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Edward Marshall Yates and Frank Moseley

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GLACIAL LAKES AND SPILLWAYS IN THE VICINITY OF MADELEY, NORTH STAFFORDSHIRE

BY EDWARD MARSHALL YATES, M.SC. PH.D., AND FRANK MOSELEY, PH.D. F.G.S.

Read 9 October 1957

SUMMARY

Captures by the River Weaver head-streams of the upper Trent drainage have breached the west-facing feature that the North Staffordshire Coalfield presents to the Cheshire plain. As the Irish Sea Ice retreated from the coalfield the gaps thus formed were linked in a spillway system through which the melt-waters impounded in lakes against the high ground were discharged into the Trent. The deepening of the channels due to the passage of the melt-water, plus the moraine deposits, has prevented the drainage from recovering completely its former course.

I. INTRODUCTION

The major glacial features of the Cheshire plain and the adjacent western flanks of the Pennines have been described and interpreted by a number of investigators. Particular attention has been paid to the evidence for periglacial lakes and spillways formed during the retreat of the Irish Sea Ice from the highland periphery. For example, there is the study by Jowett (1914) in East Lancashire, and that by Wills (1924) in North Shropshire. In the present paper a more detailed analysis is given of a small part of the intervening tract, which falls largely within North Staffordshire (Fig. 1).

The earliest reference to the glaciology of this area and its immediate vicinity was by Carvill Lewis (1894). His interpretation of certain deposits as morainic (later to be discussed) was ultimately supported by the Geological Survey. The first comprehensive work was the production of the Geological Survey map, No. 123, New Series, and memoir (Gibson & Wedd 1902, 1905, 1925). The distribution of the superficial deposits (mapped largely by C. B. Wedd) was noted in detail, and in the third edition the existence of glacial lakes and attendant phenomena was recorded. In 1920 Barke discussed some aspects of the evolution of several streams between the Dean Brook and Whitmore, whilst Jowett & Charlesworth (1929) also made a special reference to the title area in their paper on the Derbyshire dome. The most recent work is that of Yates
Fig. 1.—Relief of the Craddocks–Whitmore system. Dotted line indicates the area of the geological map, Fig. 3. Contour heights in feet. Inset, top left, shows the same area in relation to the South-East Cheshire plain and the Midland Gate, with land over 100 metres stippled.
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(1955) in which a marginal system of drainage near Kidsgrove, a little to the north, is described.

Several geological and morphological features of the area are of significance to the study of the glaciology of any part of it (Fig. 1). In the west the low-lying Cheshire plain is covered by thick deposits of drift, which for the most part conceal the underlying Trias. To the east of this, and almost coincident with the edge of the Carboniferous outcrop, there is an abrupt rise to higher ground which in the south is relatively drift-free. A south-western extension of this higher ground is formed of Bunter Sandstone. The area is crossed by the main N.-S. and E.-W. watersheds of England. In the west and north-west, drainage is westwards towards the River Weaver and the Irish Sea, in the south-west it is towards the Severn and in the east there is the NNW.–SSE. drainage of the Trent and its tributaries. There are several gaps across the watersheds leading into the Trent system which, it has been suggested, have been caused or emphasized by the action of glacial melt-waters. These include the deep trough of Rudyard Lake, the Biddulph valley, and the Kidsgrove trough, the col at Woodlane, the Craddocks–Whitmore system of basins and troughs, and the col at Maer (Gibson & Wedd 1925, p. 74; Jowett & Charlesworth 1929, p. 307; Yates 1955, p. 413). This paper is concerned with the Craddocks–Whitmore system, the lowest of those cited.

II. THE MORPHOLOGY OF THE CRADDOCKS–WHITMORE SYSTEM OF BASINS AND TROUGHES

The Craddocks–Whitmore system consists of a series of flat-bottomed basins or depressions, with linking troughs, channels and cols (Fig. 1). It extends some nine miles from north to south and is never higher than 400 feet O.D., although the adjacent uplands rise to more than 600 feet O.D. The trough may be divided into several units, which will be described in turn from south to north.

(a) The Whitmore Trough

The trough at its maximum height of 384 feet, at Whitmore Station, is an imperceptible watershed which is part of the divide between the North Sea and Irish Sea drainage. South-east of here, outside the area being considered in detail, the trough makes a double bend before it is joined by the Meece Brook. South-west of Whitmore Station, on the western side of the trough, the watershed (but here to the River Tern) is breached by an irregular col, the lowest point of which is 465 feet O.D. The trough extends for three miles to the north, averaging a quarter of a mile in width and falling gently in altitude until, near the NE.–SW. railway-line (7843), it is 365 feet O.D. A section here (Fig. 2) shows the flat peaty floor, virtually without drainage, with a break of slope in the sides at approximately 380 feet (about the same as the maximum height of the watershed described above). Near its northern end the Whitmore trough is joined from the west by a broad valley, occupied by the minute River Lea. This valley is open at its western end, where an ill-defined watershed divides it from the Tern drainage.

1 National Grid reference, as used on Figs. 1 and 3.
North of the Lea junction the trough opens out into a broad basin approximately one and a half miles from north to south and the same from east to west. It is steep-sided and has a flat sandy floor at about 360 feet O.D., rising slightly towards the margins. The flat area has been a little dissected by the River Lea, which leaves by a small gorge at 340 feet O.D. in the north-west, and by a tributary of the Hazeley Brook. This tributary occupies a flat-bottomed valley, which starts near Madeley Station (777440) and becomes deeper to the north until at the Fish Pond (780456) it is 30 feet deep and just over 100 yards wide. In addition to these two northern exits there is between them (between Higher Thornhill and Brynwood) a N.-S. drift-filled col at just over 400 feet O.D.

