Devensian glaciers and proglacial lakes in Lincolnshire and southern Yorkshire

Allan Straw

Abstract: During MOIS 2 Devensian ice spread into the Vale of York and down the North Sea coast to Norfolk. The writer has been investigating the geomorphological impact since 1954, and this paper is essentially a personal assessment of various events and their consequences. Evidence is provided for two distinct advances of ice into Lincolnshire and eastern Yorkshire, the later being the Last Glacial Maximum (LGM) and the earlier a pre-LGM event. Other views regarding the LGM in Holderness and southern Yorkshire are challenged. Consideration is given to the extents and levels of proglacial lakes, and a case is made that a bedrock sill at Gainsborough exerted stronger control on lake levels than oscillations of ice in the Humber gap. Isostatic displacements related to the two advances are held responsible for the existence of Lake Humber in two discrete phases.

It has long been known that glacier ice spread down the east coast during the last major cold phase, now referred to as the Devensian (Mitchell *et al*, 1973). The ice effected major landscape changes through deposition of tills, sands and gravels, particularly in Holderness and east Lincolnshire, and disruption of river systems through blockage of the eastern end of the Vale of Pickering, and of the Humber and Wash gaps through the Chalk escarpment (Jukes-Browne, 1885; Lewis, 1894; Kendal, 1902; Raistrick, 1934; Swinnerton, 1936; Charlesworth, 1957). One inevitable consequence was the impounding of large ice-dammed lakes in the Vale of Pickering, Humberhead and the Fens. Overflow from Lake Pickering created the Derwent gorge now occupied by the eponymous river, and contributed input to Lake Humber. The latter was presumed to be connected with Lake Fenland by the Lincoln gap with eventual escape for the water across East Anglia by way of the Lopham Gap (Raistrick, 1934).

Such a system was not challenged through the 1940s and 1950s (Charlesworth, 1957) and was the accepted situation when the writer commenced PhD research in 1954. It was reiterated by him in an account of the geomorphology of eastern England (written in 1965 but published in 1979), and was illustrated more recently (Clarke *et al*, 2004b, 2012; Bateman *et al*, 2015).

That Devensian ice reached Norfolk was originally confirmed by Whitaker and Jukes-Browne (1899) and later by Solomon (1932), but it was not till 1960 that an attempt was made, by the writer, to describe in detail its geomorphological impact. Similarly, in east Lincolnshire, although Jukes-Browne (1885), Swinnerton (1936) and Linton (1954) discussed its effects, the first detailed examination of deposits and landforms of the whole area was by the writer in the later 1950s during preparation of geological and geomorphological maps of the Lincolnshire Wolds as part of a PhD thesis (1964). Early publications of some of the results of this work (1957, 1958) were followed by a more detailed account (1961) in which close attention was given to meltwater channels and ice margins. Twidale (1956) reported an MSc study of meltwater channels in the northern Wolds, in terms of classical lake overspill.

In Holderness, much research was accomplished by Bisat (1940) in the late 1930s and 1940s (Catt and Madgett, 1981), and de Boer (1945) discussed meltwater channels in the Yorkshire Wolds. During preparation of the regional geomorphological account of eastern England, fieldwork in the 1960s revealed the arrangement of morainic landforms and meltwater channels along the east side of the Vale of York (Straw, 1979a).

Since 1979, the writer has considered further the Devensian glaciation (2002, 2010) and now, toward the end of a long career, offers a personal overview of this glaciation and its consequences, and focuses on three topics: the limits reached by the ice, the extents of the larger proglacial lakes, and the controls on lake levels.

***Figure 1**. The cliff beside the Humber at South Ferriby, in a view looking to the southwest. This is cut in till that has a shelving and formless surface on materials that are of solifluction or colluvial origin (photo: Peter Worsley).*

Figure 2. Oxidized till, with shear planes, resting on a planed chalk surface, viewed to the south at South Ferriby [SE995226]; darker sediments in the top quarter of the face could be of lacustrine or solifluction origin (photo: Peter Worsley).

Figure 3. Haugham Slates meltwater channel near its head, from where it extends 3.5 km SSW with a continuous gradient. The channel curves round the left end of the wood, then towards the camera. In front of the wood the channel side is cut in chalk at an angle of c.25°. This gives way, right of the pond, to a mound of till, marking precisely the limit of the second advance. View is to the west at TF351800 in 1978.

