# The aeolian sand record in the Trent valley

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**Abstract**: Literature on the aeolian sand record of the Trent valley is reviewed. The wind-blown sediments provide an archive of changing environmental conditions through the Late Pleistocene and Holocene. Data relating to the now-closed Girton quarry, near Newark, identify sand dune stratigraphy previously unknown within the East Midlands. This dates to the end of the Younger Dryas, with reactivation during a cold dry episode in the Early Holocene, with reversed easterly gales implied by high-angle dune bedding. The infill of an adjacent palaeo-channel yields evidence of local environmental stress at about the same time. The Early Holocene was punctuated by short sharp anomalies, including climatic oscillations at 9.3 ka and 8.2 ka, well-documented on the continent but elusive in most British palaeo-records.

The East Midlands is one of the few regions in Britain that retain evidence of Late Pleistocene coversands (Buckland, 1976; Gaunt, 1981; Bateman, 1995, 1998). These deposits consist of fine to medium-grained, well-sorted sand, lacking interstitial silt and clay. Well rounded spherical grains and rare wind-polished ventifacts are testimony to past wind abrasion. Layering is largely horizontal or sub-horizontal, and only rarely displays slip-face bedding. Besides the broad sweep of windblown sand in North Lincolnshire and the Humberhead Levels, the East Nottinghamshire sandlands around Girton occupy a small but significant outlier on the east side of the Trent valley between Newark and Gainsborough (Fig. 1). The Farndon sands (Harding *et al*, 2013) represent the most southerly surviving fragment of this former coversand sheet, and, beyond the confines of the Trent valley, involutions at Cadeby (Douglas, 1982) contain the only evidence of remnant coversand within Leicestershire, demonstrating that aeolian activity must have once extended well to the south-west.

The Lower Trent coversands are formally recognised as the Spalford Sand Member of the Trent Valley Formation (Brandon and Sumbler, 1988). These deposits were intermittently exposed in the now-closed Girton quarry in the 1990s, and examined by Trent and Peak Archaeology as part of planning conditions (funded by Lafarge Tarmac Ltd.). These archaeological records, including many unpublished reports and photographic archives, have recently been re-evaluated, and these form the basis of the interpretations outlined in this paper.

## Context and palaeogeography

The Spalford Sand Member is assigned to the Last Cold Stage (MIS2) and is associated with the deposition of the last fluvial terrace of the Trent, underlain by the Holme Pierrepont Sand and Gravel. Aggradation occurred in two phases, the first at ~28 ka, the second at ~13 ka, and reconstructions of the terrace environment suggest the presence of a wide periglacial sandur or braidplain characterised by a mosaic of vegetation generally referred to as "mammoth steppe" (Howard *et al.,* 2007). The Trent valley south of the Isle of Axholme was effectively ice-free but was inundated by proglacial Lake Humber which existed for about 4000 years during MIS2, achieving its high level stand (about 30 m O.D.) briefly at 16.6 ka (Bateman *et al.* 2008).

In Holderness, the full glacial Dimlington Stadial, including the Last Glacial Maximum (LGM), is dated to between 22 ka and 15 ka (Bateman *et al*, 2008). Within the Trent valley ice-free zone, permafrost left ice-wedge casts, involutions and some patterned ground (Fig. 2). Also periglacial in origin, coversands signify aeolian activity attributable to either the LGM or to the Younger Dryas, and their distribution is interpreted as indicating a westerly provenance, originating primarily from Sherwood Sandstone (Straw, 1979; Bateman, 1995). Sandy sediments associated with the drained bed of proglacial Lake Humber and the Trent valley sandur provided additional exposed surfaces for aeolian deflation, transportation and deposition.

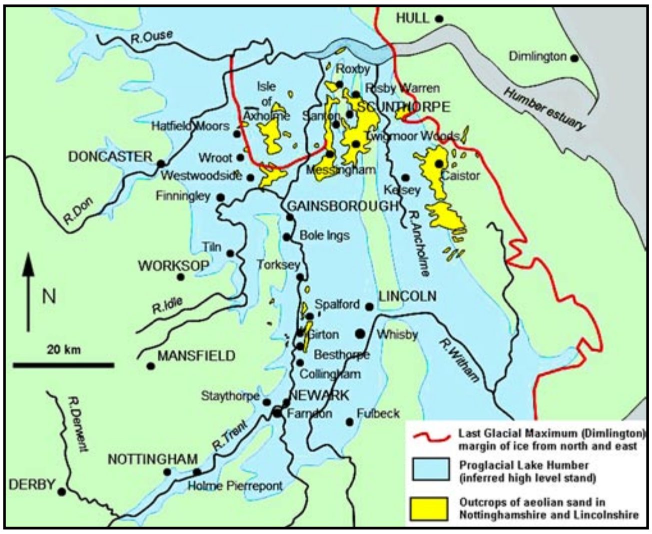

***Figure 1****. Distribution of coversand (after Knight and Howard, 2004), Devensian ice margins and the extent of Lake Humber (based on the BRITICE database, Clark et al., 2004), and main sites mentioned in the text.*

