The Quaternary sediments at Welton-le-Wold, Lincolnshire

Allan Straw

Abstract: The sediments at Welton-le-Wold have been described and discussed for some 40 years, mainly because of two important features, the discovery of artefacts beneath ancient tills and the direct overlay of Devensian till on one of these. Quarry operations ceased in 1973, and in 2004 a report for English Heritage (Aram et al, 2004) described renewed research and also presented an interpretation of environmental circumstances that differed from earlier accounts. The earlier views were re-iterated (Straw, 2005), but two recent papers (Green, 2011: Gamble 2014) relied on the 2004 version. Data concerning the sediments, their modes and environments of deposition are now confirmed, and age estimates place the older deposits firmly within MOIS 8 (300–245ka BP).

In 2014 an article was published (Gamble, 2014) romantically entitled 'Where elephants once roamed', referring to the find some 45 years ago in the Welton-le-Wold quarry [TF280882] of a massive tusk (2.2m long), several teeth and considerable, highly friable, skull bone. These fossils were discovered in the northeast part of the gravel workings that lay west of the road that runs north-south through the quarry (Fig. 1). Scanty remains of other mammals were also found, as were four palaeoliths of much interest to archaeologists. All the recovered material is lodged in The Collection, formerly Lincoln Museum. The finds alone render the site worthy of note, but there are also other geological and geomorphological features that make the Welton deposits distinctive and attractive to Quaternary scientists and others with interests in 'Ice Age' events.

Gamble (2014) reviewed past and present land-use, and schemes of conservation, because the site has been accorded SSSI, RIGS, LGS and LWS statuses. The most significant recent development has been the study carried out in 2003 to 2004 with financial support from the Aggregate Levy Sustainability Fund (ALSF), negotiated by Heritage Lincolnshire and generally endorsed by English Nature and English Heritage. The various projects that comprised the study were described and results were recorded at length in the project report for English Heritage (March 2004) entitled 'Towards an understanding of the Ice Age at Welton-le-Wold, Lincolnshire' (Aram et al, 2004). This report sets out much new information in considerable detail, but within Sections 4 (Discussion) and 6 (Conclusions and Recommendations) there are various statements and interpretations that are open to question and do not correlate with the situation on the ground. Reports on the artefacts and mammal remains are then inhibited by presumptions of a former river and temperate climate.

The writer examined and recorded workings in the quarries from 1954 until their closure in 1973 (Alabaster and Straw, 1976). Concerned by the 2004 version of events, he published a comprehensive account of the deposits and environmental circumstances in 2005, the substance of which is included below. Conclusions presented by both Green (2011) and Gamble (2014) clearly rely on the misinterpretations within the 2004 report. This paper has been prepared to provide an up-dated and comprehensive account of the situation at Welton-le-Wold.

