Late Pleistocene geology of the Chelford area of Cheshire

Peter Worsley

Abstract: The surficial stratigraphy of the nationally important Chelford area is dominated by sediments of Devensian age that relate to palaeo-climates colder than today. Changing periglacial and glacial environments can be reconstructed. A buried palaeo-valley, cut into bedrock, contains evidence of successively a cold interstadial, a glaciation, alluvial fan aggradation during an allied boreal interstadial, and finally glaciation at the Last Glacial Maximum. A history of investigation includes attempts to establish an absolute timescale using radiocarbon and thermoluminesence dating techniques. A bibliography of published works on Chelford is included.

In the context of understanding the Last Glacial Stage (Devensian) in Britain, the Chelford succession is particularly significant. The provisional systematic classification of the British Quaternary (Shotton and West, 1969), proposed that Farm Wood Quarry, Chelford [SJ812732], be designated as the stratotype site for the Devensian Stage as a whole. A late change in opinion saw Chelford being superseded in the definitive version by the newly discovered locality at Four Ashes some 65 km to the south in Staffordshire (Mitchell, *et al.* 1973; Worsley, 2005a). This switch appeared compelling, but, in the light of later stratigraphic discoveries in east Cheshire and also the desirability of having fresh glacial depositional landforms in a type area of this age, the case for it has subsequently become less convincing (Worsley 1986).

The main Chelford resource is industrial silica sand which is used in the manufacture of clear glass, fibre glass and foundry mouldings when mixed with bentonite or resin. Its value is twice that of construction sand. In 1962 Martin Bros (Chelford) Ltd operated the Farm Wood Quarry, and British Industrial Sands (BIS) worked both at Dingle Bank [SJ807718] and Farm Wood (south). BIS then absorbed the Martin Bros operation, but in the late 1970s the enlarged BIS was bought by Hepworth Minerals and Chemicals (HMC). Subsequently HMC sold their quarrying interests to WBB Minerals, the well-established miners of the Oligocene ball clays in Devon. In 2009 WBB was incorporated into Sibelco Uk, to become part of the Belgian-owned international minerals conglomerate. Fortunately, the continuous quarrying of sand has ensured availability of exposures until the present day. As a result of ground water pumping, dry quarry workings have been the norm. The principal exception was Farm Wood Quarry, where the sands were abstracted by suction dredging from a lagoon; hence the lower part of the succession there was always obscured, and recourse was necessary to borehole data and examination of material brought up by the dredge.

Inevitably over the last six decades quarrying locations have changed, although the main processing plant has remained at Dingle Bank, where it is fed by a conveyor belt network. The generalised distribution of the various quarries is shown in Figure 1, and an air photograph shows the original 1950-60s quarry at Farm Wood (Fig. 2). The pioneer Farm Wood Quarry is now a lake and part of a nature reserve. By chance, during 2015, periodically active quarry faces at the extreme north end of the Oakwood Quarry [SJ 815732] are very close to the original workings at Farm Wood Quarry.

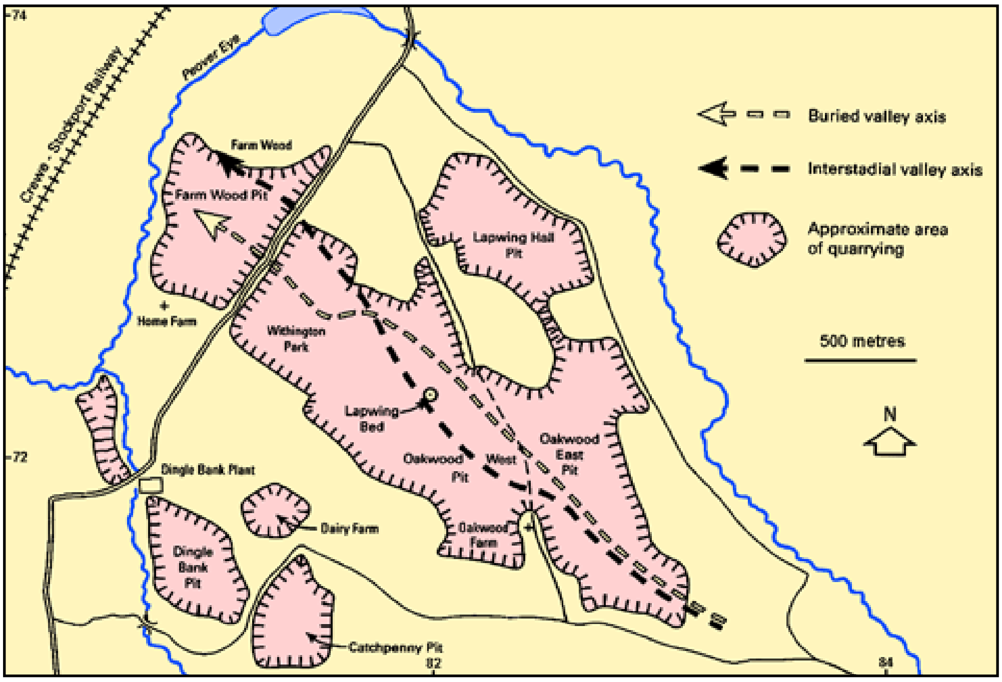

***Figure 1**. Locations of the main quarries that have yielded industrial silica sand in the Chelford area. In 2015, the active workings were extending Oakwood East Pit to the south east along the axis of the palaeovalley beyond the quarry limit shown on the map. The axis of the buried palaeovalley, which is cut into bedrock, and that of the interstadial palaeo-channel both fall towards the northwest on closely similar alignments.*