*Radiocarbon dates are in calibrated years BP (prior to 1950), using IntCal09 (OxCal version 4.1), with error range expressed at 95% probability (2σ). Luminescence ages refer to number of years prior to date of measurement, with error range at 68% probability (1σ).*

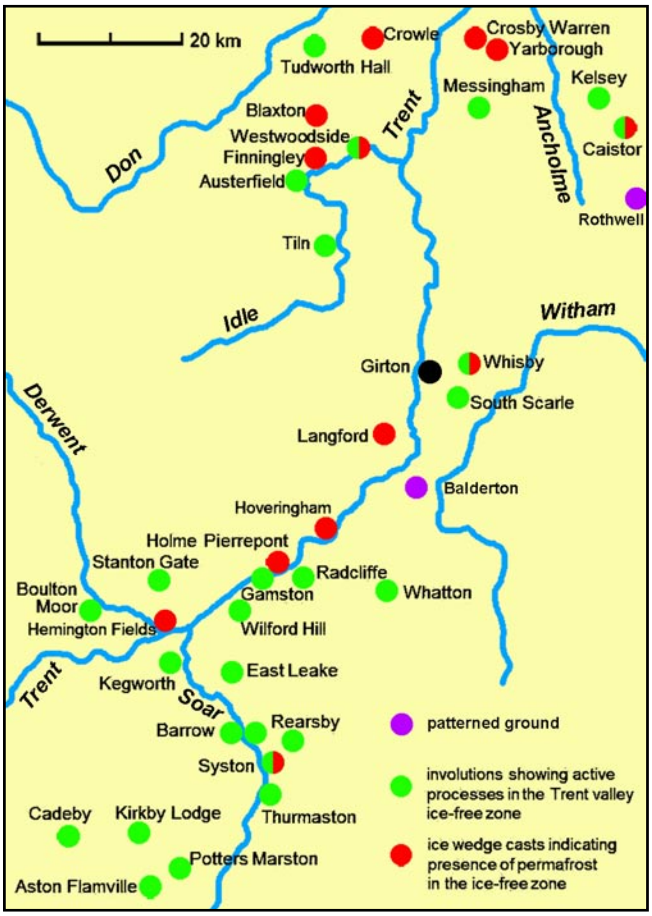

***Figure 2**. Sites of Devensian permafrost features [based on Deeley (1886), Lamplugh et al. (1908), Straw (1963, 1979), Bell et al. (1972), Gaunt (1981), Douglas (1982), Buckland (1984), Brandon and Sumbler (1991), Bateman et al. (2000, 2001b, 2008), Murton et al. (2001), Gaunt et al. (2006), Knight and Howard (2004), Howard (1995), Howard et al. (1999, 2007, 2011) and A.S.Howard et al (2009)].*

## Coversands and periglacial chronology

Coversands at the southern edge of the Humberhead Levels lie on the River Idle first terrace at Tiln (Howard *et al.,* 1999), where four sedimentary units provide a chronological framework. From the base upwards these are: an organic channel peat (C14 dated to 13,470±240 BP), a cryoturbated arctic palaeosol (Tiln Bed), horizontally-bedded coversand (TL dated to 13.71±1.3 ka), and upper drift sand (TL dated to 8.51±0.8 ka) (Fig. 3). This places local coversand after the final drainage of proglacial Lake Humber, and within the earlier part of the Younger Dryas. It also postdates a significant period of periglacial cryoturbation that appears to coincide with the Upper Periglacial Surface of Gaunt (1981). If Gaunt's Lower and Upper Periglacial Surfaces are accepted as diagnostic markers in the Lower Trent ice-free zone, they offer a potential means of differentiating coversand horizons.

Sites of Windermere Interstadial age (some of which contain evidence for periglacial activity) provide a maximum age for the principal aeolian activity to follow in the Younger Dryas. Within the coversands, however, there are no indisputable intraformational periglacial structures (Buckland, 1984) (Table 1). Of the three potential Last Glacial Maximum coversands, that at Cadeby on the Soar-Tame watershed survives within decapitated involutions that penetrate Oadby Till (Douglas, 1982) (Fig. 4). Based on typical grain properties, they were thought to equate with Younger Dryas coversand, but extreme cryoturbation implies greater age (Terry Douglas, *pers. com.*); they resemble intense permafrost degradation structures in Kent coversands dated firmly to between 23 and 21 ka (Murton *et al.*, 2003).