In the west, east, and north-east the sides of the basin are similar to those of the Whitmore trough and the main break of slope is usually at about 380 feet O.D. For example, the break of slope is at 374 feet near Madeley Heath (781459), where a flat area is followed by a steep rise to 500 feet O.D., whilst on the west side of the basin there is a similar break of slope at 380 feet O.D. followed above by a gentle rise (772435). A little higher on the same side (at 400 feet), however, there is an abrupt horizontal feature of unknown origin, fashioned from Keele marl along most of its length but of Keele sandstone at its southern end, and best described as a narrow ledge.

(c) The Valley of Checkley Brook

Checkley Brook rises in Craddocks Moss and flows south through a narrow gorge with a very youthful appearance; this gorge, according to the Geological Survey maps, follows the faulted junction of Newcastle Beds and the Black Band Series. In the extreme south, where the floor of the gorge is at 320 feet O.D., a narrow ledge above this height continues the flat and break of slope from the Madeley basin and terminates here (781463). Downstream from this point the valley widens as the Checkley Brook joins the Hazeley Brook, turns west, and becomes con-
striated again as it breaks through the outcrop of the Bunter Sandstone near Heighley. North of Heighley and east of the Bunter escarpment, there is a drift-filled depression just below 400 ft. O.D. (777471) which is in line with the one mentioned earlier (770459).

(d) Craddocks Moss

Craddocks Moss is a flat peaty basin, about half a mile in each direction. There is a break of slope at 355 feet O.D. in the east, south and north-west, above which the walls rise steeply. The break of slope is absent in the extreme west where, at Cooksgate (770483), there is a drift-filled depression only a few feet higher than the flat. This depression leads down to the Cheshire plain near Betley. To the north, the Craddocks Moss basin narrows to a steep-sided flat-bottomed trough which leads across an imperceptible watershed into the Dean Brook basin.

(e) The Dean Brook Basin

This basin, of dimensions half a mile by a mile, is crossed by the Dean Brook, which makes its western exit through a drift-filled gap in the Bunter Sandstone comparable with that at Cooksgate, except that at Cooksgate there is no longer a stream. The edge of the flat area, as in the other basins, is usually marked by an abrupt steepening of slope. This break is at the same height as that around Craddocks Moss. Towards the north, the Dean Brook basin rises to a lip or rim at 385 feet O.D. west of Audley (792509), beyond which the ground falls once more in a north-westerly direction towards the Cheshire plain. This feature forms the northern limit of the Craddocks-Whitmore system.

In all, therefore, this system of basins and troughs extends nine miles along the eastern edge of the main boulder-clay sheet of the Cheshire plain, largely between the escarpment of the Bunter Sandstone and the western edge of the coalfield. Through the cols and water gaps on its western side it provides ample outlets from the boulder-clay sheet to the Meece Brook and Trent valleys. The whole system suggests formation by an ice-margin drainage, but before considering origins it is necessary to look at the stratigraphical evidence.

III. Quaternary Deposits

The deposits to be described consist of till, sand and gravel, stoneless clays and silts (including alluvium), and peat. They are mainly concentrated in the basins and troughs of the Craddocks-Whitmore system, where they form an almost complete cover (Fig. 3). The higher ground immediately west and east has only thin and patchy drift deposits. Still farther to the west, there are the thick drifts of the Cheshire plain; these will not be described in detail.

(a) Till

The till is usually red, yellow or brown with a fine-grained but sometimes gravelly base. It usually contains numerous pebbles and boulders, mainly of Bunter quartzite and Coal Measures sandstone, with a sprinkling of rocks of northern origin, including granite, rhyolite, andesite, tuff, Lower Palaeozoic "grits" and flint (see also Gibson & Wedd 1925,
SUPERFICIAL DEPOSITS

- Peat
- Stoneless clay
- Micaceous and sandy clay (alluvium etc.)
- Hillwash and solifluxion clays derived mainly from Upper Carboniferous marl (m) and from till (t) grading into till
- Till (boulder clay)
- Sandy till
- Glacial sand
- Sand derived mainly from Bunter Sand by hillwash etc.

SEQUENCES OF SUPERFICIAL DEPOSITS ARE ILLUSTRATED AS BELOW (DEPTHS TO BASE OF DEPOSIT BELOW THE SURFACE IN FEET)

P - 3 (peat)
C - 5 (stoneless clay)
S - 20 (sand)
T - 30 (till)

SOLID FORMATIONS

B - Bunter Sandstone
KS - Keele Sandstone
KM - Keele Marl
N - Newcastle Beds
EM - Etruria Marl
CM - Productive Coal Measures

FIG. 3.—Geological map of the Craddocks-Whitmore system.
There are occasional larger erratics, several feet in diameter; for instance, the andesite near Craddocks Moss (789479) and the granite north of Madeley (769459). These characteristics suggest that the main source-rocks of the till were local red marls and, to a lesser degree, the Bunter Sandstone.

In this area till appears to rest directly on solid formations and the alternations of till and sand common on the Cheshire plain are not found. The only known exception to this occurs east of Hey House (779433) where a borehole has revealed the following sequence:

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stones and clay</td>
<td>3</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>23</td>
</tr>
<tr>
<td>Blue clay, gravelly in part</td>
<td>12</td>
</tr>
<tr>
<td>Sand</td>
<td>23</td>
</tr>
<tr>
<td>Brown clay and gravel</td>
<td>3</td>
</tr>
<tr>
<td>Red marl</td>
<td></td>
</tr>
</tbody>
</table>

The two most extensive areas of till are south of Craddocks Moss and north of Madeley, where it forms undulating hillocks. An isolated hillock protrudes through the sands and stoneless clay south of Madeley, near Hey House, and there is a certain amount of till along the flanks of the basins and troughs. The higher ground on either side of the basins and troughs usually has a veneer of till, but rarely is it sufficiently thick to warrant representation on geological maps, although the wide variety of erratics noted above can usually be obtained from any ploughed field.