History of investigation

The primacy of the Chelford Quaternary geology has led to a wide range of investigations from the mid-1950s onwards. Much of the glacial geology of Cheshire and south Lancashire was for many years classified in terms of a tripartite Lower Boulder Clay, Middle Sands and Upper Boulder Clay lithostratigraphy. This framework gave rise to the concept of two discrete glacial advances separated by a significant retreat phase of unknown duration and extent. The most ardent advocates of this interpretative model were Einar Poole and Arthur Whiteman, both British Geological Survey officers and authors of the Nantwich and Whitchurch memoir (Poole and Whiteman, 1961, 1966). This latter map sheet lies immediately southwest of the BGS Macclesfield Sheet 110, which includes the Chelford area (Pocock 1906; Evans *et al.* 1968).

Figure **2**. *Air photo of the Farm Wood Quarry in 1962 (north towards the top). This remains the stratotype site of the Chelford Interstadial.*

Whiteman initiated Quaternary research at Chelford in 1955 where he discovered a peat bed cropping out within 'Middle Sands' at the Farm Wood quarry. Since he had links with Wally Brooker, who was developing a radiocarbon dating facility at the Lamont Geological Observatory in New York, a peat sample was submitted to Lamont for radiocarbon assay (Whiteman pers com, 1972). Another early Survey worker who made observations at Chelford was R.C.B. Jones and he had speculated, along with W.B. Wright, that the sands might be of Pliocene age (Jones pers com, 1968).

In 1956 Russell Coope commenced collecting peat for the extraction of coleoptera at Birmingham. Concurrently, Morven Simpson of the Department of Geology at the University of Manchester was engaged in investigating the glacial succession in the south Manchester area which he interpreted using the well-established tripartite model (Simpson, 1959, 1960). His interest in Chelford dates from when a quarry worker arrived at his office in the University in 1957 to present him with a peat sample from the Farm Wood Quarry. Appreciating the peat's potential significance to the problem of the 'Middle Sands' chronology and palaeoenvironment, he invited Richard West to collaborate on a palaeobotanical and stratigraphical study of the peat and its context. Analyses of the macro fossils and pollen suggested that Chelford peat was of boreal forest in character and that it might correlate with the Brørup interstadial of the early part of the Last Glacial Stage in Denmark (Simpson and West, 1958). An independent study of the contained beetle faunas was undertaken by Russell Coope and his conclusions were similar, with modern south-central Finland being proposed as a modern analogue (Coope, 1959). However, both of these studies assumed that the stratigraphical position of the Chelford peat was within 'Middle Sands' of the classical tripartite model.

The writer's first visit to Chelford was in August 1962 on a field excursion led by Morven Simpson for the meeting of the annual British Association for the Advancement of Science in Manchester. The tripartite

***Figure** 3. View of the north face of the Farm Wood quarry in 1962. The undulating unconformity between the Chelford and Stockport Formations is evident. The Farm Wood Member (Chelford Interstadial) crops out just above the lake level (see Fig 4).*

***Figure 4**. The Farm Wood Member of the Chelford Interstadial at outcrop, just above the level of the lagoon, below the north face of Farm Wood quarry in 1963.*

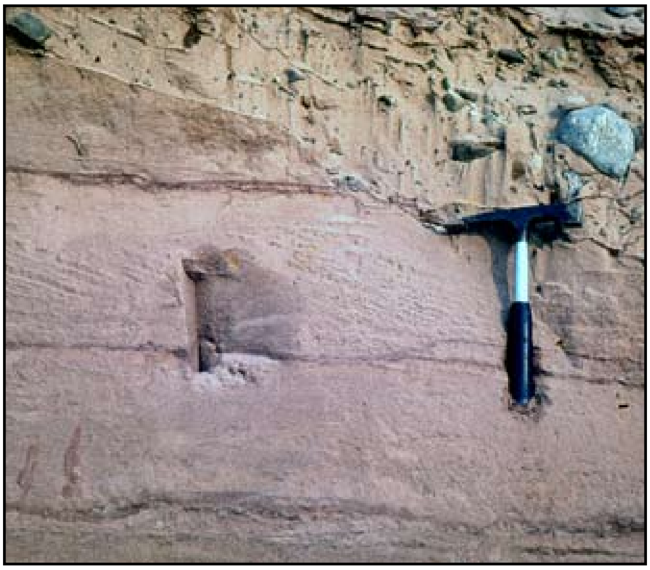

***Figure 5**. The Chelford Sands unconformably overlain by Stockport Formation outwash facies, with its range of clast lithologies, in the east face at Farm Wood in 1963.*

model was promulgated to the attendees. However, on that occasion the south-facing quarry face at the Farm Wood Quarry exposed erosional channels that separated upper 'light reddish brown' sands 5YR 6/3 and till from 'white' sands 10.5 YR 8/2 (Munsell soil colour chart notations) beneath (Fig. 3). The white sand was host to the peat bed that cropped out just above the lagoon level (Fig. 4).