***Figure 3**. Coversand section exposed at Bellmoor Quarry, Tiln (photo: Andy Howard).*

Few of the periglacial sites in Figure 2 are fully documented or dated; some may relate to early cold episodes within the Trent Valley Formation, perhaps as far back as the Early Devensian. Where small remnants of coversand of presumed Dimlington Stadial age have survived, they would appear to have been exposed to a period of intense periglacial deformation. This is why the majority of East Midlands coversands are recognised as Younger Dryas; their lack of cryoturbation implies the younger age.

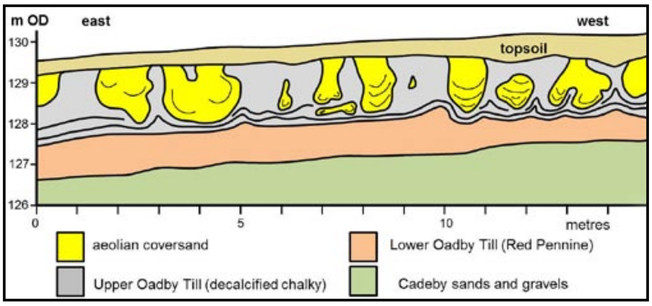

***Figure 4**. Involuted coversand of possible Dimlington Stadial age at Cadeby (after Douglas, 1982).*

| Stage | Main sites | Other probable equivalents |
|---|---|---|
| Late Glacial Stadial (Younger Dryas) | Main coversands in the Humberhead Levels and North Lincolnshire (Buckland, 1984). | Spalford Sands (this study)<br>Farndon Sands (Harding *et al,* 2013). |
| Late Glacial Interstadial (Windermere) | Upper Periglacial Surface probably relates to a cold phase, at Finningley and Tudworth (Gaunt *et al.*, 2006), and Tiln (Howard *et al.*, 1999), where cryoturbation is associated with Lake Humber deposits and coversand. | Peat beneath coversands at Messingham (12,300 BP), Nettleton (12,490 BP), Fonaby (13,850 BP) (Buckland, 1984). Sand wedge casts below peat at Crosby Warren, Caistor (Straw, 1963), Santon (Bateman, 1998; Murton *et al.*, 2001), Westwoodside (Bateman *et al.*, 2001b). |
| Last Glacial Maximum Stadial (Dimlington) | Lower Periglacial Surface at Finningley and Tudworth (Gaunt *et al.*, 2006). Cryoturbation of Lake Humber sediments at Kelsey to 22.7±1.4 (Bateman *et al.*, 2000). | Involutions and ice wedge casts containing aeolian sand in the Balderton Terrace at Whisby (Brandon and Sumbler, 1991; Knight and Howard, 2004). Ice wedging at 35–15 ka at Baston, Lincolnshire (Briant *et al.*, 2004). Cryoturbation of coversands at Cadeby (Douglas, 1982). |

***Table 1**. Association of the coversand horizons with the recorded periglacial stratigraphy in the ice-free zone of the Trent valley.*

## Continental correlation

The East Midlands coversands almost entirely correlate with the Dutch Younger Coversand II phase (Bateman and van Huistedden, 1999) (Table 2). Earlier episodes on the European mainland, such as Older Coversand I, were subject to intense permafrost degradation and wind deflation (the Beuningen Gravel), which appears to correlate with Gaunt's Lower Periglacial Surface. The subsequent Older Coversand II is poorly represented in Britain but might be found in dated sands at Bagmoor (17.8±2.5 ka) and Fonaby (18.6±2.0 ka) (Bateman, 1998).

Late Pleniglacial sandlands on the continent are dominated by horizontal or low-angled bedding in both Older and Younger Coversands, with only limited preservation of dune structures. While parabolic sand dune formation was well-developed along the Polish lowland valleys in Younger Coversand I (Isarin *et al.,* 1997), the main dune period occurred later, in Younger Coversand II. Aeolian activity in the Netherlands also appears to have increased at this time, when horizontal coversands were starting to be reworked into hummocky dunefields mainly confined to the Scheldt, Maas and Rhine valleys (Schwan, 1988). A combination of cold aridity and partial vegetation cover in the Younger Dryas promoted effective dune formation; however, evidence of high-angle slipface cross-bedding is reported in very few instances (Kasse, 2002; Renssen *et al.,* 2007).

Reactivated sands within the Holocene were invariably associated with human disturbance (van Huissteden *et al.,* 2001; Koster, 2009). "Drift sands" in the Trent valley show similar reactivation throughout the mid and late Holocene, and were almost certainly the result of vegetation removal, soil disturbance and exploitation, coupled with natural episodes of drought and high winds. The environmental impact of these combined factors was demonstrated by the unusual Lincolnshire sandstorm of March 1968 (Robinson, 1968), and sandblow continues today wherever surface vegetation is temporarily removed (Fig. 5).

