Main Late Devensian glaciation of north-east England

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> **From: Stone, P, Millward, D, Young, B, Merritt, J W, Clarke, S M, McCormac, M and Lawrence, D J D. 2010. British regional geology: Northern England. Fifth edition. Keyworth, Nottingham: British Geological Survey.**

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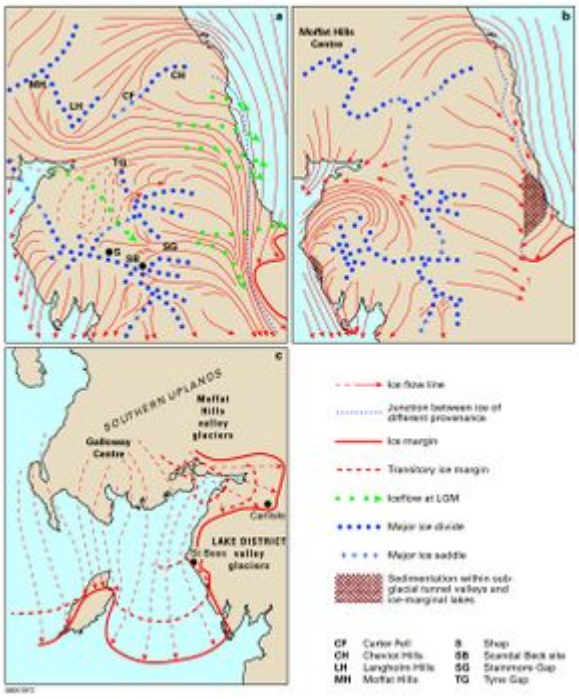
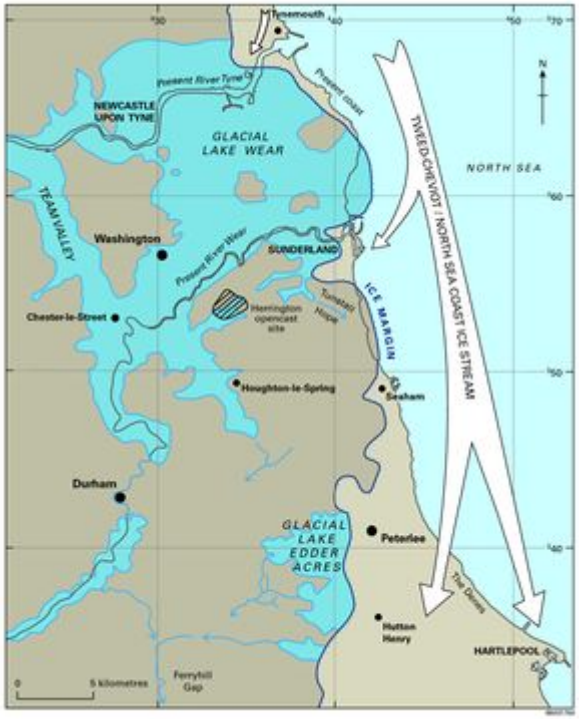


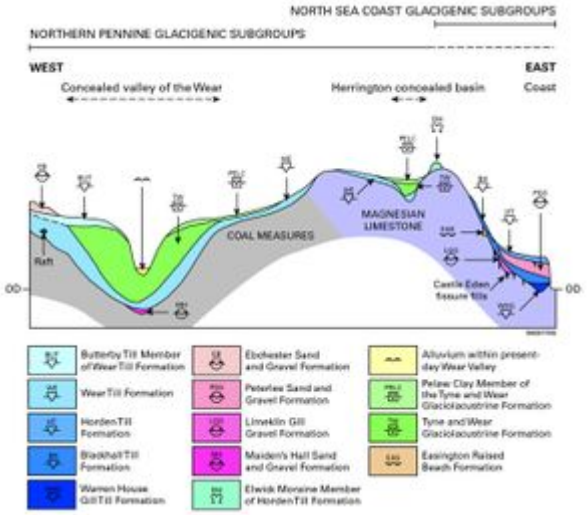
Speculative reconstructions of the last ice sheet. a At about the Last Glacial Maximum (LGM): 28–22 ka BP, but when Scottish ice had ceased flowing across Stainmore, and Scandinavian ice had advanced into the central North Sea Basin, forcing ice from the Pennines and Tweed Basin to flow into

