Glacial geology of the Shrewsbury area, Shropshire, with particular reference to a Welsh readvance

Peter Worsley

Abstract: Observations relating to the local glacial geology in the Shrewsbury area commenced even before the advent of the Glacial Theory. Work by the British Geological Survey was later supplemented by studies of the landforms and allied stratigraphy by university researchers. More recently the BRITICE glacial geomorphological mapping project has added to the regional perspective. This body of work is assessed in the context of the Last Glacial Stage history of the Shrewsbury area, and analogues from modern glacial environments are introduced. At the Last Glacial Maximum, an Irish Sea-sourced ice lobe emplaced its sediments over the entire area. Its retreat was characterised by widespread stagnation with detached blocks of ice being buried within mainly glaciofluvial sequences. Before these ice blocks had fully dissipated, a readvance of Welsh ice emanating from the upper Severn basin covered the western sector and terminated at Shrewsbury. Contrary to some interpretations, the exposures in the Mousecroft Lane quarry unequivocally demonstrate this fact. The Welsh ice meltwater fed a wide glaciofluvial delta which prograded eastwards into progressively lowering meltwater lake systems. Final melt-out of the buried ice occurred several millennia after the deglaciation and produced today's kettled landscape. Development of the River Severn drainage network was regulated by the progressive reduction in threshold height at the Ironbridge Gorge.

The Shrewsbury district landscape

The study area lies at the southern end of the gently rolling Cheshire–Shropshire Plain which is underlain by Carboniferous and Permo-Triassic bedrocks. The entire district was glaciated at the Last Glacial Maximum (LGM) which produced a blanket of glacial-sourced sediments. To the west, some 20 km distant, lies the eastern edge of the Welsh uplands and southwards the ground rises towards the Long Mynd. The drainage pattern is anomalous since the upper Severn, after leaving the higher ground, heads east to Shrewsbury rather than flowing northwards to the Irish Sea. It then flows south east, breaching the main watershed of England via the Ironbridge Gorge before turning south to the Bristol Channel (Fig. 1). Urbanised Shrewsbury spreads across the incised meanders of the River Severn inherited from the deglaciation.

Pioneer Pleistocene investigations

Glacial geological observations in the Shrewsbury district commenced at an early stage in the development of the Glacial Theory (Trimmer 1835; Murchison 1836). Despite its title, Murchison (1839), in his monumental 'Silurian System', devoted several concluding chapters to describing and discussing what are now classified as Quaternary deposits in the greater Welsh borderland region, particularly in Shropshire. His initial chapter is entitled 'Superficial detritus', although approvingly, he noted that foreign geologists were using the term 'Diluvium' to embrace superficial loose coarse and sometimes far-transported rock fragments. Nevertheless, he regretted that his English contemporaries had abandoned this term and as an alternative he proposed the term '*drift*'. Yet, he remained an unrepentant catastrophist and considered

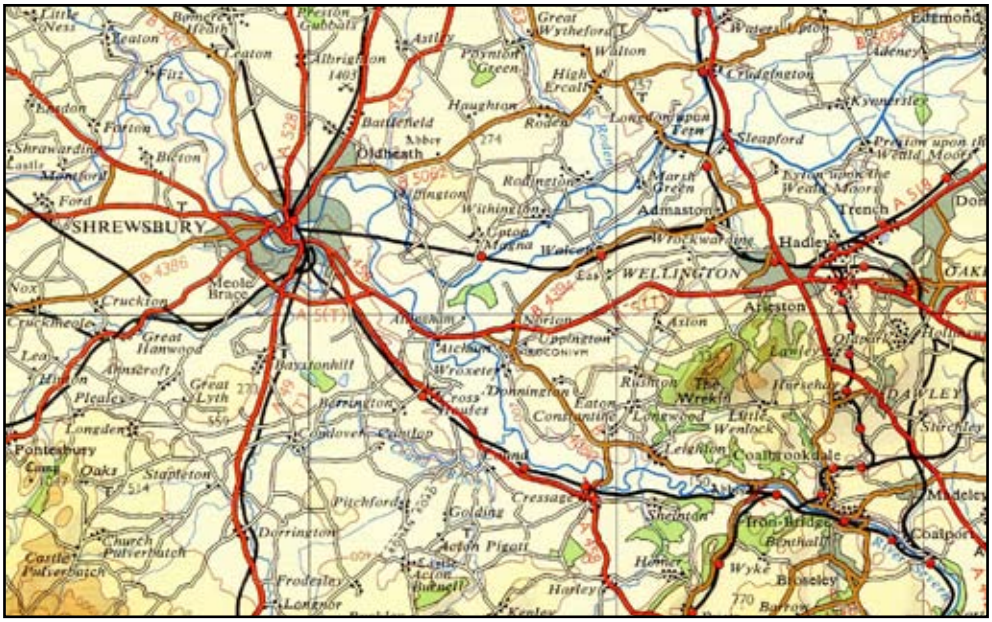

Figure 1. *Location map showing the relief of the Shrewsbury district and its drainage network. Note the incised meanders of the River Severn at Shrewsbury. All heights are in imperial units (OS 1:250,000 scale map, 1962)*

that the '*drift'* was the product of 'long-continued submarine action'. The term '*drift'* was adopted by the British Geological Survey for their superficial geology maps, although its significance was at first liberally interpreted, for example A. J. Jukes-Browne supported a glaciomarine depositional environment for its genesis (Jukes-Browne 1887). Only since 2003 has 'Drift' been replaced by 'Superficial Deposits' on BGS maps.