Seeking a suitable postgraduate research topic, the writer returned to the site. Closer examination of the sedimentology of the sands containing the peat bed at Chelford showed that there were distinctive differences between these sands and the standard 'Middle Sands', and in particular the clast lithologies were dissimilar. For example, northern derived igneous rocks were exceptionally rare, and fragments of Carboniferous coal and Pleistocene derived molluscan materials were completely absent (Fig. 5). Further, the sedimentary structures indicated palaeocurrent flows from ESE to WNW. It also became clear that a major erosional unconformity separated two distinctive sand successions; the lower was a non-outwash, alluvial-fan sequence (which also contained the interstadial peat bed), and that was overlain by glacigenic, red sands (which were the traditional glacial outwash known as the Middle Sands). Significant fluvial incision of the alluvial fans appeared to have occurred immediately prior to the area being over-ridden by glacial ice. To aid analysis and discussion these two successions were formally assigned as respectively parts of the Chelford Sands Formation (this included the Congleton Sand) and the glacigenic Stockport Formations (Worsley, 1966, 1967b).

It is noteworthy, that Pocock, during his pioneer mapping for Sheet 110 for the Geological Survey, was able to discriminate two sand sequences in the Chelford district: '… beds of gravel and reddish sand …can be seen resting on an eroded surface of the white sand' (1906, p94). Furthermore, he and his associates wrote their memoir without any reference to the tripartite scheme. The lessons from this were to be overlooked for more than half a century. During 1959-60 the Chelford area was resurveyed by Wyndham Evans, David Price and Albert Wilson as part of the Sheet 110 revision. This map was published in 1968 along with a memoir (Evans *et al*., 1968). During the resurvey, Pocock's bipartite sand sequence was confirmed but the rigid mapping convention then mandated by the District Geologist prevented abandonment of the term 'Middle Sands' and sheet 110 subsumes the Chelford Sands within the 'Glacial Sand and Gravel' classification (W.B. Evans pers com,1964).

A separate issue concerned the significance of complex glacigenic sequences (multiple tills, outwash and lake facies) and hummocky terrain in east Cheshire. Existing, simple, depositional models relating to temperate valley glaciers proved inadequate, and had to be substituted by more realistic models incorporating observations from modern sub-polar and polar glacial environments where the role of supraglacial sedimentation was recognised. Application of these concepts led to the abandonment of the classic tripartite glaciation–retreat–glaciation

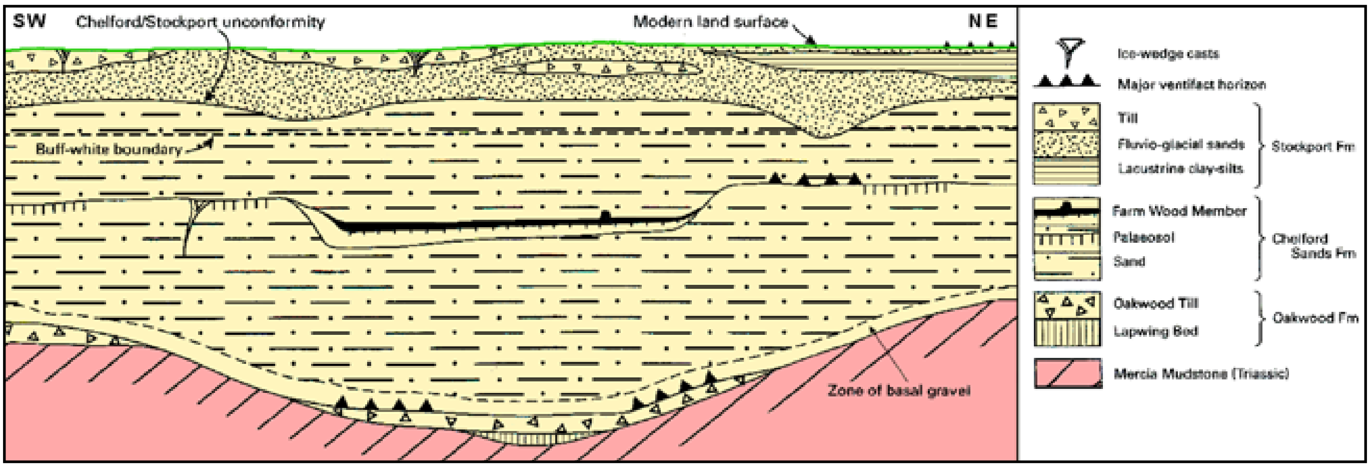

***Figure 6**. Schematic profile through the Pleistocene succession in the Chelford area. The peats and sediments of the Farm Wood Member overlie a palaeosol and sandy fill within a channel that is within the Chelford Sands Formation.*

***Figure 7**. Oakwood West Quarry viewed to the northwest, with the Farm Wood Member in the middle of the sequence. Norfolk Farm (now demolished) is behind the face on the right. Left of the pump, a conical mound was the debris from excavating the drainage sump. This material gave the first clue to the presence of a sub-till stadial deposit overlying the Mercia Mudstone.*

model, and most, if not all, of the then known glacial sequences were reinterpreted as the products of a single phase of ice advance and retreat that was associated with significant supraglacial deposition during the Last Glacial Maximum (LGM) c.20 ka BP (Boulton and Worsley 1965; Worsley 1967a; Boulton 1972).

Though this paper focuses on the immediate Chelford area, it is estimated that the Chelford sand may have extended over 100 km^2 if the Congleton and Sandbach areas are included (Evans *et al* 1968; Worsley, 1967, 1991, 2008). The bibliography includes all the published papers and theses known to the writer and containing more than incidental references to the Chelford geology. A schematic cross-section of the Chelford succession is shown as Figure 6.