the Vale of York. b Following a major glacial reorganisation involving ‘drawdown’ and ‘headward scavenging’ of the Irish Sea ice stream into the Solway lowlands and Vale of Eden. Exact timing and correlation of events is unknown, but North Sea ice pushed farther into the Teesside lowlands once ice from the Lake District ceased flowing across Stainmore. Subglacial glaciofluvial deposition probably occurred within tunnel valleys in the Durham lowlands prior to the creation of Glacial Lake Wear. c Scottish ice advances into the Solway lowlands following retreat of ice sourced in the Lake District. Multiple readvances affect the Isle of Man and the west Cumbrian coast. P916098.

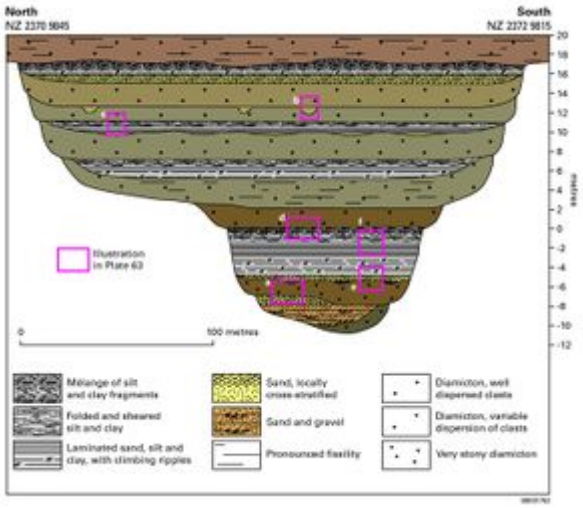
Distribution of glacigenic subgroups. The geographical boundaries are approximate, but will be refined as knowledge of the distribution of defining formations of till is improved. P916096.



Speculative reconstruction of Glacial Lake Wear and associated ice-marginal lakes. Note: North Sea ice probably extended farther inland during an earlier phase when extensive subglacial glaciofluvial and glaciolacustrine sedimentation occurred within tunnel valleys. P916103.



Schematic transect to the south of Sunderland showing lithostratigraphical relationships. P916104.



Transect across a concealed channel at Maiden's Hall opencast site. P916105.

Sediments infilling a concealed channel at Maiden's Hall opencast site (see Figure 75): a Deformation till with bevelled and striated boulders overlying cross-bedded pebbly sand. (P543552); b Truncated gravel-filled channel. (P543560); c Laminated silt, clay and very fine-grained sand with soft sediment deformation structures. (P543550); d Laminated silty clay passing up into a melange of ripped-up silt and clay, capped by deformation till. (P543555); e Cross-bedded pebbly sand with northerly palaeocurrent resting on deformation till. (P543554); f Fine-grained sand with climbing ripple-drift cross-lamination, increasingly folded and sheared upwards. (P543549).

At the LGM, north-eastern England was mainly a receiving area for ice, inundated by powerful streams that flowed eastwards across the Pennines via the Tyne and Stainmore gaps. The Tyne stream flowed towards the coast south of Blyth, whereas the Stainmore stream occupied the Teesside lowlands and possibly branched southwards into the Vale of York (P916098)a. An ice cap on Cross Fell fed eastwards down the upper dales of the Wear and Tees, where till was deposited mainly within the valleys. Another, larger and independent ice cap was positioned over Carter Fell and the Cheviot Hills, where it was almost encircled by a combination of ice flowing from the south-west and a substantial ice stream flowing from the north-west through the Tweed Basin. Blocky periglacial deposits and decomposed bedrock are particularly common within the Cheviot Hills,

where there has been relatively little glacial erosion.