Murchison's Chapter 38 is titled 'The Northern Drift' which he characterised as containing 'granite boulders and sea shells of existing species'. Like Trimmer (1835), he drew attention to sections exposed in the banks of the River Severn immediately upstream from Shrewsbury and included a sketch of an eroding section at Preston Montford Hall, SJ 430 142 (now a Field Studies Council centre). Further, he noted that in the undercut river bank at Shelton Rough, 3 km north-west of Shrewsbury, NGR SJ 467 140, and at other similar places, exposures revealed comparable sequences, although he qualified this by declaring 'different sections vary very much in their composition'. He continued 'I have at several times looked into the deep gravel pits' between Shrewsbury and Meole Brace village 'without observing certain fragments of shells'.

However, Murchison noted that a 'Mr. C. Darwin' found such shells although they were fragmented and worn. 'The coarse detritus containing the shells is 20–25 feet [7–8 m] thick and lies on purely local soft regenerated red sand'. In his autobiography, written some 50 years later, Darwin relates that whilst examining an old gravel pit, a labourer told him that he had found a 'large worn tropical Volute shell'– this was probably in 1831 (Barlow 1958, 58). Volutes are a family of marine gastropods and if the discovered shell was a genuine *tropical* species, this remains a mystery. Later in that year, Adam Sedgwick, in conversation with Darwin, was unconvinced that it was a genuine discovery although it may have been misidentified since Volute shells are found in British waters today.

Clues as to the location of one of the gravel pits visited by Charles Darwin may be found in a letter which he wrote to the Rev. W. A. Leighton (Burkhardt and Smith 1986, DCP-LETT-631). This letter was almost certainly written in July 1841 and was prompted by Darwin's enquiry about the identity of a plant which he had found growing at a pit site. Leighton (1805–1899) was a long-term friend of Darwin, they both attended Mr Case's (primary) school, Shrewsbury School, and Cambridge University. He had authored a Flora of Shropshire. In Darwin's letter was a sketch map to aid Leighton in locating the pit (Burkhardt and Smith 1986, 294–5). Michael Roberts has suggested that this pit was probably the one which yielded the Volute shell. The NGR for the pit given in Roberts (2000) is incorrect. Astonishingly, the sketch unequivocally shows that Darwin's pit was in the same location as the Mousecroft Lane quarry which was active during the period 1950–1980 (SJ 474 108). This location will be discussed later.

Twentieth century work

Although peripheral to Shrewsbury per se, the work of L. J. Wills was highly influential in the interpretation of the greater West Midlands glaciation record. Chapter 16 – the Newer Drifts – is a succinct synthesis of his mature views (Wills 1950). Essentially two glaciogenic sequences were recognised, first, an Irish Sea association (Stockport Formation) and second, a Welsh association (Shrewsbury Formation). Wills attributed Lewis (1894) with the first recognition that the Irish Sea ice sheet was 'powerful enough to advance counter to the slopes of the river drainage basins and that this implies their ability to impound extra-glacial lakes, with drainage diversions as possible consequences'. Charles Lapworth is credited with the recognition of the Ironbridge Gorge (Fig. 2) as a classic glacial lake overflow channel (Tricas 1974). Following his mapping of the river terraces and allied deposits of the middle

Figure 2*. Western entrance to the Ironbridge Gorge as seen from just east of Leighton (SJ 620 049), prior to the demolition of the A (1932–1981) and B (1969–2015) power stations. The River Severn is visible on the right and the Wenlock Limestone escarpment at Benthall Edge forms the skyline above it.*

River Severn, the concept of a Glacial Lake Lapworth was introduced by Wills as part of his explanation for the origin of the Ironbridge Gorge (Wills 1924). In the late 1950s there was a phase of questioning the validity of many of the proposed ice-dammed lakes in Britain. In Shropshire, Shaw (1972b, 628), on the basis of his interpretation of sedimentological evidence, challenged even the existence of a Lake Lapworth: 'The gorge [Ironbridge] was open during the wasting of the Irish Sea ice and a 300 ft lake is clearly impossible at this time'; and 'There is no evidence for a widespread lake of the Lake Lapworth type during the retreat of the Irish Sea ice'. The background to this debate and the counter arguments were discussed by Worsley (1975).

Wills (1937) termed an extension of the Upper Severn valley glacier down as far as Shrewsbury the 'Welsh Re-advance' or 'Little Welsh Glaciation'. He considered that the Worcester Terrace extended up the River Severn from near Tewkesbury through the Ironbridge Gorge to terminate at Shrewsbury where it became the 3rd or Uffington (highest) river terrace.

British Geological Survey research

The 'six-inch-to-the-mile' scale field mapping of the Shrewsbury district map by six BGS field geologists occurred at intervals between 1914 and 1928. The resultant 'New Series' sheet 152 (Shrewsbury) at a scale of 1:63,360 was published in 1932 in two versions – solid, and drift, and a memoir followed in 1938 (Pocock *et al*). A 'revised' edition of the solid map at the 1:50,000 scale was issued in 1978, whereas the 1932 'drift' version remains current. A sand and gravel resource assessment report (BGS Industrial Minerals Assessment Unit, IMAU), covers the immediate Shrewsbury area as defined by OS 1:25,000 Sheets SJ 41 & 51 (Cannell 1982), but understandably the tricky question of the age of glaciation is not considered. 'The glacial deposits of the Shrewsbury district exhibit marked lateral variability and consequently correlation is difficult' (Cannell 1982, 5). His mapped boundaries are based on those of R. W. Pocock, with minor amendments made by others in 1980.

