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The 'Lindholme Advance' and the extent of the Last Glacial Maximum in the Vale of York

Robert Friend, Paul Buckland, Mark D. Bateman and Eva Panagiotakopulu

Abstract: The limits of the glacier that occupied the southwest part of the southern Vale of York at the Last Glacial Maximum are defined in relation to recent temporary exposures at Lindholme and previous regional mapping by Geoff Gaunt. Erratic content of associated diamicts indicates sources in the Yorkshire Dales, over Stainmore and along the Permo- Triassic outcrops on the west side of the Vale of York. The advance is dated to an episode associated with a high level of pro-glacial Lake Humber within the Last Glacial Maximum. Lidar imagery suggests that the northeastern ice limit is concealed beneath later alluvium of the rivers Ouse and Trent.

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The existence of outcrops of calcareous gravels in the southern part of the Vale of York (Fig. 1), in a landscape otherwise largely of quartzose sands and gravels, was noted by Peck (1815) in the early nineteenth century. Sites were at the boundaries between Lincolnshire, Nottinghamshire and Yorkshire, at Wroot and Misson, and on the crest of the Isle of Axholme at High Burnham. Stonehouse (1839) referred to further exposures to the east at Low Melwood and across the Trent at Hardwick Hill and also noted that Lindholme, in the middle of Hatfield Moor north of Wroot, consisted of similar materials. In an early discussion of the origins of superficial deposits, Peck (1815) described the stratigraphic position of the gravels and their composition, noting that they are dominated by 'dolomite or magnesian lime-stone.' He commented that fragments of a 'slaty lime-stone' in the gravels could be matched with an outcrop that lay west of Doncaster, extending from Tickhill through Warmsworth northwards to Knottingley. Gravels with a significant component of Magnesian Limestone at Hensall, to the northwest, east of the outcrop, were identified by de Rance (1894). Surveying by the British Geological Survey mapped outcrops at Wroot and Lindholme and gravels with a major component of Magnesian Limestone northwest of Lindholme, at Tudworth, Bradholme and Thorne and north of the Hensall outcrop at Brayton (Gaunt et al., 1992; Gaunt, 1994).

Gaunt (1976) provided an interpretation of the calcareous gravel deposits as being marginal to the Last Glacial Maximum (LGM) glacier in the Vale of York which formed part of the British and Irish Ice Sheet. This margin is some 40 km further south than the limits denoted by the Escrick moraine. Gaunt noted that older deposits in the Vale, fluvio-glacial sands and gravels deriving from the south and the 'Ipswichian' (Marine Isotope Stage 5e or 7) Older River Gravels were thoroughly decalcified and so could be dismissed as a source. The variation in elevation of the deposits suggested that they related to deposition from a shortlived phase of expansion of the Vale of York glacier into proglacial Lake Humber. Gaunt also discussed the more extensive deposits of a lake with a shoreline at approximately 7.5 m OD.

Concepts of the lake and of extension of the Vale of York glacier southwards from the York-Escrick moraines have proved controversial. Whereas the lower level of Lake Humber seems generally to be agreed as of LGM age, the limestone-rich gravels marking the ice limit in a high level lake (32 m OD) have been less widely accepted. Straw (1980, 2002) suggested that the deposits belonged to an earlier glaciation, perhaps early in the Devensian. Ford et al. (2008) have also doubted existence of the glacier advance, after numerous cores in the Selby region failed to reveal a diamicton relating to an ice advance south of the Escrick moraine. Murton et al. (2009) and Murton and Murton (2012) have queried the timing of high-level Lake Humber, despite an LGM age ascribed to its shoreline deposits at Ferrybridge (Bateman et al., 2008). While the discrepancy in OSL dates between sites at Ferrybridge and Hemingbrough has been explained (Bateman et al. 2015), the details of the stratigraphy still present problems. More recently, a multistage recessional model of Lake Humber has been based on mapped benches around the Vale of York (Fairburn and Bateman, 2015).

This paper seeks to define the limits of the glacier in the southern part of the Vale of York, south of the Escrick moraine, and presents new data from a range of sites, in particular new exposures at Lindholme, South Yorkshire. The name 'Lindholme Advance' is proposed from the location of the series of new exposures which form the basis of this paper.

