The Last Two Glaciations of East Lincolnshire

Allan Straw

ISBN 978-0-9539533-6-3

Front cover

Top: Rush Hills spillway, Irby on Humber (TA 192054)

*Bottom: Outwash bedded sands and gravels from
Rush Hills spillway (TA 198065)*

(D. N. Robinson)

Printed by Cupit Print, The Ropewalk, 23 Louth Road, Horncastle, Lincolnshire LN9 5ED

Contents

Preamble

Lincolnshire has been invaded by glacier ice on at least three occasions, probably more. The oldest extant deposits survive in Kesteven, in central Lincolnshire, and in the central Wolds around the Bain valley, on the Kelstern 'plateau' and at Welton-le-Wold. During a period Quaternary scientists call the Devensian, an ice sheet built massively over Scotland and northern England to such an extent that, becoming excessively thick and unstable off north-east England, a glacier-like lobe of ice surged south down the east coast, claimed here to have occurred more than 40,000 years before present (BP). Along the east side of the Wolds, this ice rose to about 114m above sea-level, and it constructed the Horkstow and Stickney Moraines at the north and south ends respectively. Around 20,000 years ago, similar circumstances recurred though the surging lobe reached less far onto the Wolds. This ice built the Killingholme and Hogsthorpe Moraines.

An alternative view based mainly on research in Holderness that all the Devensian deposits and landforms were produced about 20,000 years ago has long been held. Such a model fails to account fully for the Lincolnshire situation, but a new dating technique (amino-acid geochronology) has confirmed two discrete Devensian glacial events along the east coast.

Whichever model glacial ice, apart from emplacing various stony clays, gravels and sands, obstructed the flow of water down the Wold valleys. Severe periglacial (Arctic) conditions affected the ice-free areas, and most of the water would have been spring snow-melt. In many valleys it formed ephemeral lakes, overflow from which crossed low points on Chalk ridges, coursed along the ice front and, in places, passed beneath the edge of the ice. With such drainage conditions existing perhaps for centuries some lakes became linked by erosion of new valleys, so that the general movements of meltwaters came to be directed north and south-east from the Kelstern 'plateau', to Kirmington and Spilsby respectively in the earlier stage, and to Goxhill and Alford in the later one. As the stagnant ice decayed and thinned more land became exposed, the ice edge receded north-eastward, and broadly parallel series of open-ended meltwater channels were imprinted in the landscape.

In the earlier Devensian stage, meltwaters escaped west both at Kirmington and round the south end of the Wolds by West Keal to enter a huge lake fed mainly by the Fenland rivers, the Trent, the Don and the Ouse. With ice blocking the Humber and Wash gaps, this combined Lake Humber and Lake Fenland (joined through the Lincoln gap) achieved and held a level of about 33m above sea-level, probably for no more than a few centuries. Around 20,000 years BP, in the Late Devensian, ice spread across the eastern end of the Humber estuary to impinge on the Wolds south of Brocklesby, creating a second Lake Humber reaching to about 9m above sea-level. This lake did not, unlike its predecessor, extend through the Lincoln gap into the Fen basin but it would have flooded the Humberhead area and ground around Hull and Barton, west and east of the Humber gap respectively. In this later stage the only route for Midland river water was through the Lincoln gap to the Wash, and so the Trent assumed temporarily a course from Newark to Lincoln. In the earlier stage, because the Wash gap appears to have opened before the Humber gap, the high-level lake and, later, river water including the Trent's, had also drained temporarily through the Lincoln gap to the Wash. Both Trent diversions are confirmed by sand and gravel deposits between Newark and Lincoln and bordering the lower Witham.

It is clear therefore that, although only part of Lincolnshire was actually covered by ice (twice) in the Devensian, the rest of the county suffered simultaneous and related consequences such as flooding, diversions of rivers and streams, disturbance and movement of soils and rock waste on slopes, and very severe conditions for vegetation and wildlife. Before, between, and since these glaciations, climate has been more congenial for plants and animals, for soil formation, and for 'normal' river activity.

TABLE 1

Thousands years BP	Global Marine Isotope Stages (odd - warm even - cold)	British Stages		East Lincolnshire - glacier-related events and deposits
	1	Flandrian		Sea-level rise; alluviation
10 --------				
	2	Late	Devensian	Second ice advance (LAST GLACIAL MAXIMUM) - Upper Marsh Till; Killingholme and Hogsthorpe Moraines; Lake Humber II
26 -------				
	3	Middle	Devensian	
60 -------				First ice advance - Lower Marsh Till Horkstow and Stickney Moraines; Lake Humber I and Lake Fenland
	4) 5a-d)	Early	Devensian	
115 -------				
	5e	Ipswichian		Sea-level rise; alluviation
125 -------				
	6) 7)	'Wolstonian' complex		Glaciation - Welton-le-Wold Tills
250 -------	8)			
300 -------	9) 10)			
	11	Hoxnian		
	12	Anglian		Glaciation - no extant deposits
450 -------				
	13			

Introduction

Over thirty-five years ago the Lincolnshire Naturalists' Union published a survey by this author of Pleistocene events in the county (Straw, 1969). In spite of a considerable amount of subsequent research and publication by other workers the basic claims regarding glaciation have stood the test of time. The glacial deposits that spread over east Lincolnshire from the Humber to the Wash, designated the Lower and Upper Marsh Tills (mainly reddish-brown and purplish-brown tills with associated sands and gravels), retain their status as representative of the latest if complex phase of cold climate. In 1973 a 'Correlation of Quaternary Deposits in Britain' (Mitchell et al) recommended the term 'Devensian' for this last cold phase (c.115,000 to 10,000 years before present) (Table 1), which supplants 'Last' as used in 1969. Because in glacial terms this last phase in Britain was deemed to best represented in Cheshire and north Staffordshire where the British 'Devenses' tribe had held sway, the term 'Devensian' was adopted, has been widely used, and persists as the name for this last phase in the 'Revised Correlation of Quaternary Deposits in the British Isles' (Bowen, 1999).

Discontinuous glacial deposits, older than the Devensian and named and described in 1969 as the Calcethorpe, Belmont, Wragby and Heath Tills, lie within central and south-west Lincolnshire and have also been the objects of further research. Perrin et al (1979) claimed these Tills to have been emplaced by ice splaying north-west, west and south-west from the Wash gap, but this was strongly refuted by Straw (1983) who presented detailed evidence that generally south-flowing ice was responsible. The age of these older glacial sediments is still not agreed but it can be stated firmly that no other glaciation affected the county between their deposition and that of the Devensian materials further east. Thus the terms Older Drift and Newer Drift still have great relevance in Lincolnshire.

Since 1973, Pleistocene time (approximately the last 2.5 million years – Bowen, 1999) has been subdivided into a number of stages and substages based on oxygen isotope records derived from marine sediments (Shackleton and Opdyke, 1973; Sibrava et al, 1986). Counting retrospectively, the Flandrian (post-glacial) is Marine Isotope Stage 1, the Devensian comprises MIS 2-5d, and the last or Ipswichian

Interglacial is MIS 5e (Table 1). The dominant glacial deposits of East Anglia, now designated the Lowestoft Formation (Bowen, 1999), belong to the Anglian (MIS 12). Perrin et al (1979) regarded the older glacial deposits of Lincolnshire also as Anglian but Straw (1983, 1991, 2000) prefers their emplacement during a younger MIS 8.

This paper will concentrate on features of Devensian glaciation which were discussed but briefly in 1969. Limits for the extents of ice have been identified through fieldwork on deposits and landforms and examination of borehole records, the latter also confirming the presence of the two Marsh Tills. Most discussions by other workers on Devensian glaciation along the east coast have considered all the Devensian deposits to be Late Devensian (MIS 2), but this does not square with the facts. This dating problem is addressed below.

Finally, the 1969 discussion of the Welton-le-Wold/South Elkington area has proved erroneous. It was based on a pre-1965 appraisal of the situation before the author spent two years in Canada. From late 1969 to February 1973, some artefacts and mammalian fossils were discovered in the Welton quarry in gravels below the Welton and Calcethorpe Tills and, because further working of the section had occurred, a different interpretation could be put forward (Alabaster and Straw, 1976; Straw, 2005). In 1969 it was stated that no exposure of Newer Drift resting on Older Drift had been seen or recorded, the small exposures of Marsh Till being regarded as weathered Welton Till. However, east of the road through the quarry, the newly-designated RIGS site does display Devensian till resting sharply on the much older Welton Till and Gravels, and derives much significance from being the only locality south of Dimlington in Holderness to show such superimposition.

It seems appropriate first to describe the Devensian glacial features of east Lincolnshire so that details might be traced by readers in the field or by reference to Ordnance Survey maps and, particularly, to the recently revised and published maps of the British Geological Survey (Sheet 89, Brigg, 1982; Sheet 80, Kingston-upon-Hull, 1983; Sheet 90, Grimsby, 1990; Sheet 81, Patrington, 1991; Sheet 103, Louth, 1999), and then to consider the problem of dating and the consequences of glaciation for the rest of Lincolnshire.

North Wolds and Marsh

South-east of Winteringham (SE 930223) ice-marginal deposits around Eastfield Farm (SE 945212), now largely quarried away, gave rise to low mounds of generally level-bedded sands, silts and gravels (Plate 1), in places much disturbed, separated by kettle-hole depressions and associated with reddish-brown Marsh Till (Frederick et al, 2001). South-eastward the latter forms a slight discontinuous ridge, partly buried by alluvium, across the Ancholme valley toward Horkstow (SE 986183). With features north of the Humber at Welton and Brough these deposits, which rise to c.23m OD, mark the limit reached by a lobe of Devensian ice that splayed westward from the Humber gap (Straw, 1957).

A long-exposed section, the only coastal one in Lincolnshire, in glacial and periglacial sediments at South Ferriby cliff (SE 994220) (Ussher, 1890; Straw, 1972; Gaunt et al, 1992; Frederick et al, 2001) merits more detailed comment.

Between two former jetties (for barge-loading of chalk from adjacent quarries) the cliff is cut mainly into till resting on a level surface of chalk (Plate 2). Before planation the chalk had been faulted, giving rise to steep-dipping and fractured zones along the cliff and foreshore. The till, up to 4m thick, is generally purplish-brown weathering reddish-brown, and has a wide range of northern English and Scottish erratics. This is Marsh Till, emplaced by Devensian ice as it passed west through the Humber gap to the maximum limit at Horkstow and Winteringham. It consists of layers of compact, massive diamicton separated by zones up to 30cm thick of finely-banded sediments (Plate 3). These vary from thin seams of silt and milled-out chalk interleaved with till, to laminated silts and sands, the latter occasionally showing ripple marks. Near the south-west jetty a prominent band of silts and sands is currently visible above 1m of till, and was described by Frederick et al in 2001. In 1968 this band had been traced by the author north-east to the north-east jetty, and was observed to dip a little over 1° for some 120m until it terminated against an abrupt 1m rise in the chalk surface. Over time, as various cliff sections have become available, several of these layers have been seen, two or more being evident in some instances. For example Dalton (1953) noted that, between the jetties, a 120cm-thick band of laminated clay with sandy partings was interleaved with strips of till, and photographs of 1945 (given by him to the author) show sections with two stratified bands one being at the base (Plate 4). In 1961 and subsequently the author noticed groups of close-spaced, quasi-horizontal planes within the till, unmarked by silt or sand partings (Plate 2). In 1968 good sections close to the north-east jetty revealed 1.4m of till over 17cm of banded sediment resting on broken chalk. The band consisted of 5 seams of laminated silty clay (1 to 2cm thick) separated by till layers up to 3cm thick containing some erratics and milled-out chalk. Fifteen metres to the south-west some 70cm of till intervened between the banded sediments and the chalk.