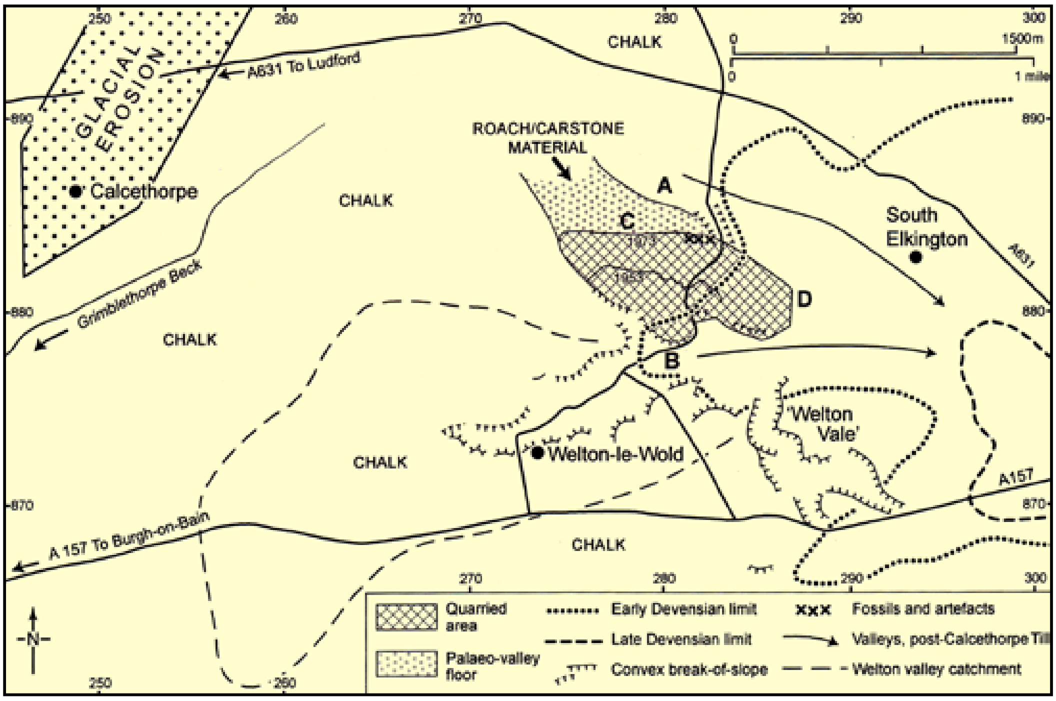


Figure 1. Location of the quarry at Welton-le-Wold, and some of the significant features in adjacent areas.

The earliest published record of workings at Welton was by A.J. Jukes-Brown (1887), and referred to small sections in the southern part of the quarry, close to the road. Wartime expansion was mainly west of the road, and by 1953 the working face lay roughly west to east and about half of the eventual quarried area had been exploited (Fig. 1). The writer's first visits were in the course of fieldwork for a doctoral thesis on the Wolds (Straw, 1964), and subsequently to monitor progress of the workings. In 1969, he described and named the various Lincolnshire tills and related deposits, and included a brief account of the Welton materials. That same year a most significant discovery was made by Chris Alabaster, pupil of Louth Grammar School, who lived close by. The writer received a letter from him in December 1969 relating the discovery of mammal fossils, which put a new dimension on the Welton situation. In early 1970 he wrote about a handaxe find, and later found a second handaxe and more mammal remains. In the summer of 1970 the writer retrieved a third axe and a worked flake from spoil, and recovered a red deer antler direct from the gravels (Alabaster & Straw, 1976).

On closure of the quarries in the 1970s, backfilling was completed, leaving sections only of the uppermost glacial deposits and a little of the underlying gravels. For 20 years or more the site was left to nature, the back-filled state of the worked-over surface being difficult for any farming activity (Gamble, 2014).

The sediments at Welton

There are five main stratigraphic units at Welton (Fig. 2). West of the road, two thick units of glacial till overlie two of sands and gravels. East of the road a third, younger till overlies the gravels. These are described briefly below under given names (Straw, 1969), from quarry-wide observations, and 43 annotated photographs, mostly by the writer, have been placed in The Collection, in Lincoln.

