A case for MIS 4 Glaciation of eastern England

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Abstract. The occurrence of two discrete advances of Devensian ice in eastern Lincolnshire was postulated by the writer over 60 years ago. Sediments related to the first advance are appreciably more weathered, degraded and dissected than those emplaced in the second, and the latter was regarded as the MIS 2 Last Glacial Maximum (LGM). It is proposed that tills along the northern Norfolk coast, overlying raised beach deposits at Hunstanton and Morston, tills at Sewerby and exposed at South Ferriby cliff in the Humber gap, all relate to the first advance, which took place in a cold stage preceding MIS 2, possibly MIS 4, when ice impounded an early Lake Humber. A later lake with surface at c.10m OD developed when LGM ice built the Killingholme Moraine and occupied eastern Holderness. In the Vale of Pickering the Hutton Buscel kame terrace, which just might be related to a questionable 70m lake, is considered much older than adjacent MIS 2 deposits that are associated with a 45m lake. The Kirkham gorge is shown to be a multi-phase feature with periods of downcutting preceding MIS 2. The prevailing view that all Devensian sediments and landforms in eastern England are Late Devensian is too restrictive, and greater credence should be accorded to the notion that some belong to MIS 4.

Evidence from the eastern side of the Lincolnshire Wolds (Straw, 1958, 1961) for a two-fold glaciation of east Lincolnshire during the Devensian (Fig. 1) includes two groups of meltwater channels, contrasts in the surface form and degree of dissection of the glacigenic deposits and, on the Marsh, identification of two suites of these deposits from borehole records. Later, the question was raised whether an Early Devensian glaciation might be recognized in eastern England (Straw, 1979a, 1980) and, in a wide-ranging account of the geomorphology of eastern England (Straw, 1979b), the hypothesis was set in a broader context that included north Norfolk, Holderness and the area around Scarborough. Ten years later (Straw, 1991) the concept of two discrete ice advances was reiterated and subsequently the east Lincolnshire situation was described in greater detail (Straw, 2008). Worsley (1991) acknowledged the bipartite Lincolnshire evidence but questioned a postulated Lake Fenland, drawing attention to the sedimentology of the Kirkby Moor Sands near Woodhall Spa. Most recently, taking account of research by the Trent Valley Palaeolithic Project in the Trent and Witham catchments (Bridgland et al,2014), these difficulties have been addressed by Straw and Worsley (2016) and Straw (2016; 2018a.)