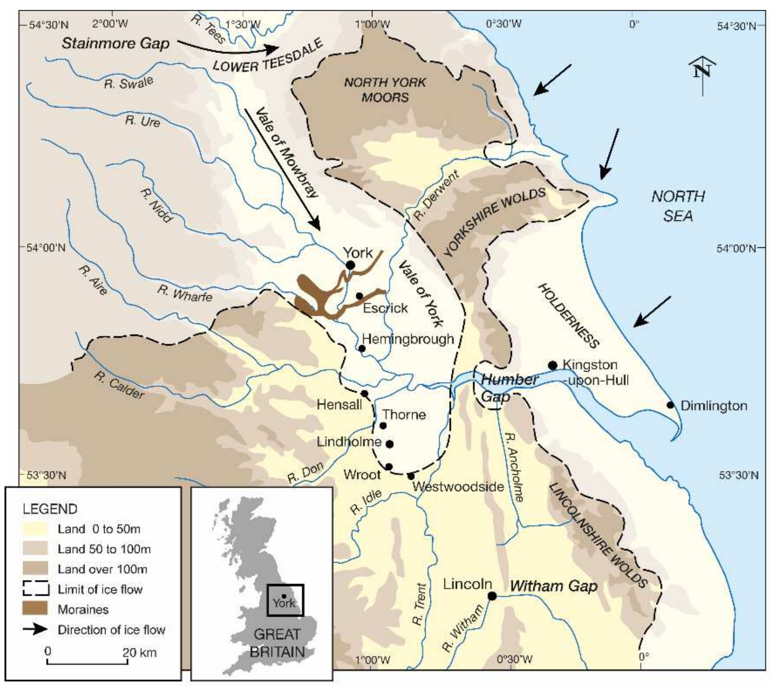

Figure 1. Regional ice limits of the Last Glacial Maximum, with ice flow directions and the York and Escrick moraines. (After Clark et al., 2004.)

Figure 2. Lindholme looking towards the northwest in 2008. The limestone rubble roads and regular plots reflect the destruction of the raised mire by peat extraction. Spoil heaps on the island are the result of topsoil stripping preparatory to an abortive attempt at gravel extraction, they have since been levelled and the site returned to grass with the exception of preserved geological sections at Sites 2, 3 and 5 on Figure 3. The island at its widest, near to the Hall, is 500m across. (Photo: Carstairs Countryside Trust.)

Lindholme

A low island of sand and gravel, 1500 m long and orientated NNW-SSE, forms Lindholme in the middle of the peatland of Hatfield Moors National Nature Reserve (Figs. 2 & 3). At a maximum height of 5.5 m O.D., it rises some 3 m above the flooded surface of the former raised mire, and forms one of a series of low ridges, partly concealed by later deposits, extending southeastwards from Snaith through Thorne and Tudworth to Wroot (Fig. 6). In 2004 the then-owner of Lindholme Hall excavated a series of test pits to ascertain the depth of gravel deposits. The pits were left open, and in 2009 the new owners of the Hall allowed geological recording of the exposures. The most easterly of the sections (Fig. 3), Site 5 shows repeated, tilted and stacked units of poorly sorted limestone-rich sands and gravels with sub-rounded to sub-angular cobbles to 40 cm to a depth of at least 3 m. These are interpreted as fluvio-glacial (Bateman et al., 2015). Sections in temporary excavations 40 and 50 m to the southwest (Site 4) provided similar, sub-horizontal sequences with poorly sorted units of cobbles and gravel in a clay matrix separated by gently cross-bedded and ripple-bedded The surface unit shows plumes of clay and cobbles intruded from below, either by dewatering or periglacial action. The coarser units are interpreted as supraglacial tills (sensu Hart, 1999), flowing from an adjacent glacier.

Some 70 m northwest of Site 5 (Fig. 3), a larger excavation provided both north-south and east-west exposures (Site 3) (fig. 5 & 6). These showed that the sediments overlie a low bedrock ridge of Permo-Triassic Sherwood Sandstone. The upper part of the section shows unsorted clast-supported gravels with sub-rounded cobbles, essentially a diamicton. Similar deposits occur 100 m to the north at Site 2, reaching a thickness of at least 2.7 m (Gaunt, 1994). Both sections show extensive disturbance by cryoturbation, and large, ventifacted sandstone cobbles litter the modern ground surface.