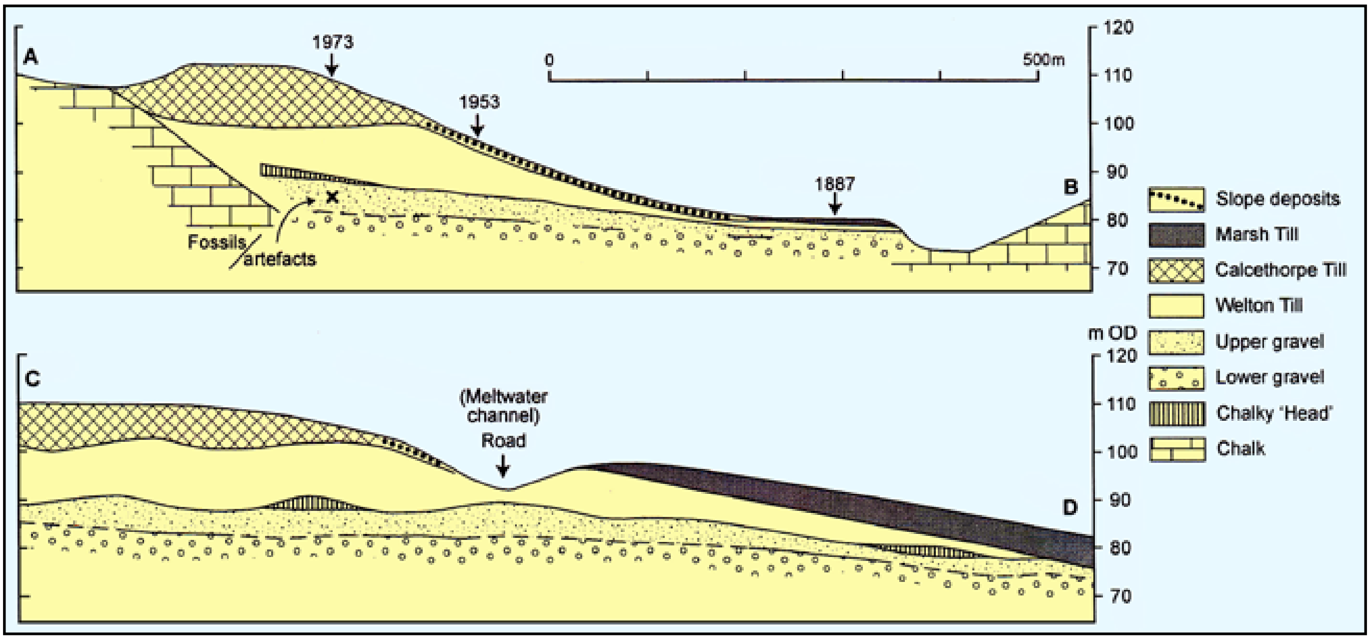
Lower Welton Gravel

This oldest deposit, not visible today, consists of well- to moderately- sorted planar and lenticular seams of clast-supported gravel, quartz sand, and silt (Fig. 3). Generally some 7m thick, it lay over the whole of the quarried area, part of the floor of a palaeovalley about 600m wide developed on Chalk at 60-70m OD. It can be interpreted as an undisturbed, braided stream deposit, indicating variable discharges within multiple channel systems, with the silts accumulating as overbank alluvial sediments. Gravel, a minor component, was wholly of small flints, and the pervasive sand content was largely of rounded and sub-rounded quartz grains with substantial quantities of limonite ooliths (Alabaster & Straw, 1976; Straw, 1976, 2005). The sources for these materials were the Lower Cretaceous Carstone and Roach beds that cropped out in the head of the palaeovalley now occupied by the upper River Bain. The absence of Chalk is remarkable, and in two places ice-wedge casts were seen to penetrate the uppermost layers (Fig. 4).

Upper Welton Gravel

This consists of some 5–8m of flint gravels disposed mainly in discontinuous interbedded planar units, variously very poorly-sorted and massive, and poorly-sorted with traces of bedding (Figs. 3, 4, 6). The massive beds result from mass-movement processes, the others from seasonal floods as bar-core sediments. All the fossils and artefacts were lodged in this deposit, in secondary context and in separate units though generally within a zone 2m thick, some 4 to 6m below the base of the overlying till. Being in different units indicates emplacement in different phases of deposition, even if they came from a single source. It is highly likely that other fossils and artefacts have been lost during quarry working.

Figure 2. The Welton deposits. Locations of the ends of the sections, A-B and C-D, are indicated on Figure 1.



There is no sedimentary evidence in this division to support the notion of a relatively fast-flowing stream that could have transported the fossils and artefacts, and certainly none that indicates a cool-temperate climatic environment (as claimed in Aram et al, 2004, Section 4). Alabaster & Straw (1976) did not describe the sediments as 'a water-lain deposit originating in a fluvial system' but as 'successive sheets of rock waste transported by mass movement processes over a generally aggrading land surface' (p53). Also, the proposals in the 2004 report that the fossils were very nearly contemporary with the sediment are misleading and unsubstantiated. Most of them were abraded, and the fresh appearance of the elephant teeth was more a consequence of protection by skull bone during transport. The field evidence showed that the remains were preserved in the upper parts of discrete sedimentary units, that they had been rafted in bodies of saturated sediment moving gravitationally, and that they must have been derived from some older hidden deposit. Size is no constraint in this situation as long as the density of the object (including that of the tusk) is less than that of the surrounding deposit, and problems concerning available stream energy do not exist.