Frederick et al (2001) considered the banded sediments near the south-west jetty to consist of material washed into subaerial standing water, but the earlier exposures revealed a multiplicity and variety of such zones, some being merely planar divisions within the till (Plate 2). Dalton (1953) claimed the banded zones as 'shear clays' following R.G.Carruthers' views on subglacial melting. This remains the better explanation and the till can be regarded with certainty as lodgement till, consisting of successive sheets of till parted by shear zones one of which at least has been observed to originate from the till base and rise gently south-west. During deglaciation it is probable that some of these banded sediments, being more permeable than the till, permitted movement of subglacial meltwater which produced the occasional rippled sandy layers and some of the bedded silts.

This discussion provides not just a longer record of observation at the locality but seeks to show that the Ferriby materials are not genetically part of the Horkstow-Winteringham Moraine and do not permit the assumption that an ice dam formerly existed at this point across the Humber gap. The presence of Marsh Till at 45m OD near Greengate Farm (TA 006218) and on the A1077 spur south-west of Barton (TA 022217) indicates that the lodgement till at Ferriby cliff was emplaced at the base of some 35m of west-flowing ice.

South from the Humber till, weathered reddish-brown, occurs on interfluves toward Burnham (TA 058172) with 'feather-edge' margins reaching no higher than 60m OD. Although close to it, these margins are undetectable viewed east from the A15 road to the Humber bridge, for the till is at best only a few metres thick with a formless surface. In places the till has been reduced to what are termed here 'drift-residual' soils (ie. materials too thin to map as till but retaining its coloration and erratics). Beneath Barton, Barrow (TA 072215) and Goxhill (TA 102213) borehole records show the Marsh Till to reach 30 to 40m in

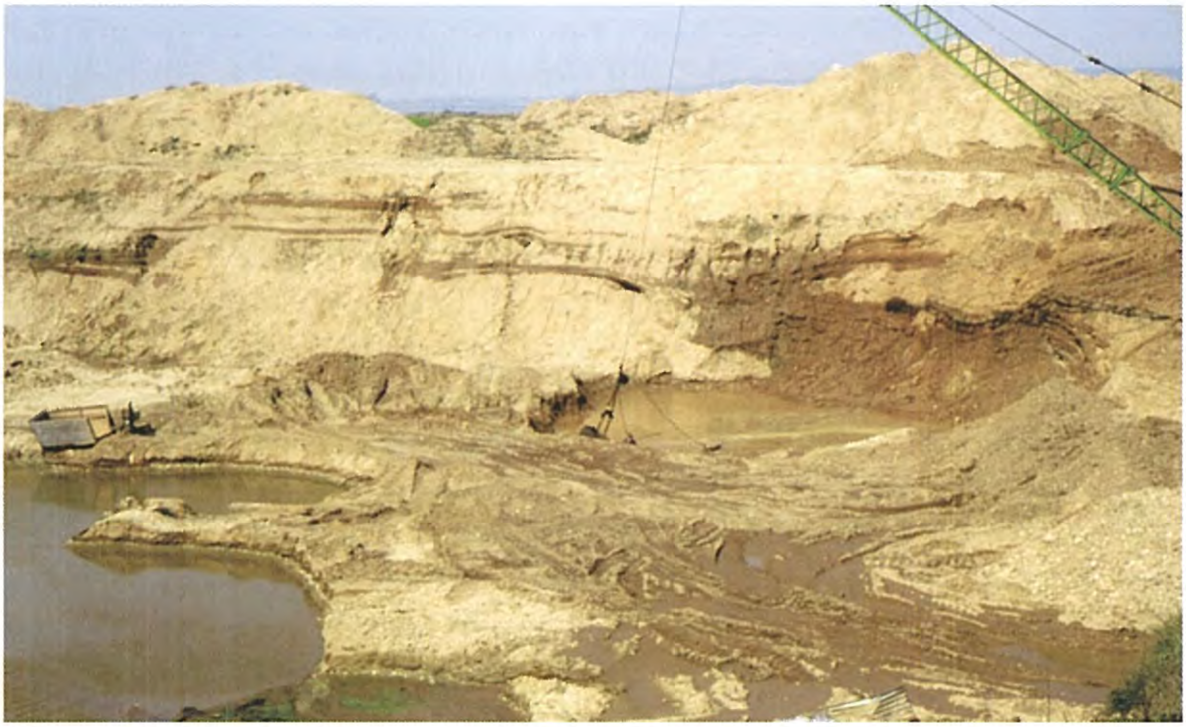


Plate 1 – TA 947213, to NNW (April, 1984). N of A1077, NE of Eastfield Farm, Winteringham. At W limit of Devensian ice penetration through the Humber gap. Mainly flat-lying outwash sands and gravels (with chalk, flints and erratics), surface at c.23m OD.

Plate 2 – TA 996222, to SE (August, 1968). South Ferriby cliff, between two former jetties. Weathered Lower Marsh Till on planed, steeply-dipping Chalk. Shear-planes visible at level of black division on rod.

thickness, mainly in a single sheet with impersistent sands and gravels. Around Thornton Curtis (TA 087178) and Wootton (TA 089160) the till, up to 8m thick, is spread smoothly over gently-inclined chalk areas lying between 23 and 40m OD. North-west of Croxton (TA 093124) till patches survive on spurs to c.45m OD. The degraded surface of this drift, its thinning and deep weathering, and its absence from valley floors show it to have been subject to a long period of erosion and denudation (Straw, 1958, 1961, 1979a; Gaunt et al, 1992).

Clearly when ice passed through the Humber gap to the Horkstow Moraine the eastern half of the North Wolds was also inundated (Fig.1). Deglacial features are missing from the chalk area except near Ashdale House, Wootton, where a narrow south-draining meltwater channel and three similar but smaller parallel runnels eastward of it mark some ice-marginal drainage toward Ulceby (TA 105147) and then to Vale House, Kirmington (TA 107133). From Vale House the ice limit is defined by a weak moraine which crosses the Kirmington valley and includes the mound on which the village (TA 104115) stands and within which lies a mass of temperate estuarine sediments and shingle of pre-Devensian age (Ussher, 1890; Straw, 1972; Gaunt et al, 1992). The higher parts of this moraine reach 32m OD. An undulating till surface east of the village, giving way in Brocklesby Park to a zone of chalky outwash deposits (Plate 5), is crossed by a stream flanked by low terraces which grade into wide spreads of flat-lying sands and gravels beyond Brocklesby Station (TA 118135). These sediments, younger than the Kirmington Moraine, are part of a train of outwash materials (Fig.1) which was laid down at a later stage by meltwaters flowing north from Habrough (TA 146136) to Thornton Abbey (TA 115189) and east of Goxhill. Its surface lies at c.14m OD around Habrough and 8m OD at the Abbey. Up to 4m thick, with cross-bedding indicative of strong braided currents, the materials consist largely of chalk and flint eroded from meltwater channels to the south, but with some erratics including coal and, most significantly, a component of derived marine molluscan shells. The latter comprise both temperate and cold types and are comparable with species present in the Kelsey Hill beds north of the Humber (Reid, 1885; Gaunt et al, 1992; Berridge and Pattison, 1994). Shells do not occur in outwash at Kirmington or Winteringham.

East of the gravel train the Marsh Till surface rises into a low ridge that attains 18m OD through North and South Killingholme (TA 152162) and at Habrough. Some 30 to 40m of till, sand and gravel lie beneath the two villages and the feature marks the ice front responsible

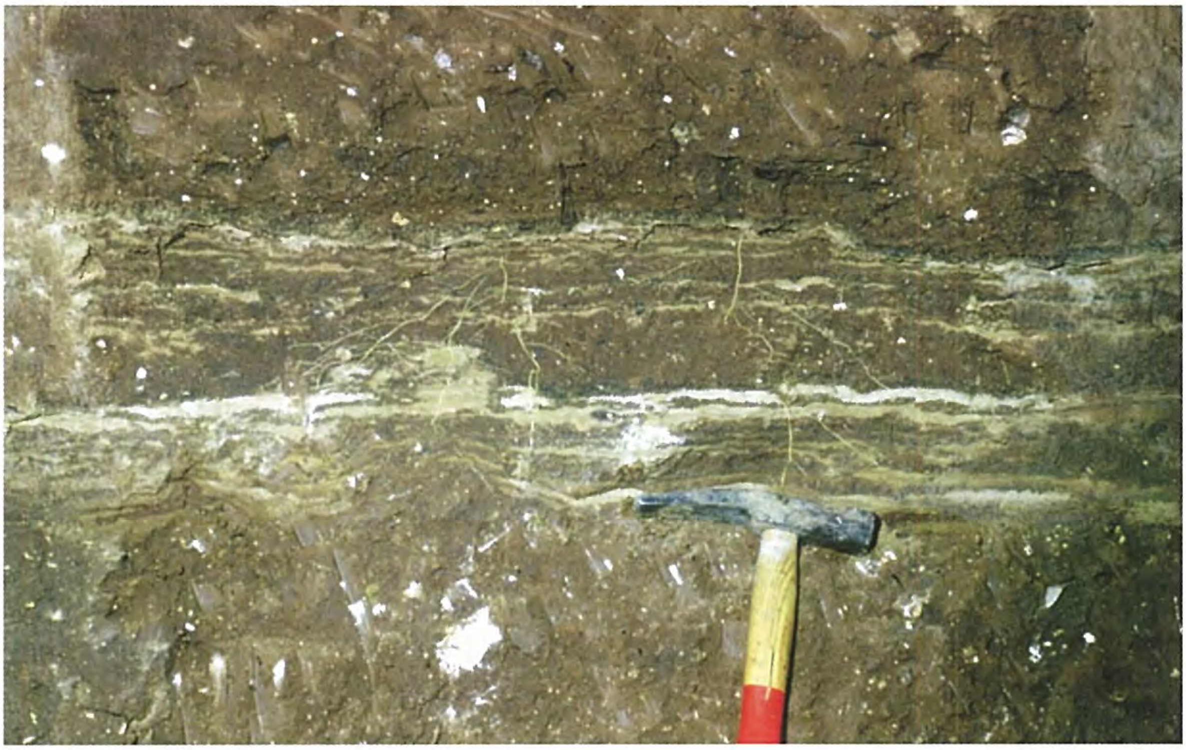


Plate 3 – TA 995221, to SE (November, 1960). South Ferriby cliff, between two former jetties. Silts and fine sands banded irregularly with thin layers of Till between massive beds of Lower Marsh Till.