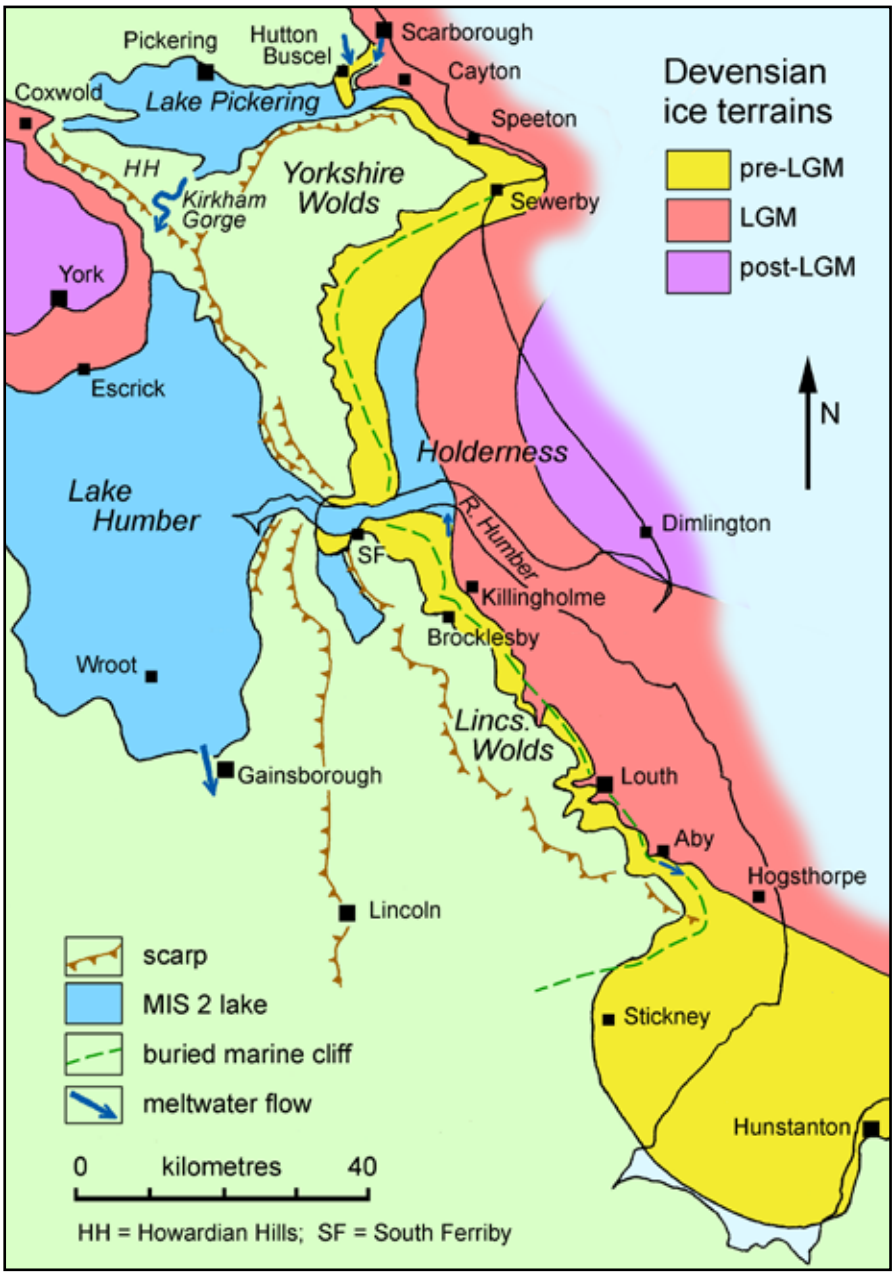

Figure 1. *Devensian ice in eastern England.*

East Lincolnshire and Holderness

Both Lincolnshire advances are referred to the Devensian (Fig. 1) because they post-date the final phase of erosion of the remarkable buried cliff, cut in Chalk, that extends for some 130 kilometres (80 miles) from the southern Lincolnshire Wolds to Sewerby near Bridlington (Fig. 2) and, on the basis of the Sewerby stratigraphy, is regarded as Ipswichian (MIS 5e) (Catt, 2001) (Fig. 3). This denies a possible MIS 6 date for the advances. Along most of its length this cliff is wholly or partly buried by deposits related to these advances (Fig. 1). Recession of this cliff involved replacement of much Chalk dipslope by an extensive marine abrasion surface, the Marsh platform (Straw, 1961), at least 16 kilometres (10 miles) wide east of Louth. So extensive is this feature that it was most probably initiated in earlier interglacials, not least the Aveley Interglacial (MIS 7), with its final trimming and aligning of the cliff following reactivation in the Ipswichian. This platform has a crucial role in elucidating the glacial history of eastern England. Before its final production ice invading from the north in MIS 8 (White et al, 2016) necessarily crossed Chalk country, the Yorkshire and Lincolnshire Wolds dipslopes then extending much further east. Resultant tills, Calcethorpe Till in Lincolnshire exposed at Welton-le-Wold (Straw, 2005,2015) and Marly Drift in north-west Norfolk (Straw, 1965) now known as the Weybourne Town Till (Lee et al, 2015) are highly chalky and light-coloured. By contrast, Devensian ice perforce traversed the Marsh platform with its mantle of marine clays, silts, and sands largely sourced from the catchments of the Humber, Tees, and Tyne, (Catt, 1991). The deposits of both advances are therefore clay/silt rich and various shades of brown, with far less Chalk than the MIS 8 tills (Fig. 4). When ice next spreads down the east coast it will no doubt rework much of the existing Devensian sediment together with Triassic-sourced materials from the inland rivers and including the glutinous Humber mud, to produce yet another brown till.

In eastern England the Holderness cliffs have been the focus for most research on Devensian glacigenic deposits, the main succession at Dimlington defining the Dimlington Stadial (MIS 2) (Rose, 1985), during which ice is held to have reached its greatest extent, the LGM (Clarke et al, 2017; Bateman et al, 2015). But the Dimlington section (Fig. 4), in spite of claims to the contrary (Catt, 2001) may not represent incontestably the complete Devensian succession in eastern England. Erosion had obviously exposed a planed surface on Basement Till before invasion by LGM ice, and older materials than MIS 2 could have been removed from that section and its vicinity (Fig. 5). The assumption that it is Dimlington Skipsea Till which extends as a single stratum from Sewerby, along the Yorkshire and Lincolnshire Wolds, to Hunstanton (Madgett & Catt, 1978; Lewis, 1999; Catt,2001) should be treated with much caution (Straw, 1978, 1991). For example, Boston et al's geochemical investigations (2010) failed to discriminate Basement, Skipsea and Withernsea types finding more variability within them than between, and Busfield et al (2015) found lithological variability within the Skipsea Till especially noticeable. Alternatively, the LGM can be delimited geomorphologically, enclosing areas with constructional surface features. Holderness east of the Hull alluvium is certainly one of these, but not the ground to the west, where Devensian deposits have a formless surface and survive mainly on dipslope interfluves. This fundamental geomorphological contrast can also be detected in east Lincolnshire.

