Meltwater channels and ice margins in the Lincolnshire and Yorkshire Wolds

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Abstract: Meltwater channels in the Wolds were formed when advancing Devensian ice twice blocked easterly-draining valleys of their dip-slopes. Impounded waters found escape either westward through the Market Weighton, Barnetby and Wash gaps, or along ice margins, or eastward over, into or under the ice itself. Some 80 channels can be identified in the Lincolnshire Wolds, but less than 20 in the Yorkshire Wolds. Three areas within the Lincolnshire Wolds are described to reveal circumstances of channel formation (including the phenomenon of ice stagnation in 'strike' valleys), and to emphasize the gentle gradients of ice margins in each advance. The dip-slope of the Yorkshire Wolds contains no 'strike' valleys and was impacted by only the first advance. Most of the marginal channels form the Middleton-on-the-Wolds system, but much meltwater apparently passed eastwards by way of a marginal zone of stagnating ice. The second advance, which covered east Holderness and invaded the central Lincolnshire Wolds, is ascribed to MIS 2 and the first to an earlier Devensian event. In contrast, outliers of higher-level glacial deposits at and north of Swanland, here considered to lie beyond the Devensian limit, are closely associated with a wide, glacially-eroded col across the scarp crest, and are probably surviving features of a pre-Devensian glaciation.

Meltwater channels in the Wolds are linear depressions eroded or modified by water produced by melting glacier ice and snow. They are of various sizes and shapes, and often occupy anomalous positions when compared with the non-glacial fluvial network, such as across spurs and into and along valley sides. In the Lincolnshire Wolds there are at least 80 channels (Twidale, 1956; Straw, 1961, 2008) but less than 20 in the Yorkshire Wolds (de Boer, 1944; de Boer *et al*, 1958). Reasons for this difference are offered below. Also discussed are the limits of ice-sheets on the Wolds dip-slopes, the heights of their upper surfaces, their thickness and flow directions, and modes of disappearance.

Associated glacier-generated deposits belong to the Devensian stage because they were emplaced after formation of a marine cliff that extends from Sewerby near Bridlington for 130 km to the southern edge of the Lincolnshire Wolds (Straw, 2019). The most recent reactivation of this cliff and the beach at its foot was during the Ipswichian interglacial stage (Catt, 2001). During the Devensian ice moved south in the western North Sea area impinging on the coastal areas of Yorkshire, Lincolnshire and north Norfolk. East-draining streams were obstructed and many ephemeral lakes must have formed in their upper valleys beyond the ice fronts. Lacustrine sediments indicate the former presence of impounded lakes, perhaps on more than occasion, in the Vale of Pickering (Kendall, 1902) and the Humberhead area (Raistrick, 1934). Claims have also been made for a large lake in the Fenlands, although the lack of tangible evidence such as deposits and landforms render this unlikely (Straw, 2018b).

In the Wolds, channels were eroded across interfluves in places linking meltwater drainage into integrated systems. Field observations can permit reconstruction of these ancient courses and reveal whether water flowed along the ice edge, passed under, into, or over the ice, or drained away from it. In the Yorkshire Wolds ice reached about 60–70 m OD along the whole of their length (higher spreads of till at and north of Swanland (SE 995 280) may survive from an earlier glaciation, as discussed below). In the northern Lincolnshire Wolds, between the Humber and Kirmington vale, identical heights were attained, although surface levels declined gently west through the Humber gap and into Kirmington vale where pressure was eased. South of Kirmington toward Louth the ice limit rose gently to 118 m OD against the Ipswichian marine cliff where the latter truncates the high ground of the Kelstern 'plateau'. It then descended through the Lud and Calceby Beck catchments to 75–80 m OD. Briefly rising over the south-east Wolds but failing to cover ground above 90–95 m OD, the ice margin declined into the lower Lymn valley to 20–25 m OD. The ice reached a meltwater channel north of Halton Holegate (TA 415 652) which traverses ground underlain by Spilsby Sandstone at 37 m OD and formed the outlet of a lake in the lower Lymn valley (Straw, 1957), well below the 75 m level of that suggested by Evans *et al* (2019). The latter was based erroneously on presumed lacustrine sediments capping Harrington Hill, one of a series of spurs of bedrock Roach stone (Roach Formation). From the Halton channel the margin extended into the Fens along the low-lying Stickney Moraine. This long, gently-undulating limit along the Wolds is marked in many places by meltwater channels, in others by the western limits of tills, sands and gravels, and 'drift-residual soils' (Straw, 1961). This latter term applies to soils that retain the colour and some erratic clasts of the tills but are too thin to map. They are here regarded as including residues of till and related deposits that have been reduced by slope processes such as creep and wash but perhaps most effectively by gelifluction. Lower-lying channels within the maximum ice margin allow definition of some of the stages of ice wastage, of the relative timing of deglacial events, and in Lincolnshire (in the opinion of the writer) of the occurrence of a second invasion by ice.

Lincolnshire Wolds

The meltwater channels in the Lincolnshire Wolds comprise two spatially-determined groups (Fig. 1) separated by the Kelstern 'plateau' (over 125 m OD). The overall drainage of the northern group was first north-north-west toward the Barnetby gap west of Kirmington, and later to the Humber near Goxhill. The southern group initially drained generally south-east with escape from the Lymn valley toward the Fens, and later from the Calceby Beck basin passing south-east of Alford onto the Marsh (Straw, 1958, 1961, 2008).

The Lincolnshire channels can also be resolved into two chronological groups, arguably related to two separate ice advances (see below; Straw, 1957, 1961, 2008, 2016). Distinction is based on channel morphology and in part on their integration into connected systems (Straw, 1961). Some channels, including both older and younger ones, remain occupied by present-day streams and retain gorge-like forms, but the dry rock-cut channels have suffered modification to greater or lesser degrees. Many second-advance channels display relatively steep sides (19–25°) and continuous through-gradients, and are associated with areas of hummocky glacial deposits. Other, first-advance channels, show gentler sides (8–15°) often gullied, undulating long profiles with reverse gradient intakes, and floor sediments of colluvial, soliflual and aeolian origins. It is postulated that slope processes have degraded the sides of the latter channels particularly during the time of the second advance when the dry steeper-sided channels were being formed. Three sample areas are presented (Figs. 2, 5, 8) to illustrate some of these features.