Bedrock geology and morphology

A thick superficial cover makes bedrock mapping difficult, but borehole data show that the area is underlain by the Triassic Mercia Mudstone Group (Evans *et al.*, 1968). The Chelford area is underlain by a 300m-thick sequence of shales and mudstones that separates the Northwich and Wilkersley Halite Formations within the Mercia Mudstone. A postulated fault in the northeastern sector may bring the Wilkesley Halite Formation (Upper Saliferous Bed) to rockhead, but the salt is likely to be overlain by a thick layer of collapse breccia derived from the overlying mudstones. Occasionally, Mercia Mudstone is recognisable on the quarry floors. The rockhead forms a palaeovalley, some 15 m deep and close to 1 km wide, trending and falling from SE to NW. This feature is infilled by the thickest sand sequence, and quarrying of the sands has progressively exhumed the valley floor (Fig. 7). Although it was not appreciated at the time when it was an active quarry, the Farm Wood succession lies above the axis of this valley (Fig. 1).

Lapwing Bed and Oakwood Till

These two beds form the lowest part of the local, known, Pleistocene succession. The tripartite interpretative model assumed that till lay beneath the main sand succession. Later, doubts arose as to the nature of the sediment immediately beneath the lower sands, since the weathered top of the Mercia Mudstone could mistakenly be identified as a till. The base of the main sand sequence was usually obscure in exposures due to a seepage zone, but a thin bed of red-brown sand and gravel was apparently widespread. Occasionally, drainage ditches and sumps were excavated in the quarry floors for ground water pumping (Fig. 7). In 1979, a commissioned

Figure 8. Planar and trough cross-stratification and horizontal lamination in alluvial sands forming part of the lower sands at Oakwood West. These were deposited prior to the incision of the interstadial palaeochannel.

trench adjacent to a sump in the Oakwood West quarry [SJ821721] exposed a metre-thick succession of silts and gravels overlying Mercia Mudstone; these formed the Lapwing Bed, which contained a cold stadial fauna and flora (Worsley *et al.*, 1983). The Coleopteran mutual climatic range (MCR) estimates have a temperature maximum between 9°C and 11°C and a minimum between –27°C and –23°C. It is significant that this succession was overlain by Oakwood Till; adjacent to this location spreads of till were up to 3 m thick, and a wide scatter of large erratic clasts on its surface had many showing evidence of wind abrasion and facet formation. Such an unambiguous till exposure was unusual.

In their review, Bowen *et al.*, (1986) were mistaken in believing that the till was beneath the fossiliferous Lapwing Bed and not above it. However, they asserted that 'a D:L determination on *Lymnaea peregra* …. is pre-Ipswichian', based on the age-sensitive proportion of D and L isomers of a particular amino acid. Unfortunately therefore, on the basis of this measurement, their statement that the till is pre-Ipswichian is unproven, although the balance of probability is that this is so.

Chelford Sands Formation

In the Chelford area the surviving thickness of the Chelford sand is determined by two factors, the relief of the basal surface, and the geometry of the unconformity between the Chelford Sands and the Stockport Formation. In only very restricted areas do the Chelford Sands crop out at the natural land surface.

Uniformity of grain size makes the identification of sedimentary structures difficult in fresh faces but after wind etching the sand sequences are characterised by a pervasive near horizontal stratification when viewed from a distance. This suggests that the relief of the depositional environment was low, and distal alluvial fans appear to provide the best modern analogue (Worsley, 1967a). In detail, there is a range of bedforms including trough, cross, and planar cross-bedding, scour fills, all dominated by horizontal and low-angle stratification (Fig. 8). Shallow, low-sinuosity stream sediments appear to dominate the lower part of the sequence, whereas the upper part has a major component of aeolian, sand-flat deposition with affinities to coversands. Ventifacts occur sporadically throughout the succession (Thompson and Worsley, 1967). Most of the sands are white in colour, but towards the top they may abruptly become buff-coloured. Uncertainty prevails as to the full significance of this colour change, and there is evidence to support both a switch in sand source (e.g. Fig. 18) and post-depositional leaching.

Farm Wood Member interstadial deposits

It is striking how the main linear development of the interstadial deposits (Farm Wood Member); lying approximately in the middle of the main sand succession, largely coincides with the palaeovalley axis beneath. In the Oakwood Quarry, a palaeochannel 4-5 m deep and <400 m wide, with sides sloping at the angle of repose for sand, contained the interstadial deposits (Fig. 9). Channel bifurcation occurred and at one location in the Oakwood West Quarry three separate channels could be identified. Several

***Figure** 9. Oakwood West Quarry. A section some 6 m high through the southwestern interstadial channel margin. A peat bed on the flat floor of the channel extends part way up the channel margin, due to post-depositional peat compaction. The erosional base of the channel lies mid-way between the peat base and quarry floor. A set of large-scale cross-strata beneath and left of the rising peat bed formed where an aeolian dune was feeding sand off the adjacent land and into the channel shortly after the incision event.*

Figure 10. [right] An example of the 'flood facies' within the palaeochannel, consisting of a tangle of reworked organic debris that signify a flashy flow regime within the incised channel system.