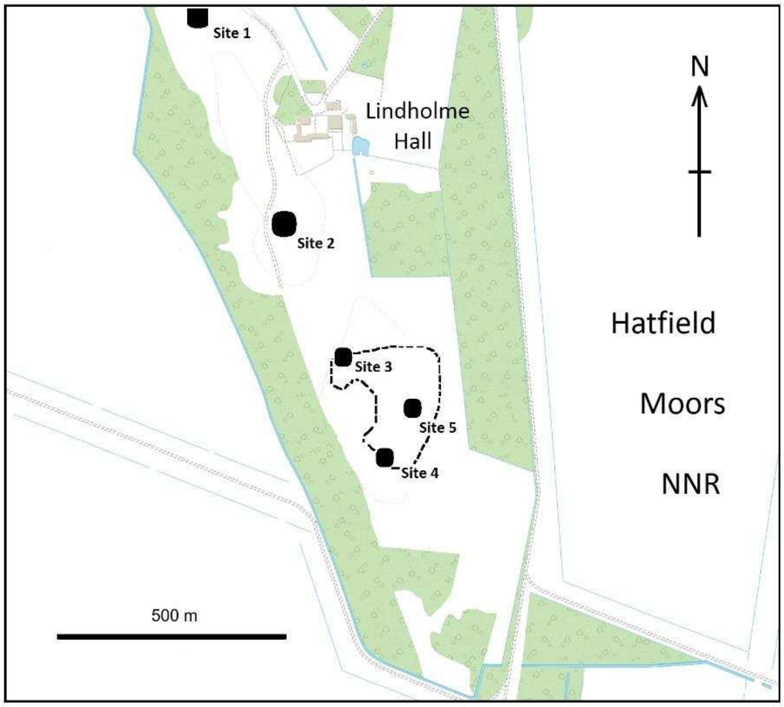

Figure 3. Locations of exposures on Lindholme. sands with scattered larger clasts (Fig. 4).

Figure 4. West section of Site 4 at Lindholme, with unsorted diamicts separated by sands with cross-bedding that dips to the south. The upper, thicker diamicton includes slabs of decalcified Magnesian Limestone, cobbles of Millstone Grit and small, round quartzite pebbles from the Sherwood Sandstone. Cryoturbation festoons in the upper sands are emphasised by the movement of iron compounds down the profile.

A small pit adjacent to Lindholme Bank Road (Site 1), a further 100 m to the northwest, now largely infilled, exposed at least a metre of similar, poorly bedded gravels. A deeper section close to that previously recorded by Gaunt (1976, 1994), Site 2, shows that the gravels rest on an irregular, erosional surface of thinbedded, orange-brown sand with occasional cobbles and pebbles intruded into it and disturbing the bedding (Fig. 7). This thin horizon, rarely more than 150 mm thick, overlies a massive, medium-grained sand, much disturbed by irregular clay-silt infilled structures, which penetrate more than a metre into the sand. These are interpreted as ice wedge casts formed in the Sherwood Sandstone rockhead, here devoid of pebbles.

Two sections were dug out at Site 3, one to expose the greater part of the drift, and the other, 15 m to the east in the floor of the pit, to examine underlying quartzrich pebbly sands that are interpreted as a remnant of the Older River Gravel (of Gaunt, 1994). The succession at Site 3 contrasts with those at other sites (Fig. 6). The basal unit consists of over 250 mm of hard-packed, ferruginous sand and gravel over which is a sequence of 0.78 m of ripple-bedded sands with occasional clay-silt units (Table 1); at 1.77 m from the top of the section an amorphous off-white layer varies between 2.5 and 5.0 mm in thickness. This unit drapes over sand ripples orientated north-south climbing to the west, and is capped by a further 40 mm of sub-horizontally bedded sand. Rare, small pebbles of limestone, quartz and flint, as well as specks of coal, occur in the sands, which are locally finely cross-bedded. A thin clay-silt horizon is overlain by further thin-bedded sands and 80 mm of thin bedded clay-silts with scattered pebbles, the upper surface of which is disturbed by an unsorted sand, cobble and gravel unit, which thins eastwards. Much of the remainder of the section is dominated by sands with traces of small-scale cross-bedding and rare stringers of small pebbles. Diamicton forms the present land surface, and is less than 300 mm thick at Site 3 but thickens northwards to more than a metre at Site 2. This unit has been extensively disturbed by cryoturbation. During fieldwork, a flint blade and an elongate flake of chert were picked up on the surface of the excavation. It is unfortunate that neither can be directly related to a stratigraphic context, since the former is likely to be Late Upper Palaeolithic. Although ploughed in the recent past, the modern ground surface has numerous ventifacted cobbles, presumably having been subjected to wind erosion during the Lateglacial episodes of Coversand deposition (Bateman, 1995; Buckland, 1982) and survival of an artefact on the surface through these episodes is unlikely. Typologically the piece should not predate the LGM (Saville, in prep.), so its context is likely to have been the upper part of the diamicton, where cryoturbation incorporated it within the sediment during the Lateglacial. Similar isolated finds are not infrequent across the region (Buckland, 1982; Harding et al., 2014).