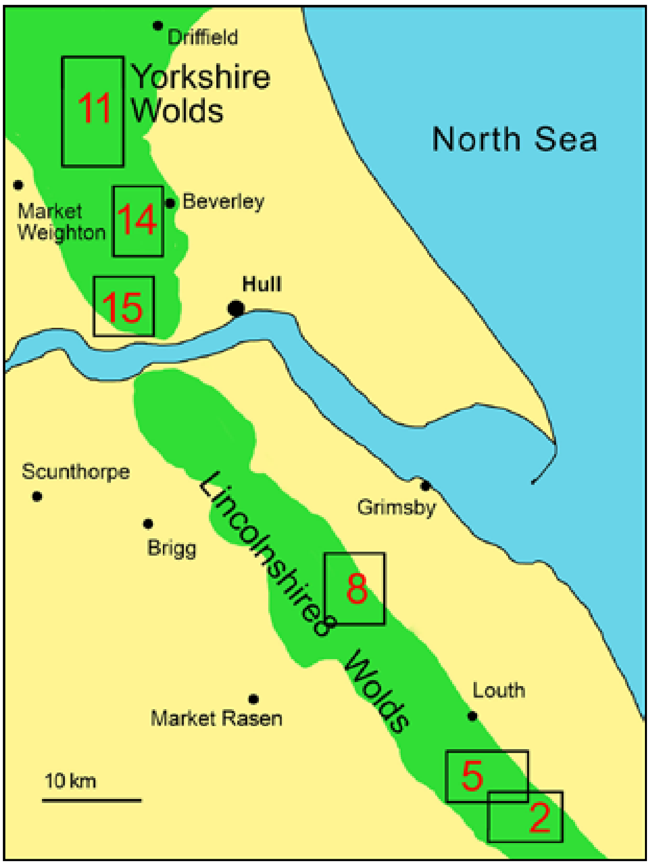

Figure 1. Location of areas described in this paper; numbers refer to text figures.

Channels in Calceby Beck catchment

The Calceby Beck basin lies in the south-central Wolds (Fig. 2). Ice pressed into the area from the north-east passing up the main valley and occupying the north-west tributary valleys of Skirbeck and Ketsby Beck. Its south-west limit has been determined by field-mapping the extent of glacial deposits and channel dispositions.

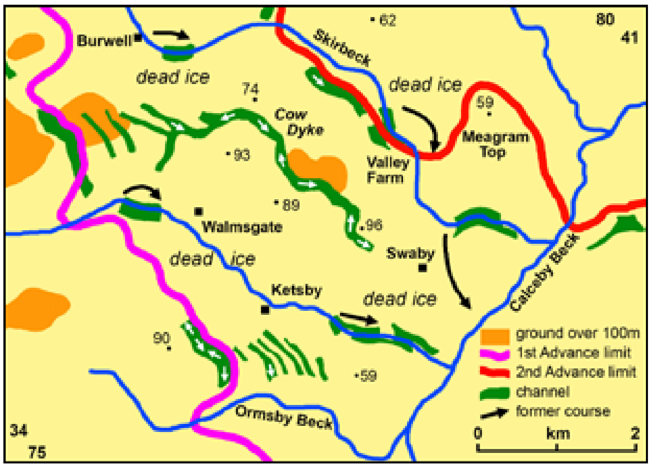

Figure 2. Channels in the Calceby Beck catchment, south central Wolds.

In the valleys the ice would have been some 60 m thick, rising only in a couple of places above 100 m OD. Chalk spurs south of Ketsby (TF 369 765) (Fig. 3) and north of Walmsgate (TF 361 776) are crossed by flights of parallel channels which step down eastward and were formed as marginal channels marking episodic down-wasting of the ice. The ice fronts stabilized long enough each time to permit a channel to be eroded. North-east of Swaby a deep channel (Fig. 4) cuts eastward across a spur end and, with the Ketsby flight of channels, reveals that the ice shrank into a stagnant detached block of 'dead ice' (Fig. 2). Of particular interest is the lowest 'Cowdyke' member of the northern flight which developed once the ice surface had lowered sufficiently to expose the chalk spur east of Walmsgate (Straw, 1961, 2008). The sinuous, 3.6 km-long channel with sides no steeper than 15° descends generally south-east but where it crosses the heads of small pre-existing valleys, reversed portions of the channel floor have been regraded to them. In the north-east the 'Valley Farm' channel was excavated where waters draining down the Burwell/Skirbeck valley were held against the valley side by second-advance ice that had just managed to creep over the Meagram Top interfluve to occupy a short section only of the Skirbeck valley.

***Figure** 3. Sites of four channels of the Ketsby flight – (i) foreground, (ii) buildings/ hedge, (iii) ploughed field (shallow notch), (iv) skyline trees; flow NW to SE. View looking SW from TF 370 762, May 2015.*

The dry channel has a steep (up to 25^{o}) south-west side cut in Chalk, its north-east flank is of till, and it has a continuous long profile. Cutting began at 54 m OD and from the farm the meltwaters passed freely down the valley until they turned east through the pre-existing Swaby channel (Fig. 4). The latter, unusually for the Wolds, is part-filled by chalky sands and gravels forming a prominent terrace which may well represent debris from the 'Valley Farm' channel (Fig. 2) (Straw, 1961).