The memoir's lead contributor on the glacial geology was Talbot H. Whitehead who, in his retirement, lived locally and continued to be an active recorder of temporary exposures. A paper reporting an investigation of the Pleistocene in the Church Stretton area would have had him as principal author but for his untimely death (Rowlands and Shotton 1971). His first published comment on Shrewsbury glaciation was a written contribution to the discussion following the reading of the paper by Dwerryhouse and Miller in November 1929 (1930) at the Geological Society, a decade before the publication of the memoir. He asserted that at Hanwood, some 4 km south-west of Shrewsbury (SJ 460 095), a terrace of 'clay gravels', which he believed was related to Lake Lapworth, were 'clearly overlain by Welsh boulder-clay'. He argued that since Lake Lapworth was linked to the retreat of the Irish Sea glacier, the two distinct ice advance events could be separated in time. Critically, the Geological Survey didn't identify the limit of the Welsh readvance ice at Shrewsbury, and Whitehead failed to recognise that the 'clay gravels' were part of a proglacial sandur succession which was subsequently overridden by a Welsh glacier.

Earlier, Lewis (1894, 297) described a section east of Hanwood Station (*c.* SJ 460 095) near the crossing of an old railway which can now be identified as the then abandoned 'Potteries, Shrewsbury and North Wales Railway' (this was later resuscitated as the Shropshire and Montgomery Railway). Two units were exposed: 'The lower one, a red stiff till, now obscured by slips, contains erratics from the north including Eskdale and Criffel granite, Carboniferous limestone and Arenig felsite', beneath a 15 m thick sequence of coarse gravel and yellow till containing 'purely local erratics mainly argillaceous shales, diabases, diabase porphyrites'. Whitehead, in the Shrewsbury memoir (p 197), states that the 'stiff red clay' (n.b. a clay rather than till), was not observed in 1926 during the field mapping. Following tree felling, in March 2023, Lewis's two-fold sequence could again be recognised (Fig. 3). There can be little doubt that this succession signifies Irish Sea-derived glaciogenic material overlain by a consanguineous Welsh outwash and till containing argillaceous shales, and dolerites. An IMAU borehole at Lower Edgebold (BGS SJ 41SE/77), 800 m north-west of the cutting exposure, revealed the same succession over bedrock. Of note is the fact that this section lies less than 2 km south-west from the Mousecroft Lane quarry exposures to be considered later.

Two British Geological Survey Regional Guides interface across the Shrewsbury district but reconciling their accounts of the glacial stratigraphy is problematic, even though they were published only two years apart. The Welsh Borderland guide (3rd edition, Earp and

***Figure 3**. Irish Sea till exposed at the base of the Hanwood Bank railway cutting in March 2023 (SJ 460 097). Scale given by A4 paper sheet.*

Hains 1971) has a particularly idiosyncratic account of the glacial chronology and one clearly influenced by the unconventional views of Poole and Whiteman (1961; 1966). A similar comment also applies to the Central England guide (3rd edition, Hains and Horton 1969) who, probably with the intent of pouring oil on troubled waters created by their radical colleagues, unconvincingly declare 'the apparent anomaly of correlating Older and Newer Drift [by Poole and Whiteman] is explained by the diachronous nature of all glacial deposits'.

The Mousecroft Lane (Radbrook) quarry succession

This quarry is the key to unravelling the Shrewsbury glacial stratigraphy and for several decades it provided the best exposures of the superficial deposits in the district (Fig. 4). It is located on a gently undulating area averaging 75–80 m OD between the shallow valleys of the Rad and Rea brooks (SJ 474 112). Kettle holes are ubiquitous.

The first investigators to publish were Poole and Whiteman (1961) who reported that in 1957 the north-westerly part of the quarry revealed a succession consisting of two basic units:

A. Till (Upper Boulder Clay) buff, yellow brown, abundant small stones, Welsh erratics) 3 m thick. Lying on a contorted contact over:

B. Fluvioglacial sediments (Middle Sands) a 21 m thick (minimum) complex of clays, silts, sands, gravels with lateral variations between each, large boulders, and numerous Irish Sea erratics.

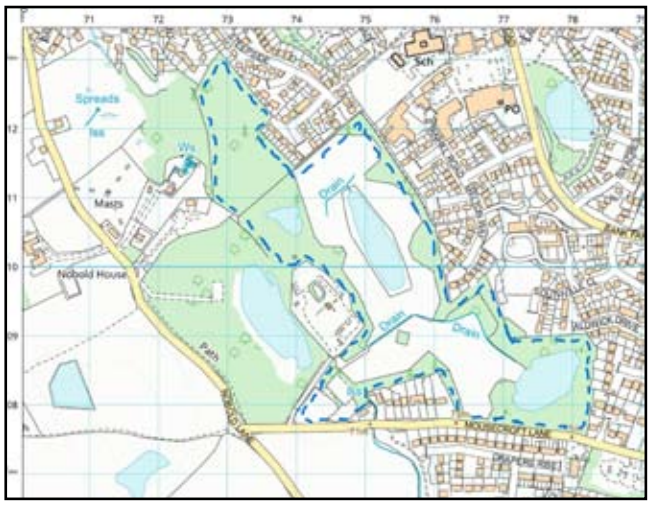

Figure 4. *Map of the area formerly occupied by the Mousecroft Lane quarry. The area of sand and gravel extraction lies within the dashed blue lines. The old quarry is currently devoted to recreational use, in part the Mousecroft Community Woodland. Scale given by the 100 m grid squares. (Source: OS Digimap with dashed lines added by author)*