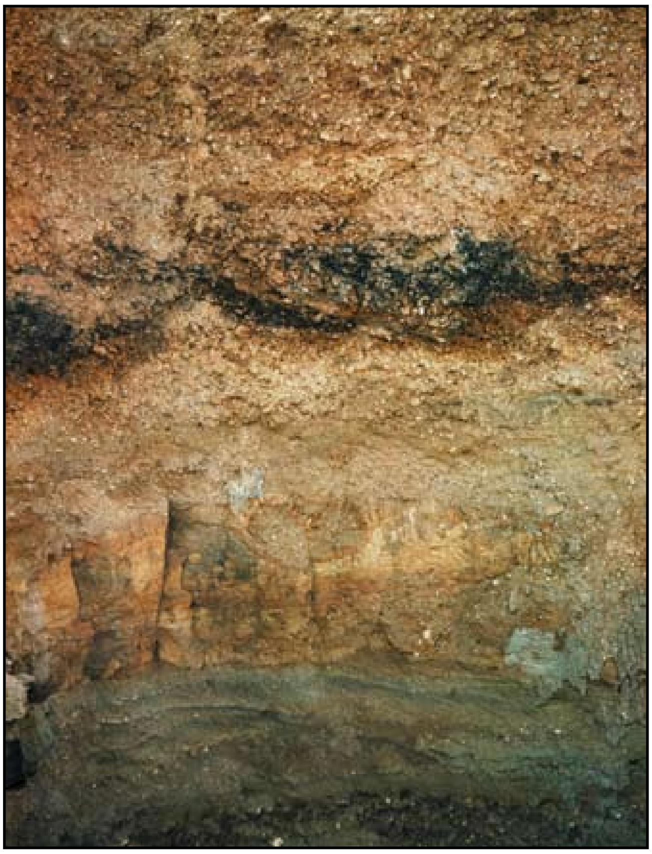


Figure 3. Coarser Upper Gravel of small flints and silty sand, with iron/manganese accretions, and its base about 30 cm below the dark band; overlying finer Lower Gravel of silty fine sands over bedded sands rich in limonite ooliths, and gravel beneath. View is to north at TF28058830; 13 May 1959; section is about 3 m tall.

In the 2004 report (p84) clast size within the gravel was taken as a measure of available stream energy, and as the former is generally less than about 7 cm (Straw, 1976) it was argued that the fossils were too large to be transported far. However, small clast size need only be a reflection of sediment availability, and not necessarily the competence of any transporting agency. Furthermore, sedimentary evidence for stream transport was non-existent. The 2004 report also laid considerable emphasis on the varied colours of the Upper Gravels, even though it had been stated (Alabaster & Straw, 1976, p79; Straw, 1976, p320) that they were the consequence of diagenetic deposition of iron and manganese oxides by movements of water through the Gravels probably long after their emplacement, and had no relevance to the original conditions of deposition. Once deposited, such oxides are very stable, and the lighter-coloured sand and gravels are merely those with little or no staining.

The intermittent layers of silt are likely to be flood-plain deposits in the Lower Gravel, but their character in the Upper Gravel is distinctly aeolian, both in particle size and field disposition (Straw, 1976). They are not evidence for the presence of lakes during accretion of the Upper Gravel. Graded lamination and ripple structures are not uncommon in wind-blown materials, and snow can be included during aggradation if in a cold climate, when sediment can also be trapped in snow-melt ponds. The thick layer of silts observed in the northeast part of the quarry was probably part of a sheet of material drifted over the land surface of the time toward the northeast side of the palaeovalley (Straw, 2005).

Figure 4. Welton Till (about 4 m thick above its dark base) overlying Upper Gravel and disturbed Lower Gravel that includes an obliquely-transected ice-wedge pseudomorph towards the lower left. View is to northeast at TF28098825; 18 May 1957; face is about 12 m high.

Figure 5. *Calcethorpe Till (whitish and 3-5 m thick, with the dragline standing on it) overlying Welton Till (10-12 m thick and greyish, except where covered by whiter, slumped Calcethorpe Till). Yellowish Upper Gravel is just visible in the quarry floor towards the near right. View is to west at TF27918837; 21 April 1963.*

Welton Till

This is a tough, brownish-grey lodgement till, containing many chalk clasts, a proportion of which are striated, and a restricted erratic suite of north British rocks (Fig. 5). By 1973 some 7–8m of till were exposed, resting on the Upper Gravel with a sharp undulating contact. Its base, over the whole of the quarry, had been altered by diagenetic processes into an orange-brown, sandy, flinty layer some 10–30 cm thick, oxidized and decalcified (Figs. 4, 6). Macro-fabric clast orientation indicates this Till was emplaced by ice generally from the north, flowing across the palaeovalley, and the scant incorporation of Upper Gravel suggests it moved over a frozen gravel surface.