Channels in Haugham–Tathwell area

Further north toward Louth, the Tathwell valley trends south to north, collecting several Wold tributaries (Fig. 5). Ice advanced from the north-east overriding the ridge carrying Kenwick Bar (TF 337 846) at just 98 m OD and descending into the valley. It passed 2 km or so up the tributary valleys, leaving small mounds of moraine and tiny stream deflections at Dovendale (TF 390 828) at 90 m OD, and near Tathwell Grange (TF 309 820) at 85 m OD. The ice limit can be traced along and round the intervening spurs, almost horizontally at a little under 100 m OD. A lake in the upper Tathwell valley with an initial surface level at 100 m OD over-flowed briefly southward taking advantage of a col west of Orgarth Hill. A little later a slightly lower channel, 'Lewis Yard', was used. These two channels are now wide and shallow. Between them are the two steeper-sided 'Orgarth Farm' channels sliced across two spurs, one draining north, the other south (Fig. 6) from a plug of moraine at the farm. These would appear to be second-advance channels, ice having pushed up to the farm but not surmounting Bully Hill to reach 96 m OD; but there may have been an earlier channel here, later subsumed (Straw, 2008). Channel erosion began at 99 m OD, the north trench taking water into the Tathwell valley and the southern one into the Burwell/Skirbeck valley (Figs. 5, 6). Waters must have come mainly from within and off the ice, there being no space westward for a lake. From the farm the ice margin trended east, north of Haugham village, then pushed up three short Wold valleys to a height of 80–85 m OD and stabilized long enough for the striking Haugham Slates channel to be excavated mostly by marginal drainage (Fig. 5). It is sinuous, 4.6 km long with flanks sloping at 20–25^{o} Although it crosses the three valley heads it maintains a constant gradient (unlike the 'Cowdyke' channel with its reversed sections) of about 1:90. The intake has a tight S-plan and, about a third of the way down, the channel widens into an almost circular loop (?indicative of a whirlpool) scoured by powerful flows of water. At 300 m further down a swallow-hole now occupies the floor (at TF 358 812) (Fig. 7) and may well feed the spring 1.5 km north-east. At its lower end the channel turns south finally crossing the spur to empty into the Skirbeck valley and supply water to the

***Figure** 4. Swaby channel; Skirbeck flows through this channel which was eroded across a Chalk spur during recession of first advance ice. The terrace consists of chalk-rich gravel derived from the upstream Valley Farm channel during the second advance. View looking E from TF 390 776, May 1959.*

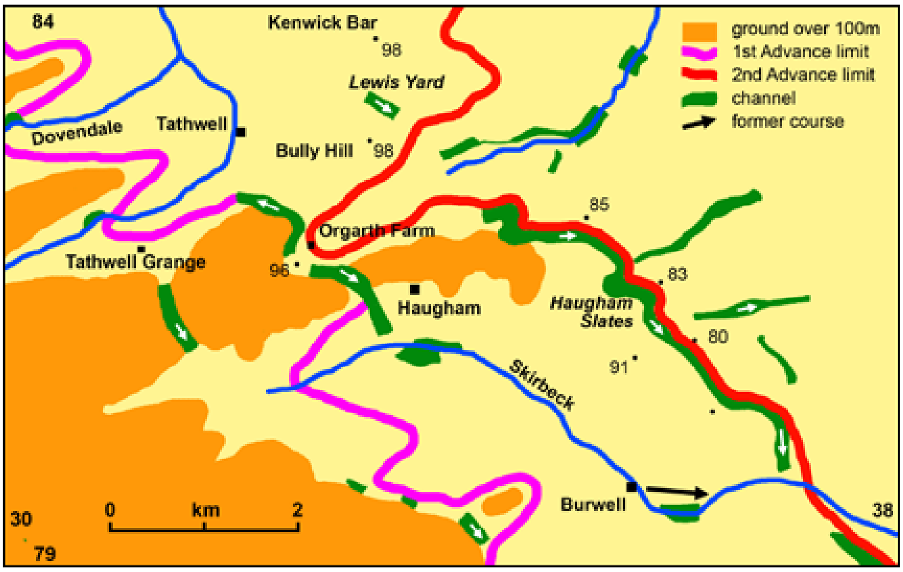

Figure 5 (top). Channels in the Haugham–Tathwell area, south central Wolds.

***Figure 6** (middle). Channel south of Orgarth farm, eroded during the second advance. Cut wholly in Chalk, its side slopes attain 23°. An intermittent stream occupies a floor somewhat modified by agriculture. View looking N from TF 333 816, May 1978.*

***Figure 7** (bottom). Haugham Slates channel eroded at the second advance limit. The sides reach 25°, and the continuous floor is here interrupted by a 5m-deep swallet, partially clogged by hedge cuttings and field rubbish. View looking SE at TF 357 812, June 1956.*

'Valley Farm' channel (Fig. 5). East of the main channel, two of the three pre-existing valleys that it crosses have been deeply cut suggesting that water eventually passed under the ice as it melted back.

Channels in Hatcliffe area

Stages in the stagnation and down-wasting of ice can also be detected in the north central Wolds area around Hatcliffe (TA 213 008; Fig. 8), this time, unlike in Figure 2, mostly related to the second ice advance. In this stage ice, some 30–40 m thick, probed south up the Newton Beck valley and south-west into the Croxby Beck valley and, on adjacent high ground, barely attained 54 m OD. It reached Thorganby, where a small 'in-and-out' channel survives. Several channels developed around a 'dead ice' block; two still hosting the modern streams plus the dry channel at Round Hill which has steep sides up to 25°. The ice block's former presence is also indicated by an extensive area of hummocky, morainic ground. When the ice had shrunk further back into the Welbeck valley, meltwaters were turned across a narrow spur and then deflected south-east at Hatcliffe Mill (TA 230 025). Two channels at higher levels related to the first advance can be identified crossing ground west and east of Beelsby Top. The higher, 'Ash Holt', channel was produced by waters draining a lake in the upper Hatcliffe and Croxby valleys that took advantage of a col at 85 m OD somewhat beyond the ice limit, the ice having failed to cover the Top. Its intake is reversed, its gullied sides are no more than 10° (Fig. 9). The easterly 'Beelsby' channel (4 km long) has a sinuous plan and from its location across the same broad interfluve as 'Ash Holt' was most likely initiated during recession of the ice margin of the first advance (Straw, 1961, 2008). However, like the 'Orgarth Farm' channel (Fig. 5) it has two opposing parts. The highest point in the long profile is at 70 m OD (TA 208 027) and is underlain by till. One part (2.2 km long) develops south through Beelsby village descending 33 m (1: 66) with sides up to 25°, and another falls north-north-west, equally steep-sided,