The Lincolnshire advances are marked by terminal moraines (Fig.1). In the south, the earlier ice entered the Wash as far as the Stickney moraine, a single low ridge rising only a few metres above adjacent Fen alluvium. In the north, ice passed through the Humber gap to build the weak till ridge at Horkstow in the Ancholme valley and kame moraine at Winteringham (Frederick et al, 2001). Till is exposed (Fig.6) at South Ferriby cliff (Frederick et al, 2001; Straw, 2008) and extends east as a formless shelf to Barton, Barrow and Goxhill, at which places boreholes record only one suite of deposits (Straw, 1961, 1972). South from Barton to

Figure 2. *East Lincolnshire: the interglacial cliff delimiting the eastern edge of the Wolds between Ludborough and Hawerby, to the northwest of Louth. Devensian ice has twice reached onto the high ground at 110-115m OD. Some 30-35m of glacigenic sediments underlie the fields, resting on the Chalk of the marine Marsh Platform, and displaying an undulating largely original surface. (West from TF342963, 30-09-2016)*

***Figure 3**. Sewerby cliff: behind the figure (Dr. John Catt) the modern Chalk cliff has an almost vertical junction with the blown sand that covers the shingle of the Ipswichian raised beach lying south (left) of Dr. Catt. The blown sand (partly obscured by wash) is overlain by chalky head, and this in turn by vegetated till and younger outwash gravels. (West at TA198684, 15-04-1972)*

Kirmington, Devensian till rises no higher than 60m OD. At Kirmington, a small ridge incorporates interglacial deposits deemed to be of Ipswichian age, arguably glacially-displaced (Straw, 2018b), overlain by up to 2 metres of reddish-brown till which rests directly on intensely-cryoturbated flint beach shingle. The second advance produced in the south the Hogsthorpe moraine, a wide, unimpressive feature partly buried by alluvium but, most significantly, retaining a constructional surface of low mounds and enclosed hollows (Suggate and West, 1959), and in the north the Killingholme Moraine. Between these moraines, the Marsh surface, where higher than the onlapping marine alluvium, is one of low swells and linear ridges of till of rarely more than 10 metres amplitude (Fig. 2) that have influenced both the courses of streams and the siting of settlements (Straw,1958). Examples occur between Laceby and Barnoldby-le-Beck, Ludborough and Fotherby, and southeast of Legbourne. The whole surface is underlain by some 20 – 30m of brown tills, and although borehole records reveal two main suites of deposits (designated Upper and Lower Marsh Tills – Straw, 1969) numerous minor seams and sandy partings exist. This character is similar to that described by Roberts et al (2018) and Dove et al (2017) for the North Sea floor between Dogger Bank and the north Norfolk coast related to MIS 2 glacigenic deposits (Bolders Bank Member) age-

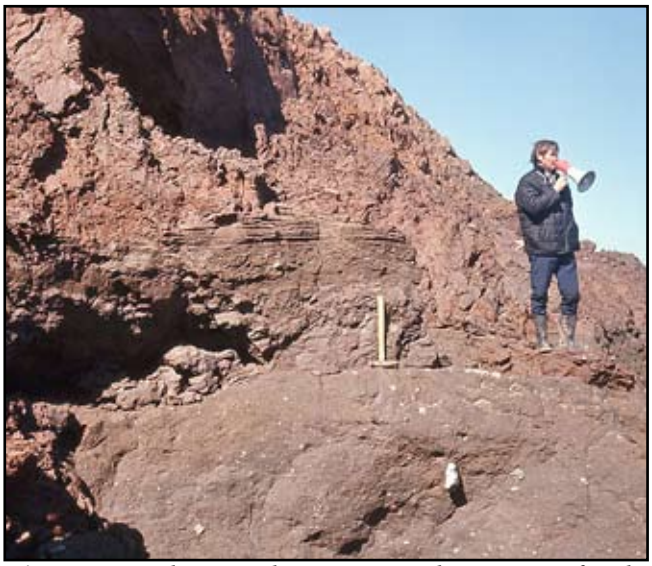

***Figure 4**. Dimlington: this section is the type site for the Dimlington Stadial (MIS 2). Basement Till (MIS 8) is overlain by a small basin, one of several, of laminated silts containing moss, that is almost obscured by slumped Withernsea Till. Nearby, the silts (carbon-dated to c.18,500 BP) pass beneath Skipsea Till, itself underlying Withernsea Till. Dr. Catt explains with his megaphone. (North at TA395213, 14-04-1972)*

constrained to 31.6 – 21.5 ka. It is entirely feasible that the ice responsible for these deposits also produced the Upper Marsh Till, and logical to identify the western limit of MIS 2 ice, not on the sea floor, but within terrestrial east Lincolnshire (Fig. 1).