(b) Sand and Gravel

Most of these deposits, which are largely attributable to glacial outwash, are medium to coarse sands. There are also occasional gravels, containing pebbles of similar type to those in the boulder-clay, with Bunter quartzite predominating. Within the Craddocks–Whitmore system the sands, with minor exceptions, form flat-topped spreads and rest either on solid formations or on till. Farther west, however, and particularly along the Woore and Wrinehill moraines (Fig. 1), the sand often forms steep hummocks and may be interbedded with till, as already noted. The largest deposit of sand in the system is around Madeley, where a level spread occupies almost all of the basin. It extends north to the Checkley Brook and south, beneath clay and peat, to Whitmore, where temporary sections showed a level bedding consistent with a water-lain deposit. It is known from records held by the Geological Survey to be 37 feet thick near Little Madeley (778454), where it rests on clay, 23 feet thick near Hey House with a further deposit below the clay (see above), and 20 feet thick at Whitmore Station, where it rests on Bunter Sandstone. A similar expanse underlies the peat of Craddocks Moss, rising slightly to the south-south-east, west and north to emerge from beneath the peat. In addition to these sand spreads, there are occasional flat-topped ridges of sand. These are at the margins of the basins and their tops are at the same heights as the breaks of slope described previously. Notable examples are those at Cooksgate in Craddocks Moss (773482), on the eastern side of the trough immediately north of Craddocks Moss.

1 The exact location of this borehole is not certain but the Geological Survey consider this to be the most likely site.
(780489), south of Madeley Heath (788446) and at Madeley Park Farm (788414).

Further sand deposits occur on the lower parts of some of the steepish slopes rising from the basins and connecting valleys. These, like the sand already described, are interpreted as glacial outwash, with the exception of the sand on some slopes below Bunter Sandstone escarpments, where it is likely to be due partly to recent downwash.

(c) Stoneless Clay and Silt

These deposits range from highly plastic calcareous clays to silty and sandy clays (including alluvium). They can only be examined by augering.

(i) Plastic clay.—Deposits have been located south of Madeley (780430), near the confluence of the Checkley and Hazelcy brooks (778463), at Craddocks Moss (779489) and south of the Dean Brook (782498). They usually rest on sand and are considered here to be lacustrine. The most extensive deposit is that south of Madeley. This occupies an area approximately one mile from north to south and a quarter of a mile from east to west and has a thickness of five feet in the centre. It is mostly a very fine-grained, grey, plastic clay, and is highly calcareous in some parts, due to an abundance of Chara. Near the centre of the deposit the clay is saturated. Elsewhere it is quite stiff, and near part of the western and eastern margins becomes silty, as it passes laterally into alluvium. The clay is everywhere underlain by sand and the southern part of the deposit is overlain by several feet of peat (Fig. 2). It thins out into the Whitmore trough in the south, where peat rests directly on sand. To the north the underlying sand is at the surface, and if the clay was ever present it has since been eroded.

Samples from the base and top of this clay, taken where it attains its maximum thickness of just over five feet (780425), were submitted to Dr. D. Walker of the Sub-department of Quaternary Research, Cambridge, who kindly allows us to quote his report:

The lower of the two samples gave the following results (frequencies are expressed as percentages of a total of 100 tree-pollen grains, in this instance Betula, Pinus and Alnus):

<table>
<thead>
<tr>
<th>Pollen Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betula</td>
<td>88</td>
</tr>
<tr>
<td>Pinus</td>
<td>9</td>
</tr>
<tr>
<td>Alnus</td>
<td>3</td>
</tr>
<tr>
<td>Corylus</td>
<td>9</td>
</tr>
<tr>
<td>Salix</td>
<td>16</td>
</tr>
<tr>
<td>Juniperus</td>
<td>3</td>
</tr>
<tr>
<td>Gramineae</td>
<td>66</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>87</td>
</tr>
<tr>
<td>Artemisia</td>
<td>7</td>
</tr>
<tr>
<td>Helianthemum</td>
<td>2</td>
</tr>
<tr>
<td>Galium</td>
<td>1</td>
</tr>
<tr>
<td>Rumex</td>
<td>3</td>
</tr>
<tr>
<td>Thalictrum</td>
<td>5</td>
</tr>
<tr>
<td>Filipendula</td>
<td>10</td>
</tr>
<tr>
<td>Plantago major</td>
<td>1</td>
</tr>
<tr>
<td>Compositae</td>
<td>2</td>
</tr>
<tr>
<td>Umbelliferae</td>
<td>1</td>
</tr>
<tr>
<td>Rosacea</td>
<td>1</td>
</tr>
<tr>
<td>Empetrum</td>
<td>2</td>
</tr>
<tr>
<td>Polyopodium</td>
<td>2</td>
</tr>
<tr>
<td>Filicales</td>
<td>33</td>
</tr>
<tr>
<td>Sphagnum</td>
<td>1</td>
</tr>
<tr>
<td>Lycopodium</td>
<td>1</td>
</tr>
<tr>
<td>clavatum</td>
<td>1</td>
</tr>
</tbody>
</table>

The upper sample contained too few pollen grains to allow a proper analysis, but the following types were recorded: Betula, Pinus, Salix, Gramineae, Cyperaceae, Filipendula, Rumex, Thalictrum, Polemonium caeruleum, and Filicales.