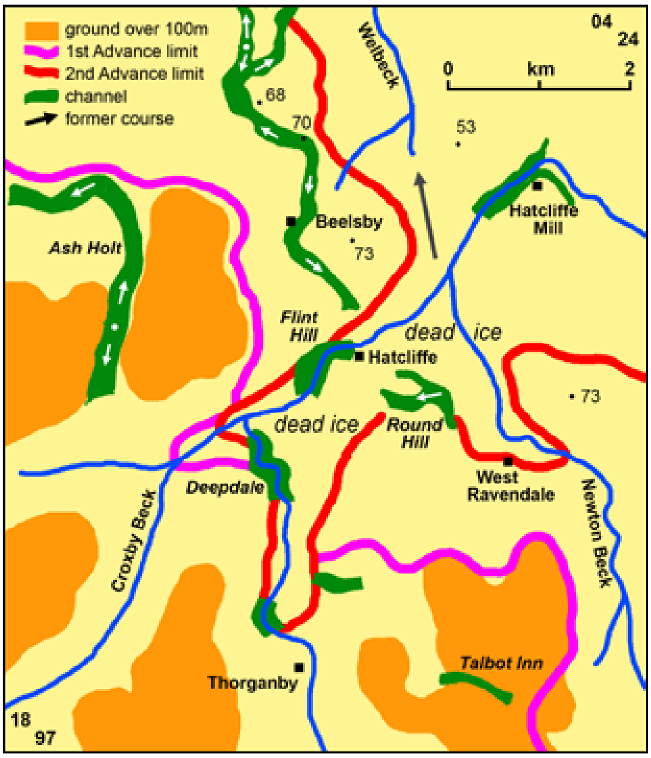

Figure 8. Channels in the Hatcliffe area, north central Wolds.

bifurcating in its northern part. Here the western branch is shallow and may be part of the first advance channel. The eastern branch turns northeast toward Walk Farm maintaining the form of the southern part. The presence of glacial materials at the highest point is now taken to indicate that second-advance ice entering the Welbeck valley did just reach the older channel north of the village at 70 m OD and from here meltwaters flowed both north and south, deepening it.

From these examples certain general proposals can be made.

(1) Ice in the first advance reached up to 100 m OD in the south-central Wolds and entered the Calceby Beck and Tathwell Beck catchments, pressing further west in the valleys than on the interfluves. Its maximum thickness in the valleys was of the order of 40–50 m, and ephemeral lakes formed in the valley heads. In the Hatcliffe basin (Fig. 8) ice also reached *c*.100 m OD, with lakes again impounded. Allowing for slightly higher margins against the Kelstern 'plateau', the ice edge was remarkably level along the length of the central Wolds (Straw, 2008).

(2) In the second advance, ice failed to invade the Calceby Beck valley and was able to enter only a short section of the Skirbeck valley after crossing ground of *c*. 66 m OD. Further north it did not get over the Kenwick Bar interfluve at 93 m OD but probed up the Orgarth valley to 96 m OD and, further north, also that of Hallington Beck (Fig. 10). In the north-central Wolds ice pushed up the Ravendale and Hatcliffe valleys, keeping below *c*. 60 m OD.

(3) A notable feature of deglaciation after both advances is that, as down-wasting proceeded, spur crests emerged first and, because of the alignment of many valleys and interfluves broadly north-west–south-east athwart the direction of ice flow, stagnant shrinking blocks of ice became isolated; in the first advance in the Ketsby Beck area (Fig. 2) and Tathwell valley (Fig. 5) and, after the second advance, in the Hatcliffe area (Fig. 8).

(4) It is significant that, whereas in the Hatcliffe area the wasting block left an area of glacial and glacifluvial deposits exhibiting constructional features, those of the first advance in the Tathwell, Skirbeck and Ketsby/Calceby valleys seemingly did not. By contrast, in these latter areas surviving tills display formless surfaces and have suffered some dissection. The absence here today of constructional features could support the claim that the first advance was older and separate from the second, were such features to have originally existed only to be eliminated later, especially during harsh climatic conditions associated with the second advance. The geomorphic contrast between the Hatcliffe area on the one hand and the Tathwell/Calceby areas on the other provides strong support for two advances.

(5) During the first advance, some lake waters flowed across major divides, channels forming marginally or a little way west of the ice front as at 'Ash Holt', 'Lewis Yard', and 'Talbot Inn'. In the Ketsby area stages in

Figure 9*. Ash Holt channel; gully developed on its W side. The channel runs L–R across the foreground. View looking W from TF 190 006, May 1959.*

down-wasting are recorded in the flights of channels cut across tributary spurs. These channels were modified, particularly during the second advance, by slope and fluvial processes which degraded their sides, eroded gullies and caused regrading of intake sections toward pre-existing valleys.

(6) In the second advance marginal channels like 'Valley Farm' (Fig. 2) and 'Haugham Slates' (Fig. 5) mark the maximum ice limit, and in the Hatcliffe area the fine gorges of 'Deepdale' and 'Flint Hill' carried waters around the 'dead ice' block.

(7) Although meltwaters would have been provided directly from the glacier ice, notably at Orgarth and Beelsby and from the ice blocks, a large quantity would have been from snow-melt over both unglaciated higher ground and the ice surface. Most of the Wold valleys would have collected water, most probably seasonally, by surface run-off, and it would have been this water that was mainly responsible for periodically flushing out and eroding the various channels. Chalk is both frost susceptible and well-jointed, and channel creation could have been rapid, reckoned perhaps in decades rather than centuries. An excellent example of snow-melt water erosion during the second advance, not figured here, comes from the Tathwell Beck catchment. The stream at and below Tathwell village, trending north, receives three tributaries from the west before joining Hallington Beck. Ice obstructed the lower part of Hallington Beck valley and all the basin's waters were directed north to erode the superb 'Hubbards Hills' channel west of Louth (Fig. 10) (Straw, 2008). The catchment covers some 26 km^2 and seasonal snow-melt run-off would have provided most of the water. Other Wold valleys have similarly large catchments. However, at Orgarth and 'Haugham Slates' no sizeable lakes could act as reservoirs, and most of the water must have come from the ice surface, together with snow-melt. Even under a cold climate regime, solar radiation was as intense then as it is today.

To conclude this section of the paper, it can be noted that only one small channel occurs in the south-east Wolds (at 93 m OD) draining away from thin ice of the first advance, and that in the north Wolds only a group of shallow, parallel, north–south grooves lie between Ulceby and Thornton Curtis, at heights between 30–25 m OD (Straw, 1961). As in the south-east Wolds, only ice of the first advance reached the north Wolds, attaining a general height of 60 m OD. Here tills survive only on interfluves, in places as outliers, and thin out westward with 'feather-edges'.