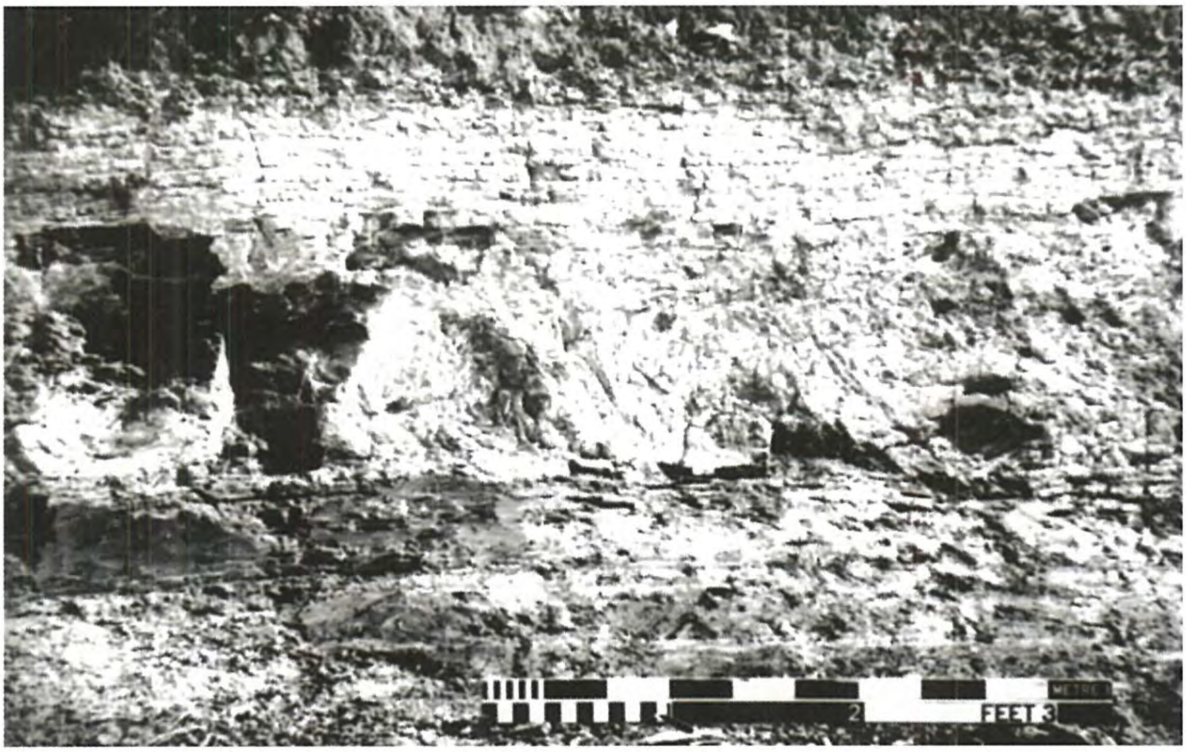


Plate 4 – TA 996224, to SE (August, 1945, A.C.Dalton). South Ferriby cliff, SW of the NE jetty. Two zones of banded silts, sands and thin layers of Till, separated and capped by massive beds of Lower Marsh Till.

for guiding northward the meltwaters from Habrough to Goxhill and from which erratics and molluscan shells were added to the gravel deposits. Designated the Killingholme Moraine (Straw, 1958, 1961) the feature, although broken west of Habrough by a slightly later outwash tract from Aylesby (TA 202076) and Keelby (TA 164100), closes with the edge of the Wolds between Brocklesby and Keelby (Fig.1).

Central Wolds

The Kelstern 'plateau' separates effectively two parts of the Central Wolds with respect to drainage patterns and Devensian features. To the north, valleys and former meltwater drainage are directed north-east and north, while to the south they decline east and south-east. The 'plateau', overlain by Calcethorpe Till (Older Drift) and lying above 125m OD, approaches the eastern margin of the Wolds (Fig.2). Devensian ice tongued into the short valleys along this old degraded cliff up to 114m OD, the highest level it reached in east Lincolnshire, but failed to creep onto the 'plateau'.

Northward, the western limit of the ice declined overall to c.32m OD toward Kirmington and can be traced by Wold Newton (TF 244968), Hatcliffe (TA 213007), Swallow (TA 176030) and Great Limber (TA 133087). West of Wold Newton, around Gunnerby (TF 216990), and between Beelsby (TA 207019) and Swallow, patches of Marsh Till and areas of 'drift-residual' soils survive on broad interfluves, after the manner of the North Wolds, with generally little surface expression. The limit of the drift is marked in places by ice-marginal meltwater channels such as Talbot Inn, Ash Holt (Plate 6), Vale (Plate 7) and Mere Hill channels (Fig.1). In sharp contrast with the North Wolds, Marsh Till and associated sands and gravels remain along the valley floors, and around Ravendale (TF 226998) and at Hatcliffe vast accumulations give rise to mound and hollow terrain, proximate to a number of steep-sided meltwater channels (Plate 8).

The marginal channels named above cross main divides between valley systems, formerly linking a series of valley-head lakes and, compared with the lower channels, have a gentler degraded form. Straw (1961) demonstrated three groups of meltwater channels in the Wolds on morphological characteristics. One group, presently occupied by streams, displays the 'freshest' forms (ie. continuous steep

Plate 5 – TA 127120, to S (May, 1959). Brocklesby Park, NW of the Hall. Second advance outwash sands and gravels derived in part from meltwater channels near Riby. Inclined beds in lenses and planar units aggraded by laterally-migrating braided streams. Clasts mostly chalk and flint, but some erratics including coal.

Plate 6 – TA 190006, to N (May, 1959). Ash Holt meltwater channel (flow to N). Col height (seepage line) c.70m OD. Sides less than 13°. Partial filling of 'head' and blown sand.

slopes, flat floors and undercut bends) as with the Rush Hills and Flint Hills channels near Irby and Hatcliffe. The other two groups, of dry channels, differ in slope angle (steepest segments between 19° and 25°, and 8° and 15°) and other features. For instance, as with the Ash Holt channel (Plate 6), the gentler-sided channels generally reveal furrowing of their flanks, undulating long profiles, and reversed intake gradients, and they lie within the areas of subdued drift. By contrast the steeper-sided group is closely associated with the hummocky valley-floor sediments, as with the Round Hill channel at Hatcliffe (Plate 8) and several near Riby (TA 185075). This disposition of deposits and channels led Straw (1961) to propose that Devensian ice had penetrated the Wolds a second time, following a period during which drifts emplaced and channels created in the earlier phase had been considerably modified by weathering and erosion. Significantly it is north from the 'fresher' features around Riby and Brocklesby that the Killingholme Moraine diverges from the Wolds (Fig.1), and that the Thornton Abbey gravel train commences.

South of the Kelstern 'plateau' Devensian ice pressed into the Lud basin covering the South Elkington (TF 295882) area and reaching the spur of Calcethorpe and Welton Tills bitten into by the Welton-le-Wold quarry (Fig.2) (Straw, 2005). The junction between Devensian till and the older drifts is well seen in the RIGS Lincolnshire Wildlife Trust Nature Reserve in the eastern part of the quarry. On Lud basin interfluves 'drift-residual' soils show that the ice edge lay at about 95m OD and extended up the valleys to Withcall (TF 283838), Dovendale, and Tathwell Grange (TF 311818) where feeble morainic mounds remain at c.85m OD. Marsh Till survives in the Tathwell-Raithby valley but has been dissected into terrace form. East of this valley a patch of till remains on the higher chalkland, but much of the latter up to 95m OD is covered only by 'drift-residual' soils. Meltwater channels of the gentler-sided group at Tathwell Grange, Orgarth Farm and Lewis Yard (Fig.2) lead out of the Lud basin, the mound of drift at Orgarth Farm marking clearly the ice limit. Nearer Louth (TF 329875) the Welton Vale and Hubbard's Hills channels (Plate 9) retain active streams. The former was probably initiated when ice melted back from the Welton quarry, but was greatly deepened by waters draining from the later ice front that left thick accumulations of ice-contact and outwash gravels at South Elkington in the manner of those at Hatcliffe. South-west of Hubbard's Hills, the second advance of ice seems to have reached Hallington (TF 304855) leaving thick till deposits and, during

Plate 7 – TA 174041, to N (May, 1959). The Vale meltwater channel (flow to N). Pit in floor in blown sand, surface c.53m OD. Slopes on Chalk up to 25°. Formed during the first advance; re-used in the second.

Plate 8 – TA 223000, to N (May, 1959). Round Hill meltwater channel (flow to N), NW of Ravendale. Intake height (road) c.49m OD. Slopes up to 26°C on Chalk in trees on E side. Foreground on Upper Marsh Till.

recession, so blocked the valley that water (much of it snow-melt) from the large catchment was forced northward to cut the Hubbard's Hills channel and join waters draining from South Elkington and from Welton Vale. Such meltwaters may then have passed south-east sub-marginally and later subaerially from Louth toward Legbourne (TF 368845) and beyond (Fig.2).

From Orgarth the western limit of Devensian ice penetration, defined by marginal channels across major divides at Haugham (TF 336815), Deepdale Firs west of Burwell (TF 355797), and Ketsby House as well as by the drifts, descends to c.65m OD. Downwasting of the ice surface is strikingly illustrated by the flight of four parallel and successively lower channels east of Deepdale Firs and another of six similar channels east of Ketsby House (Fig.2). The eastern-most of the Deepdale Firs sequence forms the head of the long Cow Dyke channel and all of these channels belong to the gentler-sided group (Straw, 1961). The Cow Dyke channel (2.2 miles long) with three reversed sections of thalweg regraded to valleys breaching its north-east side contrasts markedly and significantly with the even longer Haugham Slates channel (2.8 miles long) a mile away to the north-east (Plate 10). The latter feature has sides up to 27°, a continuous long profile and superbly undercut bends. Its sinuous northern half fixes precisely the second advance limit at just over 90m OD, the ice having overridden the ground around Little Cawthorpe (TF 357837) and Muckton (TF 375814), but the straighter southern half is a deepened pre-existing valley. Between Burwell Wood and Meagram Top (TF 393789) this ice managed to cross into the Burwell valley and hold meltwaters along the valley-side to cut channels through Valley Farm and deposit some of the eroded chalk within the older, deeper channel north-east of Swaby (TF 385770) (Plate 11). This same ice closed temporarily the Calceby Beck valley but its margin generally trended south-east by Aby (TF 410785) and Bilsby (TF 470766) to Hogsthorpe (TF 534722), diverging from the Wolds to construct the broad, irregularly-hummocky zone of till and gravel designated the Hogsthorpe Moraine (Fig.2) (Straw, 1961). Snow-melt water from the Calceby Beck catchment and meltwaters from the Valley Farm/Swaby channels were guided along the front of this Moraine to accrete a broad outwash train through Alford (TF 455760). At Aby the gravels contain derived marine molluscan shells (Jukes-Browne, 1887).

By contrast the earlier ice advance passed west of Calceby as far as South Ormsby (TF 370752), Brinkhill (TF 372736) and Driby

Plate 9 – TF 317856, to NNW (May, 1959). Hubbard's Hills meltwater channel (flow to N), west of Louth, from A153. Stream flows from SW, then turns N through the gorge. Former course to E partly filled with Upper Marsh Till. Incision into Chalk interfluve began at c.70m OD.

Plate 10 – TF 344819, to E (April, 1956). Haugham Pastures meltwater channel (flow to E). Slopes on Chalk through the trees up to 27°, floor c.85m OD. This part of the channel marks precisely the limit of the second advance.

(TF 389744), and so obstructed the wide valley opened out in Lower Cretaceous rocks around Tetford (TF 330745) that run-off and meltwaters were forced to cut a permanent escape route south through the New England channel to the east of Salmonby (TF 325735). Considerable areas of Marsh Till survive around Swaby and south-west of Calceby but the surfaces are formless and sharply cut into by the present streams.

South-East Wolds and Marsh

This part of the Wolds is a triangular block of Chalk lying south-east of the Calceby Beck valley. Most of it was covered by Devensian ice as testified by the 'drift-residual' soils with characteristic erratics remaining on interfluves up to 93m OD. Mappable till lies only below 30m OD on the east side, and along the south side west to Partney (TF 410684). Exactly and as significantly as in the North Wolds it is absent from the valleys of Well Vale and Skendleby Psalter, a consequence rather of subsequent erosion than of non-deposition. The western ice limit runs from Driby to Ulceby (TF 422728) south-west of where a small channel crosses ground at 93m OD, and thence south into the Skendleby (TF 433697) valley which is notched on its west side by another small channel above Skendleby Thorpe at 68m OD. The wide valley between Partney, Skendleby and Ashby-by-Partney (TF 429668) is occupied by Marsh Till, with permanent stream diversions at Partney and south of Ashby (River Lymn). The Till, its surface showing no constructional forms, passes imperceptibly into that which borders the southern edge of the Wolds from Great Steeping (TF 438644) to Toynton St. Peter (TF 404634). At Keal Coates (TF 366611) the Till becomes part of the Stickney Moraine, a low north-south swell of land reaching barely 10m OD and almost hidden by Fen alluvium, matched in west Norfolk by the Heacham Moraine (Straw, 1979a). On the north side of the Till a sandy terrace skirts the foot of the rising ground, declining west to c.30m OD at West Keal (TF 365633).