The absence of warmth-demanding trees from the analysis of the lower sample and the low Alnus values, together with the very considerable total frequency of pollen of terrestrial herbs, indicate the Pre-boreal age of the material. It is not possible from the results of one analysis to refer it to a particular zone, but it certainly falls into one of the zones I to IV, i.e. the Late-glacial or Pre-boreal.

None of the pollen types recorded from the upper sample conflict with this conclusion, and the occurrence of Polemonium caeruleum is particularly interesting.
The plastic clays near the Checkley–Hazeley Brook confluence are interesting in so far as they occur along the bed of a large, long-drained, artificial or partly artificial lake. This particular lithology is therefore definitely lacustrine, although very recent. At Craddocks Moss peat usually rests directly on sand. However, an isolated pocket of highly plastic, non-calcareous, fine-grained clay has been found between the peat and the sand; it is two feet thick. There are further limited deposits south of Dean Brook, likewise passing laterally (and northward) into alluvium.

(ii) Micaceous and sandy clay and silt.—This material lacks any marked degree of plasticity. Most of the alluvium falls into this category and occurs along the rather limited flood-plains of several of the streams: for example, in the upper part of the Lea valley and immediately beside the Dean Brook.

(d) Unclassified Clays

Many of the gentler slopes which characterize the ground between the flat bottoms of the basins and troughs and the steeper slopes above are occupied by stiff red-to-yellow silty clay with occasional pebbles of foreign erratics (Fig. 2). Most of this clay is designated boulder-clay on the existing Geological Survey maps. It is, however, significant that it occurs only below slopes on which the outcrops are dominantly Keele and Etruria marl, commonly with a veneer of till. Moreover, there is a gradation from deposits which are lithologically till to clay which strongly resembles weathered Etruria and Keele marl. These considerations, together with the morphological expression, lead to the conclusion that the clay has probably been formed partly by local hillwash and perhaps partly by solifluxion; some occurrences may be very little out of place.

(e) Peat

The two principal areas underlain by peat are south of Madeley and at Craddocks Moss. The former is a narrow strip extending for one and a half miles along the Whitmore trough, rising gradually from 365 feet O.D. in the north to 380 feet O.D. in the south. It is usually about five feet thick, resting on sand in the south and on stoneless clay in the north. The peat of Craddocks Moss occupies an area about half a mile in each direction. It maintains a constant thickness of ten feet over most of this area and usually rests on sand, save for the occurrence of the isolated pocket of plastic clay noted above.

IV. SEQUENCE OF EVENTS

Having considered the morphology and stratigraphy of the complex of channels and depressions there now remains the problem of their origin and relations. The more important features described in the preceding pages appear to be due largely to glacial modification of a pre-glacial drainage system. The probable chronological sequence of events will be discussed below.

(a) Pre-glacial Drainage

A first impression suggests that the Whitmore–Craddocks system has been almost entirely eroded by melt-waters and diverted streams of the
last glaciation, but this leaves many features unexplained. The Whitmore trough, for instance, is of the order of 150 feet deep, and the deposits and morphology of the Madeley basin and surrounding country show that it could not possibly have been excavated by melt-waters of the last glaciation, although they certainly made use of it. There are also the two drift-filled N.–S. depressions between Madeley and Craddocks Moss to be explained (between Thornhill and Bryn Wood and to the east of Heighley), whilst the trough north of Craddocks, like the Whitmore trough, appears to be too deep to have been eroded during the last phase of marginal drainage.

It is to be noted, however, that the Whitmore trough at its highest point, the drift-filled depressions between Madeley and Craddocks Moss, and the trough north-east of the Dean Brook, all of which are watersheds, are of similar heights at a little less than 400 feet, and that they are much stronger features than the valleys of the present west-flowing streams. Alternatively, therefore, it is suggested that these troughs and depressions are the relics of a former pre-glacial N.–S. valley (a former more extensive Meece Brook) eroded in part along the Trias–Carboniferous junction.

Immediately prior to the Irish Sea Glaciation, however, the drainage of the area probably consisted of a series of west-flowing streams, and there was subsequently a good deal of glacial diversion (Fig. 4). In the north, there appears to have been little change in the course of the Dean Brook, but the upper Checkley Brook has been diverted. The drift-filled gap at Cooksgate, the circuitous course and the narrow, obviously recent gorge suggest that the pre-glacial drainage here was directed westwards via Cooksgate. Similarly, the drainage in the upper Lea valley, now blocked at its western end by the Woore moraine, was probably formerly westward, and not eastward as at present (Barke 1920, p. 27). Furthermore, the large size of the valley makes it likely that the stream was considerably larger than that which flows therein to-day.

It seems likely that these pre-glacial westerly streams had effected a system of captures by which the formerly more extensive Meece Brook was successively shortened. Indeed, in the extreme south there is every suggestion that in pre-glacial times yet another westerly stream (the Tern) was about to make by headward erosion a further capture of the successively decapitated Meece Brook, since, as noted, the two valleys are separated by an irregular col. However, the valley of the Meece Brook (the Whitmore trough) was deepened during the glaciation, and the likelihood of capture by the Tern has thus been postponed.

In this connexion it should be noted that Wedd (Gibson & Wedd 1925, p. 74) was mistaken in considering that the slope of the pre-drift surface between Hatton (three miles south of Whitmore) and Madeley was mainly from south to north. The heights of the pre-drift surface are shown by boreholes to be about 310 feet at Hatton, 360 feet at Whitmore and about 296 feet at Hey House, near Madeley, and they indicate that the directions of slope of the sub-drift floor are the same as those of the present surface. The head of the Meece Brook before the last glacial advance to affect the area was, as now, in the vicinity of Whitmore (Fig. 4).