Figure 11. [below] Two cones of Pinus *embedded in the felted peat from the Farm Wood Member in the incised interstadial palaeochannel (50p coin for scale).*

Figure 12. [bottom] A pollen grain of Pinus sylvestris *from the interstadial member.*

sedimentary facies could be distinguished including felted peat, mossy peat, woody humified peat, detrital mud and sand with dispersed organic matter. Chaotic flood debris included broken branches and trunks (Fig. 10) plus cones of pine (Fig. 11) and spruce, all in a sand matrix, along with rare *in situ* tree stumps (Fig. 13). Some clastic stumps have conical upper ends reminiscent of beaver-felled stumps (Worsley, 2009). Palaeobotanical investigations were initiated by Richard West at Farm Wood and continued by Frances Green (1991) at Oakwood as part of a study of the interstadial palaeogeography, making comparison with potential Nordic analogues.

The flora is dominated by *Betula-Pinus-Picea* tree assemblages (Fig. 12) but with rich herbaceous species (Ericaceae) that typify forest floors. Six species of calcifuge mosses were identified (Dickson, 1967, 1973). For the first time, Green identified *Bruckenthalia spiculifolia,* a species indicating open heath conditions, which presumably existed beyond the confines of the main channel. She also elucidated the history of the interstadial forest development, with an initial phase of dense pine forest that later included spruce and became more open. Mature trees attained a girth approaching 2 m. Forest fires were recurrent as charcoal is present though much of the sequence and some of the tree trunks were obviously charred. Overall, the Chelford trees appear to have been restricted to the sheltered, incised valley and to have formed a gallery forest with acid mossy mires and pools. Moseley (1982) established that the Oakwood Coleopteran fauna is identical to that described by Coope (1959) at Farm Wood. The MCR estimates yield a maximum temperature between 15°C and 18°C and a minimum between –11° and +1°C (Coope pers com, 2005). Periodic flooding swept through the valley, damaging the woodland.

Figure 13*. A rare in situ tree stump (Picea abies) within the Farm Wood Member in the Oakwood West Quarry (55mm lens cap for scale).*

Figure 14*. The interstadial palaeosol consisting of two thin organic rich beds and allied rootlets. This marks the land surface adjacent to the incised interstadial palaeochannel.*

Palaeosol

A widespread, weakly developed palaeosol was present in a number of exposures beyond the limits of the palaeochannels. This soil developed on a land surface that was contemporary with the incised channel, as it could be traced directly to the top of the palaeo-channel walls. It is characterised by either a thin, organic-rich mat or a bed of fine rootlets extending vertically downwards (Fig. 14). Rare cylindrical structures, a few centimetres in diameter and containing more silty material, were present, and these appear to be burrow infills. In places, the soil passed into a pebble lag horizon, indicating deflation of any pre-existing soil. There appears to be little relief associated with the former land surface, which can be identified up to 1 km away from the palaeo-channels. During the interstadial stage this surface was probably covered by shrubby heathland vegetation with *Calluna sp.*, but conditions were too dry and exposed for tree growth. We may infer a cessation or much reduced sediment supply through the regional alluvial fan system during the interstadial, with the main runoff being restricted to the incised valleys.

Provenance of the Chelford Sands

Once it became clear that the Chelford sands were not glacigenic the question of their source arose. The answer was influenced by two main factors Worsley (1967a). First was a palaeo-current pattern that suggested a basic east to west flow over the entire area where the sands could be identified (this included the sands in the Congleton area). Second was a systematic examination of clast composition. This showed that the dominant clast component was derived from Carboniferous sources but there was also an important secondary contribution from the Permo-Triassic, suggesting the western Pennines and their foothills as the source region. In the early 1960s a debate on the origin of tors was raging, and tors are numerous along the sandstone escarpments of the western Pennines. The debate focussed on the role of deep chemical weathering, as opposed to mechanical disintegration under periglacial climates, in tor formation (Linton, 1964). Both hypotheses required the production of sand that was subsequently flushed away from the tor sites. The presence of tors and deeply weathered Carboniferous sandstones within river catchments that drain onto the Cheshire Plain supported the concept of mass removal of unconsolidated sands as a potential source contributor to the Chelford Sands. For example, within the catchment of the River Dane a thickness of 30 m of weak, *in situ* Rough Rock sandstones were worked as foundry sand at the Hurst Quarry, Biddulph [SJ 901595].

***Figure 15**. Massive, clast-poor diamicton of Irish Sea derivation that is typical of the Stockport Formation till overlying the Chelford Sands; in Oakwood East Quarry. A lack of disturbance to the underlying stratification, below the contact, suggests that the sands were frozen when over-ridden by the glacier.*

Later, more sophisticated techniques were applied to the problem, including heavy mineral analysis, clay mineralogy, sand grain petrology and scanning electron microscopy (Good, 1984a). The balance of evidence favoured the Sherwood Sandstone Group as an important source of the sand, but the case was not overwhelming. Data indicated that palaeo-currents were from a general easterly sector, and the clasts were dominated by Carboniferous materials. What was clear was that there could not have been a direct supply from Sherwood Sandstone sources, because suitable outcrops upstream to the east were of limited extent.

The most likely scenario is that there is no single source for the sands, and that Carboniferous and Permo-Triassic sources have both probably contributed. Apart from the Chelford Sands, there is currently no evidence from the region of aeolian sediments or glaciofluvial deposits dating prior to the Last Glacial Maximum. A major Permo-Triassic sand contribution initially requires a transport mechanism capable of moving material against the regional slope to a storage location. This would then enable the sediment to be later moved westwards by the fluvial fan systems that functioned during Chelford Sands deposition. Earlier in the Pleistocene, both or either aeolian and glacial agencies may have eroded Sherwood Sandstone outcrops and moved considerable quantities of the sand towards the Pennine footslopes. There, sands derived from the deeply weathered gritstones would have added to the sediment store.