Wroot and the Isle of Axholme

South of Lindholme, across the raised mire of Hatfield Moors and the River Torne, the village of Wroot lies on a low, sinuous, east-west ridge [SE 705033 to 716403]. Temporary exposures during house construction have shown at least 0.5 m of sands and gravels, largely derived from Triassic rocks, but Corbett (1903) also noted large boulders in the deposit. To the east, quarries at Cove Farm, Westwoodside [SE 739008] exposed a sequence of sands and gravels deposited by a proto- River Idle flowing from the southwest (Bateman et al., 2001). No diamictons were located in the 5 m sequence, which rested directly on Mercia Mudstone, although the presence of much coal, including subangular blocks to 300 mm, suggests at least partial derivation from the northwest, since the Idle catchment hardly extends into the Nottinghamshire coalfield. Northeastwards at High Burnham [SE 784012], at 30 m OD, the patch of gravels noted by Peck (1815) was also examined by Cameron (in Ussher, 1890); Gaunt (1994) observes that the deposit was reputed to be over 1.8 m thick. He also draws attention to smaller patches of gravel of similar composition to the north on Axholme, north and northeast of Epworth [SE 781051], east of Belton [SE 793059, SE 796066], and northeast of Crowle [SE 782127]. None of this material is now exposed, but the gravel composition was noted by Parsons (1878) and Cameron (op. cit.).

Tudworth and Thorne Northwest of Lindholme, the farm of Tudworth stands on a low ridge, cut through at its southern end by the M180 motorway [SE 688108]. Unfortunately, the sections exposed during construction were not available for record, but cross-bedded Permian limestone-rich gravels were noted during archaeological survey.

Figure 5. Site 3 at Lindholme, looking to the northwest. The findspot of the flint artefact is arrowed.

Gaunt (1994) records similar deposits to a depth of 5.2 m in a pit [SE 693100], now infilled, south of the motorway. In 2009, a cored NE–SW transect across the Tudworth ridge, from the edge of the former course of the River Don [SE 691108] to the motorway boundary fence [SE 68951076] showed a skim of quartz-pebble-rich sands over sands, presumed to be the weathered top of the Sherwood Sandstone; it is apparent that the gravels are banked against a bedrock ridge. A further pit, west of the A18 [SE 685106], appears to be in Older River Gravel over Sherwood Sandstone.

Northwards, there is no exposure on the ridge at Bradholme [SE 691115], but temporary sections in Thorne, during the underpinning of St. Nicholas' Church [SE 690133], exposed similar cross-bedded limestone-rich gravels. Gaunt (1994) recorded 1.8m of these sediments at Thorne South [SE 691324] and also noted a small outcrop on the southern edge of Thorne Moors [SE 727134]. Boreholes further to the east, sunk as part an archaeological (but not geological) evaluation before the erection of wind turbines in 2008 [SE 714127] revealed no similar deposits.

Clast Analysis

The composition of the Lindholme island deposits has been known since the early nineteenth century (Peck, 1815; Gaunt, 1976, 1994). Sandstones and gritstone, with some siltstones and ganisters, largely as rounded to sub-rounded cobbles, dominate assemblages (Bateman et al., 2015). Although they lack diagnostic fossils, the arkose from the Millstone Grit is distinctive and all sandstones probably derive from the Carboniferous Pennine outcrops northeast of the Vale of York. Two rounded blocks of Millstone Grit, weighing nearly a tonne each, lie close to Lindholme Hall (Harmer, 1928), along with a smaller erratic which may be a Lower Palaeozoic quartzite. Rounded to angular cobbles of limestones from the Lower Carboniferous, including fossiliferous, some silicified, angular blocks with crinoids (Fig. 4) and chert are common. Upper Permian Magnesian Limestone from the Cadeby Formation, rarely with the diagnostic bivalve fossil, Schizodus, dominate suites at some exposures. Relatively soft, angular platy blocks of the latter also occur, along with poorly coherent pieces of Sherwood Sandstone. Small, often partly decalcified pebbles of Magnesian Limestone may also be present within sand units (Fig. 6).

The matrix of the sands derives largely from the Permo-Triassic sandstone, and millet-seed grains are common. Metaquartzite and other metamorphics occur as well rounded pebbles, reworked from the Sherwood Sandstone to the south, and small grains of coal are scattered throughout the deposits. Rare tuffs and igneous rocks probably originate in the Lower Palaeozoic outcrops of the Lake District. Flint is a common component of the gravels. Corbett (1903) notes 'granite' from Wroot, and Gaunt (1976) adds Permian Brockram (from the Vale of Eden) and Jurassic oolite.