Glacial limits

In north Norfolk, Devensian ice reached just over 30m OD, and its limit is marked by the extent of glacigenic sediments and several stream diversions (Straw, 1960; Chroston *et al*, 1999). In both the Lincolnshire and Yorkshire Wolds, the Last Glacial Maximum (LGM) is placed by most authors at the maximum extent of the Devensian glacial materials and landforms, which includes weak moraines at Horkstow (west of the Humber gap), at Kirmington, and beside The Wash at Stickney and Heacham. (Fig. 8) This conventional limit of the LGM in the Wolds can and has been repeatedly challenged (Straw, 1961, 1979a, 1991, 2008). At the northern tip of the Lincolnshire Wolds Devensian till is exposed at South Ferriby cliff (Figs 1, 2), and a higher drift limit indicates there was some 60m of ice in the Humber gap, thinning west. South from Barton towards Kirmington weathered, reddish-brown till occurs on interfluves rising to feather-edge margins at c.60m OD. What is really significant however, is that till is absent from the valleys, indicating a substantial period of incision after till deposition, and the surviving till surfaces are formless (Straw, 2008). East of the northern Wolds a gravel train was aggraded by streams that drained from central Wolds meltwater channels, declining north and providing a site for Thornton Abbey. East of this, the Killingholme Moraine (Straw, 1961) is a constructional feature that meets the central Wolds south of Habrough. A similar disposition exists further south, where the southeastern Wolds retain only thin, weathered drifts, and a gravel train, deposited by meltwaters issuing from meltwater channels in the southern central Wolds, spreads southeast by Alford in front of the Hogsthorpe moraine (Fig. 8).

In east Lincolnshire therefore, these features appear to provide evidence for two advances of Devensian ice (Straw, 1961). The second of these was responsible for the constructional landscape of the ‘Marsh’ between Killingholme and Hogsthorpe, for the ‘fresh’ meltwater channels such as the Haugham Slates channel (Fig. 3), and for kami-form sands and gravels in the central Wolds, and should be regarded as the LGM. Tills and gravelly sediments of the first advance are either dissected, as at Maltby (Fig. 4), or display formless surfaces, and are commonly deeply-oxidized (Fig. 2). Some areas of sloping ground, particularly in the northern and southeastern Wolds, are covered only by ‘drift-residual soils’ (Straw, 1961, 2008), derived from till and retaining erratics, but too thin to be mapped as such (Fig. 5). Meltwater channels, such as those at Ash Holt (Fig. 6)

Figure 4. In the north-draining valley of Tathwell Beck at Maltby, thick Devensian till was emplaced during the first advance, but ice did not pass beyond the farm on the hill. In the foreground the beck is incised to the chalk, leaving the till as a bench on each side of the road, in front of the farm; this allowed development of a spring recess occupied by the group of bushes in the centre. View to the west at TF312841 in 1978.

Figure 5. Kenwick quarry [TF339853], just south of Louth, exposed 'drift-residual soil' in 1959; this is derived from, but is too thin to map as, Devensian till, and it retains coloration and erratics. Its base is piped into the chalk. The till has been thinned by surface processes of wash and creep, but also by the loss of fines into fissures within the chalk.

and Church Top Farm (Fig. 7), have less steep sides and some have undulating long profiles. These latter features are held by the writer to represent a pre-LGM event.

North of the Humber, constructional landscapes occur only east of the River Hull, whereas west of the Hull alluvial Devensian materials, as in the northern Wolds, lie only on interfluves, and retain few deglacial and meltwater features (de Boer, 1945; Straw, 1979a; Gaunt *et al*., 1992). The Killingholme moraine seems to be represented north of the Humber by the ridges at Wawne and Routh until overlapped by the Withernsea Till, so that the LGM ice may be deemed responsible only for deposits and landforms in eastern Holderness (Fig. 8). An important corollary is that the Skipsea Till is confined to the east Holderness/Killingholme/Hogsthorpe episode, is not part of the earlier advance, and is not therefore to be found in the Humber gap.

This model of two distinct advances into east Lincolnshire was not considered in the recent paper by Bateman et al (2015). They recognize the maximum limit of Devensian drifts in both the Yorkshire and Lincolnshire Wolds as the LGM, ice reaching there between c.19 and 18 ka. This was followed within a thousand years by recession of ice from Holderness while leaving a lobe in the Humber estuary. The latter was stated to constitute a plug in the Humber gap that maintained a pro-glacial Lake Humber at a 33m OD level. This interpretation ignores the 'older' character of the dissected Devensian drifts in the Wolds (described above), and renders the high lake level dependent on a precarious and unlikely glaciological situation.

North of Flamborough Head, deposits and features of the pre-LGM event, the LGM, and the Withernsea Till advances are increasingly compressed within a narrowing coastal zone. At least two phases of ice advance can be identified around the eastern end of the Vale of Pickering (Straw, 1979a).

Devensian ice in the Vale of York, sourced from northern England, reached less far south than did the east coast ice, and its southern limit was for long regarded as marked by the Escrick Moraine (Fig. 8). However, Edwards (1937; Edwards *et al*, 1950) ascribed to an Early Main Dales glaciation a group of deposits, which he named the Linton-Stutton gravels, that form a distinct ridge, probably a kame belt; they lie just to the west of the strandline deposits (Fig. 8), west of the diverted River Wharfe and the Escrick Moraine. Gaunt (1976) proposed that an LGM ice lobe had extended south of Escrick, advancing into a 33m OD Lake Humber, to account for the presence of a line of low, gravel-capped eminences between Wroot, Lindholme and Thorne. Although figured as moraine by various authors (Bateman *et al*, 2008, 2015; Clarke *et al*, 2004a) the Wroot-Thorne gravels consist of fluvial, probably glaciofluvial, sands and gravels, with bedding indicating water flow broadly southward, parallel to the postulated ice margin. Dominated by clasts of Permian Magnesian Limestone and Carboniferous sandstone (Bateman et al, 2015), the gravels up to 12m in thickness, cap a discontinuous, largely buried ridge of Triassic Sherwood Sandstone and presently display accordant tops at c.6-8m OD. Gaunt favoured ice-marginal deposition, but this seems unlikely because, if the ice had protruded into a 33m OD lake, how could these fluvial deposits have been emplaced under some 25m of lake water? These gravel-capped features, which now stand only a few metres above

Figure 6. Ash Holt meltwater channel, which is 3 km long across the interfluve between the Hatcliffe and Swallow valleys and functioned during the first ice advance. Its col height is c.70m OD and the side slopes are less than 13° above a partial filling of head and blown sand. View is to the north at TA190010 in 1959.