Stockport Formation

A major unconformity occurs at the top of the Chelford Sands, and just to the north of the Farm Wood quarry limits this is of sufficient magnitude to cut out the entire sequence. Above lies the Stockport Formation of glacigenic origin. In the various Chelford quarries the Stockport Till is relatively thin, with a thickness of 2–6 m (Fig. 15). It is highly variable in nature, including massive till, lacustrine units (Good, 1984b) and outwash lithologies. A considerable part of the latter is probably recycled from the Chelford sands beneath. Evans *et al* (1968) use the term Gawsworth sands – this is a facies within the Stockport Formation. In places an aeolian cover lies above the till (Fig. 16).

***Figure 16**. Aeolian sands with a horizon of ventifacts post-dating the Stockport Formation, at about a metre below the modern land surface, in the Oakwood East Quarry.*

***Figure 17**. An ice-wedge cast descending from the palaeosol horizon. This is seen in oblique section, and would appear vertical if viewed along the strike. The thin lag of pebble-sized clasts indicates aeolian winnowing at the contemporary land surface.*

***Figure 18**. [below left] A truncated ice-wedge cast in white sands at the Catchpenny Quarry. Above the unconformity, horizontally laminated, buff-coloured sands that characterise the upper part of the succession are probably aeolian sand-flat deposits and compare with the classic coversands of the Low Countries. The trowel handle is 13 cm long.*

***Figure 19**. [below right]A clastic dyke (water-release structure) penetrating sands within the Stockport Formation. These sands are reworked from the underlying Chelford Sands, but incorporate abundant fragments of Carboniferous coal. The trowel's wooden handle is 13 cm long.*

Evidence of permafrost

Ice-wedge casts, resulting from the decay of ice wedges, are not common in the Chelford area (Worsley, 1966, 1987), and can easily be confused with the more numerous water-release structures, which do not signify the presence of permafrost. Most, if not all, of the intraformational frost cracks originally reported from the Chelford Sands (Worsley, 1966, 1987) are now thought to be of the latter genesis. The principal interformational horizons of development are the palaeosol lateral to the interstadial palaeochannel (Fig. 17), the base of the Stockport Formation, and just below the modern land surface, although others exist (Fig. 18). They therefore range in age from after the Chelford Interstadial (post c.100 ka), immediately prior to over-riding by glacial ice (c.25 ka), and after deglaciation has commenced (c.18 ka). Clastic dykes are present within the Stockport Formation and are not palaeopermafrost indicators (Fig. 19).

Radiometric dating

Whiteman's peat sample for radiocarbon dating was collected in the pioneering days of the technique. As the Farm Wood Member was clearly pre-LGM in age, there was a particular interest in Chelford by laboratories wishing to extend the age range of the technique. At the time there was a strong belief that it would be possible to derive finite ages of <50 ka (Worsley, 1980). Eventually the inescapable conclusion was that the peat age lay beyond the physical capabilities of the method. This conclusion was strengthened by correlation of the Farm Wood Member paleobotanical record with the early Weichselian St Germain I interstadial at Grande Pile in northeast France (Woillard, 1978; Woillard and Mook, 1982). In turn, it appears probable that the Chelford Interstadial correlates with substage 5c of the marine oxygen isotope record, which has an absolute age close to 100 ka.

A pioneer study using the Optically Stimulated Luminescence (OSL) technique reported an age of 75-90 ka for sands above the interstadial horizon (Smith *et al*., 1990). An alternative approach was to employ Thermoluminesence (TL) dating, mainly using feldspars but also some quartz mineral fractions (Rendall *et al.,* 1991). This study was based on samples collected from Oakwood East Quarry [SJ826718], and results from the feldspars and quartz were in good agreement with each other. Age estimates from just above and just below the Farm Wood Member give an age range of 90-100 ka for the interstadial. Additionally a sample of Chelford Sand just below the Stockport Formation unconformity yielded an age estimate of 21 ka, very close to the Middle–Upper Devensian boundary, which is defined as 26 ka ^{14}C years (Mitchell *et al*., 1973).

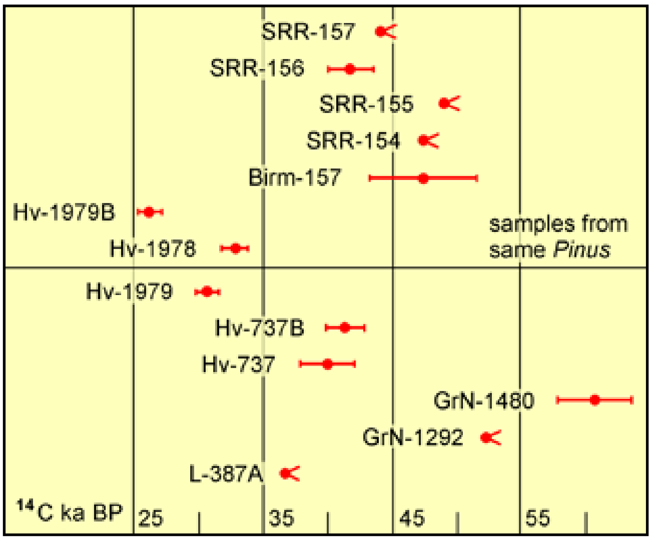

Figure 20*. Plot of all the Chelford (and Arclid) radiocarbon age estimates, with error bars or indicators that the determined age is only a minimum. For further details see Worsley, 1980. Sample GrN-1480 was isotopically enriched. The upper seven samples wer all from the same tree. These assays suggest that the organic material has a true age beyond the limits of the dating method.*

Reflections on the Chelford sediments

As befitting an area that was a leading candidate for the role of stratotype site for the Devensian cold stage, the Chelford area possesses a wide range of Quaternary geological features, both glacial and periglacial, many of which are still observable. Continued quarrying is still uncovering new exposures and new data. Although Four Ashes displaced it as the stratotype site, this was largely on the basis of 50 ephemeral, thin, organic lenses, none of which survive in the field at the present day. In contrast to Chelford, the former aggregate quarry at Four Ashes (which still defines the Devensian stratotype) is today infilled and covered by a major landfill mound.