Chronology

An OSL date of 18.7 ± 0.63 ka (average of Shfd10071 and Shfd10072) has been obtained for the lowest exposed unit at Site 5 (Bateman et al., 2015). Two additional samples were collected. One from the sand unit found between the two cryoturbated units at Site 2 (Shfd10047). The second from beneath the sand and gravel and above the clay-silt ripples found at Site 3 (Shfd10049). Replicates for sample Shfd10047 showed good reproducibility and low overdispersion (OD) (20%) so the age is based on the mean of the replicate data and is thought to represent a true burial age of 90.6 ± 4.7 ka. Replicates for sample Shfd10049 show much lower reproducibility, are skewed and have a high OD (32%), which is indicative of a partially reset sample. To extract the lowest and best reset measurements the lowest component as determined by the Finite Mixture Model was used as the basis to calculate the age (Roberts et al., 2000; Table 1). Given the OSL data, the age for site 3 of 60.7 ± 4.2 ka may still represent an over-estimate due to partial resetting prior to burial.

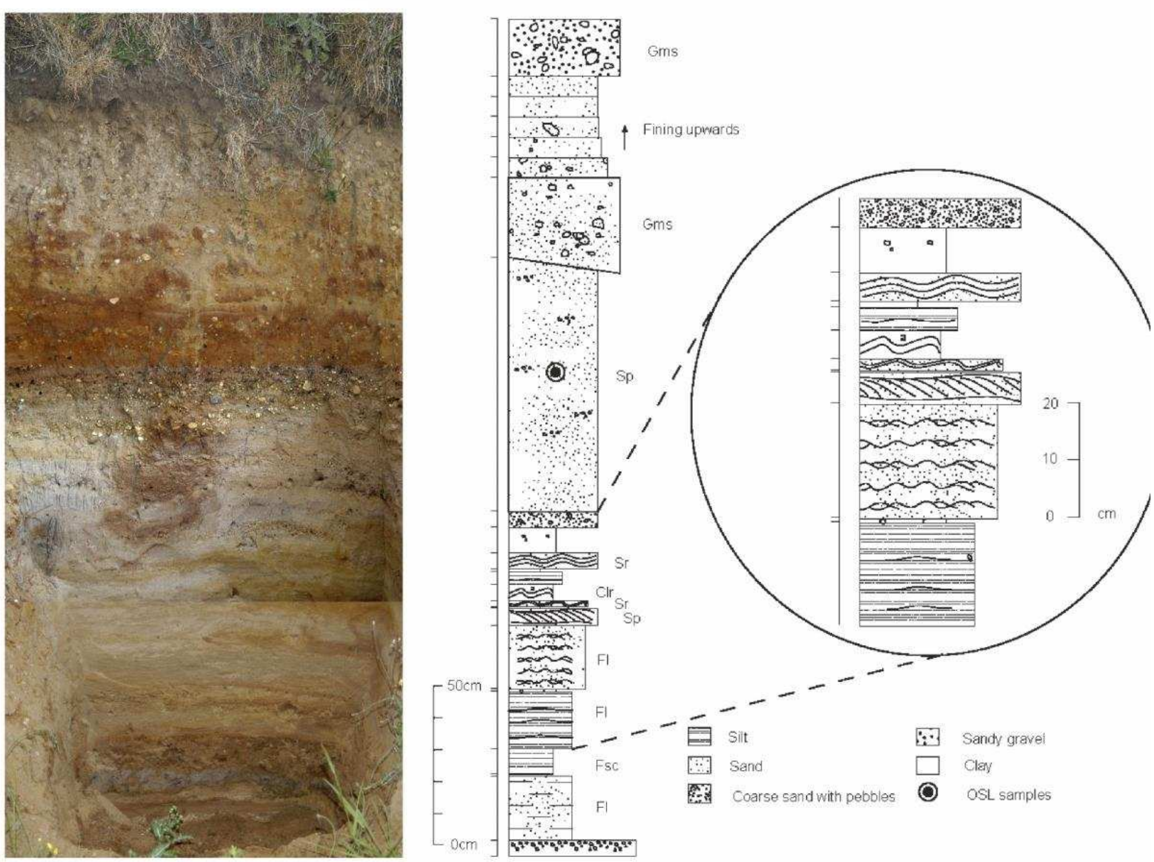

Figure 6. Exposed section and sedimentary log at Site 3 at Lindholme.