1 Slumping is still taking place along this gorge.

2 In this, and in the general interpretation of the drainage and glaciation of this region, we do not fully agree with Barke (1920, pp. 23 and 24).
(b) Sequence of Events during and after the Irish Sea Glaciation

(i) General.—With the advance of the ice the river system sketched above must have been disrupted, and often permanently diverted. It has been noted that the thick deposits of drift are to be found west of the

Craddocks–Whitmore system in the lower-lying areas, whilst the higher ground to the east is relatively drift-free. This does not mean that these eastern areas were unglaciated, for patches of boulder-clay and sand and numerous erratics show that the ice margin on the adjacent part of the Pennine flank must have been at over 1000 feet (Jowett & Charlesworth 1929, p. 317). This distribution of drift is not easy to explain;
it may be that the lower and more debris-charged layers of the ice were deflected or halted by the higher ground and were only able to penetrate it along existing valleys and depressions, such as the Craddocks–Whitmore system (Gibson & Wedd 1925, p. 72).

This group of channels and depressions on the western side of the Pennines must, therefore, have been completely covered by ice. The subsequent retreat would lead to involved systems of periglacial lakes, with spillways and marginal channels often making use of existing depressions. Jowett & Charlesworth in describing these systems of marginal drainage noted that the different channels did not all operate together but came into action in succession from south to north. Both they (p. 328) and Gibson & Wedd (1905, p. 65; 1925, p. 74) made reference to glacial lakes and spillways in the Madeley region. This interpretation is confirmed and expanded in the following account of the glacial lakes and drainage of the Craddocks–Whitmore system.

The morainic belts, overflow systems and evidence of glacial lakes suggest that retreat of the ice from the Craddocks–Whitmore area was fitful, with several stadial positions alternating with fairly rapid retreat. It is possible to observe three well-marked stages of retreat, as follows: (a) the Tern lake, (b) Woore moraine and Lake Madeley, (c) Wrinehill moraine and Lake Craddocks.

The first two of these stages belong to the Stoke Series of Jowett & Charlesworth (p. 327), the melt-waters escaping to the Trent and the North Sea. These stages can possibly be correlated, for reasons stated below, with early and later phases of Jowett & Charlesworth’s stage 2 (pl. xix), although it is not easy to associate the position of the ice front as shown on their plate with the description of the moraines in their text (p. 329). The Wrinehill stage belongs to Jowett & Charlesworth’s Severn Series, with the melt-waters reaching the Bristol Channel (p. 329), and is probably equivalent to a late phase of their stage 2 or to an early phase of their stage 3, after the abandonment of the Biddulph and Kidsgrove channels.

(ii) The Tern stage.—This is the earliest stage of retreat so far as this region is concerned, and the existence of a lake in the upper Tern valley is suggested by the col at Maer, which has the appearance of a direct overflow, and by the flat sheets of sand and gravel on the valley floor (Gibson & Wedd 1925, p. 74; Jowett & Charlesworth 1929, p. 328). The stage presumably represents a period when the ice still covered the Craddocks–Whitmore system. From a general consideration of the morphology of the region it is suggested that the ice margin probably extended north-east from the Madeley region towards Kidsgrove, keeping to the north side of the watershed. It seems unlikely that the ice could have overridden the watershed and extended into the Trent drainage at this stage. Thus the separate lakes in the north that discharged via the Woodlane (812497) and Kidsgrove gaps (Yates 1955) were probably first formed. These can be regarded as the earliest phase of Jowett & Charlesworth’s stage 2 (1929, pl. xix).

(iii) The Woore stage.—This stage is that of the Woore moraine and early Lake Madeley. The long undulating ridge north of the Tern valley which extends south-west from Bar Hill through Woore is composed entirely of drift and appears to represent an actual thickening of drift to more than 130 feet (Gibson & Wedd 1925, p. 68). There is little reason to question Carvill Lewis’s suggestion (1894, p. 36) that this is a
GLACIAL LAKES NEAR MADELEY

FIG. 5.
terminal moraine (the Woore moraine). It seems probable also that the undulating drift north-west of Madeley represents an extension of this feature. It would appear, therefore, that the ice front remained stationary along this line for a considerable period, and a study of the topographical map reveals the likelihood of a lake having existed at that time in the Madeley region (Fig. 5A). There is, of course, other evidence of such a lake. The Whitmore trough, interpreted as a spillway, has a height of 384 feet, almost exactly the same as the break of slope found on three sides of the Madeley basin. It is suggested that this break of slope approximates to a former strand. The absence of a break of slope north-west of Madeley, in the region of undulating drift (the extension of the Woore moraine), is readily explained, for the ice terminals would have formed the dam here. Besides this morphological evidence, further and virtually conclusive evidence for Lake Madeley comes from a study of the Quaternary deposits of the basin. The sand deposit south of Madeley Heath (788446) has a flattish top at about 385 feet, and is interpreted as a delta deposited by the unnamed stream which rises south-west of Keele. Another delta-like spread of sand at Madeley Park Farm (788414) extends from the west some distance across the Whitmore trough, and its top is also at about 385 feet. In addition, the spreads of sand occupying the major part of the Madeley basin are practically horizontal over wide areas, suggesting deposition in still water. The plastic clay of the Madeley basin is also considered to be a deposit of still water, although conditions of its deposition must have differed considerably from those of the sand. It probably belongs to the later history of the lake, and this is confirmed by the examination of pollen (see p. 416).