***Figure** 7. Church Top Farm meltwater channel crossing a spur 1.2 km north of South Elkington, at c.118m OD, with its sides no steeper than 12°. It marks the highest level in the central Wolds reached by ice during its first advance. View is to the south at TF293896 in March,1958.*

the adjacent ground of silt, alluvium and peat, are more likely residual hills. The surrounding materials fill depressions that were parts of an extensive valley system that was focussed on the Humber Gap and descended to at least -20m OD (Gaunt, 1981, 1992). A more realistic interpretation is that these low hills were isolated by erosion of the depressions after gravel deposition, and long before both silt accumulation and the postulated ice advance. Straw (2002) has argued that they could be vestiges of a former wider tract of pre-Devensian outwash originating from the northwest, which also accords with the lithology. Such outwash would be from ice that originated, like the Devensian, in northern England and crossed similar Carboniferous and Permian outcrops. The writer has previously noted (Wymer & Straw, 1977; Straw, 1979c) that ice in successive glaciations following similar tracks would entrain similar materials.

However, the notion of a Wroot-Lindholme-Thorne lobe has recently been championed by Bateman *et al*. (2015). They provide two new OSL ages for the Lindholme deposits, averaging 18.7 ka, but no new field evidence to support the actual presence of glacier ice. If the Wroot-Thorne gravels are dissected, pre-Devensian, residual materials then, whatever significance the OSL dates may have for the deposits, they have no bearing on the presence of an LGM ice lobe.

Another objection to the occurrence of an ice lobe is its failure to leave any ‘footprint’, notably over the Isle of Axholme where the ice could neither have floated, because the water would have been too shallow, nor be cushioned by lacustrine silts and clays in their absence. Devensian till and deglacial sediments and landforms are absent from the c.1200 km^2 area purportedly covered by the extended ice, even though the latter would have been at least 40m thick and part of the glacier that was later responsible for construction of the Escrick and York moraines. Bateman et al (2015) account for this by proposing that the lobe could have decoupled from its bed, and its flow enhanced by sliding over soft lacustrine sediments, but there is no direct evidence of this, and the presence of the lobe remains speculative and unsubstantiated.

A final point is that when the postulated lobe decayed it could reasonably be expected to have discharged meltwaters at points around its margin, and, because it was unlikely to have been debris-free, to have built subaqueous fans or kami-form features. But none exists, notably along the 55 km of its eastern border. It remains most likely then, that the Escrick Moraine corresponds to the LGM (Ford, 2008; Murton *et al*, 2009; Straw, 2002).

Lake Humber and its extensions

The presence of a former proglacial lake in the Humberhead area is confirmed by the great thickness and extent of silts and fine sands of the Hemingborough Glaciolacustrine Formation (Ford, 2008; Murton *et al*, 2009). These sediments, up to 24m thick, present extensive surfaces at c.7-9m OD (hence formerly called the ‘25-foot drifts’) over a vast area from the Escrick Moraine south to the Gringley ridge, west of Gainsborough. Gaunt (1976) regarded them as marking a prolonged low-level stage of Lake Humber, and he ascribed various locally derived sands and gravels in the Doncaster area to an earlier high-level stage at c.33m OD.; he thus complemented work by Edwards (1937; Edwards et al, 1950) that identified strandline deposits at c.30m OD on the Magnesian Limestone cuesta from the Went valley as far north as the Escrick Moraine (as in Figure 2 of Bateman et al, 2007).

A 33m-level lake in southern Yorkshire should have meant flooding of much of the Vale of Belvoir (providing low ground was available at Gainsborough) and, given the existence of a low gap at Lincoln and blockage of both the Humber and Wash gaps by ice, contemporary inundation of central Lincolnshire and the Fens. This situiation is figured by Bateman *et al.* (2015) and on the Britice Glacial Map (Clarke *et al*, 2004a). It was also supported by the writer (1979a) who was impressed by the coincidence of ice-marginal features at c.30m OD in northern Norfolk and the southern Lincolnshire Wolds, though he was aware of the general absence of confirmatory lacustrine sediments throughout the Fens and Vale of Belvoir. One locality where sedimentary evidence for Lake Fenland was thought to be forthcoming was Kirkby Moor, near Woodhall Spa. Here, on ground higher than adjacent Southrey and Tattershall Thorpe Terraces (Bridgland *et al*, 2014), a 10m-thick deposit of fine sands and meagre gravels with a remarkably flat surface at c.27m OD was deemed to be deltaic (Straw, 1979a, 2010),