General Observations

1. The Stickney and Horkstow Moraines, marking the limits of Devensian ice penetration in the Wash and Humber gaps, are considered to be contemporary. The border within the Wolds is clearly identifiable with reference to the extents of drifts and 'drift-residual' soils, but ill-defined by landform except at the weak Kirmington Moraine and the westernmost of the gentler-sided meltwater channels. The Lower Marsh Till has been deeply weathered, thinned on higher ground to 'drift-residual' soils and removed entirely from valleys of the North and South-east Wolds. It has acquired formless, dissected surfaces on broader interfluves and in the wide-bottomed valleys at Partney, Calceby and Tathwell.

2. At this maximum stage the ice edge attained its highest level of 114m OD on the east side of the Kelstern 'plateau' presumably because of increased pressure within the ice against the higher ground. From here the ice edge declined generally north and south-east across the valleys and spurs to Kirmington and South Ormsby respectively. It rose a little over the North Wolds before sinking through the Humber gap to Winteringham, and over the South-east Wolds before descending to Spilsby and the Stickney Moraine (Figs.1, 2). Edge gradients were extremely gentle but reflect the east coast phenomenon of an overall flatness of the ice margin from the North York Moors (c.245m OD) to the Yorkshire Wolds (137m OD), to the Lincolnshire Wolds (114m OD) and to north Norfolk (30m OD) – a mean gradient of only 1:750.

3. Devensian ice seems therefore to have invaded the Wolds quite gently and, after getting as far as it could, to have stagnated. Drift margins within the Wolds are often contour-like, curving round minor hills and spur ends. The impression gained is that the ice surface was extremely smooth, rising imperceptibly north and north-east, and its edge very low. The exceptional 'carry' of the ice down the east coast compared with the Vale of York suggests that it was subject to a massive surge originating off the Tees valley (Boulton et al, 1977; Straw, 1979a). Soon after reaching its maximum extent it would have stagnated. Related glacial and glaci-fluvial features, including the now gentler-sided group of meltwater channels, were produced within this limit during deglaciation.

4. The Killingholme and Hogsthorpe Moraines are demonstrably coeval and mark a second advance of ice which pressed only into the Central Wolds and which deposited the Upper Marsh Till. This shows ranges of colour and far-travelled erratics similar to the Lower Marsh Till. The Moraines diverge from the Wolds precisely where meltwater channel systems around Brocklesby and Riby and in the Calceby Beck basin discharged water and sediment that flowed and accumulated along the west and south-west sides of the Moraines. This ice emplaced thick deposits with constructional features in the larger Wold valleys but failed to reach either the North or South-east Wolds, or to pass west of the River Hull in Holderness. Its meltwaters eroded the steeper-sided channels and most of the currently stream-occupied ones. Because the main ice front receded from the Wolds and across the Marsh in a pivotal manner, escape routes for meltwaters opened up first near Fotherby (TF 315917) by Louth and Legbourne to Aby, later at Barnoldby-le-Beck (TA 235033) where Hatcliffe Beck emerges from the Hatcliffe channel and is deflected sharply eastward, and finally at Laceby.

5. This second advance of ice as far south as Hogsthorpe is also likely to have been the consequence of an elongated surge. The broad, undulating and kettle-holed nature of the Hogsthorpe Moraine and the strong evidence within the Wolds for detachment of blocks of ice at South Elkington, Ravendale and Hatcliffe (Straw, 1961) argue for cessation of internal movement soon after the ice reached its limit, with thinning of the ice during deglaciation rather than retreat of an active front. By rising onto the Central Wolds over a distance of some 25 miles south-east of Brocklesby to a height of almost 90m OD the ice, albeit standing northward away from the Wolds at the Killingholme Moraine, would have obstructed Humber drainage effectively for a second time within the Devensian.

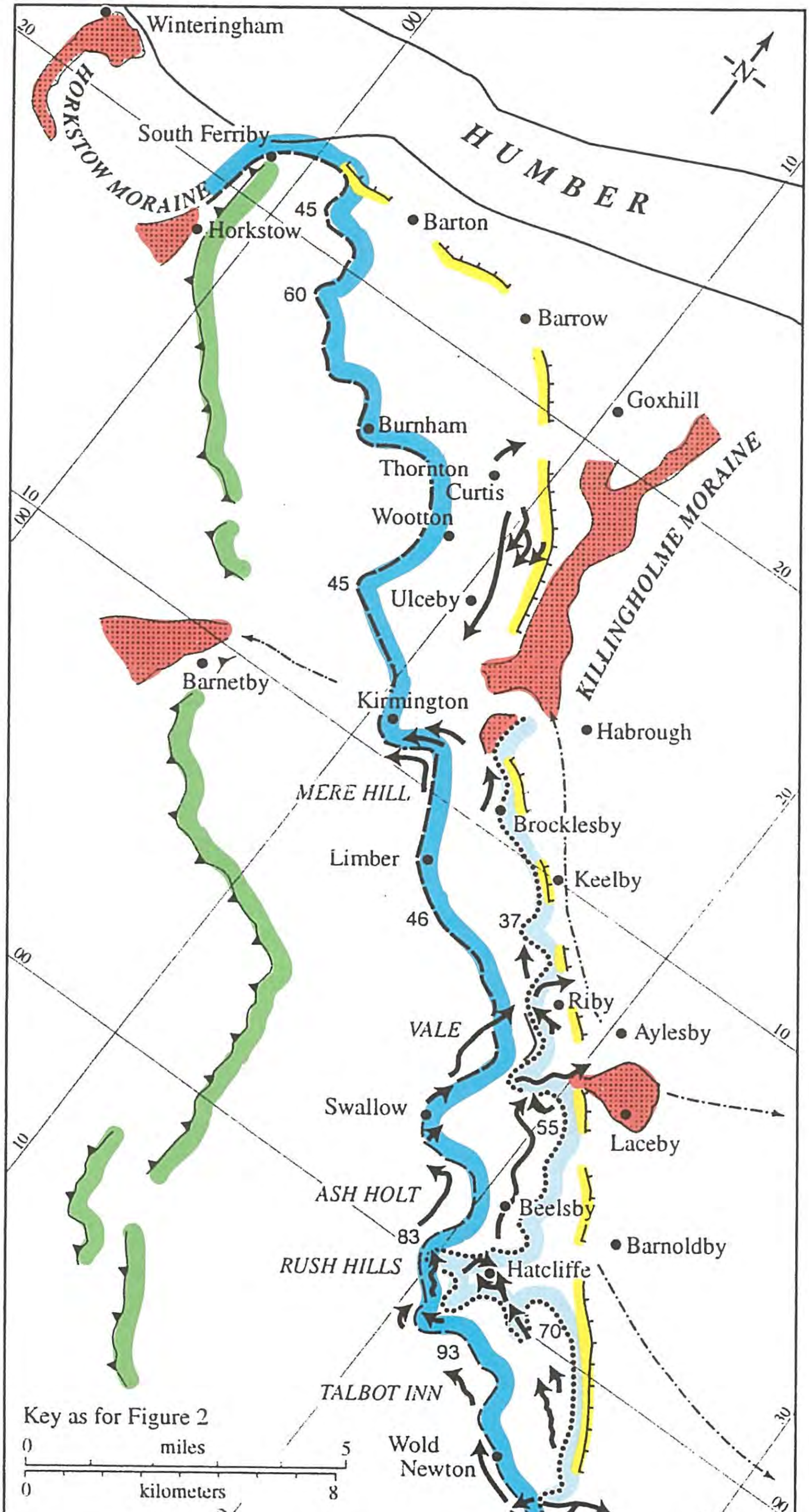
Devensian Glaciation – the orthodox view

In spite of many decades of research, agreement on the stages and dates of Devensian glaciation in eastern England remains elusive. In 1973, Mitchell et al, in effect summarizing previous work, placed the Hunstanton boulder-clay of Norfolk, the Lincolnshire Marsh Tills and Moraines, and all the Holderness drifts (excluding only the Sewerby 'raised beach' and the Basement Till) within the Late Devensian (26,000 to 10,000 years BP). This view was supported by the work of Madgett and Catt (1978) on the petrography of the east coast tills. Discounting the 'Hessle Till' as a weathering product they confirmed two Devensian tills in Holderness naming them the Skipsea and Withernsea Tills (formerly Drab and Purple). These Tills were held to be younger than c.18,250 years BP (uncalibrated radiocarbon dates on mosses from silts directly beneath the Skipsea Till at Dimlington) and the Skipsea Till was unequivocally claimed to extend to north Norfolk thereby subsuming the Hunstanton boulder-clay.

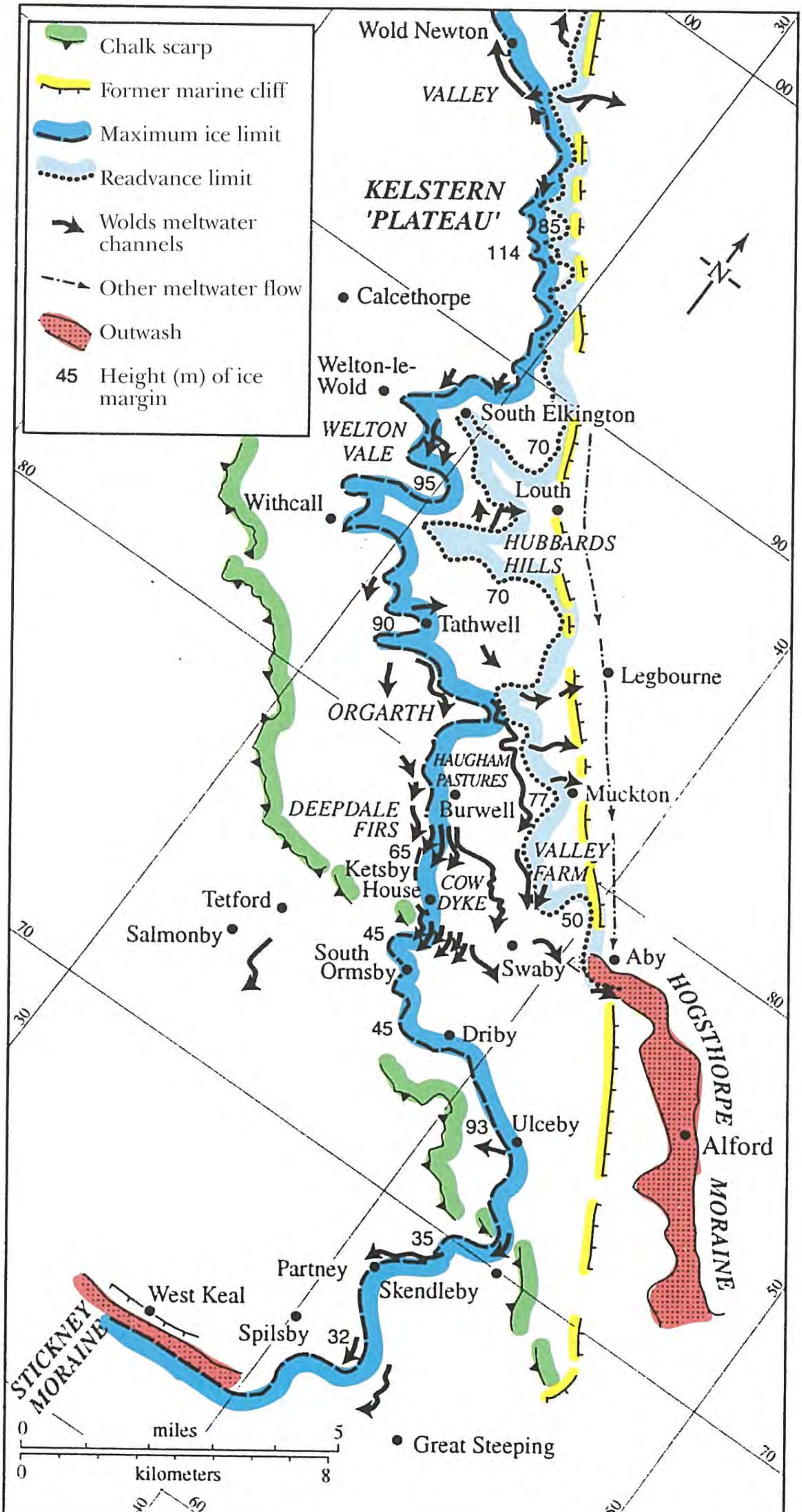
In 1985 Rose was bold enough to recommend the term 'Dimlington Stadial' to describe the Late Devensian glacial event for the whole country, and two years later Catt (1987) restated his opinion that the Skipsea Till was the only till south of the Humber. More recently the 'Revised Correlation of Quaternary Deposits in the British Isles' (Bowen, 1999) allocated Skipsea and Withernsea Tills to MIS 2 (Late Devensian) but surprisingly included within it the Basement Till (Bridlington Member) following the claim by Eyles et al (1994) that the Holderness Tills were all the consequence of repeated surges of Late Devensian ice over marine sediments.

