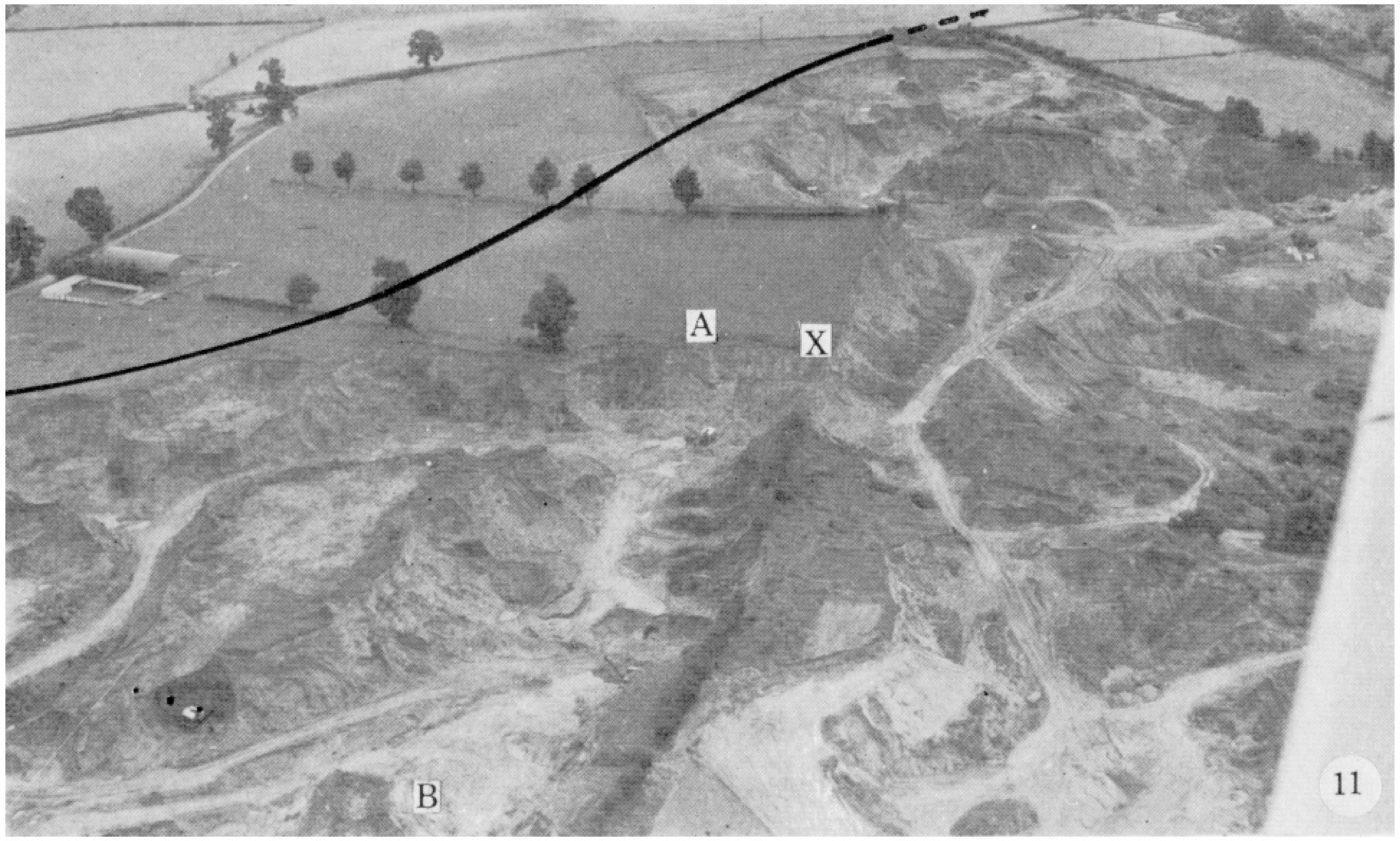
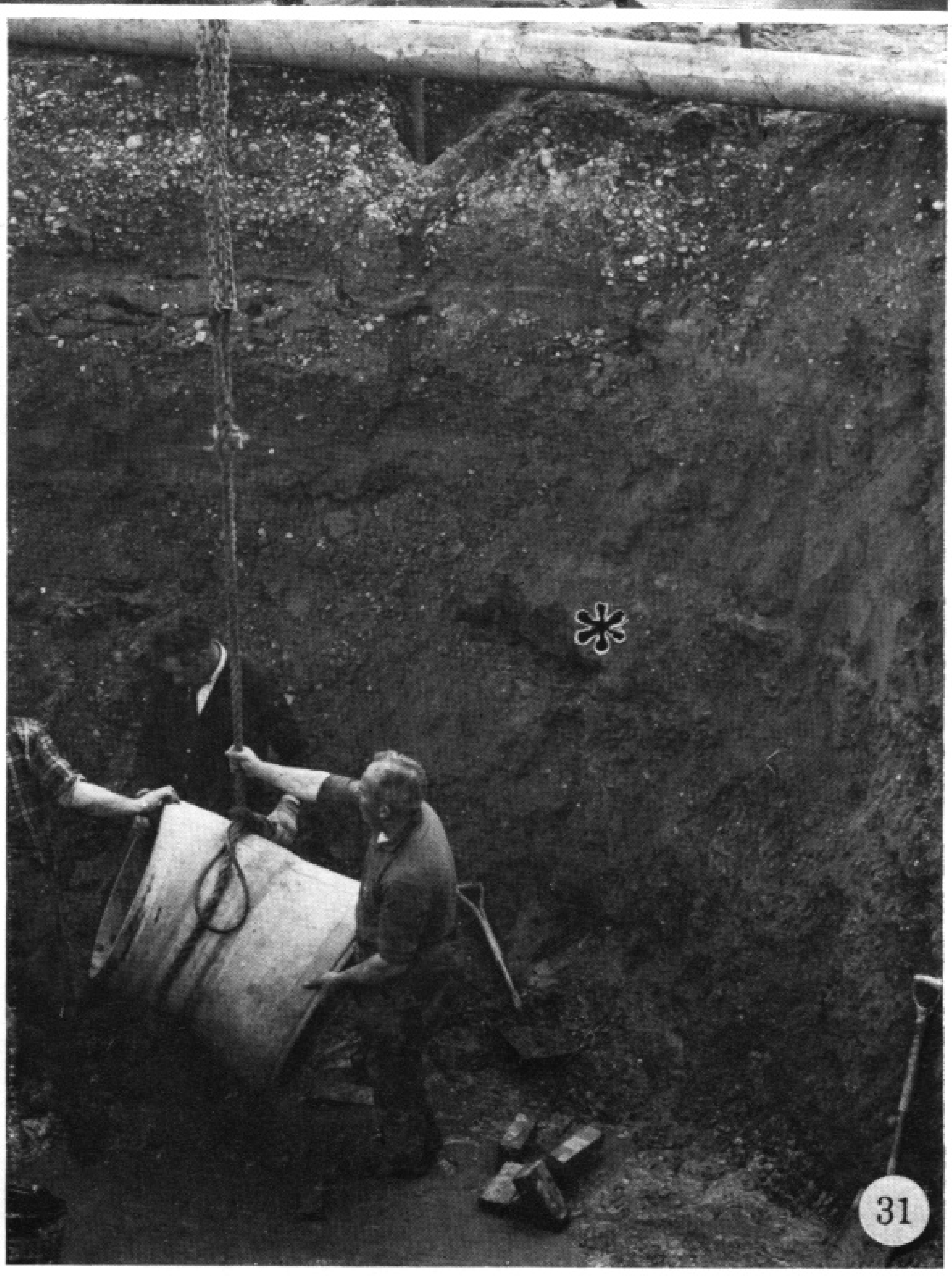


FIGURE 11. View east toward Trysull. Approximate position of northern edge of Seisdon–Stourbridge Channel lined in black. Sections A and B marked (see figures 12 and 13, and 14 and 15, this plate). Corner X at the junction of Lowe's Pit and Cooper's Pit is also marked. August 1969.

FIGURE 14. Section B, Lowe's Pit, showing the relationship between the interglacial deposits and the underlying Trysull sands and gravels, view looking north; July 1969.

FIGURE 15. Section B, Lowe's Pit, illustrating the collapsed nature of the Trysull sands and gravels underlying the interglacial organic sequence. View toward the south-west, February 1970.



FIGURES 23, 26, 28 AND 31. For legends see facing page