Extent of the ice advance

Similar gravels, all topographically high in the landscape, from a range of sites spread across a wide area requires explanation. There are four lines of sound evidence for deposition by a Lindholme advance of the Vale of York glacier, rather than a fluvial origin:

 # 1. It is clear that many of the clasts must have come from the northwest Pennines and Yorkshire Dales, which is counter to the current drainage in the southern end of the Vale of York, which is from the south via the Idle and Trent rivers. The erratic assemblages clearly indicate that sources lie across Stainmore, and were transported by a glacier advancing over Permo-Triassic rocks down the western side of the Vales of Mowbray and York, and extending at times as far as Wroot.

 # 2. Clasts of soft material, including angular blocks of Permo-Triassic rocks (Fig. 4), preclude far-travelled fluvial deposition, but are compatible with transport on or in glacier ice.

 # 3. The spread of gravel sites, and their elevations, would have required deposition by multiple rivers or a large, braided river at a time of higher base level, followed by significant erosion that left only remnants. There is no evidence of such fluvial activity elsewhere in the region, and low sea-levels induced lower river base levels during glacial episodes.

 # 4. Ages of sediments from sites 2 and 3 are within the Last Glacial. The age of the Lindholme gravels at site 5 falls within a time-window in which the eastern parts of the British Irish Ice Sheet is known to have been advancing (Bateman et al., 2015). Although without further excavation to provide a direct stratigraphic linkage with Site 5, previously dated to 18.2 ± 2.1 ka (Bateman et al. 2015), the new dating evidence precludes attribution (Straw, 1980, 2002) of the deposits mapped by Gaunt (1976b, 1994) from Brayton southwards to Wroot and High Burnham to an earlier glaciation. Whereas the age determination of 60.7 ± 4.2 ka provides an earliest date for the sands and diamicton at Site 3, the date of 90.4 ± 4.7 ka relates to a heavily cryoturbated surface beneath the diamicton at Site 2. All lie firmly within the Devensian.

The evidence supports the clasts being transported in or on part of the Vale of York glacier, followed by deposition marginal to the ice. This does not, however, explain the full erratic suite. A significant component of the clasts is of southern and eastern origin, from the Sherwood Sandstone outcrop where quartzite pebbles are both more frequent and larger, or from the east from Upper Cretaceous flint. This can be accounted for by the northward movement of material from previous glaciation(s) in the Older River Gravel and the fluvio glacial sands and gravels of the Rossington-Doncaster ridge (Gaunt, 1994; Gaunt et al., 2006). These earlier deposits are extensively decalcified and the Cretaceous is only represented by small, deeply patinated flint. Jurassic rocks are rare, as small pebbles of oolite. Sources for this minor component in pre-Devensian Quaternary deposits to the south may be more relevant than more direct pathways from outcrops to the northeast.

sample	stratigraphy	depth (m)	water (%)	total dose rate (Gy/ka)	N	D_e (Gy)	OD (%)	**age (ka)**
Shfd10047	Sand unit, between cryoturbated units at Site 2	1.50	20 ± 5	1.654 ± 0.083	17	149 ± 5.9	20	**90.6 ± 5.8**
Shfd10049	Sand unit, between silty/clay ripples and sands and gravels at Site 3	1.85	20 ± 5	1.646 ± 0.083	19	99.8 ± 4.7	32	**60.7 ± 4.2**

Table 1. OSL (Optically Stimulated Luminescence) age determinations for samples from Lindholme. N = number of measurements; De = measured palaeodose; OD = overdispersion of De data.

Figure 7. Site 2 at Lindholme, looking northwest. Below the spade level, dark red Sherwood Sandstone, is much penetrated by frost structures. This is overlain by a lighter red, unconsolidated sand, followed by up to 2 m of diamicton with pebbles of Permian limestone and Carboniferous sandstone.