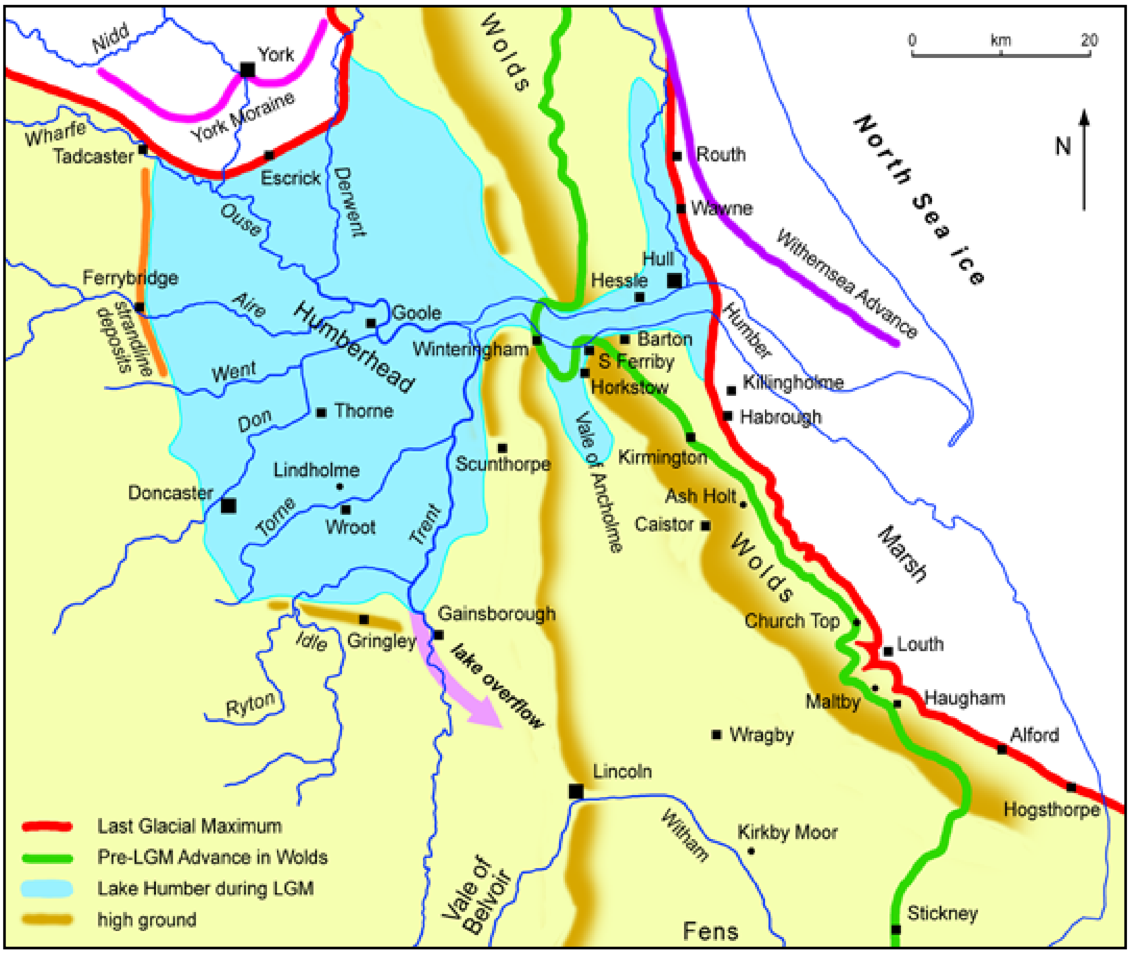

***Figure 8**. The extent of Lake Humber in relation to the limits of the Devensian ice sheets. Most of the high ground is formed by the escarpments, which all face west with dip slopes towards the east; but the Gringley ridge is a low bedrock feature formed across the Triassic succession. Strandline deposits are from Edwards, 1937.*

though it was interpreted by Worsley (1991) as a pre-Devensian sandur. However, in the light of definitive work by Bridgland *et al* (2014), which showed the terraces to be older (MOIS 6/7) than Devensian, interpretation of the Kirkby Moor Sands as deposited in a Devensian lake is now untenable.

Further evidence for a high-level lake shoreline in central Lincolnshire is presented by Bateman *et al* (2000) in a study of coversands near Caistor that comprise a group of low-angle fans along the foot of the Cretaceous scarp (Straw, 1963). They described an exposure of a basal sand unit lying at c.33m OD, capped intermittently by a silty clay only a few centimetres thick. A thermoluminescence age estimate of c.22.67 ka was determined from the upper part of the sand that was considered to have been laid down at the margin of Lake Humber . However, the coversands were generally aggraded by fluvial and aeolian processes in a periglacial environment, and the silty clay had been subject to cryoturbation. Straw (2008) has pointed out that the location would have been exposed to the effects of wave action over fetches of several kilometres from some directions yet there is no recorded disturbance or erosion; the silty clay could well represent suspended material settled out in a snow-melt pond. Recognition of the sand and possibly the silty clay, fortuitously at c.33m OD, as strandline deposits may have been influenced by the dating and by belief that a MOIS 2 lake at about that height had existed elsewhere. But, more crucially, a high-level lake in central Lincolnshire at the LGM, when the Holme Pierrepoint Terrace of the Trent was aggrading at a considerably lower level some 36 km away at Lincoln (Bridgland *et al*, 2014), is inconceivable.