The above evidence points conclusively to the former existence of a lake whose surface was at about 385 feet O.D. The horizontal ledge in Keele marl west of Madeley may be a strand-line associated with a higher level of water at 400 feet before any considerable erosion of the spillway had lowered the surface, but interpretation is difficult since the feature may be, at least partly, man-made. There is, however, one other aspect which requires comment. Although the present level of the spillway in the Whitmore trough is 384 feet, the sub-drift surface is approximately 360 feet. The sand infilling which raises the floor to its present level can be assumed to have accumulated as the flood of melt-water abated and became unable to carry away the detritus.

The ice margin north of the Madeley region during this stage is thought to have been against the higher ground of the Coal Measures east of Craddocks, for the following reasons (Fig. 5A). There is no evidence of the extension of Lake Madeley north of the Hazeley Brook–Checkley Brook confluence, and it therefore seems likely that there was ice north of this point at least up to a height of 400 feet. The Woore moraine reaches 500 feet and the surface of the ice presumably exceeded this elevation, so that its eastern edge would rest against the Coal Measures at least as high as 500 feet and probably rising to the north.

The Kidsgrove and Woodland spillways almost certainly continued to function at this stage; indeed, like the Woore moraine, the dimensions and height of the main spillway at Kidsgrove point to a long stationary period of the ice front.1 Ultimately, however, these northern spillways

1 This represents the main phase of Jowett & Charlesworth's stage 2.
became, it is thought, deserted, as the marginal drainage was linked with Lake Madeley. The initial deepening of the upper Checkley Brook gorge can be attributed to this linkage, cut by melt-water following the ice edge southward into Lake Madeley, the gorge forming the southernmost member of an aligned sequence of severed spurs.

(iv) The Wrinehill stage.—The next stadial position of the ice is considered here to have been associated with a moraine at Wrinehill, a late phase of Lake Madeley, and the main phase of Lake Craddocks.

North of the Woore moraine the drift deposits are low-lying and intermixed, but another line of hummocky drift, with heaps of sand, can be distinguished extending south-westwards from Cooksgate through Wrinehill. The Checkley Brook flows to the south of and parallel with this line, partially repeating the situation of the Tern south of the Woore moraine. Although the feature is lower and less continuous than the Woore moraine, it has many similar characteristics and it is suggested that it also is a moraine (the Wrinehill moraine). North-west from this feature the drift consists of flat spreads of till with occasional broad sandy tracts.

With the ice margin in this position, Lake Madeley would have been largely drained. Gibson & Wedd (1925, p. 74) considered that it was first drained by a tributary of the Hazeley Brook which cut the channel from Madeley Station to the Fish Pond (see p. 412). Finally, however, the pre-glacial drift-filled valley north-west of Madeley was reopened and the drainage recaptured, leading to the formation of the composite River Lea and the abandonment of this channel. This seems to be the most probable explanation. It is also suggested that the occupation by ice of the Wrinehill position was accompanied by the growth of a lake in the Craddocks Moss region, the evidence for which is given below (Fig. 5B).

Around Craddocks Moss the marked break of slope at about 360 feet occurs largely where the level top of the peat abuts against the steeper slope and would be less well marked if the peat were removed. However, if this were done a hollow would be left, in itself sufficient indication of a pre-peat body of water. Additional support for the existence of a lake is afforded by the deposit of plastic clay1 beneath the peat and by the level-topped sand east of Cooksgate and north of Craddocks Moss, here interpreted as deltas. These would indicate a water-level of about 369 feet, the Cooksgate sand being laid down presumably by a stream flowing east from the ice margin through the Cooksgate gap, and the more northerly sand by a small stream cut into the side of the trough. The sand underlying the peat of Craddocks is also likely to have been laid down in the lake. It extends towards, but does not reach, the gorge of the upper Checkley Brook, where indeed the solid rock is at the surface. It has, in fact, been deposited in a basin and is largely below the level of the outlet.

It has already been suggested that the pre-glacial drainage in the Craddocks region was west via the gap at Cooksgate, the original stream course having been blocked by the drift of the Wrinehill moraine (Fig. 4). This drift, and the ice front of the time, extending north, must also have blocked the valley of Dean Brook where it crosses the outcrop of Bunter

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1 This clay is post-sand pre-peat and could well be of a much later date than the main phase of Lake Craddocks (p. 416).
Sandstone. The lake thus formed must have extended north from Craddocks, through the trough into the Dean Brook basin, where there is likewise a dominant break of slope at about 360 feet, together with deposits of plastic clay and sand. Into this northern extension of Lake Craddocks came probably a considerable body of melt-water discharged southward along the ice front via the channel east of Audley. The spillway of Lake Craddocks must have been the same as its present outlet, via the gorge of Checkley Brook. It would appear that this gorge had already been lowered to the order of 370 feet, since there is no evidence of any lake-level higher than that in the Craddocks Moss basin, and, as noted above, this erosion was achieved by marginal streams of the late Woore stage, when ice still occupied the Craddocks region. Since Lake Craddocks was largely dammed by drift it seems likely that it persisted well into the Post-glacial and quite probably both it and the remnants of Lake Madeley remained until infilled by peat.

The final stages of retreat are indicated by a moraine-like drift feature traced by Wedd (Gibson & Wedd 1925, p. 69) from Foxley to Alsager (north of Audley). This is beyond the limits of the present study but relevant, since the alignment is N.-S. and therefore points to the ultimate abandonment of the coalfield by the ice, leaving a considerable channel between, and the disappearance of the conditions initially responsible for the impounding of the drainage.