Calcethorpe Till

This deposit, in part a lodgement till, overlies the Welton Till but with a diffuse junction (Fig. 5). The Till contains well-striated pieces of chalk and flint, some up to 60 cm across, in a brownish-cream matrix mainly of pulverized chalk. Parts are stratified and contorted. The contact with Welton Till was not marked by weathered horizons, nor by subaerial outwash materials. It is considered that the Calcethorpe Till ice had, in flowing south, traversed more of the Wolds' Chalk outcrop, and had overridden Welton Till ice in the vicinity of the quarry, implying no break in the glacial condition. This Till did not become exposed in the working face until the later 1960's, but had been incorporated in slope materials over the Welton Till in the southern parts of the quarry. By 1973 some 13m of the combined tills were visible.

Marsh Till

East of the road, this glacial deposit lies on an east-inclined plane cutting sharply across weathered Welton Till and Gravels (Fig. 6). Reddish-brown in colour, it was laid down by ice advancing from the east after much erosion of the Calcethorpe and Welton Tills. This ice was a westerly lobe from a sheet that had moved down the east coast as far as Norfolk, and which at Welton advanced up slopes developed on the older deposits, to about 100m OD. Its limit in the quarries is marked by the small meltwater channel occupied by the road (Fig. 1).

Environmental conditions

The Lower Gravel is interpreted as deposited by shallow, braided streams, and the Upper Gravel as sediments accumulated by alternating niveo-fluvial and aeolian processes under cold, possibly permafrost, conditions (Alabaster & Straw, 1976). The 2004 report (Sections 4 and 6) chose to rebut this interpretation, seemingly on new evidence derived from borehole investigations in 2003; denying the derived character of the temperate fossils and the artefacts, it claimed the Welton Gravels as 'temperate-climate sands and gravels', and regarded the fossils and artefacts as marking a '(probable) interstadial or cool temperate interglacial episode'. Since there is no sedimentary evidence for such an episode, no elephant could have died on the banks of a stream at the time of Upper Gravel deposition (as proposed in the report, Aram et al, 2004, p84).

The Welton palaeovalley, some 10 km long, was one of a group that drained the central part of the Wolds; earlier Quaternary erosion had produced a valley that at Welton was some 600m wide on Chalk, and 50–60m below adjacent higher ground (Straw, 1976). Thus a vast amount of Chalk had been removed before deposition of the Lower Gravel began. There is no direct evidence for the conditions that prevailed over this long period of time, but the Wolds had undoubtedly been glaciated once before (Anglian). After that, they must have had, at various times, covers of broadleaved, boreal and perhaps tundra vegetation in response to profound climatic changes (as witnessed in other parts of the country and in the isotope stages of deep sea sediments).

The Chalk within the Welton catchment is largely flint-free; easily broken down mechanically, it was also removed by solution and carbonation, so little sediment would have been available for stream transport. It is then debatable as to why accumulation of the Lower Gravel began. The answer probably lies within the Gravel itself. It was noted in 1976 (and above) that much of the sand-grade material in the Gravel was of rounded quartz grains and limonite ooliths and that it was very likely that these were derived from Lower Cretaceous rocks that had become exposed by valley-deepening in the upper reaches of the palaeovalley. This was a sediment source producing more than streams were able to remove from the valley, and its exposure was an environmental threshold across which processes of rock removal and fluvial activity were changed. The Gravel however contains no Chalk, which suggests minimal direct erosion of vegetated valley-sides. The vegetation could have been boreal in character and, with the sediment indicating a prevalence of mechanical weathering, braided stream transport and variable seasonal discharge, a Subarctic Nival climate seems to have prevailed. Near the top of the Lower Gravel, ground-ice structures confirm the eventual establishment of permafrost (Fig. 4).

***Figure 6**. Section in the quarry's eastern pit, with 4-6 m of Devensian Marsh Till overlying 4-5 m of weathered Welton Till and about 5 m of Upper Gravel (partly in deep shadow). More than a metre of stratified Lower Gravel is visible at bottom-right. The red colour is due to reworked Triassic material within the till at the top of the section. View is to north at TF28598808; 21 April 1963; the visible face is about 16 m high.*

This new situation marks another vital threshold, a change in depositional environment. The Upper Gravel resulted from debris flows bringing masses of small flints from higher slopes within the catchment, with spring floods partly re-sorting the material across the valley floor and with silts being moved in drier summers. Active-layer processes and gelifluction point to the presence of permafrost that would occur under an Arctic Nival climate (Straw, 2005). These Arctic, periglacial conditions continued until the incursion of Welton Till ice, then Calcethorpe Till ice, from the north; this was a third environmental threshold of immense significance. During and after deglaciation, fluvial erosion began to produce the present Welton valley and its tributary on the west side of the quarry area (Fig. 1). At least one interglacial period (Ipswichian) occurred (more likely two, with a cold phase between), followed by a prolonged cold interval and eventual glaciation when ice just managed to reach the quarry area to deposit the Marsh Till.