It appears therefore, that proglacial lakes in the Fenland, central Lincolnshire and by inference in the Vale of Belvoir (Bridgland *et al*, 2014) at c.30-33m OD never existed, in sharp contrast to the situation in the Humberhead area. Significant in this connection is the Gringley ridge. Part of an ancient west-east divide, this undulating ridge of Mercia Mudstones and Sherwood Sandstone extends west of Gainsborough between gaps occupied by the River Trent and the River Idle, and has a general height of 40–80m OD. It is possible therefore that it bounded the southern margin of Lake Humber, but only if the gaps did not then exist. Bridgland *et al* (2014) have plausibly suggested that the Gainsborough gap took overflow from a 9-12m OD lake but, if that overflow actually eroded the gap then the water level must initially have been higher, and what then produced the Idle gap? Straw (1979a, b) has proposed that the gaps, together with low ground east of Gainsborough, are likely consequences of pre-Devensian (MOIS 8) glacial erosion. A major question must now be addressed: why does evidence for a high-level lake exist north of the Gringley ridge, but not to the south?

Figure 9*. The low ridge of the York Moraine, viewed from the south.*

Lake levels

Recently, Fairburn and Bateman (2016) have presented detailed evidence for strandlines, mostly recessional, of Lake Humber in its northern sector. They identify and describe a flight of eight terraces between 42m and 5m OD seemingly unaffected by isostatic movement and relating to a single body of water impounded by LGM North Sea ice that blocked the Humber Gap at c.17 ka. They do not, however, explore implications of their results for areas to the south, one of which is that the Wroot-Thorne lobe (if it ever existed) must have disappeared entirely before erosion of the strandline sequence commenced.

A 33m OD terrace (Stage 2, c.16.6 ka) subsuming the deposits mapped by Edwards (1937; Edwards et al, 1950), was mapped on the York Moraine, and also at Hessle, in the Humber Gap, on assumed Skipsea Till that was emplaced, according to them, during the LGM. Lower terraces (at 30, 25, 20 and 15m OD) were identified around the York and Escrick moraines and towards Hessle, implying that the ice front in the Gap had begun to recede eastwards. A 10m OD terrace (Stage 7) was associated with silts of the Hemingborough Formation (Gaunt's low-level lake phase). There is however, no consideration of lake dynamics, which, in view of the great extent of the lake and the narrow vertical spacing of the terraces, could have been useful. Wave action, wind drag and currents that could have caused oscillations of water level of several metres, available fetch, and relative amounts of energy expended on differently orientated parts of the strandlines, were not assessed. Neither was there much consideration of the finer sediments that settled in the deeper parts of the lake.

The flight of terraces was presented as resulting from uninterrupted, phased lowering of lake level relating to a steady rate of outflow. This was in spite of a postulated switch of outlet from a southerly route by Gainsborough and the Lincoln gap to the Fens, to an easterly one through the Humber Gap where, it was suggested, possible oscillations of the ice front were taking place to control Stage 3 and lower terraces. The advance of ice into the gap was placed at c.17.5 ka, and it was suggested that Lake Humber persisted for some 3.5 ka.

The question may fairly be asked as to whether the Hemingborough silts accumulated only during Stage 7 (10m OD), or during the whole of the time represented by all of the emergent shorelines. At Stage 7, the lake level was controlled by the Gainsborough gap, and the vast quantity of silts and clays would seem to require a prolonged still-stand at this level. Yet it is likely that silt accumulation took place through all stages, so why are there no high-level silts? At least part of the answer could be that the lake level was never higher than c.9-12m OD, being controlled by the sill at Gainsborough and not by oscillation of ice in the Humber gap. If this was the case, why do shorelines exist up to 33m OD (or possibly 42m OD). This discrepancy could be accounted for by isostatic displacement related to ice loading (Bridgland *et al*, 2010). Crustal depression would undoubtedly have occurred when ice moved down the Vale of York and when North Sea ice crossed Holderness and eastern Lincolnshire. As soon as the Humber Gap was blocked and the lake initiated, deposition of silt and clay could commence, continuing as the lake level rose high enough for overflow to develop through the Gainsborough Gap at c.9-12m OD. If the Gringley ridge was unaffected by subsidence (possibly by virtue of being south of a fault or structure like the north Lincolnshire monocline), this sill would maintain control of overflow while the lake gradually deepened as subsidence proceeded; this then , allowed progressive silt deposition and creation of what later became the 33m OD shoreline identified by Fairburn and Bateman. Once recession of the ice sheet was under way after construction of the Escrick and York Moraines, isostatic recovery would begin to elevate successive shorelines and raise the lake floor until at Stage 7 the lake was able to drain through the Humber Gap. In this interpretation, the flight of terraces, rather than reflecting a steady fall in lake level, is testimony to the phased uplift of shorelines cut consecutively at a constant level controlled by the Gainsborough Gap.