As discussed above, a major, undated glacial readjustment occurred within the Vale of Eden, probably following the LGM, eventually leading to a complete reversal of flow. An immediate consequence of this reversal would have been a weakening of the eastward flow of ice through the Tyne Gap and Stainmore. The Tweed ice stream, together with ice from central Scotland, was deflected south-eastwards, parallel to the coast of northern England. Augmented by ice sourced in the Cheviot Hills, it became a powerful 'North Sea ice stream' that constrained ice flowing from the Pennines, deflecting it south-eastwards, possibly partially into the Vale of York (P916098)b. The most likely reason for the deflection is that Scandinavian ice occupied the North Sea Basin. The 'North Sea ice stream' laid down the distinctive suite of deposits assigned to the North Sea Coast Glacigenic Subgroup and found along the coast as far south as Norfolk (P916096).

The traditional view is that there followed a substantial retreat of 'Pennine' ice and possibly a contraction of the North Sea ice stream too, but the latter remained immediately offshore, obstructing drainage. As the two bodies of ice decoupled and separated northwards, large ice-marginal lakes occupied the Durham lowlands, particularly in the valleys of the rivers Tyne and Wear, west of the escarpment formed by Permian (Zechstein Group) carbonate rocks. The largest was 'Glacial Lake Wear', which stood at several levels (132, 90 and 43 m OD) governed by the elevations of spillways that became available sequentially, including the Ferryhill Gap (NZ 300 330). Another, Glacial Lake Edderacres, lay in the vicinity of Peterlee. A very substantial volume of laminated sand, silt and clay (formerly known as the 'Middle Sands') was deposited within these bodies of water (P916103).

There is very good evidence, including glacially deformed glaciolacustrine deposits and the widespread occurrence of an 'upper' till towards the coast, that the North Sea ice stream encroached inland during a late-stage readvance. The western limit of this readvance is represented by a belt of morainic deposits strewn with kettleholes lying to the east of Castle Eden (Elwick Moraine Member). There is some evidence for a contemporaneous advance of Pennine ice into the lakes, which suggests that the event was climatically driven rather than simply involving a surge of the potentially unstable North Sea ice stream, but although the sequence of events is generally agreed, the chronology is not yet known.

Tills laid down by Pennine ice (North Pennines Glacigenic Subgroup) are generally dark brown to grey, very compact and stony. They form a gently undulating, 5 to 10 m thick sheet across much of lowland Northumberland and Durham, but within the Tyne Gap, Weardale and Teesdale they are strongly drumlinised and more variable in thickness. The till sheet thins and becomes more patchy across interfluves, thickening locally in the lee of bedrock highs and into concealed valleys, where thicknesses locally exceed 80 m. Erratics of a variety of rock types are common in the till sheet with some, better described as glacial rafts, large enough to have been quarried.

The tills have been named only where it is possible to distinguish more than one unit separated by glaciolacustrine or glaciofluvial deposits of the former 'Middle Sands'. This so-called 'tripartite sequence' is mostly restricted to the Durham lowlands, where the Wear Till Formation (formerly the Durham Lower Boulder Clay) generally lies directly on rockhead, and is the thickest, most laterally extensive, stony and consolidated of the till units (P916104). Its erratics include: andesite, tuff and granite from the Lake District; wacke and granodiorite from southern Scotland; red sandstones probably of both Triassic and Devonian age and from a variety of sources. The upper of the two tills, the Butterby Till Member (formerly the Upper Stony Clays in part), contains a similar suite of clasts to the Wear Till, but is less compact and stony. It is generally thin and patchy, but up to 15 m thick locally. It is widely believed to have formed either as cohesive debris flows from ice margins or as solifluxion flows from surrounding deglaciated slopes. However, its wide extent, relatively consistent

thickness and the dispersion of its clasts suggest that it formed subglacially as a deformation till, possibly during a glacial readvance.

The Butterby Till is difficult to distinguish from, and locally passes laterally into, the enigmatic Pelaw Clay. This widespread, surficial unit of reddish brown silty clay contains well-dispersed stones and commonly small calcareous concretions towards the base of the weathering zone. It occurs up to an elevation of about 132 m OD, is generally 0.5 to 2 m thick, though locally up to 9 m, and includes contorted beds of sand. It generally rests on fine-grained glaciolacustrine deposits and is widely believed to have formed by periglacial processes and mass flowage following the draining of the ice marginal lakes.