In east Lincolnshire therefore the earlier advance must, on this interpretation, be regarded as a cold stadial, pre-LGM but still Devensian, event. Hence suggestions of Early Devensian and MIS 4 (Straw, 1979a, b, 1980,2005,2008). This two-stage model has also been argued elsewhere in relation to proglacial lakes (Straw, 2016) but observations can also be offered beyond Lincolnshire.

***Figure 5**. Dimlington: the unstable cliffs consist largely of Withernsea Till overlying Skipsea Till (MIS 2), which rests on a planed surface of Basement Till (MIS 8) similar to the modern one. Just as the Withernsea and Skipsea Tills are being totally eroded today, so tills older than the Skipsea Till could have been removed from this locality before its deposition. (WNW at TA395213, 14-04-1972)*

***Figure 6**. South Ferriby cliff: the chalky and dark-toned layers comprise 'made ground', consisting of spoil dug from a cutting east of the section, linking a former chalk quarry with a jetty for barges. The band of 'shear-clays', which parts two seams of brown lodgement till (the upper one being drier), descends gently northeast for 120m before fading out on a planed Chalk surface continuous with that visible beneath the till, and probably correlative with the Marsh Platform. (South at SE996224, 15-09-2001)*

North Norfolk

In north Norfolk, Devensian glacial deposits overlie raised beach deposits at Morston and Hunstanton. Those at Morston may relate to the Aveley Interglacial (Lee et al, 2015), and so may those at Hunstanton usually considered Ipswichian. The dominant unit is the Holkham Till Member, traditionally regarded as Late Devensian and part of the MIS 2 Holderness Glacigenic Formation (Lee,et al, 2015; Lewis et al, 1999). In 1960, the writer was content to regard its extent as the limit of the Last Glaciation, but as research proceeded in Lincolnshire it became apparent that although the Holkham Till certainly marked the furthest southerly extent of Devensian ice, it was the Hogsthorpe Moraine that represented the LGM. Ice at this latter stage is considered by Roberts et al (2018) to have reached the Norfolk coast at Garret Hill (TG 999438), 2 km east of Stiffkey (TG 975430), where thin weathered red-brown till overlies outwash materials deposited by proglacial meltwaters flowing west-north-west, presumably toward an ice-free area, in front of advancing MIS 2 ice. However, the Garret Hill deposits lie just east of the mouth of the lower Stiffkey valley and can only have been deposited after that valley's formation. The latter was a consequence of glacial diversion brought about when ice entered the former Stiffkey valley at Wareham and forced impounded waters eastward to excavate a gorge into the chalk (Straw, 1960; Brand et al, 2002) (Fig. 7).The Garret Hill deposits, laid down by westward-flowing water belong therefore to a wholly separate and later glacial episode, OSL- aged to 22.8-21.5 ka (Roberts et al, 2018). Buried channels, slightly younger than the Stiffkey gorge, parallel to and just north of the old coastline may also have resulted from easterly flows (Chroston et al, 1999; Moorlock et al, 2008). West of Stiffkey the Holkham Till Member, rarely more than a few metres thick, weathered, and with weak surface features, extends along a narrow zone to Hunstanton. This onshore outcrop is separated from the offshore tills of the Bolders Bank Member by seafloor exposures of chalk and they cannot be stratigraphically linked. Roberts et al (2018) ascribed the separation to marine erosion but, if the MIS 2 ice margin ran from Garret Hill west-north-west to the Hogsthorpe Moraine in east Lincolnshire (Fig.1), then the Holkham Till Member (excluding the Garret Hill deposits) and associated features (including the lower Stiffkey gorge) would represent a pre-MIS 2 advance contemporary with that which reached the Devensian maximum limit in east Lincolnshire. It is maintained here therefore that, on both geomorphological and geological grounds, there is no requirement for the Holkham Till Member to belong to MIS 2, and a MIS 4 age does not conflict with the field situation.