Since then researchers centred on the Department of Geography, University of Sheffield have published, under their BRITICE project, a 'Glacial Map of Britain' at a scale of 1:625,000 illustrating landforms and features related to the last British icesheet (Clark et al, 2004), compiled from as much relevant literature as possible. A GIS database, comprising 20 thematic layers, was also produced, accessible on website

continued on page 26



Winteringham
HUMBER
N
HORKSTOW MORAINE
South Ferriby
Horkstow
Barton
Barrow
Goxhill
Burnham
Thornton Curtis
Wootton
Ulceby
KILLINGHOLME MORAINE
Barnetby
Kirmington
Habrough
MERE HILL
Brocklesby
Limber
Keelby
Riby
Aylesby
VALE
Swallow
Laceby
ASH HOLT
Beelsby
Barnoldby
RUSH HILLS
Hatcliffe
TALBOT INN
Wold Newton
45
60
45
46
37
55
83
70
93
Key as for Figure 2
0 miles 5
0 kilometers 8



Chalk scarp
Former marine cliff
Maximum ice limit
Readvance limit
Wolds meltwater channels
Other meltwater flow
Outwash
45 Height (m) of ice margin
Wold Newton
VALLEY
KELSTERN 'PLATEAU'
85
114
Calcethorpe
Welton-le-Wold
South Elkington
WELTON VALE
70
95
Louth
Withcall
HUBBARDS HILLS
70
90
Tathwell
Legbourne
ORGARTH
HAUGHAM PASTURES
77
Muckton
DEEPDALE FIRS
Burwell
65
VALLEY FARM
Ketsby House
COW DYKE
Tetford
50
Salmonby
45
South Ormsby
Swaby
Aby
HOGSTHORPE
45
Driby
93
Ulceby
Alford
MORAINE
35
Partney
Skendleby
West Keal
Spilsby
32
STICKNEY MORAINE
0 miles 5
0 kilometers 8
Great Steeping
N

(http://www.shef.ac.uk/geography/staff/clark_chris/britice.html). The map portrays the maximum extent of Devensian ice in Great Britain, identified as both the 'Dimlington Stadial' and the Last Glacial Maximum. A complementary review of all the evidence used for the Map and database has also been published (Evans et al, 2005) of wide coverage (over 1000 sources) and valuable synthesis.

As far as Lincolnshire is concerned the BRITICE Glacial Map depicts a single limit (essentially the western drift limit) for the Devensian icesheet from the Humber to the Wash and north Norfolk, the Moraines at Hogsthorpe, Killingholme and Horkstow/Winteringham, and the postulated extents of proglacial Lakes Humber and Fenland. Westward of Scunthorpe, beyond the Trent, an ice limit and a moraine between Wroot (SE 715030) and Thorne (SE 690132) are shown. Unlike the area of Holderness no subordinate morainic ridges are indicated over the Lincolnshire Marsh and none of the 80-plus meltwater channels in the Wolds (Figs.1, 2) discussed above is shown. Positions for ice dams for lakes are shown at the Stickney Moraine and at South Ferriby.

The text accompanying the Map (Clark et al, 2004) describes how and why these features were included, but the review paper (Evans et al, 2005) presents a summary and assessment of the available literature with statements but no evaluation of controversies.

Two-fold Glaciation

In 1957 and 1958 Straw claimed that the 'Newer Drift' (ie. Devensian) deposits had been emplaced in at least two stages separated by a substantial period of erosion. Limits of the two ice advances were illustrated in 1958, 1961 and 1979a, and contrasts in the landforms and attitudes of the deposits associated with these advances were also described. In 1961 reference was made to complementary bore-hole information and a detailed analysis of meltwater channels in the Wolds was presented. In 1979 it was claimed that a third ice advance was evident in east Holderness during which the Purple (Withernsea) Till was laid down, and the River Hull and the lower Humber given their final south and south-east alignments.

The period between the two advances in Lincolnshire was vaguely defined as of 'interstadial character', the implication being no more than time between two stadials, ie. two distinct and separate ice advances and not just a period of halt in recession nor a slight readvance within one stadial. Attention was drawn to the greater weathering and denudation of the drifts related to the first advance, including the removal of drift from the valleys of the North and South-east Wolds, and the degraded morphology of the meltwater channels related to them, which seemed to require a length of time reckoned in many millennia rather than some centuries. Such modifications, on the presumption that drifts had originally occupied the valleys and had a surface relief similar to that of the Upper Marsh Till and Holderness Tills, indicate a long ice-free period before the second advance took place, though periglacial processes operative during the second advance could account for some of them. Similar modifications have affected the drifts on the Yorkshire Wolds' dip-slope west of the River Hull. Madgett and Catt (1978), Catt (1980, 1987) and Evans et al (2001) claim that the smoother topography of the tills in west Holderness is merely a consequence of partial burial of glacial features by Hull alluvium, but this totally ignores Straw's point that west of the Hull alluvium itself the Chalk dip-slope carries Devensian till with a formless surface only on interfluves up to 75m OD and which is associated only with degraded meltwater channels now of wide and shallow form, for example at Middleton-on-the-Wolds (SE 945495) (de Boer, 1945), similar to the Chalk of the North Lincolnshire Wolds and parts of the Central Wolds. The geomorphological contrasts between these drifts and those of east Holderness are so obvious that it would truly be perverse to deny them.

In the published discussion on Madgett and Catt's paper (1978) and again in 1979 and 1980 Straw reviewed the case for an east Lincolnshire glaciation earlier in the Devensian than the Late Glacial Maximum and challenged Madgett and Catt's findings, including also the undue reliance placed on Dimlington radiocarbon dates as defining the maximum age of all Devensian glacial deposits in Britain.

In 1978 Straw had questioned the sensitivity of petrographic techniques to separate tills produced by successive icesheets that had followed similar tracks over similar rock types. Madgett and

Catt's sample sites in Lincolnshire ranged over drifts of both the ice advances demonstrated above and, far therefore from accepting the petrographic data as conclusive, it could equally well be the case that either the technique is insufficiently discriminating or that (apart from the Withernsea Till for which special circumstances of transport were claimed by Madgett and Catt) several tills in Holderness and east Lincolnshire have similar petrographic signatures.

In 1980 Straw pointed to the significance of the stratigraphic position and geographic location of the Late Devensian shell-bearing gravels east of the North Wolds around Thornton Abbey and at Kelsey Hill north of the Humber (Reid, 1885; Gaunt et al, 1992; Berridge and Pattison, 1994), and of the fact that shells have been reported from outwash at Aby in front of the Hogsthorpe Moraine (Jukes-Browne, 1887). These marine shells must have been picked up by the ice that built the Killingholme and Hogsthorpe Moraines and laid down the Skipsea and Withernsea Tills at Kelsey Hill eventually to be incorporated in the outwash. However, if only a single icesheet invaded east Lincolnshire why are shells not included in the Winteringham and Horkstow outwash and in the Kirmington and Stickney Moraines? This crucial question is resolved if some shells originally accumulated, and some became exposed in older beds, in a Middle Devensian Humber estuary that came into being after the first advance and recession of ice and was subsequently overrun during the second one.

The situation therefore of a single ice advance over east Lincolnshire to north Norfolk as shown on the BRITICE Map creates more difficulties than it solves, for instance with proglacial lakes and river terraces, as discussed below. It ignores the real geomorphic contrasts in glaciated terrain within both Lincolnshire and Holderness acknowledged by Evans et al (2005) and the fact that (on bore-hole records) two layers of Marsh Till lie at and eastward of the second advance limit compared with single layers around Goxhill and Barton and round the southern end of the Wolds. It also denies, by contrast with the Fens, the existence of Early and Middle Devensian sediments in the Humberhead and east coast areas. These points are summarized fairly by Evans et al (2005) who outline the conflicting interpretations of the field evidence.

Independent assessment of the age of the Last Glacial Maximum in the British Isles (Bowen et al, 2002) supports the model of two-fold glaciation of Lincolnshire in the Devensian. In eastern England shells from Dimlington and Hunstanton are shown, on the application of amino-acid geochronology, to belong to two separate amino-zones which have been calibrated by Uranium-series and radiocarbon ages. Amino-acid ratios from shells in the Hunstanton till fall into the older zone (more than 37,500 years BP) whereas the Dimlington shells are younger than c.22,000 years (calibrated radiocarbon dates). Bowen et al accept that the Late Devensian ice limit lies at the Hogsthorpe Moraine and that the Hunstanton till (equal to the Stickney Moraine) advance was an earlier Devensian event. This conclusion weighs heavily against the view that Skipsea Till is to be found throughout east Lincolnshire and confirms that it does not subsume the Lower Marsh Till.

The case therefore for two glacial stadials in east Lincolnshire is a compelling one and, on all lines of evidence including the disposition of drifts, the contrasts in landforms and effects on the functions of the Humber and the Wash as drainage outlets for Midland and northern rivers, it is the second of these that should be identified as the Last Glacial Maximum (Table 1). The earlier probably occurred before MIS 3, more than 40,000 and perhaps 50,000 years BP. The third advance, that affected east Holderness, represents a readvance soon after the Last Glacial Maximum.

Pro-Glacial Lakes

In the southern Vale of York, the Humberhead area, and in the Fenland evidence has been adduced (Edwards, 1937; Straw, 1963, Gaunt, 1976) for the existence of large impounded lakes during times of Devensian glaciation. Such lakes, initially proposed by Lewis (1894), formed because of ice obstruction to the easterly flow of Humber and Wash rivers. The postulated extents of the various lakes are shown on the BRITICE Map (Clark et al, 2004) and contrasting views on the circumstances and ages pertaining to these lakes were summarized by Evans et al (2005). These are discussed below.

Lake Humber

Gaunt (1981, 1994) has most recently described and considered the features relating to Lake Humber. Strandline deposits at c.33m OD in various locations in the Doncaster and Tadcaster areas were held to represent the highest level reached by lake water. These, as noted by Straw (1979a) all occupy interfluve situations between valleys draining off the Magnesian Limestone. By contrast, the '25-foot Drift', mainly silts and sands, presents large areas of undissected surface, passes up valleys as low terraces, and indicates flooding to a level of about 8 or 9m OD following a drop to at least –4m OD. Gaunt (1974, 1994) considered both water levels to have existed during the Late Devensian as stages of a single Lake Humber. This model arose from the presumption that ice and morainic blockage at Horkstow and Winteringham was a Late Devensian event, and from a claim that Vale of York ice had contemporaneously surged south into high-level Lake Humber (Gaunt, 1976), but this has been challenged by Straw (2002a) who argued that Devensian ice has never extended further south than Selby.