The predominantly glaciolacustrine deposits sandwiched between the aforementioned tills in the Durham lowlands form the Tyne and Wear Glaciolacustrine Formation (formerly known as the Durham and/or Tyne-Wear complex) which is locally up to 60 m thick. This complex sequence was deposited in Glacial Lake Wear and associated lakes; it tends to fine upwards and southwards, but with fine-grained units successively overlapping coarser ones northwards. Thinly laminated, greyish brown to brownish grey silty clay and micaceous silt predominate with subordinate units of fine-grained sand, gravel and diamicton formed of pebbly sandy clay. Complex interdigitation of units is common, especially towards the coast. Dropstones are common and crustacean traces have been noted in laminated silt in the former Herrington opencast coal site (P916103).

Tills and related deposits laid down by the North Sea ice stream (North Sea Coast Glacigenic Subgroup) crop out up to about 15 km inland of the coast. As seen farther inland, two widespread till units may be distinguished where glaciofluvial or glaciolacustrine deposits intervene, commonly within concealed valleys. In addition, cliff sections along the Durham coast and inland in incised stream valleys (denes) reveal isolated hollows in the carbonate rocks of the Zechstein Group that are filled with cemented gravel and sand beneath the lower of the two tills. These ‘Lower Gravels’ (Limekiln Gill Gravel Formation) typically contain a high (50–60 per cent) proportion of locally derived limestone pebbles and a varied suite of far-travelled clasts including Carboniferous lithologies, andesite, granite, gneiss, schist, flint, quartz, quartzite and dolerite, together with unabraded shell fragments. The age of the gravels is unknown and their genesis unclear. They are almost certainly younger than the Castle Eden Fissure Fills (though they occur in the same general area) and contain a similar suite of pebbles to the overlying till, suggesting that they formed as glaciofluvial outwash in front of the advancing ice sheet. If so, the supposed presence of pristine shell fragments is puzzling.

The lower till of the coastal sequence generally lies directly on rockhead, and is the thickest, most laterally extensive, stony and consolidated of the till units in the North Sea Coast Glacigenic Subgroup. It is generally dark grey to greyish brown, locally reddish brown and up to 15 m thick. It contains clasts mostly of Carboniferous lithologies in Northumberland, with far-travelled rocks from the Southern Uplands and, south of Blyth, additionally from the Lake District; local Permian lithologies predominate south of the Tyne. Along the coast of Durham it is named the Blackhall Till Formation and is overlain extensively by sandy, glaciofluvial and glaciolacustrine deposits of the Peterlee Sand and Gravel Formation (formerly part of the ‘Middle Sands’). The Peterlee Formation commonly coarsens upwards to gravel from red fine-grained sand, silt and clay, but within buried valleys may locally comprise up to 30 m of laminated clay. The cross-bedded Ryhope Sand Member of the formation formed at an early stage when Glacial Lake Wear drained eastwards, subglacially, towards the coast north of Seaham. The Blackhall and Peterlee formations are overlain by the Horden Till Formation (formerly known as the Durham Upper Boulder Clay), which is typically a weathered, brown or reddish brown stony clay containing a relatively higher proportion of clasts from upper parts of the Zechstein Group than is seen in the lower till; it also contains clasts of volcanic rock from the Cheviot Hills.

The youngest widespread till-like deposit in the coastal lowlands is the Prismatic Clay, which derives its name from closely spaced, subvertical, prismatic jointing that probably formed in dry periglacial conditions. It is generally less than 1 m thick, dull brown, and differs from the more widespread Pelaw Clay in being more sandy and containing smaller pebbles. The Prismatic Clay apparently overlies ice wedge casts in the Ryhope Sands and so is probably of periglacial origin. A similar red or reddish brown deposit caps the Teesside Clay Formation, which is widespread beneath the Teesside lowlands up to about 92 m OD. Varves in the laminated Teesside Clay have been tentatively matched with the late glacial Greenland ice-core record, and dated very approximately by thermoluminescence to between 18.0 and 18.5 ka BP.