The Welton deposits therefore allow the reconstruction in part of geomorphological and environmental processes before the main glaciation, of events immediately before and during the glaciation, and of the formation of the present landscape once the older ice disappeared. But how much time did all this take?

Dating the sediments

This has always been a problem. In the 1950s and 1960s dating techniques were fewer than today, and suitable material was not available. Mapping by the writer (1964) revealed the extent of the Calcethorpe Till across the Wolds from Welton to the Bain valley (Straw, 1966) and its remarkably sharp junction from Sixhills to Tattershall with the contemporaneous Wragby Till that covers central Lincolnshire. Geomorphological and regional relationships of the tills provide evidence that they had been deposited during what was then termed the 'Wolstonian' stage and not during the much older 'Anglian' stage. The discovery of derived artefacts and temperate mammal remains in the Welton Gravels seemed to support this situation, but did not indicate a firm date. Although the writer continued to claim a 'Wolstonian' age (Straw, 1979, 1983, 1991), other researchers persisted in placing the Welton deposits in the 'Anglian'.

An important part therefore of the 2003-4 project was to obtain samples that could be analysed by the Optically Stimulated Luminescence (OSL) technique in an attempt to obtain numerical age estimates, because dating of the horizon that was deemed to have produced the fossils and artefacts was the single most important aspect of the study (Aram et al, 2004, p73).

However, it must be noted that comprehensive research work within the Trent catchment has since been carried out during 2005 to 2007 by the Trent Valley Palaeolithic Project (TVPP) supported by ALSF funds through English Heritage (White et al, 2007;

Bridgland et al, 2014). Their extensive fieldwork, laboratory analyses and thorough literature review, all presented in the masterly report of the TVPP in 2014, has allowed revision of the sequence of Trent terraces, including those produced when the Trent flowed through the Lincoln gap.

Organic materials discovered in the Southrey terrace (at Coronation Farm [TL154668] and Tattershall Thorpe [TF211610]) and near Newark (at Norton Bottoms [SK863588]) belong to a MOIS 7 ('Aveley') interglacial. In central Lincolnshire these deposits rest on Wragby Till (Straw, 1969), which TVPP ascribes unequivocally to a glaciation within MOIS 8, indeed designating it the Wragby Glaciation. In the Bain valley (from Sixhills to Tattershall) Wragby Till lies alongside and is contemporary with the Calcethorpe Till (Straw, 1966), which spreads over the Wolds via Calcethorpe to Welton where it co-exists with the Welton Till. If these field relationships hold true then the Welton glacial deposits also belong to MOIS 8, a correlation long held by the writer (Straw, 2000, 2010). It has been argued, above, that the Welton Gravels were laid down under SubArctic and Arctic Nival conditions immediately preceding glaciation, and can therefore be confidently assigned to early MOIS 8. This stage appears to date from c.300–245ka BP, and the Welton Gravels in their extent, thickness and continuous aggradation could by comparison with gravel bodies elsewhere, have accumulated within a period of no more than 20ka.

Such a chronology is at variance with those suggested later (Gamble, 2014; Green, 2011). Gamble refers to a 'date' of c.365ka BP for the Upper Gravel beneath the artefacts and fossils, and indicates that the latter may be between c.330 ka and c.200ka BP. Green refers the 365ka BP 'date' to the Lower Gravel, notes that the Upper Gravel is likely to be at least 337,000 years old, and suggests that glaciation (Calcethorpe and Welton Tills) probably took place in MOIS 6 (180–130 ka BP). These age estimates originate in the supplement (Schwenninger et al, 2007) to the main report (Aram et al, 2004) that discussed the application of OSL dating (which attempts to determine the length of time since a target mineral, usually quartz, was last exposed to light).