Yorkshire Wolds

The lower parts of the dip-slope were invaded by Devensian ice which overwhelmed and buried the Ipswichian cliff that extends from Sewerby to the southern edge of the Lincolnshire Wolds. Glacial deposits, south of Kilham, as mapped on British Geological Survey Sheets 64 Great Driffield (1993), 72 Beverley (1995), 80 Kingston-upon-Hull (1983) rarely rise above 60 m OD (de Boer, 1944, noted that for the most part they do not rise above the 200-foot contour). As south of the Humber this indicates a persistently level ice margin. This ice moved into the area from the north-east, its western part surmounting Flamborough Head, where glacial sediments lie up to 110 m OD, before descending south. Straw (1961, 1979, 2008) and Gaunt *et al* (1992) observed that both north and south of the Humber, glacial materials extend further west along the interfluves than they do in the valleys, suggesting that there has been considerable post-depositional erosion, for the streams now pass onto such materials lower down the valleys (Figs. 11, 14). The mapped margin is therefore very irregular in plan. Initially however the ice must have passed further up the valleys than on the spurs, and this can be demonstrated in the valley south of Bishop Burton at Crawberry Hill (SE 981 382) (Fig. 14) where a small mound of moraine still obstructs the course of the modern stream, just as at Dovendale and Tathwell Grange in the Lincolnshire Wolds (Fig. 5).

Between Kilham (TA 063 645) and Middleton-on-the-Wolds (SE 945 495) the generalized mapped limit of glacial deposits rises gently south from 40–50 m OD

***Figure 10**. The Tathwell/Hallington valley, W of Louth, from the A153. When ice blocked the valley just E of the gorge, waters flowing from W and S were forced north to erode this superb Hubbards Hills channel. To the W, an older smaller channel notches the spur. View looking N from TF 315 855, May 1978.*

to 62 m OD, but does not always accord with that to which the ice reached, because of the erosion noted above. Further south, north-west of South Dalton (SE 967 454), the mapped limit lies 2 km east of the marginal 'Holmedale' channel, whereas ice manifestly rose to 72 m OD at its eastern edge (Fig. 11). West of this village a mass of till reaching 48 m OD, separates two valleys but one kilometre to the west lies the marginal 'Old Dale Plantation' channel. The spur areas between the mapped glacial deposits and ice limits are 'bare' because they have lost any superficial cover to gelifluction (snow-melt and frost) and soil creep, though erratic clasts remain in 'drift-soils' on the spurs. These features argue for a considerable relative age for the glaciation, as observed in Lincolnshire and considered below.

From South Dalton both ice and mapped limits remain between 50 m and 65 m OD as far south as Bishop Burton (SE 990 397), then rise gently to 73 m OD at Walkington (SE 998 371) and 75 m OD west of Skidby (TA 005 336), descending thence slowly to 55 m OD south-east of Swanland and finally turning west into the Humber gap. However, at and northward of Swanland, glacial deposits are mapped on higher ground up to 100 m OD and have traditionally been regarded as part of the Devensian deposits (de Boer, 1944; de Boer *et al*, 1958; Gaunt *et al*, 1992; Bateman *et al*, 2018), but their elevation and geomorphic situation prompt a revision of the Devensian ice limit and permit a different interpretation (see below, Fig. 15).

Channels

Whereas there are more than 80 channels in the Lincolnshire Wolds, there are less than 20 north of the Humber, and only half of these form connected systems. Two reasons may be offered.

First, although both Wolds are underlain by Chalk, the physiography of the Yorkshire Wolds is very different from that south of the Humber. In Lincolnshire, there are valleys that have a 'strike' orientation, generally north-north-west–south-south-east, separated by broad spurs. With ice flow from the north-east, these spurs had to be overridden for ice to reach the valleys (for example, those of Welbeck (Fig. 8), the river Lud, Tathwell Beck (Fig. 5), Skirbeck and Ketsby Becks (Fig. 2) which eventually became the locations of stagnant ice masses during deglaciation. There are no such 'strike' valleys in the Yorkshire Wolds, south of the Gypsey Race. Here, the overall dip-slope gradient is steeper than in Lincolnshire, the high ground is higher, and the mostly east-draining valleys are closely spaced (Figs. 11, 14). Although much branched in their upper parts, they do not receive major tributaries that could have provided confluences where potentially ice could have been trapped to melt *in situ* and thereby create more opportunities for channel formation.

Second, the Yorkshire Wolds were only invaded once by Devensian ice. In the Lincolnshire Wolds, as described above, many of the channels are considered to have been eroded during a second advance, particularly in the central Wolds. The Yorkshire Wolds lack this second phase of channel formation because the second advance only covered Holderness east of the river Hull (Straw, 1979, 2016). Bateman *et al* (2015), Bateman *et al* (2018) and Evans *et al*, (2019) recognize a second glacial phase but regard it as a recessional feature, not as a new advance. It is nevertheless curious that so few channels in the Yorkshire Wolds were cut across spurs during the first advance, when all the east-draining valleys were obstructed. Only in two localities, described below, were systems of meltwater drainage developed at or close to the maximum ice margin. The reasons for this shortfall are not immediately obvious.