Figure 5. *The Shrewsbury Formation, consisting of Welsh till overlying its proglacial outwash at Mousecroft Lane (SJ 4727 1125). Scale – rucksack at the section base. The outwash shows a coarsening upwards in grain size in response to the increasing proximity of the ice margin. However, the silt bed between the till and outwash signifies meltwater ponding phase immediately before overriding by ice.*

Poole and Whiteman's interpretation did not separate the Irish Sea and Welsh glaciofluvial sequences, and they regarded the succession as part of their 'Upper Boulder Clay (A) and Middle Sands (B)' model, an extension of their controversial all-embracing glacial tripartite succession within the Shropshire–Cheshire basin. However, they commented that there was much more clay and gravel than was typical for the 'Middle Sands' of Cheshire and Lancashire. They *did* recognise that sequence B was the product of an Irish Sea ice incursion that was subsequently overidden by Welsh ice depositing sequence A. Nevertheless, they ascribed sequence B to their 'Lower Boulder Clay' glaciation. Unit A and the Welsh-derived gravels below it (Fig. 5) is now the Shrewsbury [Glaciogenic] Formation stratotype (Worsley 1999a).

At Conduit Head, from the sixteenth century until abandonment in 1947, natural springs had been adapted to supply Shrewsbury with water; the aquifer being glaciofluvial sediments. Shotton (1962) described a water supply borehole (SJ 472 111) within 100 m of the southern quarry border. This revealed a 28 m-thick glacial succession over bedrock. Unexpectedly it was dominated by 23 m of silt and clay with dispersed pebbles in stark contrast to the high-energy fluvial successions in the adjacent quarry. There is some doubt as to whether this clay was glacio-lacustrine or a thick till. He also reported a similar glaciogenic stratigraphy to that recorded by Poole and Whiteman in the quarry.

The writer first visited the quarry in 1964 and periodically for two decades thereafter. Initially he recorded a 19 m thick sequence close to the extreme eastern quarry limit (Worsley 1967; 2005). This showed four glaciogenic sedimentary units (in stratigraphic order):

A. 1.8 m Red and grey till with *c.* 1 m of laminated silts at the base.

B. 4.7 m Grey sands and gravel of westerly derivation.

C. 1.4 m Red-brown till, brecciated at the base.

D. 7.8 m Lower red sands and gravel, very variable lithologies with widespread collapse structures, base obscured.

The basal units D and C are related to the Irish Sea ice. Units B and A are related to a subsequent overriding by ice from a Welsh source (Fig. 6). A major near-horizontal unconformity between units C and B could be recognised throughout the segmented quarry exposures which extended north-west to south-east for 800 m. Later observations in the 1970s revealed the extent to which the entire sequence had been gently deformed due to subsidence in two distinct phases. First, syndepositionary within the Stockport Formation and second, after the deposition of the Shrewsbury Formation (Fig. 7). Many exposures revealed that blocks of glacier ice had been buried within an ice-contact glaciofluvial environment (Worsley 1977).

As part of a higher degree project devised by the writer, John Shaw, during the period 1966–1969 monitored the changing exposures at the western end of the pit (Shaw, 1969, 1971, 1972a, 1972b). Based on sedimentological criteria, he suggested a depositional model with the lower sequence of Irish Sea glacier provenance being a product of sedimentation by low sinuosity meltwater flows confined between glacial ice walls. He recorded a stacked vertical sequence of gravels with no significant fining upward in grain size, signifying little if any lateral channel migration. On the basis of some thirty cross-bedding measurements he deduced a unimodal palaeoflow direction from north-west to south-east. Further, he envisaged sedimentation

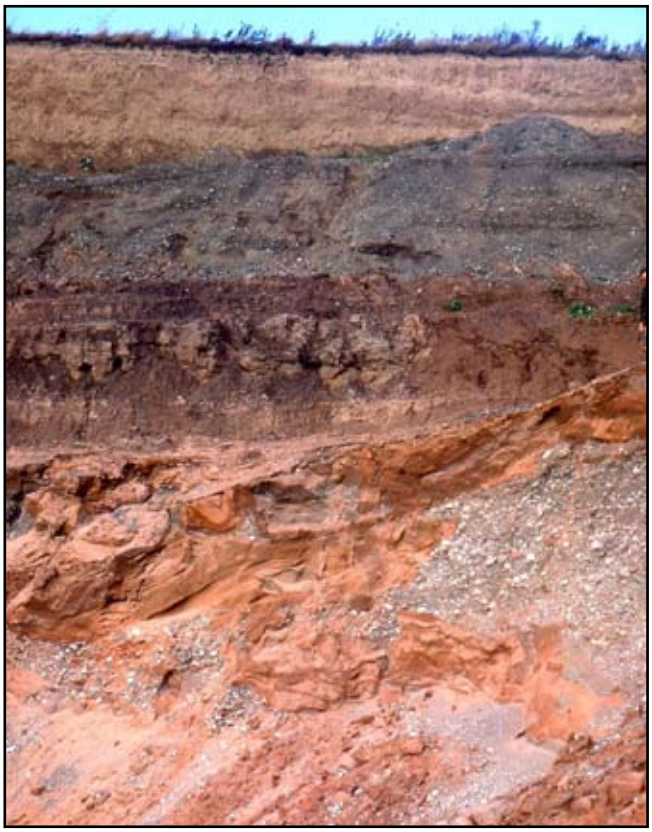

Figure 6*. The glacial succession at the Mousecroft Lane quarry – a lower complex Irish Sea glaciofluvial unit capped by a red flow till (Stockport Formation) unconformably overlain by the Welsh ice sandur sediments and Welsh till (Shrewsbury Formation). Person on far right for scale.*

in an essentially supraglacial major meltwater channel system, within which a deeper central zone was dominated by high-energy gravel aggradation and laterally to this, under lower energy conditions, sands accumulated along with some interbedded silt and clay