The fine-grained deposits of the Tyne and Wear Glaciolacustrine Formation commonly occur within buried, concealed valleys that cannot be delineated easily at the surface. These features occur beneath the coastal lowlands, where ice flowed south-eastwards across preexisting valleys such as the lower reaches of the Tyne and Wear, and they are particularly common to the south of Durham. Most are palaeovalleys cut by drainage flowing directly towards the North Sea before at least the last glaciation. Others, such as beneath the Team Valley, were carved out by ice across the grain of the country. Some concealed channels have been graded to a base level below -30 m OD during periods of low sea level, but others have humped longitudinal profiles and clearly formed subglacially.

Although the locations of many concealed valleys are known from borehole records, it is rarely possible to examine closely the sequences filling them, which are generally complex and difficult to understand. A rare example was revealed in 1999 during excavation of the Maiden's Hall opencast coal site, 13 km north-north-east of Morpeth. There, an approximately 30 m deep, east–west orientated linear depression cut into bedrock is concealed beneath till of the North Sea Coast Glacigenic Subgroup (P916105) and (P543549). A basal unit of weathered, shelly till of possible pre-Devensian age is confined to pockets at the base of the incision, which are overlain by iron-stained gravel deposited in a braided river environment. The overlying succession includes seven or more distinct cyclic sequences made up of units of laminated silt and clay, sand, gravel and diamicton, many of the latter containing well-dispersed clasts typical of deformation till. A small, truncated, gravel-filled channel preserved beneath one of the diamictons toward the top of the sequence was almost certainly formed by subglacial drainage. The uppermost till unit oversteps the entire succession within the depression to rest on bedrock at its margin. The rhythmic sequence was probably formed entirely subglacially as a result of seven or more surge events of the North Sea ice stream across a 'tunnel valley', although readvances of ice across an ice-marginal lake confined within the channel cannot be ruled out.

Most elements of the Maiden's Hall sequence may be seen in cliff sections at Sandy Bay, Whitley Bay and Whitburn Bay, and it is likely that much of the Tyne and Wear Glaciolacustrine Formation was laid down within tunnel valleys before the overlying ice thinned and broke up to form ice marginal lakes such as Glacial Lake Wear. This would help explain the absence of totally convincing evidence for the extent of the lakes shown in (P916103), such as widespread shorelines and deltas, and the presence of extensive concealed glaciolacustrine deposits that occur towards the Ferryhill Gap and southwards towards Middlesbrough and Darlington.

Following the creation of Glacial Lake Wear and associated lakes, the Pennine ice shrank into separate glaciers that retreated up the major valleys leaving proglacial trains of outwash sand and gravel and moraine, much of which was subsequently reworked into terraces by meltwater. Substantial deposits occur within the South Tyne valley up to Haltwhistle, and westwards into the Tyne Gap col at Gilsland. In Northumberland, meltwaters were concentrated a few kilometres inland from the coast along the former suture zone between Cheviot–Carter Fell ice and the relatively active North Sea ice stream. This resulted in a string of glaciofluvial ice-contact deposits that

probably formed sequentially northwards as the two ice masses decoupled and separated. A good example is the complex linear assemblage of features that stretches 13 km south-south-east from Spindlestone (NU 152 233); components include eskers, flat-topped open crevasse fills, and the well-known Bradford Kames. Another complex of interconnected eskers, kames and plateaux studded with kettleholes subsequently formed to the east, when ice stagnated south-east of Wooler. Further retreat led to the deglaciation of a large topographical depression between the Cheviot Hills and the Fell Sandstone cuesta in northern Northumberland. A glacial lake was impounded there, to the south of the dwindling Tweed ice stream, in which at least 22 m of laminated silts and clays were deposited, and then overlain by alluvium, to form the Millfield Plain.

Numerous glacial drainage channels occur in the area. Most were cut sequentially within ice marginal zones during deglaciation, like those previously described along the Northern Pennine escarpment. Others were cut earlier across cols when ice was less constrained by the underlying topography. Fine examples of subglacial channels with humped longitudinal profiles include the Beldon Cleugh (NY 915 505) and East Dipton (NY 962 600) channels to the south of Hexham, and the Butt Hill channel (NY 627 504) that carried water across the main Pennine watershed north-west of Alston. The Humbleton Hill channels and the Throws are two classic, anastomosing channel systems that lie 4 km west of Wooler in the eastern Cheviot Hills.

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