One further perceived anomaly can be considered. The 33m OD level is regarded by Gaunt and by Fairburn and Bateman as the most prominent one, and includes the littoral deposits mapped by Edwards (1937), but the geomorphological attitude is revealing in that they all occupy interfluve locations. Near Tadcaster, Edwards' strandline terminates abruptly against the valley of the diverted River Wharfe in a manner suggesting that originally it may well have continued north, being there destroyed by advancing Escrick ice. But Fairburn and Bateman claim that washings and notchings around the York Moraine, built up after the LGM, also belong to the 33m terrace, dating it to c.16.6 ka. There is no necessity for these features to be contemporary with those observed by Edwards. The latter were cut into Magnesian Limestone and Triassic sandstone requiring appropriately high energy conditions and unrestricted fetch, conditions that could not be met in the angle close to the Escrick Moraine had it then existed. Edwards' strandline appears to have been broken into fragments by valley incision before advance of ice to the Escrick position, and signifies an inundation of Humberhead and the Vale of York prior to the LGM.

Gaunt's 33m OD deposits (1976, 1981, 1994) also occupy interfluve positions and consist of reworked local sediments such as the pre-Devensian Older River Gravel. It is therefore as reasonable to claim that two separate inundations of the Humberhead area reached approximately to the 33m level, as to constrain all features into one event.

The two ice advances

Underlying the analysis given above has been the sentiment that it is difficult to compress all the recognizable Devensian glacial and related events in eastern England into a relatively short period of time, namely MOIS 2.

The field evidence in east Lincolnshire points strongly to two advances of ice from the North Sea onto the Wolds, the later of which this writer allocates to the LGM, when the ice fronts stood at the Killingholme and Hogsthorpe moraines (Fig. 8). This denies the presence of ice in the Humber gap at the LGM, as claimed by Bateman *et al* (2015) and Fairburn and Bateman (2016). In the Vale of York, a case has been made that the notion of an ice advance south of Escrick during the LGM is ill-founded, and that the LGM is better placed at the Escrick Moraine (Ford, 2008, Murton et al (2009). A pre-LGM advance in the Vale of York might be marked by the Linton-Stutton gravels (Edwards, 1937; Straw, 1979a) or it may have terminated north of the Escrick and York moraines. There it formed the northern margin of the earlier lake witnessed by Edwards' strandline deposits, some of which were subsequently overrun by LGM ice, as were the eastern Pennine valleys (Bridgland *et al*, 2010).

In the Wolds, the earlier advance accords with the maximum limit of Devensian glacigenic sediments (Fig. 8) and the Stickney and Kirmington moraines. It would have been this ice that penetrated the Humber Gap, created the Horkstow Moraine in the Ancholme valley, deposited kami-form materials at Winteringham and impounded the earlier Lake Humber. Overflow from this lake entered the Trent system at Gainsborough, probably at its Scarle Terrace stage, and then utilized the gap at Lincoln to pass down what is now the Witham valley into the Fens. Although ice had reached the Norfolk coast, a lake was not impounded in the Fens because the combined overflow and river waters were able to escape eastwards beneath the ice front parallel to the north Norfolk coast (Chroston *et al*, 1999).

It has been suggested above that the lake for which Fairburn and Bateman have delineated a flight of terraces in its northern sector, and incidentally was probably responsible for beach deposits at Ferrybridge (Bateman *et al*, 2008), formed at and after the LGM. At that time, ice was standing at the Killingholme moraine and not in the Humber Gap, and parts of the Ancholme and Hull valleys were also flooded (Fig. 8). The lake level was again controlled by the sill at Gainsborough (i.e. not by ice in the Humber Gap), overflow again entering the Trent system this time at the Holme Pierrepoint Terrace stage, with eventual free egress from the Fens because the North Sea ice then reached no further south than Hogsthorpe.

This element of duality, with two ice advances and two lakes, may seem contrived, but it accommodates other features. The period between the ice advances in the Lincolnshire and Yorkshire Wolds was one of dissection and weathering of the earlier drifts. In the Humberhead area, the Hemingborough Formation silts bury an extensive valley system that focussed on the Humber Gap (Gaunt, 1981, 1994). Excavation of this could relate in part at least to the emptying of the earlier Lake Humber, when it is probable that the east-trending buried valley was produced, cutting into Chalk to -50m OD beneath the LGM deposits of east Holderness (Straw, 1979a; Gaunt, 1992). In the Vale of York, the dissected nature of the high-level strandline deposits contrasts with the 'freshness' of the features described by Fairburn and Bateman (2016).