Figure 7*. The Mousecroft Lane working face c.1972 (SJ 755 093). The Welsh till has been removed and stacked in the background. The Welsh gravels are being stripped and the unconformity between the Irish Sea and Welsh successions is being exhumed. Note how this newly exposed surface undulates with ponded water in the depressions and the syncline in the gravel face below the excavator. This deformation is caused by post-depositionary melt-out of ice within the underlying Stockport Formation. Red till related to the latter is evident in the left foreground.*

***Figure 8**. The south-facing 23 m-deep section in the early 1970s showing the Stockport and Shrewsbury formations (SJ 4728 4124). One of the minor asymmetric till bodies enclosed by stratified sediments within the Welsh till as described by Shaw (1969, fig. 11/2) and Shaw (1971) can be seen as an integral part of the Welsh till member.*

units (Fig. 8). He also argued that lacustrine laminated material lying on top of the proximal sandur deposits had been frozen into the base of the overriding ice and later deposited during basal melt-out over two shallow flow till bodies with asymmetric profiles. He reasonably argued that the basal thermal regime must have oscillated between temperate and cold ice.

For the Annual Field Meeting of the Quaternary Research Association in 1978, a field handbook was prepared by Francis (1978). Mousecroft Lane was included in the itinerary and to prepare for this a University of Keele group made some observations on the exposures around SJ 475 110 (Francis 1978, 67–74, 92–93). Their reports added some descriptive detail such as further evidence for flow till processes influencing the Welsh till properties, but the existing interpretation remained unchanged.

Kettle hole infill stratigraphy

Condover lies 4 km SSE of the Mousecroft Lane quarry and an outline account of the glacial geological context of its kettle holes and allied famed mammoths was given by Worsley (2005a). Later ^{14}C data from a more detailed stratigraphic examination of the find site (Allen *et al* 2009; Scourse *et al* 2009) suggested that subsidence due to the melt-out of buried glacial ice within the Stockport Formation had commenced before 14.7 ka BP and possibly continued into the early Holocene *c.* 8 ka BP. After calibration, the ^{14}C age estimate of 12.3 ka BP (OxA-20129) from the adult mammoth tusk gave a time span of 14.8–13.9 cal year BP at 2 σ. These workers posited that some buried ice might have survived until *c.* 12.65 ka BP. This implies a melt-out delay of *c.* 10 ka. The survival of buried glacier ice for a similar time span was identified by the writer during field mapping in the Sachs River lowlands in Banks Island in the Canadian Arctic. Despite the main deglaciation event occurring before 10 ka BP, during present summers, buried glacier ice was being exposed at the head of retrogressive mudslides induced by thermal erosion. Admittedly, contemporary Banks Island is within the zone of continuous permafrost, but it demonstrates that kettle hole formation does not necessarily date from the time of deglaciation (Worsley 1999b).

Shrewsbury in the regional stratigraphical context

It has been widely accepted that the bulk of Irish Sea glacier-derived sediments in the Cheshire–Shropshire plain are assigned to the Stockport [Glaciogenic] Formation (Worsley 1967). However, more recently the British Geological Survey, in its wisdom, has proposed the subdivision of the Stockport Formation into two separate formations (McMillan *et al* 2011). The Stockport Formation type site at (SJ 908 916) is retained but the glaciogenic sediments on the western Pennine fringe and the plain in the south-east sector down to the extreme LGM limit have been assigned to the 'Brewood Till Formation' defined by the Four Ashes till at the Devensian Stage type site (SJ 916 082). Brewood village *per se* lies two km to the west of Four Ashes.

The validity of this distinction is unclear. They claim that south of the Wrexham–Bar Hill moraine ridge (a) the tills are thinner, and (b) more eroded, weathered and cryoturbated. Almost 60 years earlier, Boulton and Worsley (1965) placed the glacial advance limit at the Wrexham–Bar Hill moraine because of the same apparent contrast. A scheme by McMillan *et al* (2011) pertaining to a two-phase Irish Sea advance model has an inconsistency when applied to the Shrewsbury area. Outside the limits of the Welsh readvance till (Shrewsbury Glaciogenic Formation) the

criteria underlying their proposals are simply absent. Indeed, in the Telford area, some 20 km due east of Shrewsbury they cite a maximum till thickness of 17 m for the Brewood Till inside the Late Devensian glacial maximum. Despite this, thin tills are given as a characteristic of the Brewood Till. A possible unhelpful influence might be the views expressed by Bowen *et al* (2001), who claimed a two-phase Devensian Irish Sea glaciation, of respectively Middle and Late Devensian age. Essentially this latter hypothesis was heavily dependent on so-called 'amino acid dates' from various locations in northern Britain, a technique which until that time has proved to be unreliable. In the light of the clear linkage between the Stockport Formation and the River Severn Main Terrace in south Shropshire, this chronology was not endorsed by Worsley (2006, 2011).