***Figure 5**. Sandblow during archaeological work at Girton quarry in February 1999, in conditions that were probably common during and after the Neolithic period (photo: TPA).*

***Table 2**. Correlations of coversand stratigraphy (after Bateman, 1998; Bateman & van Huissteden, 1999; van Huissteden et al., 2001; van Geel et al., 1989; Kaiser et al., 2009).*

| Stage | Age (ka) | Chronozones | Lithostratigraphy | | |
|---|---|---|---|---|---|
| | | | East Midlands | East Netherlands | Central European Lowlands |
| Holocene | 11.65 | Subatlantic<br>Subboreal | Human impact from Neolithic onwards | Inland dune fields and drift sands, Veluwe, Twente (Kootwijk) | Human-triggered dune period |
| | | Atlantic<br>Boreal<br>Preboreal | Reactivated drift sands, Tiln unit 1, Girton units 3-4, Farndon units 3-4 | | Small dune reactivation |
| Late Glacial Stadial (GS-1) | 12.85 | Younger Dryas | Humberhead and North Lincolnshire coversands, Spalford Sands (Girton unit 1), Tiln unit 2, Farndon unit 5 | Younger Coversand II (Wierden) | Main dune period |
| Late Glacial Interstadial (GI-1) | 14.7 | Windermere (Allerød, Bølling) Interstadial | Sub-coversand peat horizon | Usselo palaeosol | Finow palaeosol |
| | | | | Younger Coversand I | Dune period |
| | | | Tiln units 3 and 4<br>Upper Periglacial Surface (?) | Lower loam | |
| Last Glacial Maximum Stadial (GS-2) (Late Pleniglacial) | 23.0 | Dimlington Stadial | Proglacial Lake Humber<br>Bagmoor sand unit V<br>Fonaby sand unit V<br>Lower Periglacial Surface (?)<br>Cadeby sand (?)<br>Whisby cover deposit unit 4 (?)<br>Brough patterned ground (?)<br>Baston sand (?) | Older Coversand II (Lutterzand) | Coversand period Kamion palaeosol |
| | | | | Deflation surface (Beuningen)<br>Intense permafrost degradation | Ventifact horizons<br>Continuous permafrost<br>Fluvio-aeolian period |
| | | | | Older Coversand I (Beverborg) | |

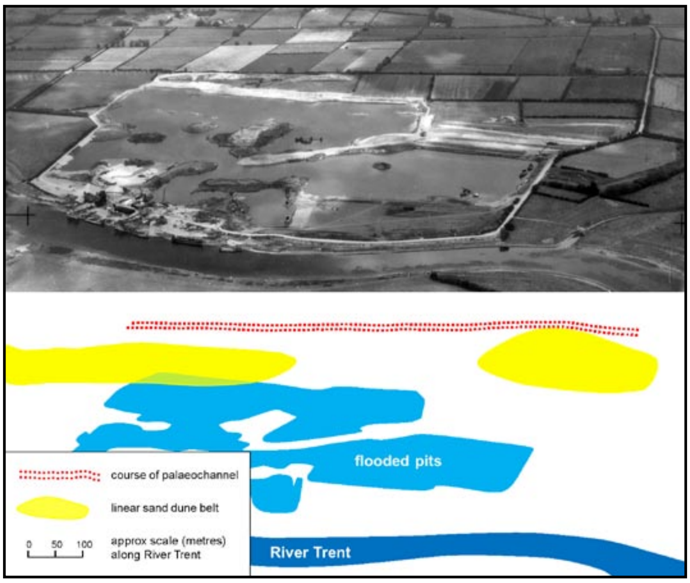

***Figure 6**. Girton quarry in oblique aerial photograph towards the east (Photo: Cambridge University), with positions of the linear sand dune mound and the palaeochannel.*

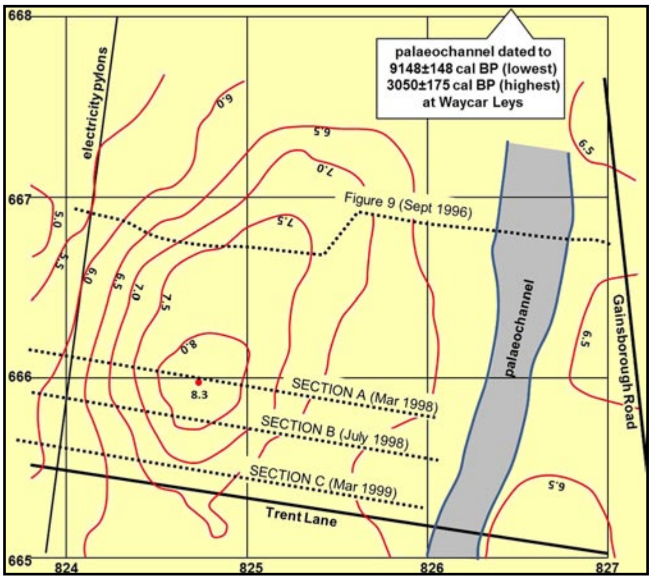

***Figure 7**. Girton dune mound topography, with positions of cross-sections and the Holocene palaeochannel (EDM survey after Ensor et al., 1996).*