Under the 2003-4 Project, eight samples were taken from two boreholes and one from material near the base of the Welton Till, all in the western pit. One was also taken from material in the base of the Marsh Till in the eastern pit, so that bracketing dates for the Gravels might be obtained (Aram et al, 2004). However, only the two till-related samples and the next-to-deepest borehole sample proved capable of giving finite age estimates (Table 1); several others gave only minimal ones. In the supplement, it was considered that these numbers did provide a framework for the deposits, but that it was not at all secure and further work was needed. Indeed, the contradiction can be noted that the material at the base of the younger Marsh Till (X1786) produced a date almost twice as old as that at the base of the much older Welton Till (X1785), and this must question the reliability of the single assay for the Gravels of c.365ka.

X1785 (base of Welton Till): 96ka +/-10ka
X1786 (sand lens in base of Marsh Till): 166ka +/-22ka
X1909 (next-to-deepest in Gravels): 365ka +/-28ka

***Table 1**. Questionable OSL dates obtained in 2003-4.*

Validity of the dating

Reasoning about ages for the Welton deposits and the presence of early man led to speculation about the various Marine Oxygen Isotope Stages represented (Green, 2011), but, based solely around this single 'date' and some minimum ones, these proposals have little credibility. The Gravels were estimated to date between c.400ka BP (late MOIS 12) and c.150ka BP (late MOIS 6), but it might not be realistic to assume that the Gravels accumulated continuously for such a length of time. On the descriptions above and earlier (Alabaster & Straw, 1976; Straw, 1976; Straw, 2005) such a span is a gross overestimate. Sedimentary evidence for environmental changes across the MOIS boundaries is also lacking, especially as the claims (Aram et al, 2004) for a temperate phase within the Upper Gravels have been discounted. Over the 20 years of the writer's association with the quarry, no relevant sedimentary evidence for any substantial climatic fluctuations was revealed. There were no exposures of organic horizons (even in the silt layers), nor of palaeosols, nor of major erosion planes, nor of channelling.

As described above, the Welton Gravels, on all rational counts, reveal continuous accretion under a single phase of steadily worsening climate that included a significant change of process when permafrost became established. Referring the Tills to MOIS 8, and the Gravels to earlier in the same phase is the least complex situation, with the derived fossils and artefacts probably no older than MOIS 9. It is suggested therefore that it is unwise to give credibility to preliminary and provisional age estimates while ignoring the field evidence. It is better to consider why the 'date' might be unreliable and excessive. It was acknowledged (Aram et al, 2004; Schwenninger et al, 2007) that difficulties of inhomogeneity of sediment and of inaccessibility were met, and that the method is limited in situations of high environmental dose rate, which seemingly exist at Welton. Also, some novel procedures were introduced. Determining an age from a sample is a complex procedure with inherent estimations and corrections, but one can also point to field problems that increase uncertainty about the Welton Gravel numbers.

Firstly, it had not been possible to take gamma-ray spectrometry measurements exactly where the borehole samples were taken, through having to use parallel boreholes, estimate relevant depths and allow for compression and distortion of cores.

Secondly, the variability of water content through the burial period (at least 200ka) had been substantial and was very difficult to determine given the local circumstances, although a standard correction factor was used. Permafrost had prevailed at times during aggradation of the Upper Gravel, and the disposition of iron and manganese oxides in the Upper Gravel indicates fluctuating water-tables and alternating phreatic and vadose conditions beneath the Tills. When the Gravels subsequently had been exposed at the surface by valley formation east and south of the eastern pit, lateral flow of groundwater to springs would have affected the water-table. When Marsh Till ice moved west toward Welton, ponding of water (including within the Gravels) was inevitable and is witnessed by laminated sediments beneath the Till and by initiation of the Welton Vale meltwater channel (Fig. 1). Such fluctuation of water content may have been more complex than this, making environmental dose-rate determinations very difficult.

Thirdly, OSL measurements can be made on sand-sized quartz grains, even individual ones, but most of them in the Gravels are derived from Lower Cretaceous marine rocks buried for tens of millions of years and were only transported over relatively short distances before re-burial. Such grains could carry a residual geological signal from their previous depositional environment. Should OSL dates for the Gravels prove more variable and excessive than those for the Tills, then it just might be because the latter contain no Lower Cretaceous material, though it could be that sampling from the Tills was better controlled than from the boreholes.

On several counts therefore, the OSL assays on the Welton Gravels must now be regarded not only as highly provisional but also as unreliable and obviously inconsistent. To use them in isolation without considering the implications is unwise, and serves only to make the simple, straightforward, logical, demonstrable situation at Welton unhelpfully complex, and to raise implications that cannot be sustained.