Significantly, the recently completed BRITICE project found no support for the two-phase Devensian model (Chiverrell *et al* 2021). On the basis of luminescence techniques applied to single grains of quartz from glaciofluvial sediments, the project team concluded that the Irish Sea LGM ice limit in south Shropshire close to Bridgnorth was achieved *c.* 26.5 ka and that deglaciation had commenced *c.* 25.3 ka. The ice had retreated northwards beyond Cheshire after *c*. 22 ka. It was also concluded that where the retreat was down reverse slopes, the impeded meltwater drainage generated abundant ephemeral proglacial lakes in the same manner as anticipated by Lewis (1894).

Modern glacial analogue environments

Kettle holes

These landforms are enclosed depressions resulting from the melting of glacier ice blocks buried in sediments and are usually associated with stagnant glacial ice terrain. In the Shrewsbury district hummocky morainic terrain with numerous kettle holes was first identified in the 1920s during the original Geological Survey (Pocock *et al* 1938). Observations of modern analogues in section are limited but an example occurred in the early 1960s at Austerdalsisen (Østerdalsisen), an outlet glacier of the Svartisen ice cap in north Norway. In the mid twentieth century the glacier terminated in two ice-dammed lakes (Liestøl 1956). As the ice retreated, the westernmost of these lakes commenced draining subglacially in a catastrophic manner into the eastern lake during the summer and serious downstream flooding ensued. This became an annual drainage event with many ice bergs which had previously calved off the glacier terminus, becoming stranded on the newly exposed lake bed. The lake-bed sediments were subject to fluvial erosion by extra-glacial drainage streams extending their courses to the new lowered base level and the creation of a new delta (Fig. 9). Allied to this process, a number of ice blocks which had been buried by earlier erosional events became exposed in section (Figs. 10, 11). Although comparatively on a small scale, the mechanisms involved are likely to be analogous to the processes which prevailed during the wastage of the Shropshire Irish Sea Glacier.

Ice advance signatures

Glacier advances over proglacial sandur deposits are relatively common. An example was afforded by in the 1980s–90s by the advance of Sólheimajökull, an outlet glacier of the Mýrdalsjökull ice cap in southern Iceland. The glacier moved forward fronted by a low push moraine ridge the sediments of which were progressively overridden creating a till bed over the former sandur surface (Fig. 12). By chance, at this locality, the banks of the modern sandur were eroded into the deposits of an earlier advance phase and a till bed *c.* 1.5 m thick lay horizontally over undisturbed sandur sediments, not unlike the Welsh glacier sequence at Mousecroft Lane (Fig. 13).

Figure 9. *Part of a modern delta aggrading into a glacial lake. Note the calved icebergs on the lake and the developing kettle holes deforming the delta top when melting buried glacial ice blocks occur in the subsurface. Austerdalsisen, N Norway.*

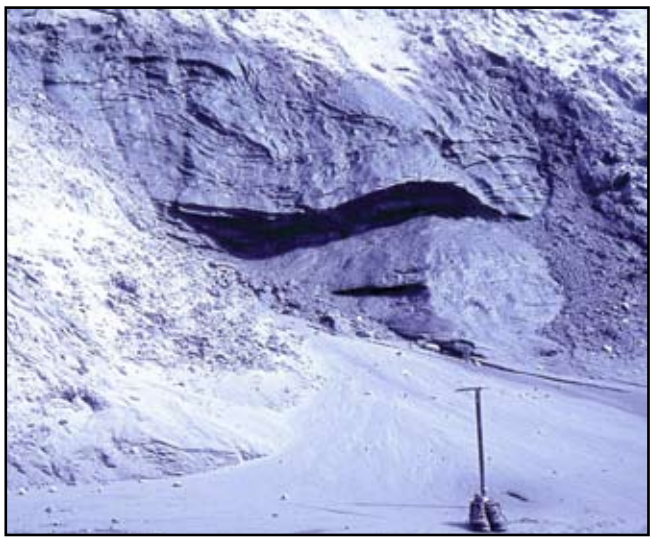

***Figure 10**. A glacial ice-block buried within glaciofluvial sediments, Austerdalsisen, Svartisen, north Norway 1964.*

***Figure 11**. Close-up of the interface of a former grounded iceberg buried within outwash sediments, Austerdalsisen, north Norway 1964.*

***Figure 12**. A valley glacier snout advancing over its proximal meltwater sandur and pushing up a minor moraine ridge, Sólheimajökull, south Iceland 1993.*

***Figure 13**. Section eroded through a terrace with till over a sandur, the sedimentary signature of a glacial advance sequence, Sólheimajökull, south Iceland. This has parallels with the Welsh advance stratigraphy in the Mousecroft Lane quarry exposures (see Fig. 6).*

Defining the Welsh ice readvance limit

This topic has proved to be controversial for reasons which are not immediately obvious. This is a puzzle since the unambiguous presence of the Severn Glacier in Shrewsbury, as demonstrated by the exposures in the Mousecroft Lane pits, has been known since Poole and Whiteman (1961). This finding was endorsed in the work of Shaw (1969, 1971, 1972 a & b) and Worsley (1967, 1970, 1975, 1977, 1991, 2005a). A further problem is that the advance limit is likely to be a 'feather edge' feature without a phase of ice marginal stability building an end moraine. Additionally, the delayed melt-out of buried glacier ice has helped to obscure the till–outwash transitional zone.