(v) Post-Irish Sea Glaciation.—The suggested sequence of events following the retreat of the Irish Sea Glacier may be summarized as follows. In the north the Dean Brook drainage re-established itself, possibly by headward erosion through the drift barrier. The Craddocks Moss drainage continued to flow southwards through the upper Checkley Brook gorge. The recapture of much of the drainage of the Madeley basin by a stream occupying the north-western exit, and the diversion of the upper reaches of the River Lea by the Woore moraine, led to the appearance of the present composite stream. The plastic clays, thought to be lacustrine, must also have followed the Irish Sea Glaciation. From a pollen analysis the Madeley clays have been dated as Late-glacial or Pre-boreal (p. 416). It is impossible to be more precise than this without a detailed examination of the pollen or a radio-carbon dating, for the field evidence shows only that they are post-sand pre-peat, both junctions being abrupt. Indeed, Lake Madeley could well have persisted, in a diminished form, until Pre-boreal time or even later, held up after the retreat of the ice by the drift features north-west of Madeley. The same sort of argument also applies to the Craddocks clay deposit. The formation of peat finally occurred in the badly drained areas of these former lake basins.

In conclusion, it may be said that in the form of the channels it is often difficult to ascertain how much deepening was due to the events before the Irish Sea Glaciation and how much to the activities of melt-waters of that glaciation. Within the bounds established by a study of the evidence there is room for a certain variation in emphasis given to one or the other.

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V. List of References


Discussion

Dr. A. J. Whiteman read the following contribution submitted by himself and Mr. E. G. Poole jointly:

The ground described in the paper lies only six miles east of the boundary between sheets 122 (Nantwich) and 123 (Stoke-upon-Trent) of the Geological Survey one-inch map, and part of it was studied by members of the Manchester office of the Geological Survey in the course of linking the two sheets together.


Recent deposits, including peat.

Fluvio-glacial deposits, including sand, gravels and silts associated with melt-water channels and lake features cut at 335 feet, 305-300 feet, 260-250 feet, 220-200 feet, and 125 feet O.D. (Upper Sands).

Upper Boulder-clay.

Middle Sands.

Lower Boulder-clay.

This sequence of two tills, separated and succeeded by deposits formed during separate melt phases in the upper catchments of the Severn, Dee and Weaver, resembles that which already proved over much of West Lancashire and the Lancashire Coalfield (1931, Manchester Memoir, pp. 178-85; and 1938, Wigan Memoir, pp. 112-31) and Cheshire (1954, Summ. Progr. Geol. Surv. G. B. for 1953, p. 40; 1955, Summ. Progr. for 1954, p. 37; and 1956, Summ. Progr. for 1955, p. 40). It is unlike that reported by Wedd (1925, Stoke Memoir, 3rd edition, pp. 66-75) and this led us to reinvestigate the drift of the western part of Stoke-upon-Trent (Sheet 123) in the Betton, Madeley, and Burton areas.

Wedd (op. cit., p. 67) appears to have been convinced that there was evidence for one glaciation only, followed by a warmer period during which the ice retreated northwards and ice-dammed lakes were held up in the "pre-glacial" valleys of the Staffordshire anticlinal ridge, causing some of the water to spill over into the Trent drainage. This interpretation appears to have been accepted by Mr. Yates and Dr. Moseley, with minor modifications.

We cannot agree that the glacial sequence in the Madeley area and nearby parts of Staffordshire and Cheshire can be explained in terms of a single advance and retreat of an "Irish Sea" ice-sheet. Taken as a whole, the evidence in the Madeley, Thornhill, Wrinehill, Betley, Onneley, Woore, Burton, Norton-in-Hales and Whitchurch areas clearly points to two glaciations with intervening and succeeding melt phases. The ground described by Mr. Yates and Dr. Moseley cannot be considered in isolation from the rest of the Shropshire-Cheshire basin; its glacial history must be considered against the stratigraphical pattern now proved to hold over 3000 square miles of surveyed ground in the basin.

The boulder-clay which rests on the sand and gravel of the Woore-Onneley-Bar Hill moraine (Wedd op. cit., p. 68) forms part of a continuous till-sheet which maps into the Upper Boulder-clay spread of Sheet 122 on at least an eight-mile front. This boulder-clay was mapped by Wedd on the flanks and in places over the crest of the moraine on Sheet 123, and in our opinion, the field relations of the till clearly show that it is the younger. The moraine is the eastern extension of the Duckington-
Whitchurch–Adderley Middle Sands moraine which runs for over 16 miles across Sheet 122 through Calverhall, Wirswall (near Whitchurch) and No Man's Heath to join the Mid-Cheshire Permo-Triassic ridge near Duckington. A further extension of the Middle Sands moraine passes through Oldcastle, Hamner, Ellesmere, Dudleston Heath, Knoton, Erbistock and Overton to Wrexham, where it runs against the Welsh hills. The length of this section is over 25 miles. That the moraine is composed largely of sand and gravel, from Bar Hill in the east to Wrexham in the west, has been demonstrated from borehole evidence and field mapping. It is also clear from field mapping that the sands and gravels are underlain by Lower Boulder-clay which in places is over 70 feet thick. Upper Boulder-clay resting on sand and gravel has been seen in many sections and has been proved in numerous boreholes. The sands and gravels which occur beneath the Upper Boulder-clay in this part of the Shropshire–Cheshire basin are therefore Middle Sands and were deposited during a major stand of the retreating Lower Boulder-clay ice-sheet.

During the melting of the Upper Boulder-clay ice-sheet the ice stood along the western side of the Mid-Cheshire Permo-Triassic ridge and the Billinge–Upholland ridge in West Lancashire, and melt-waters streamed eastwards through gaps and overflow channels into the 330-foot, 305-foot and 250-foot lakes which were ponded up by high ground at the edges of the Shropshire–Cheshire basin. The 330-foot and 305-foot lake features are at elevations similar to those said to mark the edges of Lake Newport and Lake Lapworth (Stafford Memoir 1927, pp. 72-3) near Newport and Wrekin. Features have been recorded at similar elevations in Lancashire, Cheshire, Flintshire and Shropshire, and it appears that Lake Newport and Lake Lapworth extended into parts of South-East Lancashire, all of East Cheshire (east of the Permo-Triassic ridge) and most of Shropshire, between the 330-foot and 300-foot contours. Have the authors of the present paper any evidence of these lakes in the ground north of Madeley?