## The Girton sand dune complex

Girton quarry, 15 km downstream of Newark, lies in the edge of the main body of East Nottinghamshire aeolian sands extending about 10 km between North Clifton and Besthorpe. Outliers of sand also survive around Sutton-on-Trent, Torksey and Farndon. At Girton a linear dune-like mound about 1 km long and 200 m wide rises to 8 m O.D.; it stands about 3 m above floodplain level, and to the east, a palaeochannel lies beneath a swale channel (the northern extension of The Fleet) between the sand mound and Gainsborough Road (Fig. 6)

Gravel extraction at Girton quarry revealed the internal structure of the coversand overburden in west-east sections cut between September 1996 and March 1999 (Fig. 7). In 1998, the receding north-facing quarry wall revealed in its centre a double-crested dune profile rising gently to 8 m.O.D. (Fig. 8), and the face had revealed both the dune and the channel in 1996 (Ensor *et al.,* 1996) (Fig. 9).

## Sand dune sedimentology

Early archaeological reports (Grattan, 1990; Lillie and Gearey, 1992) failed to establish a direct link between dune sand and palaeochannel organic sediments, but the 1996 section confirmed that the palaeochannel cuts into, and thus postdates, *in situ* coversand and is itself overridden by later drift sand. Quarry exposures in March 1999 revealed more of the dune's internal structure (Fig. 10). Sand beds achieve a maximum thickness of 4 m, lying conformably on Holme Pierrepont terrace sands and gravels. In its lowest layers, the sandsheet is horizontally or sub-horizontally bedded with clear laminations (Fig. 11), which is interpreted as aeolian sediment modified by snowmelt or seasonal river flow (Buckland, 1982; Schwan, 1988; Kasse, 2002).

Horizontal bedding extends for about 100 m (Fig. 10C, a to j) in sand derived from the adjacent Trent sandur to the west, under prevailing westerly palaeowinds. The highest 2-3 metres of the sand dune have been modified into at least five small north-

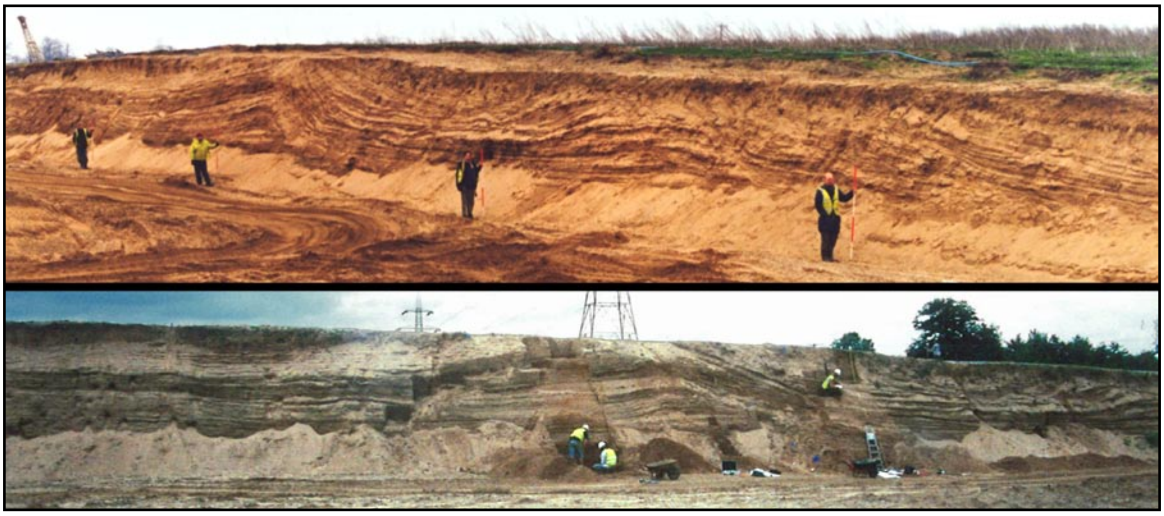

***Figure 8**. Dune stratigraphy exposed in north-facing quarry walls (with east on the left) at Girton, above in March 1998 and below in July 1998 (photos: Trent and Peak Archaeology).*