Whilst the BGS IMAU programme was progressing, the first attempt was made to integrate the exploration borehole data into a regional stratigraphic model (Wilson *et al* 1982). These workers adopted the essentials of Poole and Whiteman's tripartite scheme but accepted the regional lowland chronology as presented by Worsley (1970). This led to the bizarre assertion that the tripartite Lower Boulder Clay (glaciation) – Middle Sands (retreat/advance) – Upper Boulder Clay (glaciation) events all post-dated the Four Ashes interstadial deposits, i.e. were of Late Devensian age. In the present context, their recognition of the Welsh glacier limit coeval with Irish Sea ice 7 km west of Shrewsbury is of relevance (Wilson *et al* 1982, fig. 2, p 32). They ignored the then known stratigraphy at Mousecroft Lane.

The second attempt to interpret a database of over 700 mainly IMAU boreholes related to a 20 x 40 km block of ground between Shrewsbury and Whitchurch (Shropshire) (Thomas 1989). It is important to appreciate that these boreholes were the product of the cable percussive 'shell and auger' drilling technique widely used in site investigation. After adding some 50 other borehole records, an average coverage of one

per square kilometre was achieved. Thomas's main approach was to reconstruct a series of stratigraphic sections through his study area. A secondary objective was to devise geomorphological maps of sediment-landform assemblages rather than ones based simply on lithology. Critically it was *assumed* that all the glaciogenic sediments proved in the boreholes were attributable to the Late Devensian glaciation (Dimlington Stadial). Considering the extent of LGM sedimentation which remains in the current interglacial, the question arises as to the plausibility of erosion during the last interglacial removing all traces of any earlier glaciations.

In agreement with the conclusions of earlier workers, e.g. Peake (1981), till of Welsh origin was found to be restricted to west of a zone between Shrewsbury and Ellesmere. Surprisingly, the borehole evidence was interpreted as indicating that the Welsh till did not represent a readvance after the retreat of the Irish Sea glacier; rather the dominant picture was of Irish Sea till overlying Welsh. This was the case in 10 of the boreholes out of 14 where the two tills were present. This conclusion was contrary to the observations of many workers who had observed Welsh over Irish Sea till in field exposures. Unfortunately, there remains ambiguity about the position of the Severn Glacier maximum or where the Irish Sea Ice Sheet was in contact with the former. In some of the cross-sections, the two till types were not discriminated (Thomas 1989, figs 1, 3, 8, 11 and 14). Confusingly, in others a black triangle symbol denoted Irish Sea till (figs 6, 7, 9), but in others the converse applied with black triangles denoting Welsh till (figs 4, 6, 7, & 9). The index map to figure 7 showed a Welsh till limit some 5 km west of Shrewsbury. In a review of north-east Wales, Thomas (2005, fig. 4) has a map showing the maximum extent of both the Irish Sea and Welsh glaciers in Shropshire, although these limits are somewhat revised from the positions shown in Thomas (1989, fig. 4). Again, the Welsh ice maximum is clearly shown to lie west of Shrewsbury.

***Figure 14**. Map of the Irish Sea (yellow) and Welsh (purple) ice advance limits in the Shropshire borderlands extracted from the 'Glaciation of Wales: flow direction of the Welsh and Irish sea ice' map in Howells (2007, fig 65, p 184). The Welsh readvance limit (green) is labelled as the 'Arvon Advance' but is not defined. The eastwards Welsh ice advance limit is incorrect being at variance with the glacial stratigraphy in the Shrewsbury area. (BGS © UKRI)*

The current BGS regional guide (Howells 2007) covers all of Wales and combines the former separate North and South editions. It also extends into the English-Welsh borderland region. Chapter 9 Cainozoic – features a map titled 'Glaciation of Wales: flow direction of Welsh and Irish Sea ice' (fig. 65). This is compiled from unspecified 'various sources'. An extract from the map covering the Shrewsbury borderlands is shown in Figure 14, with the claimed extents of the Irish Sea and Welsh ice in the area. Yet again, the outstanding anomaly is that the Welsh ice limit is placed some 5 km west of Shrewsbury and forms a roughly north–south trending limit extending for *c*. 30 km from Ellesmere in the north down to the Long Mynd.

It is difficult to understand why the many-times-published unambiguous stratigraphic evidence at the Mousecroft Lane pit has been persistently disregarded.

Conclusion

An attempt to define the Welsh ice limit in Shrewsbury is shown in Figure 15 using the base map taken from Cannell (1982). The position of the hypothetical advance maximum is guided by the distribution of surface till (Boulder Clay) to the east of the Mousecroft Lane exposures. Beyond this limit, Welsh glaciofluvial sediments predominate at the land surface for some 3 km towards the south east and these are interpreted as representing the extension of the Welsh palaeosandur. This surface falls some 5 m per km to the vicinity of Fox Farm (SJ 520 840) where there is an abrupt fall of 15 m. An extract from the BGS Digimap is shown in Figure 16. It is suggested that this abrupt termination was controlled by the level of a glacial lake occupying the low ground adjacent to the present-day River Severn (effectively a lower-level successor to Lake Lapworth). In part, the steep slope is possibly a relict delta front (Fig. 17). The major kettle holes at Fox Farm relate to melt-out of buried glacier ice after the delta functioned and this is likely to have obscured the original deltaic geomorphology (Fig. 15). Nevertheless, the interfluves in the landscape have a planar landform which reflect the wider relief when the Welsh sandur gravels were deposited.