Silts with organic remains at Dimlington beneath Skipsea Till have yielded uncalibrated radiocarbon dates of 18,500± 400 and 18,240± 250 years BP (Penny et al, 1969) and these have been taken generally just to predate the advance of Late Devensian ice into Holderness and the impounding of Lake Humber to its 33m level (Gaunt, 1994). Gaunt (1974, 1976) has also reported a radiocarbon date of 21,835± 1660 years BP on a piece of bone found at or near the base of a sand and gravel deposit purported to relate to high-level Lake Humber 1 near Brantingham (SE 938291), and suggested it put an older limit for the ice advance and the existence of that lake. This bone fragment, found 3.05m below the surface, is apparently several thousands of years older than the ice advance at Dimlington and was therefore 'around' for such a while before being incorporated in the Brantingham deposit that it is unwise to place any reliance on the date.

A more recent attempt to confirm a date for Lake Humber 1 was contained in a study of Coversands near Caistor (TA 116013) (Bateman et al, 2000). Thermoluminescence dating suggested the sands could range in age from c.22,600 to 6,460 years BP. The basal sand unit lying at c.33m OD, containing a silty clay no more than a few centimetres thick, was considered to have been laid down on the margin of Lake

Humber 1, and to confirm its existence at c.23,000 years BP (ie. Late Devensian). However, the sands aggraded generally in a periglacial environment under frozen ground and seasonal snow-melt conditions. The silty clay in itself is not especially diagnostic of a lake margin situation and could equally well represent suspended material settled out in a local snow-melt pond. This is therefore very slim evidence on which to postulate the presence of Lake Humber 1. Rather it would appear that the coincidence of altitude and date influenced interpretation of the sediment as a marginal deposit of Lake Humber 1, the existence of a Late Devensian lake having already been presumed. To claim then that the silty clay confirms Lake Humber 1 is circular reasoning. Curiously, the sediments reveal no effects of wave action although in a relatively exposed location on the east shore of what would have been an extensive body of water where the fetch from some directions could have been several miles.

Further south, Lake Humber 1 at a level of c.33m OD would have extended up the Trent valley beyond Newark and covered most of the Vale of Belvoir. No sediments directly related to it have been described, but it should be noted that the higher Trent terraces between Newark and Lincoln would have been largely inundated. Lower ones could have formed after it had drained away.

Two Lakes

An alternative interpretation, that the water levels refer to two lakes widely separated in time, has been offered by Straw (1963, 1979a, 1979b, 1980, 1991). One compelling reason for this is that if the 33m lake were Late Devensian then, because the Lincoln gap provided a sufficiently low connection, a similar lake should also have existed in the Fen basin but no evidence for a Late Devensian lake at that height has been reported nor, significantly, are there any deposits in the Fen basin to compare with the wide-spreading '25-foot Drift'. West (1993) has described deposits at Somersham (TL 375800), ten miles west of Ely, which include groups of varves and rhythmites lying between +0.15m and –1.00m OD. These were regarded as lacustrine in origin and shown to be of Late Devensian date. However, a water level no higher than 3m OD was suggested for what was named 'Lake Sparks' impounded when ice reached Hunstanton and closed the Wash gap.

It is more likely, in light of the discussion earlier in this paper, that impounding was related rather to the Hogsthorpe Moraine which marks the Last Glacial Maximum in Lincolnshire. It is argued instead that it was a 33m Lake Fenland that was impounded when ice reached north Norfolk (the Stickney-Heacham advance) and that this was coeval with Lake Humber 1 in an event earlier than the Last Glacial Maximum. Both lakes drained during deglaciation; Lake Fenland through the Wash with some Lake Humber 1 water coming via the Lincoln gap and Lake Humber 1 later through the Humber gap. Gaunt (1994, Fig.42) produced a contour map essentially defining the base of the '25-foot Drift' in the Humberhead area, which reveals an integrated system of buried valleys focussed on the gap with floors as low as –20m OD. This erosion, preceding '25-foot Drift' deposition, provides clear evidence of lake water egress eastward, is a realistic measure of the magnitude of the time gap between the two lake stages, and accords with the scale of valley erosion and drift removal and modification that is so manifest in the North Wolds of Lincolnshire and the Yorkshire Wolds.

Assuming that Lake Humber 1 emptied largely through the Humber gap, two questions must be levelled at Gaunt's (1994) interpretation: if ice remained in or even east of the gap where, during lowering of level, did the water go, and how could an insubstantial morainic dam survive between Winteringham and Welton to impound Lake Humber 2? There is no evidence for tunnel valley development (ie. escape beneath the ice) across southern Holderness nor any signs of substantial marginal meltwater flow south-south-east across the North Wolds dip-slope. In other words the ice must have withdrawn a long way east and north allowing Lake Humber 1 to drain completely and permit the cutting of the valleys buried by the '25-foot Drift'. The surviving morainic material at Winteringham is mostly unconsolidated sand and gravel (Plate 1), and there is no reason to assume it was any more substantial across the present estuary. To presume that it persisted for hundreds of years to a height of 9m OD or so to impound Lake Humber 2 is at best special pleading, for even the diminutive River Ancholme was able to breach the Horkstow Moraine. Indeed the lacustrine deposits (= '25-foot Drift') around the Ancholme valley (Gaunt et al, 1992) which joins the Humber east of Winteringham proves that it did not. In all probability the 9m Lake Humber 2 stretched east through the gap to

Plate 11 – TF 390776, to E (May, 1959). Swaby meltwater channel (flow to E), N of the village. This stream-occupied channel was initially cut across a Chalk spur during recession of first advance ice by meltwaters diverted E by ice blockage of the former valley at and S of the village. Terrace features relate to sand and gravel aggradation and subsequent erosion during the second advance.

Plate 12 – TF 221629, to ESE (September, 1977). Kirkby Moor Sands. Over 8m of thinly-bedded, shallow-water sands with some trough cross-bedding, probably aggraded by the River Bain on the margin of Lake Fenland.

the Killingholme Moraine and received the meltwaters responsible for transporting the shelly gravels at Thornton Abbey and Goxhill.

In summary, during the second advance, ice reached neither the Humber nor the Wash gaps but, by rising onto the Wolds south of Keelby, it did deny passage of Humber waters eastward. In the Vale of York, ice flowed no further south than Selby, Gaunt's claim (1976) that it extended toward Doncaster being unsupported by incontrovertible depositional or erosional evidence (Straw, 2002a). Lake Humber 2 level rose to c.9m OD and the '25-foot Drift' filled it almost to the brim. In the Fens, Lake Sparks rose briefly to c.3m OD, receiving marginal deposits only, including outwash fronting the Hogsthorpe Moraine.

Lake Fenland

Positive evidence for a 33m OD lake in the Fenland is meagre, probably for the reason that it also was ephemeral and the relatively few strandline and bottom sediments have been largely reworked by subsequent fluvial and periglacial processes. A convincing survival remains however at Kirkby Moor (TF 228630) at the south end of the River Bain valley. Around Tattershall (TF 212576) the Bain has spread a large gravelly fan far into the Fen margin. Organic materials within these deposits have yielded radiocarbon dates between 30,800 and 44,300 years BP (Catalogue Nos. BIRM(INGHAM) – 448, 450, 398, 409, 341, 408), ie. Middle Devensian. The gravels pass up the Bain valley as terrace features (Straw, 1979a). West of Kirkby-on-Bain (TF 242624), beyond and above a low valley-side exposing Wragby Till (Older Drift), lie the Kirkby Moor Sands (Plate 12), a wide-spreading fan-like deposit with a remarkably level surface at c.30m OD, clearly older than the Tattershall gravels, and believed by Straw to have been built out into a body of water, ie. Lake Fenland. Worsley (1991) denies this origin and regards the Sands as comprising a pre-Devensian outwash plain or sandur deposited during the disappearance of Older Drift ice.

The Sands relate to the Hemingby Terrace (Straw, 1958, 1964, 1979), the highest in the lower Bain valley, which can be traced upstream until it fades out in the floor of the middle Bain valley around Donington-on-Bain (TF 235830). Here the valley has been eroded into Lower Cretaceous rocks beneath the Biscathorpe Gravels and Calcethorpe Till (Straw, 1966). A small proportion only of the Kirkby Moor deposit is flint (pieces rarely more than 7cm across), erratics are very rare, and the bulk of the Sands is derived by erosion from bedrock Spilsby Sandstone and the Biscathorpe Gravels. Clearly therefore the Kirkby Moor Sands long post-date deposition of, and disappearance of the ice responsible for, the Older Drift. In any case, outwash from ice responsible for the Calcethorpe and Wragby Tills would expectedly have had a higher proportion of erratics.

The sedimentary style of thin (up to 15cm), level, rippled, planar beds with some cross-bedding and trough cross-bedding typical of shallow water deposition with braided currents or streams is consistent from bottom to top of at least 9m of the Sands seen in the 1970's (Plate 12), indicating accumulation keeping pace with a steadily-rising water level and maintenance of generally low gradients. The absence of intra-formational ground-ice structures is also notable because it contrasts with their presence in both the contemporary Hemingby Terrace (eg. in the West Ashby gravel pit – TF 250727) and the younger Tattershall gravels and may well be a consequence of the Sands' largely subaqueous deposition. The author prefers therefore still to regard the Kirkby Moor Sands as having aggraded on the margin of Lake Fenland the emptying of which was likely to have been rapid as ice cleared the Wash gap thereby creating conditions for deepening of the Bain valley, along a former line, before deposition of the Middle Devensian Tattershall gravels.

It was noted above that, in the Vale of Belvoir, certain of the Trent terraces would have been submerged at the highest level of the southern part of Lake Humber 1. Correlative Martin and Southrey Terraces flanking the present Witham valley below Lincoln would likewise have been drowned by Lake Fenland, the implication of the above being that, although altitudinally higher, the Kirkby Moor Sands are younger than these features.

Evidence of sedimentation in the northern part of Lake Fenland is slight, but some of the flat-lying outwash materials at Winteringham (Plate 1), a small outwash fan at Horkstow, a larger fan south-west of Barnetby-le-Wold (TA 057093) and the sandy terrace along the north side of the Stickney ice lobe all lie at accordant heights and are closely associated with the earlier Devensian advance.

Consequences for the River Trent

A final comment pertains to the effects of glacial closure of the Humber and Wash gaps and the creation of pro-glacial lakes on the behaviour of the River Trent, currently tributary to the Humber. In 1963, Straw detailed events relating to the diversion of the Trent to and through the Lincoln gap on at least two occasions during the Devensian, first when Lake Fenland and some of Lake Humber 1 drained away while the Humber remained closed, and second when Humber drainage was shut off by the second advance ice. This model clearly incorporates two mechanisms; opening of the Wash gap before that of the Humber during recession of an icesheet, and closure of the Humber gap before that of the Wash (if at all) during an ice advance. Diversions were claimed to be witnessed by the Beeston and Floodplain Terraces which lie between Newark and Lincoln. However, pre-Devensian dates (Brandon and Sumbler, 1991) for the Balderton Terrace (part of the Beeston Terrace) indicate aggradation of its sands and gravels some time before the Ipswichian Interglacial (MIS 5e). This requires revision of the model in that, while deposition of the Floodplain Terrace remains a Last Glacial Maximum-related event and thereby contemporaneous with Lake Humber 2 and the '25-foot Drift', it could well be the Scarle Terrace (Brandon and Sumbler, 1988; Maddy, 1999) that was emplaced following drainage of Lake Fenland and Lake Humber 1 (through the Lincoln gap), the latter having previously inundated the Balderton Terrace.