It has generally been assumed that the Chelford Sands Formation is entirely of Devensian age. Nevertheless, a significant part of the lower sand sequence at Chelford clearly antedates the eponymous interstadial. It could be pre-Devensian in age, since the sole lower biostratigraphic constraint is the non-specific Lapwing Bed and Oakwood Till. Therefore, from a lithostratigraphic perspective, the lowermost sands might correlate with one of several earlier cold stages.

Acknowledgements

Grateful thanks for their cooperation are extended to Ken Dale who was the manager at Dingle Bank, and to Mike Lavender who was the BIS/HMC chief geologist. Many people have discussed aspects of Chelford geology, but I would particularly like to thank Ian Bryant, Tim Good, Frances Green, and the late Wyndham Evans, Chuff Johnson and David Thompson. Hilary Jensen and Tony Waltham kindly assisted with the figures. Much of this paper is revised and updated from Worsley, 2005a.

References and bibliography

Boulton, G.S., 1972. Modern Arctic glaciers as depositional models for former ice sheets. *J. Geol. Soc.*, **128,** 361-393.

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

Bowen, D.Q., Rose, J., McCabe, A.M. & Sutherland, D.G., 1986. Correlation of Quaternary glaciations in England, Ireland, Scotland and Wales. *Quat. Sci. Rev.*, **5**, 299-340.

Brown, J.E., 1972. *The application of selected recent sedimentological techniques to some Pleistocene sands of NE Cheshire*. Unpublished MSc thesis, University of Manchester.

Brown, J.E., 1973. Depositional histories of sand grains from surface textures. *Nature,* **242**, 396-398.

Coope, G.R., 1959. A Late Pleistocene insect fauna from Chelford, Cheshire. *Proc.Roy. Soc.*, **B151**, 70-89.

Coope, G.R., 1977a. Stop 4: Oakwood sand pit, Chelford. In Shotton, F.W. ed. *The English Midlands*. Guide book A2, Norwich, X INQUA Congress, 32-33.

Coope, G.R., 1977b. Fossil coleopteran assemblages as sensitive indicators of climatic changes during the Devensian (Last) cold stage. *Phil. Trans. Roy. Soc.*, **B280**, 313-340.

Dickson, J.H., 1967. The British moss flora of the Weichselian glacial. *Rev. Palaeobotany Palynology*, **2**, 245-253.

Dickson, J.H., 1973. *Bryophytes of the Pleistocene*. Cambridge University Press. 256pp.

Evans, W.B. & Arthurton, R.S., 1973. North-west England. *Geol. Soc. Spec. Rept*., 4, 28-36.

Evans, W.B., Wilson, A.A., Taylor, B.J. & Price, D., 1968. Geology of the country around Macclesfield, Congleton and Crewe. *Mem. Geol. Surv*., 328pp.

Glasser, N.F., 2002. Chelford. In Glasser, N.F. & Huddart, D. eds. *Quaternary of Northern England*. Geological Conservation Review **25**, 131-135.

Good, T.R., 1984a. *The sedimentology of the Pleistocene Chelford Sands Formation, Cheshire*. Unpublished PhD thesis, University of Reading, 277pp.

Good, T.R., 1984b. Wave ripple-marks in glaciolacustrine clays at Chelford, Cheshire. *Quat. N/L.,* 42, 8-16.

Green, F.M.L., 1991. *The palaeogeography of the Chelford Interstadial, Cheshire*. Unpublished PhD thesis, University of Nottingham, 547pp.

Heijnis, H. & van der Plicht, J., 1992. Uranium/thorium dating of Late Pleistocene peat deposits in NW Europe, uranium/thorium isotope systematics and open-system behaviour of peat layers. *Chemical Geology*, **94**, 161-171.

Holyoak, D.T., 1983. The identity and origin of *Picea abies* (L) Karsten from the Chelford Interstadial (Late Pleistocene) of England. *New Phytologist*, **95**, 153-157.

Hunt, C.O., 1984. Erratic palynomorphs from some British tills. *J. Micropalaeontology*, **3**, 71-74.

Linton, D.L., 1964. The origin of the Pennine tors: an essay in analysis. *Zeit. Geomorph*., **8**, S, 5-24.

Mitchell, G.F., Penny, L.F., Shotton, F.W. & West, R.G., 1973. A correlation of the Quaternary deposits in the British Isles. *Geol. Soc.Spec. Rept*. 4, 99pp.

Moseley, K.A. 1982. *Climatic changes in the early Devensian cold stage interpreted from Coleopteran assemblages*. Unpublished PhD thesis, University of Birmingham, 472pp.

Pocock, T.I., 1906. The geology of the country around Macclesfield, Congleton, Crewe and Middlewich. *Mem. Geol. Surv*., 138pp.