Sewerby

A similar situation exists at Sewerby (Figs. 3, 8), where an Ipswichian raised beach can be seen at the foot of the buried Chalk cliff (Lamplugh, 1891; Catt, 2001). The beach however is covered by blown sand and 'head' beneath a glacigenic deposit interpreted as Skipsea Till and ascribed to the LGM (Madgett and Catt, 1978; Catt, 2001) (Fig. 3). If this is the situation the long time interval between beach and till, of the order of 70-80 ka, has only the modest accumulations of 'head' and sand to represent it. These may also be regarded as MIS 2, but Bateman et al (2015) report OSL age estimates of c.89-102 ka for the blown sand that would have accreted soon after the sea withdrew, and c.59.7 ka for loess within the 'head' which may have formed at the time when the Kirmington shingle

***Figure 7**. North Norfolk: when ice blocked the River Stiffkey valley at Wareham, meltwaters were forced northeast across higher ground thence excavating a sinuous gorge 3 km long, subsequently occupied by the river and partly by the village. (ENE at TF963434, 10-04-1984)*

was being cryoturbated (Straw, 2018b), that is during a cold phase soon after the Ipswichian, possibly MIS 4. There is no reason why the overlying till should not be MIS 4 also. Its designation as Skipsea Till depends on mineralogical analyses that link it with Skipsea Till as identified at Dimlington. The writer has challenged the view that this till includes all east coast tills other than the Withernsea and Basement Tills on several occasions (Straw, 1978, 1991, 2008) noting that ice advances which traverse similar outcrops may well produce similar tills. In the light of data provided by Boston et al (2010) and Busfield et al (2015) it seems likely that the Skipsea Till is not a single stratigraphic unit extending from Flamborough Head to north Norfolk. The writer would prefer the term Skipsea Till to apply only to MIS 2 sediments, and not to deposits west of the Hull alluvium in Holderness, nor to tills of the north and southeast Wolds in Lincolnshire, nor the Holkham Till at Hunstanton. At the Sewerby section, the alignment of the Cayton-Speeton Moraine on the headland (Farrington & Mitchell, 1951) indicates the probability that, as claimed by Valentin (1957), the LGM ice front was deflected east and south by the headland and so screened from the Sewerby site (Fig. 1). Because the beach, sand and 'head' deposits have survived in the shelter of the old cliff (Fig. 3) south-flowing ice which did overspread the headland was more likely responsible for till emplacement (Fig. 8) than ice from a more easterly direction which would have been parallel to the cliff with greater likelihood of removal of the soft sediments. It is proposed that only relatively short time spans separated beach, sand, 'head' and till deposition within MIS 4, and that only the outwash Sewerby Gravels (Catt,2001; Evans et al, 2017) should be regarded as MIS 2 materials.

Vale of York

Here there has been much confusion regarding the LGM limit since Gaunt's proposal in 1976 that a lobe of ice extended south to Wroot before construction of the Escrick moraine. Recent support has come from Bateman et al (2015) and Friend et al (2016), but the absence of any 'footprint' other than the Wroot-Thorne gravels along its supposed western margin had prompted scepticism. Straw (1979b, 1991, 2002, 2016) has persistently denied the lobe's existence, and Ford et al (2008) and Murton et al (2009) take a similar view, accepting the Escrick moraine as the LGM limit. The Wroot-Thorne gravels do not constitute a moraine and however detailed their description and dating may be (Bateman et al, 2015; Friend, 2016) the fact remains that there are no contiguous glacigenic deposits and the disparate OSL age estimates relate only to the gravels and not to an ice lobe. Gaunt (1976, 1981) also proposed that the lobe had advanced into a Lake Humber with a surface level at c.33m OD. Postulated shorelines of such a lake have been described by Fairburn and Bateman (2015) who identified 8 levels between 42 m and 5m OD, all **post-dating** the York moraine and disappearance of the Wroot lobe (if it existed) and constrained by OSL age estimates of c.17.5 to 15.2 ka. It was stated that "to account for the different lake levels the Humber gap must have been blocked with different thicknesses of ice and till on multiple occasions", whereas the field evidence (Fig. 6) points to the gap having been occupied only once (Straw, 1972, 2008; Frederick et al, 2001) and then arguably by pre-LGM ice. Bateman et al (2017) present evidence for a later advance, but their calculated 100 to 200 metres of ice in the gap is unrealistic given a mapped till limit to the south of 60m OD, and the situation that ice nowhere overtopped the North Wold scarp crest (Fig.1) which is everywhere below 105m OD. Alternatively, the postulated lake levels may have been glacio-isostatically controlled (Straw, 2016), and be testimony to phased uplift following ice recession. It should be noted however, that Murton (2018) has reinterpreted some of the strandline features along the scarp of the Yorkshire Wolds as colluvial in origin and not lacustrine, and has declared the highest MIS 2 lake level to be that at 10m OD. Evans et al (2018) have ascribed a large fluvioperiglacial fan at the foot