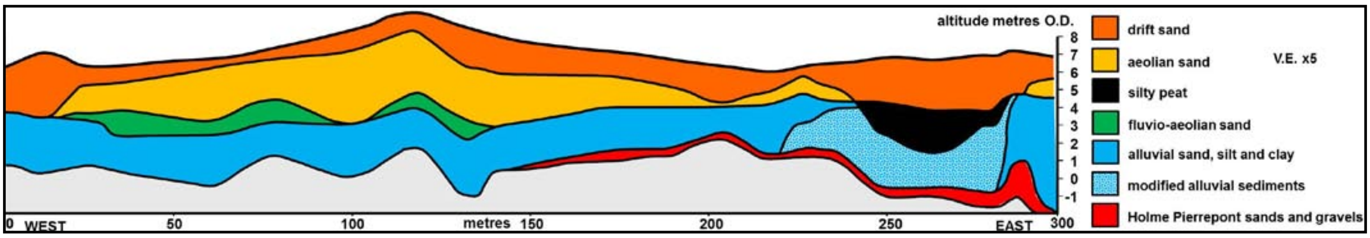

**Figure 9**. *Stratigraphic relationship between sand dune and palaeochannel in a reversed section of the north-facing quarry wall at Girton in September 1996 (after Ensor et al., 1996).*

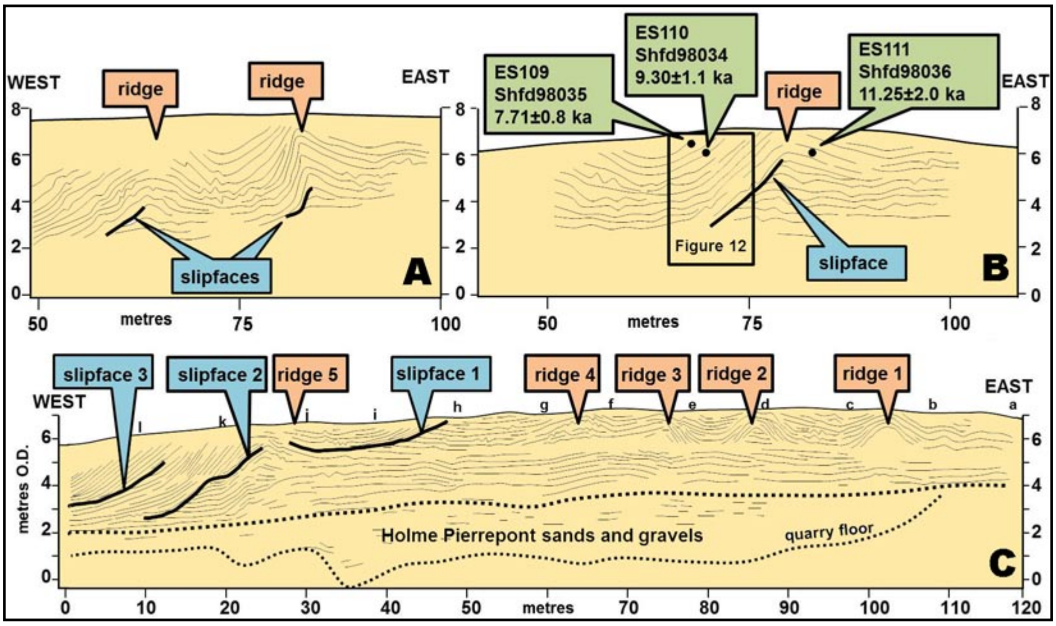

**Figure 10**. *Interpretation of three quarry sections based on Trent and Peak Archaeology photographs, showing increased dune complexity southwards. Section A was in March 1998, section B was in July 1998 and section C was in March 1999. Note that all sections, originally visible on north-facing quarry walls, have been reversed. Vertical exaggeration is x3.*

south transverse ridges. Coversand layering is further modified (h to m) where three inclined slipface planes cut across horizontal beds. Two of these, between k and m, are associated with sand descending steeply on the western flank. This high-angle slipface bedding is interpreted in terms of an easterly palaeowind driving sand temporarily backwards across the mound to then avalanche down the western (lee) side.