Undoubtedly an advance of a Welsh glacier attained Shrewsbury after the withdrawal of Irish Sea ice as the Mousecroft Lane quarry evidence attests. An attempt to define the Welsh readvance ice limit in Shrewsbury

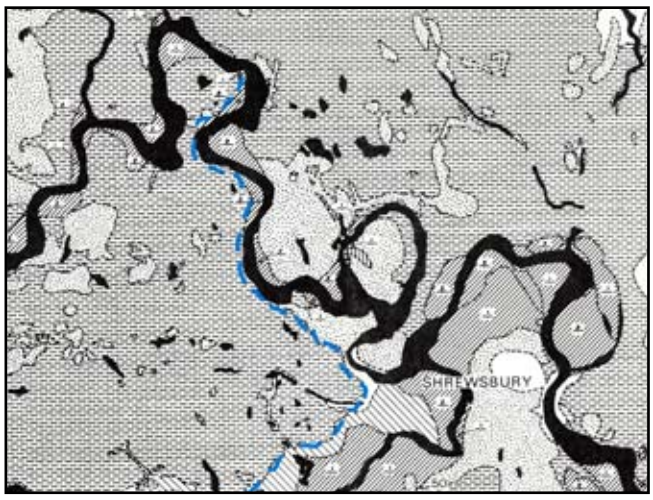

***Figure 15**. The dashed blue line approximates to the Welsh ice advance limit south of the River Severn in Shrewsbury. This is superimposed on part of the 'Drift geology map' in the Shrewsbury Mineral Assessment report (Cannell 1981, fig. 4). (Geological map data BGS © UKRI 2023)*

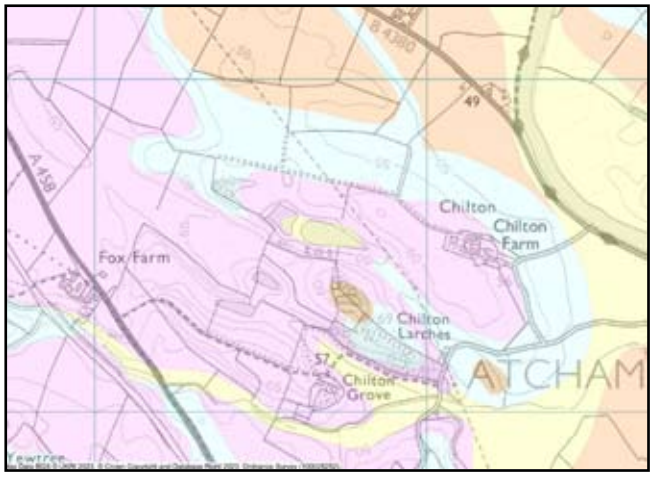

***Figure 16**. British Geological Survey Digimap of the Fox Farm area. Pink areas represent the distribution of glaciofluvial sediments, in large part those of the Welsh readvance sandur. (Geological map data BGS © UKRI 2023)*

is shown in Figure 18, adapting the map from Cannell (1982). The postulated position of this hypothetical advance maximum is guided by the mapped junction of till and glaciofluvial sediments. Beyond this limit, Welsh glaciofluvial sediments provide the present land surface for some 3 km towards the south-east and these are interpreted as representing the proglacial Welsh ice palaeosandur. In the early 1960s a gravel pit (SJ 517 097) 0.5 km north-west of Fox Farm showed 2–3 m of Welsh gravels lying unconformably over Stockport Formation red till, red sands and silts. Unfortunately, this was later landfilled.

Undoubtedly, a major causative factor in determining the landform character of the Shrewsbury area away from the river valleys is the former presence of buried ice. The resultant kettle-hole landforms are widespread and urban expansion has seen the hummocky kettled terrain utilised for housing. A good example is the area immediately north and east of the former Mousecroft Lane quarry where the Radbrook Green housing estate design has incorporated the kettle holes as green oases in the urban landscape. An impression of the hummocky kettled landscape beyond the northern limit of the quarry prior to the development of the Radbrook estate in the mid 1970s may be seen in Figure 19. The developer was aware of the dangers posed by kettle infills and in seven cases piles and ring beams were specified for house foundations. Alas, an injudicious failure affected two closely built detached houses (SJ 787 117) and these were demolished in 1981, with the site being incorporated into an enlarged adjacent garden (Fig. 20).

Much of the former Mousecroft Lane quarry site is now owned by Shrewsbury Town Council and is devoted to recreational use (Fig. 4). Part constitutes the 'Mousecroft Community Woodland' and the Mousecroft Pool is a fishery. The unwary might be fooled into thinking that the major hollows at the site are natural features akin to kettle holes. The Mousecroft pool is due to a shallow dam across a minor tributary of the Rea Brook.

***Figure 17**. A view to the south-east of the Fox Farm palaeo-delta surface on the skyline and adjacent possible ice-contact collapse slope (SJ 523 092).*

***Figure 18**. View north-east from the surviving delta top surface with two kettle holes, the farthest one over 15 m deep, which puncture it (SJ 524 093).*

***Figure 19**. The hummocky landscape, covered by Welsh till immediately north of the Mousecroft Lane quarry before the construction of the Radbrook Green housing estate in the late 1970s. A small kettle hole lies in the foreground. View to the north east from SJ 474 113.*

***Figure 20**. Two houses built over a shallow kettle hole infill: (a) No 1 Loxdale (left) and No 12 Six Acres (right) showing differential subsidence just before demolition in 1981; the builder had erected a high boundary fence so as not to publicise the problem; (b) the site as seen in 2023.*

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Peter Worsley, School of Archaeology, Geography and Environmental Science, University of Reading, RG6 2AB. p.worsley@reading.ac.uk