***Figure 8**. Sewerby cliff: the Quaternary Research Association group is standing opposite the point where the present shoreline transects the buried Lincolnshire/ Holderness interglacial cliff, and the Chalk gives way to unconsolidated deposits. It is argued in this paper that the till overlying the Chalk could be of MIS 4 age. (ENE at TA198684, 14-09-2001)*

of the Yorkshire Wolds scarp west of North Cave and composed of sands and gravels of the Pocklington Gravel Formation, to MIS 3 on OSL age estimates, and overlying clay and Bielby Sand as MIS 2. But the Bielby Sands rise to 35m OD and are also considered to provide evidence for higher, post-York levels observed by Fairburn and Bateman (2015). If the dominant MIS 2 lake level was controlled by the Gainsborough gap (Fig. 1), then the Bielsby Sands may confirm elevation of earlier strandlines by glacio-isostatic recovery (Straw, 2016).There is strandline evidence along the west side of the Vale at c.33m OD for a lake (Edwards, 1937; Gaunt, 1981) which appears to have **preceded** formation of the York and Escrick moraines levels and could well have been the consequence of the earlier one-off Humber blockage (Straw, 1979, 2016). Although Evans et al (2018) found no trace of lake sediments beneath the North Cave fan, they acknowledged that a pre-Pocklington Gravel Formation high-level lake could have existed, any shoreline evidence being eroded by later intense periglacial activity. At the LGM, as argued above, ice stood eastward of the Humber gap at the Killingholme moraine when Lake Humber was no higher than 10m OD. (Fig. 1). Significantly, this lake part-submerged the Horkstow - Winteringham moraine, manifestly older, and may be witnessed at the southwest end of South Ferriby cliff where weathered, pre-LGM till is overlain by sandy, chalky, cryoturbated 'head' that forms an undissected but cliffed terrace at 8-15m OD (Straw, 1972, Fig. 14) Here the 'head' becomes horizontally inter-stratified with thin silt layers suggestive of its movement into standing water at about that height.

Vale of Pickering

Recently, a QRA Field Guide (Lincoln et al, 2017) has documented the impressive amount of recent research into the nature and origin of the sediment infill and associated landforms of the Vale. The first five Sections of the Field Guide review the geomorphology and geology of the Vale, the fifth being dedicated to the Late Quaternary Glaciation.

It has long been appreciated that glacier ice had on one or more occasions obstructed the east end of the Vale thereby preventing free drainage to the North Sea (Kendall, 1902) and, in combination with Vale of York ice at the west end, had created conditions that resulted in the formation of proglacial lakes. Lincoln et al (2017, pp.19-22) conclude that features at the east end of the Vale belong to MIS 2 and include a prominent kame-terrace consisting of the Hutton Buscel Gravels (Fig. 9), fine meltwater channels at Forge Valley and the Mere valley, lower-lying gravels at Seamer, and the blocking Cayton-Speeton Moraine (Penny & Rawson 1969). To the west former lake levels are accepted at 70, 45, and 30m OD, seemingly controlled by sills within the Kirkham Gorge, or possibly the Hunmanby gap (Evans et al, 2017).