A slipface sequence within Section B (Fig. 10) was sampled in detail (Fig. 12). Grain size distribution (Fig. 13) centres on well-sorted medium sand, typically aeolian but slightly coarser than coversands in North Lincolnshire; this may reflect closer proximity of the Trent sandur as source area. Further analysis (Fig. 14) shows four sand units, below and above the slipface horizon. Below, unit 1 contains fluvio-aeolian elements, characterised by fine sand-silt laminae; to the east of the slipface, this expands into typically well-sorted, horizontal coversand beds. Above and ahead of the slipface, unit 2 consists of steeply-inclined (20º), moderately-sorted, gravelly coarse sand, cross-cutting the horizontal beds below. Unit 3 is well-sorted medium sand, inclined to the west at lower dips. Unit 4 is structureless fine reddish-brown drift sand. This four-fold sequence is interpreted as initial coversand

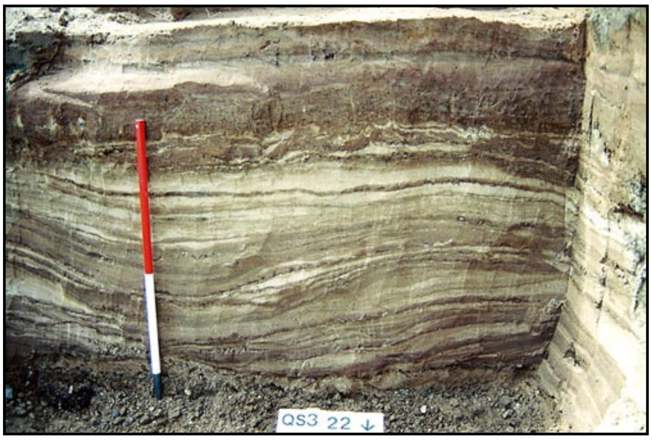

**Figure 11**. *Sand laminations within the basal fluvio-aeolian layers of the coversand sheet, exposed in June, 1998 (photo: Trent and Peak Archaeology).*

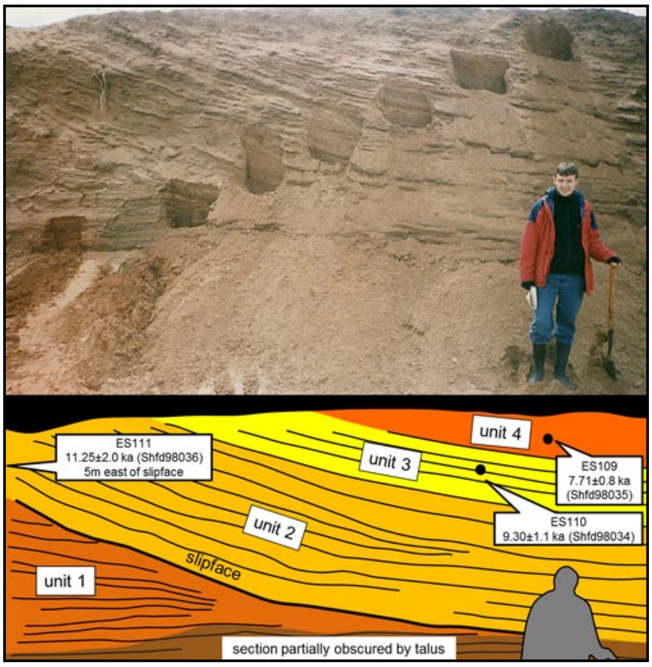

**Figure 12**. *High-angle dune bedding in Section B of Figure 10.*

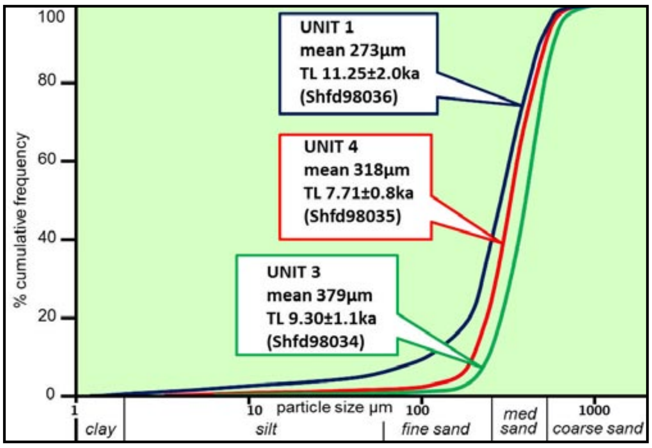

***Figure 13****. Grain size distribution for three sedimentary units in Section B.*

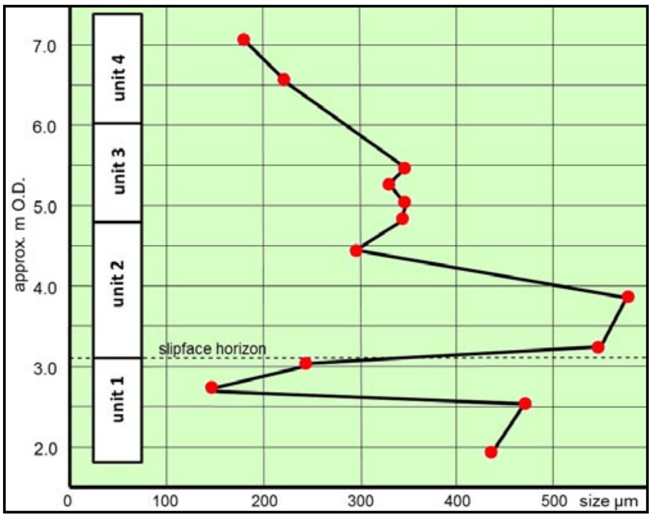

***Figure 14****. Mean grain size variation for four units in Section B.*

deposited in the Younger Dryas, followed by at least two phases of reactivation in the Early Holocene. Sand avalanching occurred at least three times (Fig. 10C).