Lakes, constantly replenished by snow-melt water, must have existed in the Yorkshire Wolds valleys but there is little trace of them overflowing across bounding interfluves. De Boer (1944) identified a channel at Danesdale (TA 082 662) draining his 'Lake Rudston' into the Kilham valley and noted that a 'Lake Garton' was drained by a small channel (SE 940 506) notched into a spur north of Middleton-on-the Wolds. However, his description implies that 'Lake Garton' at 65 m OD,

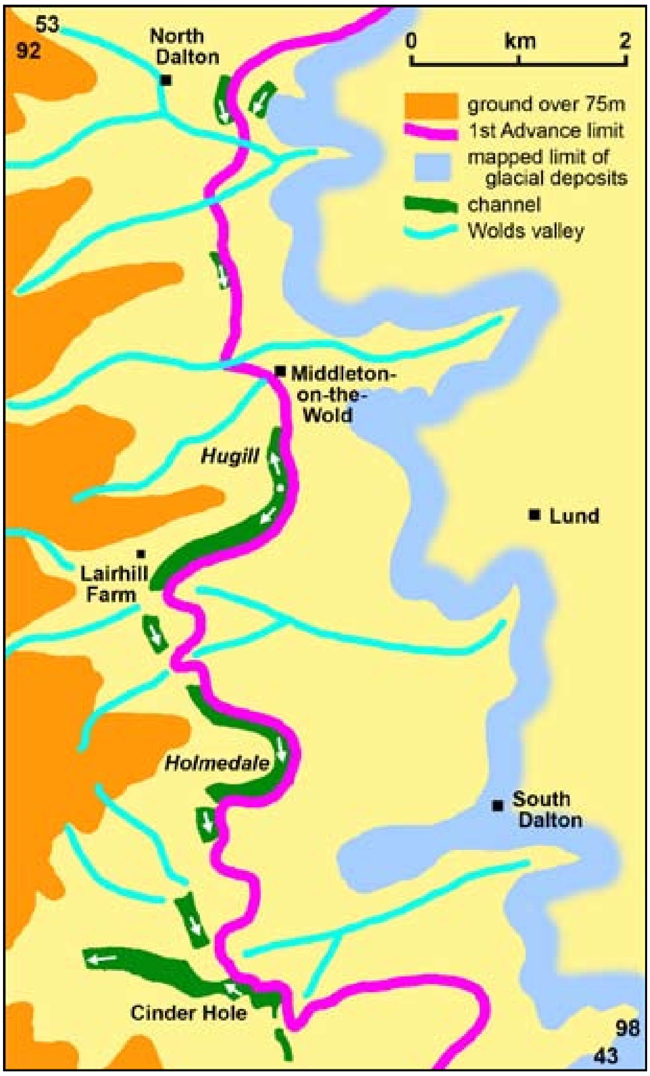

Figure 11. The Middleton channel system, Yorkshire Wolds.

extended for some 10 km south of the village. Yet this could not be, with prominent spurs north and south of Tibthorpe (SE 960 555) reaching over 75 m OD, totally un-notched. De Boer (1944, p. 227) also argued for the initial existence of a vast lake at 80 m OD that 'would drown all the spurs between this col [Market Weighton] and Hunmanby Dale'. Certainly, one big lake or even several slightly smaller ones could have prohibited the development of cross-spur channels, but where did the water go? Repeatedly the high ground of the Wolds could have produced large volumes of snow-melt water within the many-branched upper valleys, especially under permafrost conditions. If the lake or lakes did not drain marginally then the water can only have gone over, into or under the ice. For example, the broad Wetwang valley to the southwest of Garton must have contained water but its only egress could have been eastward beneath the ice. Such a general circumstance of sub-glacial drainage was seriously considered by de Boer *et al* (1958, p. 193). Evidence for a few instances were noted above in the Lincolnshire Wolds, and in the Yorkshire Wolds it might well have occurred also at Risby (de Boer *et al*, 1958) and at Bishop Burton (Fig. 14). More broadly, flow under the ice might account for some of the post-depositional removal of glacial sediments from valleys at the ice margin, but the real nature of water escape from the zone between Kilham and North Dalton can only be surmised.

Only south of Middleton-on-the-Wolds (Fig. 11) does an integrated system of channels exist (de Boer, 1944). It may commence with the small notch some 8 m deep across a spur tip at Mill Farm (SE 940 455) north of the village where cutting at the ice margin began at *c*.72 m OD, but its floor descends south into the valley that runs east, north of the village. Till and gravels survive beneath the western part of the village at 55 m OD near the reversed intake of the 'Hugill' channel (Fig. 11). The high point of this channel's floor is in Pricketts Hollow at 58 m OD (SE 945 485) where both sides rise to 75 m OD. This impressive channel (Fig. 12), 1.4 km long and clearly marginal, descends at 1:140 south-west to open at 48 m OD into a Wold valley south of Lairhill Farm (SE 932 478). It is continued across a small spur by a short 200 m channel at 48 m OD, and south of this is the intake of the 'Holme Dale' channel (Fig. 13). Of similar form to 'Hugill' the latter sweeps round the end of a spur through Short Dale and Long Dale having been held by ice at 72 m OD, is 2.4 km long with sides up to 25° and its floor descends at 1:240 (Fig. 11). It opens into a small bowl-shaped Wold valley, and the system is then completed by a short channel 9 m deep through Old Dale Plantation. From here meltwater flow turned abruptly west because ice blocked any route eastward. Marking the ice front here, a short, sinuous marginal channel drained northwest to Cinder Hole from near Westwood House (SE 948 434) to add its waters to the flow. Overall the system was 7.5 km long to Cinder Hole linking six valleys, and discharge took place through the Market Weighton gap (de Boer, 1944; de Boer *et al*, 1958). De Boer however noted that the floors of the three southern channels were below the height of that in the gap, suggesting they may have been used for a while after water ceased to drain westward.

A shorter system at Risby Park (Fig. 14) is also described by de Boer (1944; de Boer *et al*, 1958). Here, three marginal channels lie about one kilometre east of the till limit, cut after recession from the maximum ice margin had begun. From Walkington village these decline south for 1.2 km to meet a north-draining channel in Risby Park. From here a deeply-eroded valley exposing chalk trends east-north-east for over 1 km, seemingly cut by waters from the convergent channels escaping sub-glacially.

Meltwater erosion can also be detected at Garton-on-the Wolds (SE 983 595) where ice reached 60 m OD. Three south-draining notches transect glacial materials south of the village but must have been fed by seasonal snow-melt because the topography prohibits formation of a lake to the north. At Bishop Burton a branched

Figure 12. *Central curving part of the Hugill channel. View looking upstream to Lund Wold House farm, ENE from SE 940 479, April 2019.*

Figure 13. N portion of the Holme Dale channel, which crosses the foreground, then turns into the woods behind Holmedale Farm. View looking ESE from SE 936 467, April 2019.