Aggradation of the Balderton Terrace as a pre-Devensian event does not invalidate the relevant mechanism of diversion, rather it provides an instance of its operation at an earlier date. Specifically, the Trent first flowed northward by way of the valley it had cut across the Mercia Mudstones' dip-slope from Newark to Gainsborough and beyond (Straw, 1963, 2002b) before laying down the Balderton Terrace deposits. This early route, leading to and through a glacially-eroded breach in the Gainsborough-Gringley ridge (Straw, 1979a, 1991) had to be available and low enough after deposition of the Balderton Terrace to allow the Trent to abandon its course to Lincoln and return to the Humber, just as it had to be again after the later Scarle and Floodplain Terrace diversions (Straw, 2002b).

The Balderton Terrace might be regarded therefore as a pre-Devensian example of drainage of the Lincolnshire area responding to a 'Wash open/Humber closed' situation during an earlier glaciation. The possibility exists that it might not be widely separated in time from the higher Eagle Moor Terrace. Deposits of this survive on eminences of a relief produced subglacially (Straw, 1963, 2002b) and must have been laid down by water flowing partly on ice during a glacial recession. The Balderton Terrace could then have occupied lower ground when the ice finally disappeared.

The feasibility of the second mechanism cannot be in doubt and it is merely a statement of the obvious that ice advancing from the north in any glaciation would interfere with drainage through the gaps. Advance into the Midlands would not only close the Humber and Wash gaps but also, successively, those at Lincoln, Ancaster and Bytham, no doubt causing diversions in each case.

Conclusion

This paper has sought first to describe again the glacial geomorphology of the Lincolnshire Wolds and Marsh, with particular reference to the series of meltwater channels and their relationships to the two separate ice advances that can clearly be identified in east Lincolnshire. The intervening period was therefore inter-stadial in the strict sense of the term, and there is considerable geomorphological evidence for it being a period to be reckoned in many millennia rather than centuries. Denudation and weathering of the Lower Marsh Till, recognizable west of the limits of the second advance, seems to have been achieved in part at least before this later ice invaded the Central Wolds and before accumulation of the Thornton Abbey and Aby outwash trains. Slope processes operating on the interfluves and on broader spreads of drift in the Tathwell and Partney valleys under severe climatic conditions during the second advance no doubt also account for some of the thinning and smoothing of the drift, and for the partial filling (with gelifluction material and blown sand) and side-slope angle reduction of many of the older meltwater channels. The scale of these landscape changes, which need to be seen in the field, requires a period of time longer than that which might be expected between recession and readvance of a single icesheet. It is not too extravagant to claim that two glacial landscapes exist within the area affected by Devensian glaciation.

Secondly has been consideration of the evidence for one or two ice advances and the controls they exerted on pro-glacial Lakes Humber and Fenland. Accepting a two-fold glaciation of east Lincolnshire the question of date resolves into which advance should be regarded as the Last Glacial Maximum. The second advance was the less extensive and it has been shown above that Lake Humber 2 and accumulation of the '25-foot Drift', firmly allocated to the Late Devensian, were consequences of this second advance when ice built the Killingholme and Hogsthorpe Moraines and rose onto the Central Wolds. In the Fens conditions were created for impounding Lake Sparks. By contrast Lake Humber 1 and Lake Fenland existed only when ice reached north Norfolk. It is the unequivocal message of this essay therefore that the Last Glacial Maximum should be identified at the Hogsthorpe and Killingholme Moraines and that the first, maximum, advance testifies to a much earlier incursion of ice in the Devensian.

References

Alabaster, C. & Straw, A. 1976. The Pleistocene context of faunal remains and artefacts discovered at Welton-le-Wold, Lincolnshire. Proceedings of the Yorkshire Geological Society, 41: 75-93.

Bateman, M.D., Murton, J.B. & Crowe, W. 2000. Late Devensian and Holocene depositional environments associated with the coversand around Caistor, north Lincolnshire, U.K. Boreas, 29: 1-15.

Berridge, N.G. & Pattison, J. 1994. Geology of the country around Grimsby and Patrington. British Geological Survey, Sheet Memoir (81, 82, 90, 91), England and Wales.

Boulton, G.S., Jones, A.S., Clayton, K.M. & Kenning, M. 1977. A British icesheet model and pattern of glacial erosion and deposition in Britain. In Shotton, F.W. (ed.) British Quaternary Studies: Recent Advances (Clarendon), 231-246.

Bowen, D.Q. (Ed.) 1999. A Revised Correlation of Quaternary Deposits in the British Isles. Geological Society of London, Special Report No.23, 174pp.

Bowen, D.Q., Phillips, F.M., McCabe, A.M., Knutz, P.C. & Sykes, G.A. 2002. New data for the Last Glacial Maximum in Great Britain and Ireland. Quaternary Science Reviews, 21: 89-101.

Brandon, A. & Sumbler, M.G. 1988. An Ipswichian fluvial deposit at Fulbeck, Lincolnshire, and the chronology of the Trent terraces. Journal of Quaternary Science, 3: 127-133.

Brandon, A. & Sumbler, M.G. 1991. The Balderton Sand and Gravel: pre-Ipswichian cold stage fluvial deposits near Lincoln, England. Journal of Quaternary Science, 6: 117-138.

Catt, J.A. 1980. Till facies associated with the Devensian glacial maximum in eastern England. Quaternary Newsletter, No.30: 4-10.

Catt, J.A. 1987. The Quaternary of east Yorkshire and adjacent areas. In Ellis, S. (ed.) East Yorkshire. Field Guide, Quaternary Research Association, 1-14.

Clark, C.D., Evans, D.J.A., Khatwa, A., Bradwell, T., Jordan, C.J., Marsh, S.H., Mitchell, W.A. & Bateman, M.D. 2004. Map and GIS database of glacial landforms and features related to the last British Ice Sheet. Boreas, 33: 359-375.

Dalton, A.C. 1953. Some sections of glacial drift in the Wirral and north Lincolnshire re-examined. North West Naturalist (September), 435-441.

De Boer, G. 1945. A system of glacier lakes in the Yorkshire Wolds. Proceedings of the Yorkshire Geological Society, 25: 223-233.

Edwards, W. 1937. A Pleistocene strandline in the Vale of York. Proceedings of the Yorkshire Geological Society, 23: 103-118.

Evans, D.J.A., Thomson, S.A. & Clark, C.D. 2001. The glacial history of east Yorkshire. In Bateman, M.D., Buckland, P.C., Frederick, C.D. and Whitehouse, N.J. (eds.) The Quaternary of east Yorkshire and north Lincolnshire. Field Guide, Quaternary Research Association, 1-12.

Evans, D.J.A., Clark, C.D. & Mitchell, W.A. 2005. The last British Ice Sheet: a review of the evidence utilized in the compilation of the Glacial Map of Britain. Earth Science Reviews, 70: 253-312.

Eyles, N., McCabe, A.M. & Bowen, D.Q. 1994. The stratigraphy and sedimentological significance of Late Devensian ice sheet surging, Holderness, Yorkshire. Quaternary Science Reviews, 13: 727-759.

Frederick, C.D., Buckland, P.C., Bateman, M.D. & Owens, B. 2001. South Ferriby cliff and Eastfield Farm. In Bateman, M.D., Buckland, P.C., Frederick, C.D. and Whitehouse, N.J. (eds.) The Quaternary of east Yorkshire and north Lincolnshire. Field Guide, Quaternary Research Association, 103-112.

Gaunt, G.D. 1974. A radiocarbon date relating to Lake Humber. Proceedings of the Yorkshire Geological Society, 40: 195-197.

Gaunt, G.D. 1976. The Devensian maximum ice limit in the Vale of York. Proceedings of the Yorkshire Geological Society, 40: 631-637.

Gaunt, G.D. 1981. Quaternary history of the southern part of the Vale of York. In Neale, J. and Henley, J. (eds.) The Quaternary in Britain (Pergamon), 82-97.

Gaunt, G.D. 1994. Geology of the country around Goole, Doncaster and the Isle of Axholme. British Geological Survey, Sheet Memoir (79, 88), England and Wales.

Gaunt, G.D., Fletcher, T.P. & Wood, C.J. 1992. Geology of the country around Kingston-upon-Hull and Brigg. British Geological Survey, Sheet Memoir (80, 89), England and Wales.

Jukes-Browne, A.J. 1887. Geology of part of east Lincolnshire. Memoir of the Geological Survey of England and Wales (Sheet 84, Old Series).

Lewis, H.C. 1894. Glacial Geology of Great Britain and Ireland (Longman).

Maddy, D. 1999. English Midlands. In Bowen, D.Q. (ed.) A Revised Correlation of Quaternary deposits in the British Isles. Geological Society of London, Special Report No.23, 42.

Madgett, P.A. & Catt, J.A. 1978. Petrography, stratigraphy and weathering of Late Pleistocene tills in east Yorkshire, Lincolnshire and north Norfolk. Proceedings of the Yorkshire Geological Society, 42: 55-108.

Mitchell, G.F., Penny, L.F., Shotton, F.W. & West, R.G. 1973. A Correlation of Quaternary Deposits in the British Isles. Geological Society of London, Special Report, No.4, 99pp.

Penny, L.F., Coope, G.R. & Catt, J.A. 1979. Age and insect fauna of the Dimlington silts, east Yorkshire. Nature, 224: 65-67.

Perrin, R.M.S., Rose, J. & Davies, H. 1979. The distribution, variation and origins of pre-Devensian tills in eastern England. Philosophical Transactions of the Royal Society, B, 287: 535-570.

Reid, C. 1885. Geology of Holderness and the adjoining parts of Yorkshire. Memoir of the Geological Survey of England and Wales.

Rose, J. 1985. The Dimlington Stadial/Dimlington Chronozone: a proposal for naming the main glacial episode of the Late Devensian in Britain. Boreas, 14: 225-230.

Shackleton, N.J. & Opdyke, N.D. 1973. Oxygen isotope and palaeomagnetic stratigraphy of Equatorial Pacific Core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and a 10^6 year scale. Quaternary Research, 3: 39-55.

Sibrava, B., Bowen, D.Q. & Richmond, G.M. (Eds.) 1986. Quaternary glaciations in the northern hemisphere. Quaternary Science Reviews, 5: 514pp.

Straw, A. 1957. Some glacial features of east Lincolnshire. East Midland Geographer, 1: 41-48.

Straw, A. 1958. The glacial sequence in Lincolnshire. East Midland Geographer, 2: 29-40.

Straw, A. 1961. Drifts, meltwater channels and ice margins in the Lincolnshire Wolds. Transactions and Papers, Institute of British Geographers, 29: 115-128.

Straw, A. 1963. The Quaternary evolution of the lower and middle Trent. East Midland Geographer, 3: 171-189.

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

Straw, A. 1966. The development of the middle and lower Bain valley, Lincolnshire. Transactions of the Institute of British Geographers, 40: 145-154.

Straw, A. 1969. Pleistocene events in Lincolnshire: a survey and revised nomenclature. Transactions of the Lincolnshire Naturalists' Union, XVII: 85-98.
Straw, A. 1972. North Lincolnshire. In Penny. L.F. (ed.) East Yorkshire and North Lincolnshire. Field Guide, Quaternary Research Association, 25-39.
Straw, A. 1979a. Eastern England. In Straw, A. and Clayton, K.M. Eastern and Central England. Geomorphology of the British Isles Series (Methuen), 1-139.
Straw, A. 1979b. An Early Devensian glaciation in eastern England? Quaternary Newsletter, No.28: 18-24.
Straw, A. 1980. An Early Devensian glaciation in eastern England reiterated. Quaternary Newsletter, No.31: 18-23.
Straw, A. 1983. Pre-Devensian glaciation of Lincolnshire (eastern England) and adjacent areas. Quaternary Science Reviews, 2: 239-260.
Straw, A. 1991. Glacial deposits of Lincolnshire and adjoining areas. In Ehlers, J., Gibbard, P.L. and Rose, J. (eds.) Glacial Deposits in Great Britain and Ireland (Balkema), 213-221.
Straw, A. 2000. Some observations on 'Eastern England' in A Revised Correlation of Quaternary Deposits in the British Isles (ed. Bowen, D.Q.). Quaternary Newsletter, No.91: 2-6.
Straw, A. 2002a. The Late Devensian ice limit in the Humberhead area – a reappraisal. Quaternary Newsletter, No.97: 1-10.
Straw, A. 2002b. Lincolnshire – gaps and more gaps. Geology Today, 18: 17-22.
Straw, A. 2005. Glacial and pre-glacial deposits at Welton-le-Wold, Lincolnshire. Studio Publishing Services, Exeter. 33pp.
Ussher, W.A.E. 1890. Geology of parts of North Lincolnshire and South Yorkshire. Memoir of the Geological Survey of England and Wales (Sheet 86, Old Series).
West, R.G. 1993. On the history of the Late Devensian Lake Sparks in southern Fenland, Cambridgeshire, England. Journal of Quaternary Science, 8: 217-234.
Worsley, P. 1991. Possible Early Devensian glacial deposits in the British Isles. In Ehlers, J., Gibbard, P.L. and Rose, J. (eds.) Glacial Deposits in Great Britain and Ireland (Balkema), 47-51.