The lacustrine events would appear dependent on the crustal displacements induced by the ice advances. If the early advance to Norfolk and its contemporary in the Vale of York induced subsidence of the Humberhead area north of the Gringley ridge, allowing formation of the earlier lake, then recession would permit uplift that encouraged valley deepening and dissection of the earlier sediments. The LGM advance repeated the process, with crustal depression facilitating the formation of the second Lake Humber, followed by uplift during recession to control elevation of the terrace flight depicted by Fairburn and Bateman. The scale of displacement was not great. If the Gainsborough gap was isostatically stable and controlled lake outflows

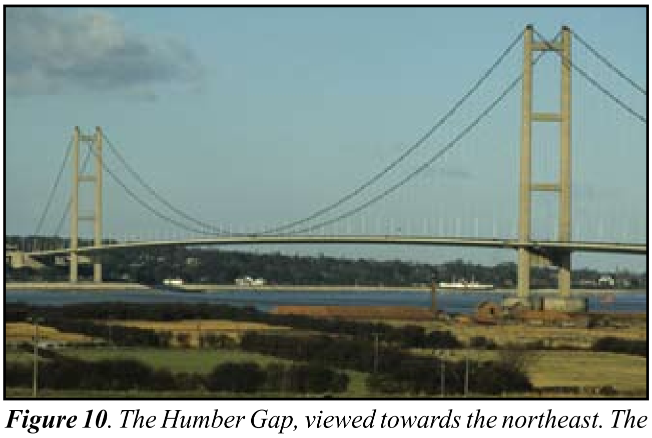

***Figure 10**. The Humber Gap, viewed towards the northeast. The height and arch of the road on the suspension bridge roughly follows those of the ice surface when the Gap was glacierized.*

at c.9-12m OD, and if the 33m OD shorelines mark approximately the maximum elevations, then movements of the order of 20-25m are indicated, about the average height of Lincolnshire church towers, and close to that suggested by Bridgland *et al* (2010).

A final point concerns age. The LGM is firmly allocated to MOIS 2 (Bowen *et al*, 1999). Ice then reached its furthest extent in eastern England at c.21-18 ka, but what of the pre-LGM advance? Various ages for it have been discussed elsewhere without consensus (Straw, 1979a, 1980; Bowen, 2002; Clarke *et al*, 2004b, 2012). It possibly occurred early in MOIS 2 but, on the purely qualitative basis of relative degrees of dissection and weathering of drifts in the Lincolnshire Wolds, this writer prefers more time between the ice advances, and could accept an advance within an earlier Devensian cold phase, i.e. late MOIS 4. Further research is needed.

Acknowledgements

Thanks are due to Professor Peter Worsley, for his very helpful comments on kindly reading an original draft.

References

Bateman, M.D., Murton, J.B., & Crowe, W., 2000. Late Devensian and Holocene depositional environments associated with the Coversand around Caistor, N. Lincolnshire, UK. *Boreas*, **29**, 1-15.

Bateman, M.D., Buckland, P.C., Chase, B., Frederick, C.D. & Gaunt, G.D., 2008. The Late Devensian proglacial Lake Humber: new evidence from littoral deposits at Ferrybridge, Yorkshire, England. *Boreas*, **37**, 195-210.

Bateman, M.D. and 9 others, 2015. Last glacial dynamics of the Vale of York and North Sea lobes of the British and Irish Ice Sheet. *Proc. Geol. Assoc*., **126**, 712-730.

Bisat, W.S., 1940.Older and Newer drift in east Yorkshire. *Proc. Yorks. Geol. Soc*., **24,** 137-151.

Bowen, D.Q. (ed.), 1999.*A revised correlation of Quaternary deposits in the British Isles*. Geol. Soc. Special Report, 23, 174pp.

Bridgland, D.R. and 7 others, 2010. The role of isostasy in the formation of post-glacial river terraces in relation to the MIS 2 ice limit: evidence from northern England. *Proc. Geol. Assoc*., **121**, 113-127.

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

Catt, J.A. & Madgett, P.A., 1981. The work of W.S. Bisat FRS on the Yorkshire coast. 119-136 in Neale, J. & Flenley, J. (eds.), *The Quaternary in Britain*. Pergamon: Oxford.

Charlesworth, J.K., 1957. *The Quaternary Era*. Arnold: London.

Chroston, P.N., Jones, R. & Makin, B., 1999. Geometry of Quaternary sediments along the north Norfolk coast: a shallow seismic study. *Geol. Mag*., **136**, 465-474.

Clark, C.D. and 7 others, 2004a. Map and GIA database of glacial landforms and features related to the last British Ice Sheet. *Boreas*, **33**, 359-375.

Clark, C.D., Gibbard, P.L. & Rose, J., 2004b. Pleistocene glacial drifts in England, Scotland and Wales. 47-82 in Ehlers, J. & Gibbard, P.L. (eds.), *Quaternary glaciations: extent and chronology, Part 1, Europe*. Elsevier: Amsterdam.

Clark, C.D., Hughes, A.L.C., Greenwood, S.L., Jordan, C. & Sejrup, H.P., 2012. Pattern and timing of retreat of the last British-Irish Ice Sheet. *Quat. Sci. Rev*., **44**, 112-146.

de Boer, G., 1945. A system of glacial lakes in the Yorkshire Wolds. *Proc. Yorks. Geol. Soc*., **25**, 223-233.

Edwards, W., 1937. A Pleistocene strandline in the Vale of York. *Proc. Yorks. Geol. Soc*., **23**, 103-118.

Edwards, W., Mitchell, G.H. & Whitehead, T.H., 1950. Geology of the district north and east of Leeds. *Mem. Geol. Surv*..