The authors have associated the lake features recorded at 380 feet and 360 feet with the sands and gravels of the Madeley area, making them contemporaneous with the moraine. The sands and gravels of the Madeley area are Middle Sands, since they pass northward beneath the Upper Boulder-clay of Higher Thornhill and westwards beneath the Upper Boulder-clay of Moor Hill, which is continuous with the upper till sheet of Nantwich (Sheet 122). If the authors' correlation is correct, the lake features are of considerable antiquity and have survived the Upper Boulder-clay glaciation and retreat phase and post-glacial denudation. Is it not more likely that the features were cut during the retreat of the Upper Boulder-clay ice and represent early stages in the development of the Newport–Lapworth lake system?

According to the authors, the Woore and Wrinohill moraines belong to separate and well-marked stages of the retreat. This seems to us to be an unwarranted refinement, because the ridges and deposits form part of the same Middle Sands morainic belt which swings almost due north, north of Bar Hill, more or less parallel to the solid ground. The Middle Sands morainic belt elsewhere is commonly between two and four miles wide and contains several separate ridges. Can the authors explain more fully why they have separated the Woore and Wrinohill stages?

The evidence put forward in the paper of the existence of a Lake Tern appears to the present writers to be slender. No marginal lake features have been described, and the existence of a col at Maer (which may be of composite origin) and the general configuration of the ground between the Adderley–Woore–Bar Hill moraine and the solid ground seem to be the main reasons for postulating its existence. Have the authors mapped any features or deposits belonging to this lake and where do they visualise the ice-dam to have stood to the south-west? Also, bearing in mind that the Lower Boulder-clay and Upper Boulder-clay retreat phases affected this area, we should like to know whether Lake Tern should be regarded as a Middle Sands or an Upper Sands lake, or both.

Professor F. W. SHOTTON referred to a difficulty which was often encountered in Midland Pleistocene stratigraphy. Ice attributed to the Irish Sea Glaciation was represented as damming up a Lake Madeley in which silts were deposited. The Irish Sea Glaciation was the earliest ice stage so far recognizable in England after the Eemian Interglacial and must, from C14 dates established in the Severn and Avon valleys, be at least earlier than 42,000 years ago—yet the pollen analysis of the Madeley silts suggested a date of perhaps 10,000 or 12,000 years before the present.
What happened in that gap of time? It did not solve the question to suggest that the lake continued after the ice retreat, dammed up by moraine, for the deposits of this earlier period should then be represented.

He asked the authors whether sufficient organic material existed in those silts to enable an age determination to be made. If so, it was important that this should be done, as indeed it was in every case of organic material associated with the stages of the Würm Glaciation.

Dr. Moseley, replying, said that Dr. Whiteman would realize that the Madeley area was a valley system marginal to the Pennines and one would not necessarily expect to find there the full sequence of the Cheshire plain; indeed, much of the surrounding ground was free from drift. The authors did not say, imply, or believe that there was evidence of only one glaciation on the Cheshire plain, but they maintained that within the Madeley area there was evidence of only the latest period of glaciation: that is, the Irish Sea Glaciation.

The main issue raised by Dr. Whiteman and Mr. Poole revolved about the Madeley Sands. They claimed that these sands passed beneath the upper tills, whereas the authors held that the tills passed beneath the sands. It was possible that Dr. Whiteman and Mr. Poole had been confused by the fact that the sands were usually at a lower altitude than the tills. In both the localities they mentioned, and also north and northeast of Heighley Castle, the till was plastered against hills of Bunter Sandstone and Upper Carboniferous, and rested directly on those formations, which protruded through at many points. In those districts, and also near Hey House, Hungerford Farm and elsewhere, it was clear from mapping and augering that the Madeley Sands occupied the lower ground, thinning out towards the higher ground, where the till emerged from beneath them to partly cover the slopes, leaving the higher ground drift-free. Thus the authors agreed that the till was Upper Boulder-clay and their evidence was that this was succeeded by the Madeley Sands (presumably the "Upper Sands" of Dr. Whiteman), clay and peat in that order. They did not therefore consider the lakes they had described to be pre-Upper Boulder-clay, but to be features of the last ice retreat from the area.

The reasons for the two main retreat stages were given in the paper. Briefly, all the evidence pointed to the level of Lake Craddock, the later stage, having been 20 feet lower than that of Lake Madeley. The only escape route for Lake Craddock would have been across an area previously occupied by ice damming back Lake Madeley. This obviously involved a retreat of the ice front, and was in accordance with the other field evidence.

As the Cheshire plain was outside the area they had mapped, the authors would not offer decided views on the succession referred to by Dr. Whiteman and Mr. Poole. It might be that the main feature of the Woore moraine was due to an older glaciation, but nevertheless the ice margin of the Upper Boulder-clay glacier must also have stood in this position when Lake Madeley was formed. With regard to the Tern valley, the authors suggested that the configuration of the ground and the existence of clay deposits pointed to the one-time presence of a lake there. Thelake levels below 330 feet on the Cheshire plain were not relevant to the Madeley area, which was everywhere above that altitude.

In reference to Professor Shotton’s remarks, Dr. Moseley said that the only direct evidence the authors had of the age of any of the deposits was
that of the pollen analysis of the clays. It was possible that the pollen represented a facies and was much older than it appeared to be. This could be checked by C14 dating, for which the material was suitable.