Wold valley, Flowery Dale, was occupied by ice as far as Crawberry Hill (Fig. 14). From here the valley turns north through the village exposing Chalk, then north-north-east to the east of the College. Collecting three small valleys from the west and a short channel at Mill Farm from the south-east its waters may then have passed under the ice. At North Dalton (Fig. 11) two south-draining channels received water along the ice edge from the northeast and might seem to be the headward part of the Middleton system, but their floors slope down to the valley on the south side of the village below that system's intake.

South of Risby no spurs are notched although glacial deposits survive on interfluves west and south of the village. The valley containing Eppleworth and followed by the minor road exposes Chalk for 2.5 km east of the glacial limit. Upstream to the south-west it is very deeply cut and separates two high-level outliers of till. It has a large catchment around Riplingham to provide snowmelt a-plenty.

Ice at some stage manifestly interrupted the drainage of the Yorkshire Wolds, and channels formed in a variety of situations, but none as complex as some of those in the Lincolnshire Wolds. Only with the Middleton system did water escape away from the ice. If much water passed over or into the ice, all evidence for that has disappeared.

High-level glacial deposits

These deposits, mainly till, are disposed in three outliers at and north of Swanland (Fig. 15), and have always been regarded as lying within the Devensian ice limit (de Boer, 1944; de Boer *et al*, 1958; Gaunt, 1992; Bateman *et al*, 2015; Bateman *et al*, 2018) deserving mention only for their height. The south-easterly outlier underlies the western part of Swanland between 80 m and 90 m OD, extending south-west toward Trinity House farm (SE 985 271) and north-east along the spur south-east of Westwinds Farm (SE 998 296), here at 75–80 m OD. It is separated from the central outlier by the north-east-draining valley followed by the minor road. This central outlier occupies a spur directly in line with a wide col over the scarp crest (Fig. 15). Its surface lies at 80–85 m OD and it extends northeast for 2 km or so to Rawdales (TA 008 308). The third outlier is a narrow strip of till capping a spur aligned west–east to the north of Braffords Hall. It is over 2 km in length and descends from 100 m OD in the west to about 60 m OD in the east. It is likely from the soils that more

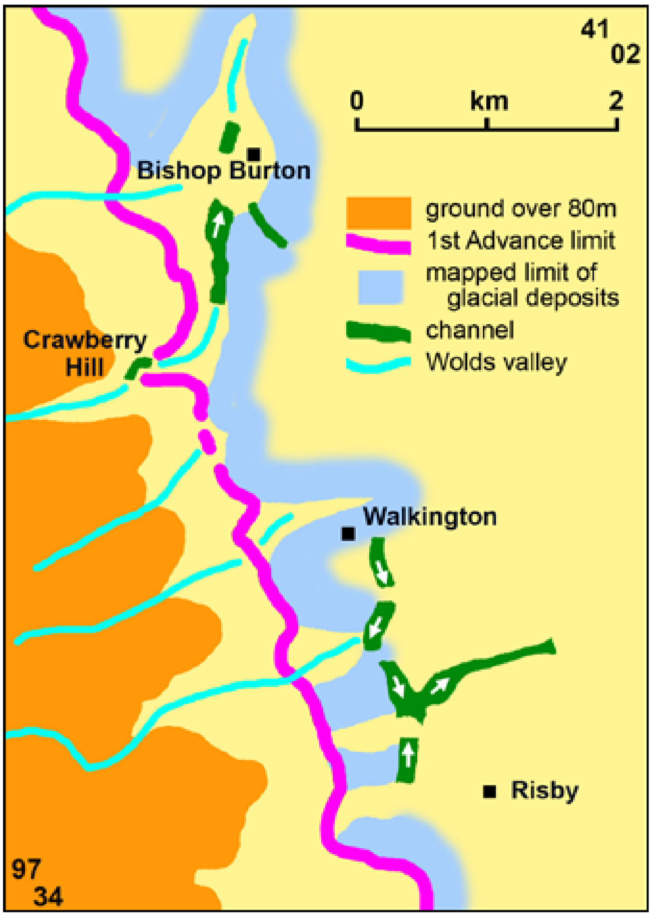

Figure 14. Channels north of Risby, and at Bishop Burton.

survives on a broad spur southwest of the Hall. The central and western outliers are separated by the very deep, central section of the Eppleworth–Riplingham valley.

These three outliers, the surface of the central one accordant with the col floor (see below) occupy a position in the landscape, not previously acknowledged, different from that of the lower-lying glacial deposits the boundary of which in this area seems to run south from Eppleworth in the north to West Ella, thence east of Swanland into the Humber gap at North Ferriby, within a height range consistent with that of the ice margin in the north Lincolnshire Wolds and through the gap. In the gap, the ice surface height decreased west to Winteringham and Horkstow as pressure was relieved (Straw, 2008). Bateman *et al* (2018) attempt a reconstruction of the ice surface in the gap using estimation procedures based on modern surface profiles of steady-state glaciers. Taking the Winteringham kame-moraine as the maximum extent of the ice, it was calculated that the gap was occupied by 100–200 m of ice, and this doubled to 400 m at the position of Hull. As noted by Straw (2019) this is quite unrealistic, because the glacial materials lie below 30 m OD at Melton and also, on the south side of the Humber, between Barton and South Ferriby. In Barton, field mapping reveals till rising to *c*. 60 m OD, and this level persists south to Kirmington (see above). Were the ice to have exceeded 100 m OD it would have overtopped the north Lincolnshire Wolds, which is manifestly not the case.

The continuity of altitude shown by the lower-lying glacial deposits emphasizes the anomaly of the higher Swanland ones. Why, when the first advance ice clearly had a consistently level margin should it there rise 30–40m higher? De Boer claimed increased pressure within the ice, but glaciologically this seems very unlikely in a zone just north of the Humber gap, where pressure was being released. This writer considers that these higher deposits, in their relatively greater height and separation into outliers by the formation of deep Wold valleys could well survive from an earlier, pre-Devensian, glaciation, and geomorphologically they are associated with the col west of Swanland.