Fairburn, W.A. & Bateman, M.D., 2016. A new multi-stage recession model for proglacial Lake Humber during the retreat of the last British-Irish Ice Sheet. *Boreas*, **45**, 133-151.

Ford, J.R., Cooper, A.H., Price, S.J., Gibson, A.D., Pharaoh, T.C. & Kessler, H., 2008. Geology of the Selby district. *Brit. Geol. Surv. Sheet Explanation*, Sheet 71, 34pp.

Gaunt, G.D., 1976. The Devensian maximum ice limit in the Vale of York. *Proc. Yorks. Geol. Soc*., **40**, 631-637.

Gaunt, G.D., 1981. Quaternary history of the southern part of the Vale of York. 82-97 in Neale, J. & Flenley, J. (eds.), *The Quaternary in Britain*, Pergamon:Oxford.

Gaunt, G.D., 1994. Geology of the country around Goole, Doncaster, and the Isle of Axholme. *Brit. Geol. Surv. Sheet Memoir*, 79 and 88.

Gaunt, G.D., Fletcher, T.P. & Wood, C.J., 1992. Geology of the country around Kingston-on-Hull and Brigg. *Mem. Brit. Geol. Surv*., Sheets 80 and 89.

Jukes-Browne, A.J., 1885. The boulder clays of Lincolnshire: their geographical range and relative age. *Q. J. Geol. Soc*., **41**, 114-131.

Kendal, P.F., 1902. A system of glacial lakes in the Cleveland Hills. *Q. J. Geol. Soc*., **58**, 471-569.

Lewis, H.C., 1894.*Glacial Geology of Great Britain and Ireland*. Longman Green: London.

Linton, D.L., 1954. The landforms of Lincolnshire. *Geography*, **39,** 67-78.

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

Murton, D.K., Pawley, S.M. & Murton, J.B. 2009. Sedimentology and luminescence ages of glacial Lake Humber deposits in the central Vale of York. *Proc. Geol. Assoc*., **120**, 209-222.

Raistrick, A., 1934. The correlation of glacial retreat stages across the Pennines. *Proc. Yorks. Geol. Soc*., **22**, 199-214.

Solomon, J.D., 1932. The glacial succession on the north Norfolk coast. *Proc. Geol. Assoc.*, **43,** 241-271.

Straw, A., 1957. Some glacial features of east Lincolnshire. *East Mid. Geogr*., **1,** 41-48.

Straw, A., 1958. The glacial sequence in Lincolnshire. *East Mid. Geogr*., **2**, 29-40.

Straw, A., 1960. The limit of the 'Last' Glaciation in north Norfolk. *Proc. Geol. Assoc*., **71**, 379-390.

Straw, A., 1961. Drifts, meltwater channels and ice margins in the Lincolnshire Wolds. *Trans. Inst. Brit. Geogr*., **29**, 115-128.

Straw, A., 1963. Some observations on the cover sands of north Lincolnshire. *Trans. Lincs. Nat. Union*, **15**, 260-269.

Straw, A., 1964. *An examination of surface and drainage in the Lincolnshire Wolds*. Ph.D thesis, University of Sheffield.

Straw, A., 1979a. Eastern England. 1-139 in Straw, A. & Clayton, K.M., *Eastern and Central England*. Methuen: London.

Straw, A., 1979b. The geomorphological significance of the Wolstonian glaciation of eastern England. *Trans. Inst. Brit. Geogr*., **4**, 540-549.

Straw, A., 1979c. Age and correlation of Pleistocene deposits in west Norfolk. *Bull. Geol. Soc. Norfolk*, **31**, 18-30.

Straw, A., 1980. An early Devensian glaciation in eastern England reiterated. *Quat. N/L*., **31,** 18-23.

Straw, A., 1991. Glacial deposits of Lincolnshire and adjoining areas. 213-222 in Ehlers, J., Gibbard, P.L. & Rose, J. (eds), *Glacial deposits in Great Britain and Ireland*. Balkema: Rotterdam.

Straw, A., 2002. The Late Devensian limit in the Humberhead area: a reappraisal. *Quat. N/L*., **97**, 1-10.

Straw, A., 2008. *The last two glaciations of east Lincolnshire*. Louth Nat. Ant. Lit. Soc., 46pp, (www.thecollectionmuseum.com).

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

Swinnerton, H.H., 1936. The physical history of east Lincolnshire. *Trans. Lincs. Nat. Union*, **9,** 91-100.

Twidale, C.R. 1956. Glacial overflow channels in north Lincolnshire. *Trans. Inst. Brit. Geogr*., **22**, 47-54.

Whitaker, W., & Jukes-Browne, 1899. The geology of the borders of the Wash. *Mem. Geol. Surv*..

Worsley, P. 1991. Possible early Devensian deposits in the British Isles. 47-51 in Ehlers, J., Gibbard, P.L. & Rose, J. (eds), *Glacial deposits in Great Britain and Ireland*. Balkema: Rotterdam.

Wymer, J.J. & Straw, A. 1977. Hand-axes from beneath glacial till at Welton-le-Wold, Lincolnshire, and the distribution of palaeoliths in Britain. *Proc. Prehist. Soc*., **43**, 355-360.

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