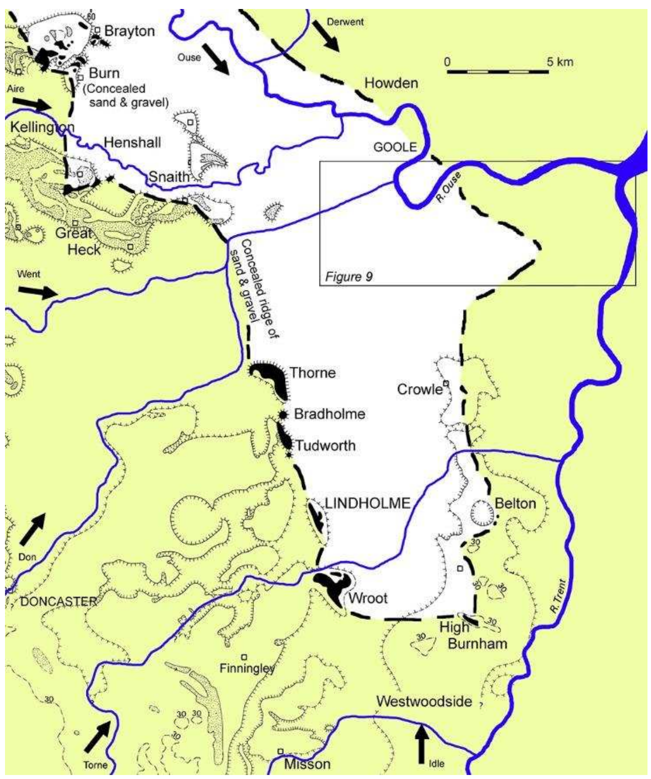

Figure 8. Limits of the Lindholme advance of the Vale of York glacier.

By accepting the Lindholme advance an explanation of the apparent absences of diamict in BGS cores is necessary. Establishing an ice limit line is challenging as the advance was potentially short-lived, and the limits are primarily constrained by outwash gravels that have been subjected to later re-working. There are also gaps where the Lateglacial and Holocene river systems have obscured or removed sections and topographic features have been created by coversands.

For the IGS map of glacial deposits in Britain, Gaunt (1976) defined an ice limit in the Vale of York that linked outcrops from Brayton and Gateforth southwards through Hensall, Thorne, Lindholme to Wroot and High Burnham. Perhaps influenced by older records of limestone in gravels at Low Melwood [SE 804019] and Hardwick Hill on Scotton Common, east of the Trent [SK 838997] (Stonehouse, 1839), he extended the limit eastwards to the base of the Jurassic escarpment and northwards to cross the Humber at Alkborough, continuing along the eastern side of the Vale of York (Fig. 6). Based on previously published sources, Clark et al. (2004) are more circumspect about limits in the north, though they extend the southern margin across the Trent. Current exposures at Low Melwood show no drift cover over the Mercia Mudstones, and any outcrop at Hardwick Hill (Gaunt et al., 1992; Gaunt, 1994) is obscured by forestry.

A more parsimonious ice limit, would restrict the Lindholme advance to a lobe on the west side of the Isle of Axholme encompassing the limited gravel outcrops mapped north of Epworth and east of Crowle (Gaunt, 1994, Fig. 43). The western and southern limits are well defined, and a line is suggested along the west side of the Isle of Axholme, joining small patches of similar deposits from High Burnham to north of Crowle. Further north, any surface expression is obscured by modern alluvium, but LiDAR imagery reveals a buried feature, probably the low levees of a channel draining westwards to the Ouse between Swinefleet and Goole (Fig. 9), contrary to other drainage in the region. This may reflect short-lived flow off the backslope of a moraine, which appears to turn northwestwards, before being breached and obscured by deposits on the floodplains of the Ouse. Gaunt (1994) mapped sand outcrops between Hemingbrough and Howden as levees of a former course of the Ouse, but it is probable that the northeastern edge of the glacier is partly encapsulated within these ridges. Obstruction by a low moraine north of Barmby-on-the-Marsh would also explain the aberrant course of the former Derwent; before its medieval or earlier diversion (Gaunt, 2012), this turned southeastwards to join the Ouse southeast of Howden. The eastern boundary of the Lindholme advance northwards from Hemingbrough to the Escrick moraine remains uncertain.

Figure 9. LiDAR image of the palaeo-drainage features used to constrain the eastern limit for the Lindholme advance south of the River Ouse. Higher ground is darker green in the false colour. The southern part of the dashed yellow line follows the crest of a slight rise north of the former course of the river Don; it then turns northeast along a break in slope, between former drainage eastwards to the Trent Ouse confluence and anomalous westward flow, putatively off the backslope of a low moraine. (Image: Environment Agency, and T. Prosser.)

This much less extensive ice lobe would be about 13 km across between Thorne and Swinefleet and be restricted wholly to the west side of the Vale of York, extending the line of Bateman et al. (2015) northwestwards. Although this revised limit explains both the erratic content and Ford et al.'s (2008) difficulty in finding the Lindholme advance in the Selby area to the east, there remain problems in interpreting the stratigraphy in relation to the deposits of Lake Humber (cf Fairburn, 2014; Fairburn & Bateman, 2015). The relationship between the lake and ice advance remains uncertain. Only one section, at Lindholme Site 3, has a laminated clay-silt deposit; however, this unit, only up to 100 mm thick and beneath a thin diamicton (Fig. 4), lies within shallow-water crossbedded units with an erratic content indicating that the ice front was nearby. Thin carbonate draped over ripples, was probably a result of rapid warming of a superficial pool (cf Chutko & Lamoureux, 2009), reinforcing the view of shallow, ephemeral pools rather than a lake along the ice front. Similar deposits continue until they are over-ridden by the diamicton that forms the current ground surface and is correlated with deposits exposed at the top of pits 1 and 2.