In the early 1960s, the writer conducted numerous field classes for Sheffield University Geography students, based at Scarborough, when opportunity was taken to examine landforms, and deposits wherever exposed – Hutton Buscel, East Heslerton, and the cliffs between Scarborough and Cayton – to build up over the years a sequence of events, or model, to account for the geomorphology of the area. What became apparent at that time (and still does) was that the Hutton Buscel kame terrace was not only the oldest glacigenic feature in the area but was considerably older than the Ayton/Seamer gravels to the east, and that Forge Valley had been utilized by meltwaters on two separate occasions when ice had blocked the former Derwent valley southwest of Scalby. It was considered that during the first stage waters coursed down Forge Valley, originally a small dipslope valley, eroding and transporting vast quantities of sand and gravel southwest and south across the Corallian dipslope and along an ice edge to build the Hutton Buscel kame terrace with a surface reaching c.60-68m OD. (Fig.9). This ice had to be more, perhaps considerably more, than 70m thick to deflect Forge Valley waters rather than allow sand and gravel to be spread over its surface. East of the Hutton Buscel terrace, the Vale floor at 20-40m OD is covered south of East Ayton by sediments carried at a later stage through a deepened Forge Valley, and by the Seamer fan gravels built out from the Mere valley. These relatively thin deposits, generally less than 10m thick, incorporate basins, the sites of residual ice masses, providing classic 'dead-ice' country (Lincoln et al, 2017, Sections 14-18). The traditional assumption is that this represents the 'melt-out' of Hutton Buscel ice (considered to be MIS 2), but that ice was 70 or more metres thick, and conditions would have had to become such that a great deal of water was released before its surface became low enough (and level enough) to allow deposition of the Ayton/Seamer gravels over it. This water could not drain eastward because these later gravels were transported through Forge Valley and the Mere by meltwaters derived from ice to the east. But it might have gone westward and been responsible for the Yedingham Gravels west of the Hutton Buscel terrace (Eddey & Osguthorpe, 2017). It can also be queried whether it was likely that thick Hutton Buscel ice, if dated to c.18 ka, could indeed melt down so evenly and so quickly over an area of at least 20 km² to allow free spread of the Ayton/Seamer gravels and its burial, ultimately to provide the large number of thin ice blocks responsible for the kettle basins.

A plausible alternative is that the ice blocks were vestiges of a lobe of thinner ice that, preceding construction of the Cayton-Speeton Moraine, managed to extend only up to the Hutton Buscel terrace (Fig. 1) before stagnating and breaking up into discrete masses while being veneered supra-glacially by Ayton/Seamer gravels. Such ice would not have been thick enough to deflect waters and control deposition of the kame terrace, nor to impound a 70m lake, but it might relate

***Figure 9**. Hutton Buscel: the surface of the kame terrace lies at 60-68m OD, and an old quarry reveals frost-disturbed gravels of Calcareous Grit derived mainly from Forge Valley. The gravels, which underlie an area 2 km broad, extending 3 km or so south of the village, are at least 30m thick; they accumulated against a tall ice front that deflected the Valley meltwaters southwest throughout the period of deposition. (East at SE970837, 12-04-1961)*

to the 45m lake, the strandline of which passes through the gap between the south end of the terrace and the Chalk scarp as far east as the Cayton-Speeton Moraine (Evans et al, 2017). It is here proposed that the stages and ages reported in Sections 6, 14-18 of the Field Guide (Lincoln et al, 2017) relate to this ice and not to receding Hutton Buscel ice, and that there is reason enough to identify a glacial event that preceded the MIS 2 LGM, as outlined previously by Straw (1979b, pp.25-26, Fig. 3.1). It is of much interest that the Yedingham gravels, with affinities to the Hutton Buscel materials and yielding OSL ages of 32-39 ka (Eddey & Osguthorpe, 2017) could be outwash or more probably reworked materials deposited by Hutton Buscel meltwaters.

Consideration of lake levels in the Vale has long been more of an art rather than a science. The two main levels at 45 and 30m OD are supported by recent research although there may have been stillstands during both rising and falling phases. Water level at each stage was constant for considerable periods and the QRA Field Guide contains much discussion about controls on them, but less certainty attaches to the 70m level, because its presumed existence depends merely on the approximate altitudinal coincidence of the upper surface of the Hutton Buscel terrace with the high ground of the Howardian Hills in the west where they are transected by the Kirkham Gorge (Kendall, 1902) (Fig. 1). Part of the difficulty in explanation stems from the persistence of researchers in regarding it as a MIS 2 phenomenon. Yet it can be shown that a 70m, MIS 2 lake could never have existed, for the simple reason that MIS 2 ice responsible for the Escrick Moraine did not press against the steep western slopes of the Howardians (Straw, 1979b). This moraine lies west of the ice marginal Bulmer/Spital Beck and reaches only c.50m OD. The Gorge however, crosses ground at c.90m OD between Whitwell-on-the-Hill and Westow, and because ground somewhat lower than this lies northward, east and west of Castle Howard, the writer previously proposed (Straw, 1979b) that this must necessarily have been occupied by pre-Escrick ice, as was the Coxwold-Gilling gap, to deny its use by lake overflow. There is further evidence for pre-Escrick activity. The disposition of the MIS 2 strandline Sherburn Sands shows that the 45m lake drained through and was controlled initially by a sill within the Gorge. Vale drainage has utilized the Gorge ever since. But a 45m lake, impounded by MIS 2 ice at the east end of the Vale, required the existence of an outlet previously incised to the 45m level, specifically a proto-gorge cut some 40m into Corallian bedrock. To account for such incision it is necessary to invoke an ice presence in the area before MIS 2 (Eddey & Lincoln, 2017). If outflow from a high-level lake was involved it might have been in MIS 4 for which the Hutton Buscel terrace (though it is not necessarily a subaqueous feature) might stand proof in the east. In the west, if downcutting of the gorge did commence at 90m OD, ice had to lie on the Howardian Hills at Castle Howard. Outflow then ceased at the 45m sill level presumably when ice receded east from the terrace allowing the lake to drain to the North Sea. But another factor may be involved since Eddey and Lincoln (2017) note that Edwards (unpublished thesis, 1978) and Franks (1987) have suggested that the gorge could have been initiated as a subglacial conduit during a glacial episode prior to the Late Devensian. Powell et al (2017) have provided convincing evidence for MIS 8 glaciation within the Vale, also indicating (see their Fig. 13b) the possibility that ice then could have crossed the Howardians over the site of the Gorge. Here therefore is a plausible mechanism for initiation of the Gorge, and because the east end and the Coxwold-Gilling gap whatever its contemporaneous depth would have been