Glossary

Alluvium – Holocene river sediments beneath floodplains.

Amino-acid Geochronology – A relative-dating method based on time- and temperature-dependent changes in particular amino-acids recovered from proteinaceous residues, especially those found in fossil molluscan shells. After death of the organism L-amino-acids convert to D-amino-acids until a 50:50 mixture obtains. D/L ratios range between 0 and 1 and appear to fall into groups or zones. A large number of ratio determinations have now been calibrated by other methods and this has allowed establishment of a geochronology for up to at least one million years.

Boulder-Clay – A redundant term for **Till** (many till deposits are boulder-free).

Catchment – That area of a drainage basin producing **Run-Off**.

Chalk – Marine limestone rock of Upper Cretaceous age (95 to 65 million years before present).

Clast – Fragment of rock.

Diamicton – Deposit with clasts in a finer matrix ('two-fold mix').

Dip-Slope – A land surface declining in accord with the dip (inclination) of the underlying rocks.

Drift – An archaic but useful term for superficial deposits overlying solid rock. It survives from the 19th Century when **Glacial** and **Glaci-Fluvial** materials were believed to have been produced, or drifted, by a universal flood.

'Drift-Residual' Soil – Surface material usually less than 75cm thick that constitutes the modern soil and which has been derived mainly from **Till** that has been weathered and denuded. It retains characteristic till **Erratics**.

Erratic – A rock fragment transported by a glacier from its original location.

Geomorphology – Pertaining to land form, ie. the shape of the ground. The study of landforms and the processes that produce them.

Glacial – Pertaining to a glacier or icesheet.

Glaci-Fluvial – Pertaining to glacial meltwater.

Ice-Contact or **Ice-Marginal Deposits** – Glaci-fluvial and glacial materials accumulated adjacent to or over an ice margin. Subsequent movement or melting of the ice may cause disturbance such as faulting and folding.

Ice-wedge Cast – The infill or cast of a former downward-tapering, wedge-like mass of ice that developed in a contraction crack in permanently-frozen ground under **Periglacial** conditions. Wedges grow through repetitive cracking and filling with meltwater and sediment. When climate improves the melting ice is replaced by more sediment which preserves the shape and extent of the feature.

Interfluve – High ground separating two valleys and forming a watershed or divide.

Kettle-hole – An enclosed depression within an area of **Glacial** or **Glaci-Fluvial** deposits resulting from the subsequent meltout of an included mass of ice.

Last Glacial Maximum – The limit of Late Devensian glaciation.

Lower Cretaceous Rocks – In Lincolnshire, a series of marine sandstones, clays and limestones deposited before accumulation of the Chalk.

Meltwater Channel – A valley, usually open-ended, cut by meltwaters draining from a glacially-impounded lake, along an ice front or beneath the ice.

MIS (Marine Oxygen Isotope Stage) – A global glacial or interglacial oscillation inferred from variations in $^{18}O/^{16}O$ ratios determined in carbonates from marine microfossils.

Moraine – A ridge or mound of debris laid down directly by a glacier or pushed up by it. Materials may include till, gravels, sands and silts, with erratics.

Outwash – Sorted silts, sands and gravels transported, distributed and deposited by streams of meltwater. **Train** – outwash deposits along a narrowly-defined tract.

Periglacial – Literally, around a glacier, but now applied to areas that can be far from a glacier but experiencing severe climatic conditions, or to the conditions themselves. Conditions may involve permanently-frozen ground, and are characterized by intense frost action and by nival (snow-related), aeolian, and strongly-seasonal fluvial processes.

Petrography – The description and classification of rocks, especially by thin-section microscopy and hand specimens.

Pleistocene – The geological period comprising the bulk of **Quaternary** time. The Holocene constitutes the last 10,000 years.

Quaternary – the fourth geological Era, comprising the last 2,500,000 years.

Radio-Carbon Dating – Radio-active 14Carbon is present in the environment and becomes part of all living organisms. On death it begins to decay at a known rate (half-life of c.5,730 years). Determination of the amount of 14C remaining in fossil material gives a measure of time since death, and provides reasonably reliable dates back for about 40,000 years. Uncalibrated dates assume that environmental 14C production has been constant over time, but comparison with tree-ring data has revealed some variability. 14C dates are now adjusted by a factor derived from cross-matching with a large amount of data provided by other techniques. The calibrated age is older than the uncalibrated because a 'radio-carbon year' is somewhat shorter than a 'calendar year'.

Rhythmites – Banded sediments resulting from repetitive cyclic conditions of deposition, not necessarily annual.

RIGS – Regionally Important Geological Site.

Run-Off – The water output of a drainage basin.

Stratigraphy – Pertaining to the composition, spatial distribution and correlation of layered rocks, and their sequence of deposition.

Subaerial – open to the sky.

Sub-Aqueous Fan – A splayed deposit of sand and gravel built out beneath the surface of standing water by a stream flowing from a glacier or off adjacent land.

Sub-Marginal – Beneath the edge of an icesheet or glacier.

Surge – A short-lived phase of accelerated glacier or icesheet flow.

Terrace – A bench-like, mostly valley-side, landform fronted by a steeper slope produced by erosion and dissection of a spread of superficial deposits such as till, fluvial and glaci-fluvial sands and gravels, and periglacial materials.

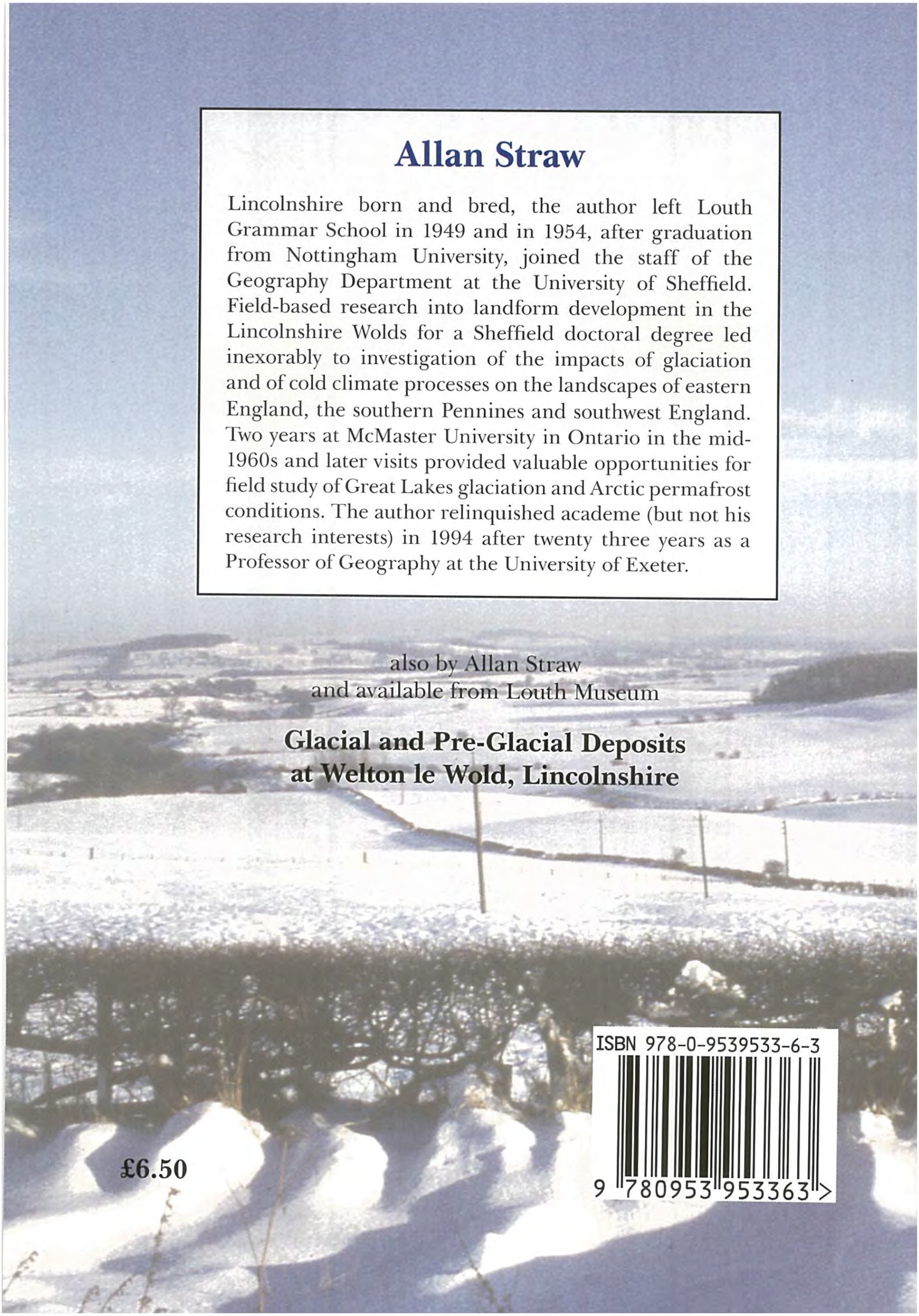
Thalweg – The long profile of a valley floor.

Thermoluminescence Dating – A radio-metric dating technique depending on the circumstance that sediments are continually subject to bombardment by radio-active particles from materials such as uranium, thorium and potassium, and to accumulation of metastable electrons. Trapped electrons are released from sediments by warming, eg. by sunshine on a land surface. On burial however, 'zeroed' sediments begin to accumulate such electrons. A sample, especially of quartz grains, will on heating emit light proportional to the quantity of trapped electrons. Measurement of the intensity of emitted light can provide an estimate of time since burial.

Till – Normally unstratified material deposited directly by glacier ice.

'25-Foot Drift' – Silts and sands deposited in Lake Humber during its 9m stage, and extending widely over the southern Vale of York and Humberhead area.

Varves – annual, usually cold climate, **Rhythmites** deposited in standing water. Each layer is coarser near the base (spring melt) fining upwards with settlement of suspended material.



Allan Straw

Lincolnshire born and bred, the author left Louth Grammar School in 1949 and in 1954, after graduation from Nottingham University, joined the staff of the Geography Department at the University of Sheffield. Field-based research into landform development in the Lincolnshire Wolds for a Sheffield doctoral degree led inexorably to investigation of the impacts of glaciation and of cold climate processes on the landscapes of eastern England, the southern Pennines and southwest England. Two years at McMaster University in Ontario in the mid-1960s and later visits provided valuable opportunities for field study of Great Lakes glaciation and Arctic permafrost conditions. The author relinquished academe (but not his research interests) in 1994 after twenty three years as a Professor of Geography at the University of Exeter.

also by Allan Straw
and available from Louth Museum

Glacial and Pre-Glacial Deposits at Welton le Wold, Lincolnshire

ISBN 978-0-9539533-6-3

£6.50