The col is a unique and old landform (Fig. 15) mentioned by de Boer as a wind-gap (de Boer *et al*, 1958). It is 2.5 km long, and 1.5 km wide between the 90 m OD contours. It retains exceptionally straight and smooth sides; the north-west one, the least gullied, slopes at 3°30’ between the 100 m and 75 m contours. The south-east flank is steeper, at 5°12’ between the 85 m and 65 m contours, having possibly been modified by the development of a southerly-draining valley which receives tributaries only from the west and northwest within the confines of the col. This valley, obviously formed after the col was created, dissects the floor of the col but two remnants survive. At the north-east end an area trending northeast–southwest in the middle of

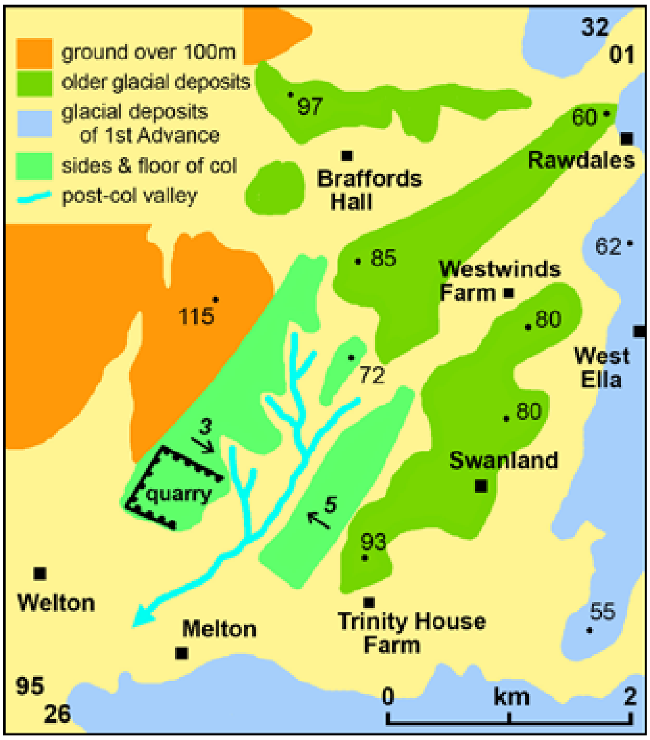

Figure 15*. High-level glacial deposits and col, N and W of Swanland.*

the col is enclosed by the 70 m contour (centred on SE 984 289), and 1 km south-west a broad spur west of Skiftings Clump (centred on SE 978 283) also lies on the 70 m contour. If these are true remnants, the col was initially some 30 m deep. At the south-west end the floor has been utterly destroyed by the Melton Bottoms quarry. Its form is not that of a fluvial feature, and its size and shape betray a more robust origin, most likely one of glacial erosion some time before the Devensian stage. The north Lincolnshire Wolds are known to have been overrun by pre-Devensian, south-west-flowing ice that carried chalk and distinctive flints into central Lincolnshire (Harmer, 1928; Straw, 1983, 2018a). There seems no reason why the col and the higher-level glacial deposits should not relate to this glaciation, and thereby be contemporaneous with the Basement Till of Holderness and the Welton Till of the central Lincolnshire Wolds.

Conclusions

(1) Many differences are apparent between the Lincolnshire and the Yorkshire Wolds in terms of channel morphology and frequency. Geological, geomorphological and glaciological reasons have been offered to account for some of them. Many complex systems existed in the central Lincolnshire Wolds, only one in the Yorkshire Wolds. Yet significant similarities are to be noted, especially in the heights reached by the ice edge along the foot-slopes of the Yorkshire Wolds and the north Lincolnshire Wolds and in the dissection and erosion of the glacial deposits along marginal zones of formerly stagnant and permeable ice.

(2) The relative paucity of meltwater channels in the Yorkshire Wolds coupled with the instances where water can reasonably be inferred to have entered the ice are considered to be both consequences and indicators of degeneration of the ice at least along a marginal zone. It may be claimed that most of the water which accumulated in pro-glacial lakes drained away over, into, or under the ice.

(3) The greater complexity of the north central Lincolnshire Wolds systems is ascribed by the writer to a second advance of ice that did not penetrate the valleys to quite the same extent as in the first. Field-mapping shows that the second-advance ice, allocated to the Last Glacial Maximum (Straw, 1958; 1961; 1979; 2008), diverged from the Wolds at Keelby and, northward, built the Killingholme Moraine. The latter is represented north of the Humber at Routh and Wawne.

(4) Bateman *et al* (2018) and Evans *et al* (2019) regard this second stage as a recessional feature in the withdrawal of ice from the Wolds dip-slopes, all during MIS 2. Both papers cite numerous OSL age estimates within the range 22–18 ka, but no samples derive from the dip-slope sediments. This paper has sought to draw attention to the noticeably fretted nature of the first-advance margin, in part a consequence of substantial erosion of till from some areas within the ice limit, as a mark of greater relative age. The margin also lacks prominent features along the Yorkshire Wolds dip-slope, such as moraine ridges, kettle-holes, kames, outwash fans, and eskers, possibly because of subsequent degrading processes, all of which are present east of the river Hull. A contrast between the Hatcliffe and the Tathwell–Calceby areas is also explicable in such terms. Further, were all the Devensian deposits in the Wolds to belong to MIS 2, then a time gap of some 100 ka with no glacial or geomorphological expression opens up between their deposition and formation of the Ipswichian cliff they bury. These facts have persuaded the writer over many years that while the second advance may well be a MIS 2 event, emplacement of the Yorkshire Wolds glacial deposits (excluding the higher Swanland ones) together with some in the Lincolnshire Wolds took place in an earlier glaciation, possibly MIS 4 (Straw, 2019), still within the Devensian (Straw, 2019), but considerably before 22 ka.

(5) The highest elevations of the first-advance ice margin were in the vicinities of Middleton north of the Humber and the Kelstern 'plateau' to the south, where ice met somewhat higher ground on the Chalk. By contrast, the relatively low altitude (*c*. 50–55 m OD) of the margin (noted by de Boer, 1944) from Tibthorpe to Kilham may reflect the influence of Flamborough Head in retarding ice flow over it compared with the stronger flow which would have prevailed round and southward of the promontory.

(6) Delimitation of the first-advance sediment and ice margins has raised the probability that pre-Devensian glacial materials, associated closely with an ice-eroded col over the scarp crest, survive at and north of Swanland, at heights of 75–100 m OD. It can also be observed that they lie west of the Ipswichian buried cliff, and could therefore have been emplaced before its development.

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