Poole, E.G. & Whiteman, A.J., 1960. The glacial drifts of the southern part of the Shropshire-Cheshire basin. *Q. J. Geol. Soc.*, **157**, 91-130.

Poole, E.G. &nd Whiteman, A.J., 1966. Geology of the country around Nantwich and Whitchurch. *Mem. Geol. Surv*.. 154pp.

Rendell, H., 1992. A comparison of TL age estimates from different mineral fractions of sand. *Quat. Sci. Rev.*, 11, 79-83.

Rendell, H., Worsley, P., Green, F. & Parks, D., 1991. Thermoluminesence dating of the Chelford Interstadial. *Earth Planetary Sci. Letters*, **103**, 182-189.

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

Simpson, I.M., 1959. The Pleistocene succession in the Stockport and south Manchester area. *Q. J. Geol. Soc.*, **155**, 107-122.

Simpson, I.M., 1960. Stone-Counts in the Pleistocene of the Manchester area. *Proc. Yorks. Geol. Soc.*, **32**, 379-387.

Shotton, F.W. & West R.G., 1969. Stratigraphic table of the British Quaternary. *Proc. Geol. Soc.*, **1656**, 155-157.

Smith, B.W., Rhodes, E.J., Stokes, S., Spooner, N.A. & Aitken, M.J., 1990. Optical dating of sediments: initial quartz results from Oxford. *Archaeometry*, **32,** 19-31.

Thompson, D.B. & Worsley, P., 1967. Periods of ventifact formation in the Permo-Triassic and Quaternary of the North East Cheshire Basin. *Merc. Geol.*, **2**, 279-297.

Whitehead, P.F., 1977. A note of *Picea* in the Chelfordian Interstadial organic deposit at Chelford, Cheshire. *Quat. N/L.*, 62, 14-15.

Woillard, G., 1978. Grand Pile peat bog: a continuous pollen record for the last 140,000 years. *Quat. Res.*, **9**, 1-21.

Woillard, G. & Mook, W.G., 1982. Carbon dates at Grande Pile: correlation of land and sea changes. *Science*, **215**, 159-161.

Worsley, P., 1966. Some Weichselian fossil frost wedges from east Cheshire. *Merc. Geol.*, **1**, 357-365.

Worsley, P., 1967a. *Some aspects of the Quaternary evolution of the Cheshire Plain*. Unpublished PhD thesis, University of Manchester, 388pp.

Worsley, P., 1967b. Problems in naming the Pleistocene deposits of the North-East Cheshire Plain. *Merc. Geol.* **2**, 51-55.

Worsley, P., 1970. The Cheshire-Shropshire Lowlands. In: Lewis, C.A. ed. *The glaciations of Wales and adjacent areas*, London: Longmans, 83-106.

Worsley, P., 1977. Oakwood Quarry, Chelford. In: Bowen, D.Q. ed. *Wales and the Cheshire–Shropshire Lowland.* Guidebook A8 and C8, Norwich, X INQUA Congress, 53–56.

Worsley, P., 1978. Chelford. In: Francis, E.A. ed. *Field handbook.* Keele: Quaternary Research Association, 29-36.

Worsley, P., 1980. Problems in radiocarbon dating the Chelford Interstadial of England. In: Cullingford, R.A., Davidson, D.A. & Lewin, J. eds. *Timescales in geomorphology.* Chichester: Wiley, 289-304.

Worsley, P., 1985. Pleistocene history of the Cheshire-Shropshire Plain. In: Johnson, R.H. ed. *Geomorphology of North-west England*. Manchester University Press, 201-221.

Worsley, P., 1986. Excursion report: the glacial geology of the Cheshire-Shropshire plain. *Merc. Geol.* **10**, 225-228.

Worsley, P., 1987. Permafrost stratigraphy in Britain: a first approximation. In: Boardman, J. ed. *Periglacial processes and landforms in Britain and Ireland*, Cambridge University Press, 89-99.

Worsley, P., 1991. Glacial deposits of the lowlands between the Mersey and Severn rivers. In: Ehlers, J., Gibbard, P.L. & Rose, J. eds. *Glacial deposits of Great Britain and Ireland.* Leiden: Balkema, 203-211.

Worsley, P., 1999. Cheshire, Shropshire and Staffordshire lowlands. *Geol. Soc. Spec. Rept*., 23, 32-34.

Worsley, P., 2005a. The Cheshire–Shropshire Plain. In: Lewis, C.A. & Richards, A eds. *Glaciations of Wales and adjacent areas*, Logaston Press: Little Logaston, 59-72.

Worsley, P., 2005b. Quaternary geology of the Chelford area, Cheshire. In Crofts, R.G. ed. *Quaternary of the Rossendale Forest and Greater Manchester Field Guide*, Quaternary Research Association, 57-70.

Worsley, P., 2008. Pleistocene and Flandrian natural rock salt subsidence at Arclid Green, Sandbach, Cheshire. *Merc. Geol.*, **17**, 11-18.

Worsley, P., 2009. The physical geology of beavers. *Merc. Geol.*, **17**, 112-121.

Worsley, P., Coope, G.R., Good, T.R., Holyoak, D.T. & Robinson, J.E., 1983. A Pleistocene succession from beneath Chelford Sands at Oakwood Quarry, Chelford, Cheshire. *Geol. J.*, **18**, 307-324.

Peter Worsley,
Wager (Geoscience) Building,
University of Reading RG6 6AB
p.worsley@reading.ac.uk