The values of the Welton-le-Wold site

The Quaternary sediments recorded at Welton-le-Wold make the site special on a number of counts, and these are widely recognized in its several designations (Gamble, 2014).

1. The Welton Gravels are the sole occurrence in the Wolds of a valley-floor deposit sourced entirely within a single catchment.
2. They testify to a single period of increasingly cold climate characterized in its later stages by permafrost and glaciation, with no evidence for warmer phases.
3. Deposition of the Welton Gravels in early MOIS 8 was abruptly curtailed when the valley was overrun c.270ka BP by south-flowing ice that eventually sealed the Gravels under some 13m of lodgement till; the unconformity has no time span.
4. Although they constitute a meagre sample, the recovery of four artefacts from a deposit underlying undoubted till is a rare occurrence in Britain.
5. The artefacts and mammal fossils in the Upper Welton Gravel have been derived from some earlier deposit, somewhere up-valley, and do not testify to warmer conditions during Gravel deposition.
6. The superimposition of Marsh Till (Devensian) on much older Welton Till and Gravels is unique in Lincolnshire.
7. The unconformity marking the base of the Marsh Till spans at least some 220ka, during which the landscape around Welton was substantially altered.

References

Alabaster, C. & Straw, A., 1976. The Pleistocene context of faunal remains and artefacts discovered at Welton-le-Wold, Lincolnshire. *Proc. Yorks. Geol. Soc.,* **41**, 75-93.

Aram, J., Hambly, J., & Rackham, J., 2004. *Towards an understanding of the Ice Age at Welton-le-Wold, Lincolnshire*. Project Report for English Heritage. 103p.

Bridgland, D.R., Howard, A.J., White, M.J., & White, T.S. (eds.)., 2014. *Quaternary of the Trent*. Oxbow: Oxford, 434pp.

Gamble, H., 2014. Where elephants once roamed! *Trans. Lincs. Nat. Union* (*for 2013),* **28**, 161-167.

Green, C., 2011. *The origins of Louth*. Lindes: Louth. 177pp.

Jukes-Brown, A.J., 1887. The geology of East Lincolnshire (Old Series Sheet 84). *Mem. Geol. Surv*., 181pp.

Schwenninger, J-L., Aram, J., Hambly, J., Rackham, J., & Williams, J., 2007. *Optically Stimulated Luminescence (OSL) dating of Pleistocene glacial tills and interglacial gravels.* English Heritage Research Report, 36/2007.

Straw, A., 1964. *An examination of surface and drainage in the Lincolnshire Wolds, with brief consideration of adjacent areas.* Unpublished Ph.D thesis, University of Sheffield.

Straw, A., 1966. The development of the middle and lower Bain valley, east Lincolnshire. *Trans. Inst. Brit. Geogr.*, **40**, 145-154.

Straw, A., 1969. Pleistocene events in Lincolnshire: a survey and revised nomenclature. *Trans. Lincs. Nat. Union***., XVII**, 85-98.

Straw, A., 1976. Sediments, fossils and geomorphology: a Lincolnshire situation. 317-326 in D.A. Davidson & M.L. Shackley (eds), *Geoarchaeology, Earth Science and the past*. Duckworth: London.

Straw, A., 1983. Pre-Devensian glaciation of Lincolnshire (eastern England) and adjacent areas. *Quat. Sci. Rev*., 2, 239-260.

Straw, A., 1991. Glacial deposits of Lincolnshire and adjoining areas. 213-221 in J. Ehlers, P.L. Gibbard, & J. Rose (eds), *Glacial Deposits in Great Britain and Ireland*. Balkema: Rotterdam.

Straw, A., 2005. *Glacial and Pre-glacial deposits at Welton*-le-Wold, *Lincolnshire*. Studio Publishing: Exeter, 39pp.

Straw, A., 2000. Some observations on 'Eastern England' in 'A Revised Correlation of Quaternary deposits in the British Isles', D.Q. Bowen (ed), 1999. *Quat N/L*., 91, 2-6.

Straw, A., 2010. The Saale glaciation of eastern England. *Quat N/L.,* 123, 28-35.

White, T.S., Bridgland, D.R., Howard, A,J,, and White, M.J., 2007. *The Quaternary of the Trent valley and adjoining regions.* Field Guide, Quaternary Research Association, 163p.

Allan Straw,
31 Tilmore Gardens, Petersfield, Hants GU32 2JE
allan.straw@btinternet.com