blocked by MIS 8 ice, lacustrine conditions may also have existed in the Vale during MIS 8 deglaciation.

The history of the Kirkham Gorge is obviously complicated. Overflow of the 45m lake initiated the MIS 2 phases of down-cutting outlined in the Field Guide (Eddey and Lincoln, 2017) but before that, the early stages of incision may have occurred in MIS 8 followed, possibly in MIS 4, by deepening of the gorge down to the 45m level. It seems unlikely either that the gorge could have been cut down to the 45m level entirely in MIS 8 or alternatively that lake outflow in MIS 4 was wholly responsible. Speculatively therefore, MIS 8 incision might have provided a sill in the gorge which later controlled a 70m lake impounded at the Hutton Buscel MIS 4 stage, but it cannot be substantiated. However, the gorge is obviously not an exclusively MIS 2 feature. What does seem certain is that MIS 2 events include rise of a lake to 45m and subsequent renewed down-cutting of the gorge by its overflow. This might be recorded by fragmentary terraces surviving within it, possibly controlled by Lake Humber acting as base-level in the Vale of York (Eddey and Lincoln, 2017), but these terraces could just be expressions of more-resistant bedrock strata, and attempts to equate strandline heights directly between Lake Pickering and Lake Humber must respect the need for gradients to exist through the Gorge to permit erosion, and also to allow for possible glacio-isostatic movement in the area.

Glaciation in MIS 4

This paper has set out reasons for considering seriously the hypothesis of a MIS 4 glaciation, and for abandoning the view that **all** Devensian events in eastern England must be ascribed to the Late Devensian (MIS 2). This latter view has followed from beliefs that all can be ascribed to a Dimlington Stadial (Rose, 1985) and that apart from the younger Withernsea Till all Devensian tills throughout east Yorkshire and east Lincolnshire to Norfolk merit description as Skipsea Till (Madgett and Catt, 1978). Over many years the writer has recognized two distinct glacial stages in east Lincolnshire and Holderness, the second regarded as the LGM of the Dimlington Stadial, and has argued that because of demonstrable landscape contrasts there cannot be a single wide-ranging till, even if mineralogical analysis reveals some uniformity. The latter stems from ice in successive glaciations following similar tracks down the east coast and is no guarantee of equivalent age. Skipsea Till and Withernsea Till should be associated only with the Dimlington Stadial, and if necessary another name (Ferriby Till?) be applied to Devensian tills west of the LGM limit. Straw (1969) grouped them in Lincolnshire as the Lower Marsh Till.

It has been argued above that the tills at Hunstanton and north Norfolk and at Sewerby could also be earlier than MIS 2, for there is no direct proof that they are of that time and a MIS 4 allocation better fits the regional situation. In the Vale of Pickering, as revealed in the Field Guide, it has proved difficult to compress all Devensian episodes into MIS 2. Indeed some features presumed to correlate with MIS 2 may relate to MIS 8, and some, like the 70m lake if it ever existed, may be MIS 4, but the Hutton Buscel terrace, and the pre-Escrick 33m lake in the Vale of York seem readily to fall into place as MIS 4 circumstances. It is claimed therefore that a zone of Early Devensian deposits and landforms lies outside the LGM limit (Fig. 1) and represents a full glacial event preceding MIS 2. This writer therefore favours one in MIS 4 and holds that the advance of east coast ice to the maximum Devensian limit was its manifestation. Such an extent of Devensian ice beyond the LGM could be unique in Britain, but the concept and evidence for it are plausible and deserve closer examination than has happened to date.

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