The heavily cryoturbated nature of this unit, with no incorporation of laminated clay-silts, plus the occurrence of large ventifacts, is evidence that Lake Humber did not extend over the ridge. However, at a maximum elevation of only 5 m, the whole structure lies below the average level of 7.6 m OD (25 foot) of shoreline of the low-level lake (Gaunt, 1994). Similar problems attend Tudworth at ~6 m and Thorne at ~5 m, where Hemingbrough Formation deposits are also absent. All, however, are largely surrounded by claysilts, containing rare, large dropstones, including an angular block of Millstone Grit from beneath Thorne Moors [SE 721150] and a 300 mm block of coal at Sandtoft [SE 734089] (Buckland, 1979; Samuels & Buckland, 1978). At the latter site, the clay-silts are overlain by a thin peat, which thickened northeastwards, and yielded a thermophilous insect fauna, implying a closing date for the lake deposits of >12,500 BP (Bateman et al., 2001). Whereas the two dates from Sections 2 and 3 are significantly older, the dates from Section 5 place the event around 18,700 BP (Bateman et al., 2015), providing a short time interval for lakes and glacier expansion. In addition, Fairburn's (2014) geomorphological mapping suggests limited, if any, isostatic depression by the Vale of York glacier, thereby requiring either subsequent removal of any laminated clay-silts of the Hemingbrough Formation or a mechanism for non-deposition.

The high-level lake may have been sufficiently shortlived to leave minimal deep-water deposits (Bateman et al., 2008), and these may have been removed during its rapid drainage down to -4m OD (Gaunt, 1994), although Fairburn and Bateman (2016) argue for a much more complex pattern of drainage. At Cove Farm on the edge of the Isle of Axholme [SE 738007], where deposits along the former course of the River Idle have removed any ice marginal deposits, Carpenter et al. (2001) report an OSL date of 14,100 ± 2100 BP within sands and gravels which, on the presence of rafted blocks of coal from the northwest, must relate to flow into Lake Humber. An AMS date of 14,115–13,323 BP from peat in a channel over these deposits further narrows the time window for the lake.

The shortage of glacio-geomorphic evidence for ice advance between the Escrick moraine and Lindholme may be due to the ice became disconnected from its bed on entering the pre-existing proglacial Lake Humber. Gaunt (1976b) surmised that a rapid advance south-eastwards was facilitated by the glacier floating in Lake Humber. However, the glacier would have to be less than 36 m thick to float in a lake 33 m deep, and this would appear to be unlikely. It may be that the ice was also transient, moving into the lake as a surge, and riding over the easily deformable sediments. Glacier surges tend to cause ice-sheet thinning as they are not driven by the overall balance of the glacier but by internal re-organisation. The ice front of Franz Josef Glacier, New Zealand, is known to have surged periodically, and its ice front is only 50–150 m thick (Kehrl et al., 2015). Surges can advance an ice front by a kilometre per year, so it could have covered the distance from Escrick to Lindholme and Wroot rapidly. Surges are also known to stop rapidly (Lønne, 2016), and ice reaching Lindholme may not have lasted long before it became unsustainable.

The restriction of the Lindholme advance to the west side of the Vale of York is difficult to explain since there are no clear topographic barriers. Given the proposed limited width of the Lindholme advance, a surge would be unlikely to have occurred from just a small proportion of the Vale of York glacier front unless this front itself had some topographic control. Such control could be provided if the Vale of York glacier had already partly established a moraine around Escrick before ice breached this on its western edge; but evidence for this is lacking. Although the Escrick moraine has gaps (e.g. where the Derwent and Ouse pass through it), it is assumed these were formed after, rather than during, glaciation.

The new exposures at Lindholme in South Yorkshire provide evidence of extension of a glacier along the western edge of the Vale of York as far south as Wroot in North Lincolnshire. Its western and southern margins from Heck southwards are marked by diamictons and associated fluvio-glacial sediments that are rich in erratics indicating an ice source in the Yorkshire Dales and North Pennines and over Stainmore. For a short period around ~18.7 ka, this extended into South Yorkshire constrained by the Isle of Axholme to the east, but further research is needed to establish the complete boundaries of the ice lobe.

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