Unit 2 is notably coarse, with individual gravel clasts up to 10mm in size. Since no higher bedrock or terrace source exists locally for such coarse material, it must have been introduced directly by wind-saltation. Fine gravel (2-5 mm) can be raised to a height of 50 cm during winter storms with winds exceeding 8 m/s, or 30 km/h (De Ploey, 1977). Because of its higher density, cold air may be more effective in transporting coarser aeolian sediment (McKenna Neumann, 1993). Winds responsible for the deposition of unit 2 were therefore strong (in excess of 30km/h), from the east, and almost certainly indicative of cold winter events. Reduction in easterly wind speed is inferred in unit 3, after which more normal westerly winds resumed. Rapid burial beneath units 3 and 4 ensured preservation of the cross-bedded structure in unit 2.

## Palaeochannel infill

A well-defined Holocene palaeochannel lies parallel to the sand dune mound (Fig. 6) and is in contact at one point (Fig. 9). Base of the channel lies at about 2 m O.D. near Trent Lane, dropping to 1.6 m O.D. at Waycar Pasture and below O.D. at Clifton Hill. It is matched elsewhere in the Lower Trent valley by similar palaeochannels at Staythorpe and Bole Ings. Organic silts and peats are over 2 m thick in the meander channel (Grattan, 1990) (Fig.15). Unstratified aeolian sands appear to have been eroded laterally on its outer east bank. Its inner west bank is composed of stratified and cross-bedded fluvial beds interpreted as point bar and chute bar sediments prograding from west to east. Further west, windblown sands with dune-like structures and some gravel stringers were exposed at about 6m O.D., resembling the aeolian stratigraphy further south, and laminated silts and sands beneath the dune sand might be interpreted as the basal fluvio-aeolian unit.

Five peat samples were radiocarbon dated (Garton, 1999) (Table 3). These suggest that the palaeochannel was probably disconnected from the main river in the pre-boreal period, and remained open for as much as 7000 years throughout the Early-Mid Holocene until the Iron Age, when reactivated drift sand overrode it (Fig. 16). Organic sedimentation is divisible into six zones (G/A to G/F) based on pollen stratigraphy (Green, 1996), three of which yielded beetle assemblages (Dinnin, 1992). Pollen zone G/C, constrained between 9148 and 7454 cal BP (the Later Mesolithic boreal period) converges with the TL sand chronology (see Table 4), falling between 10,000 and 8000 BP. Within this zone, pollen is dominated by hazel shrub (and almost eliminated at one point) with a strong grass component (Girton was only lightly wooded). The coleopteran species list (verified by Paul Buckland) shows a notable reduction in water and woodland indicators; terrestrial beetles are severely abraded, suggestive of local soil erosion. Most significantly, abundant macro-charcoal occurs throughout zone G/C. A period of local drought and fire damage spanning several centuries is inferred.

Environmental stress must have occurred in the boreal period, perhaps a combination of drought, natural fire, and woodland dieback leading to inevitable wind erosion. How widely this extended in eastern Britain is uncertain. The Early Holocene climatic oscillations (well-established in continental records) have so far proved elusive in most British pollen records, and regional pollen sequences from Bole Ings, Routh, Willow Garth and Stafford show no comparable disturbance horizons. No consistent pattern of regional forcing is found in high-resolution

***Table 3****. Radiocarbon dates for peat samples from the Waycar Pasture palaeochannel.*

| *context* | *lab code* | *sample depth (cm)* | *height O.D.* | *pollen zone* | *C14 years BP* | *cal years BP* |
|---|---|---|---|---|---|---|
| primary channel | AA 29321 | 39-40 | 3.72 m | E/F | 2890±60 | 3050±175 |
| | AA 29320 | 85-86 | 3.25 m | D/E | 5360±50 | 6140±139 |
| | AA 29319 | 119-120 | 2.91 m | C/D | 6565±60 | 7454±121 |
| | AA 29318 | 166-167 | 2.44 m | B/C | 8170±60 | 9148±148 |
| secondary channel | AA 29317 | 105-106 | 3.00 m | - | 7515±65 | 8275±112 |

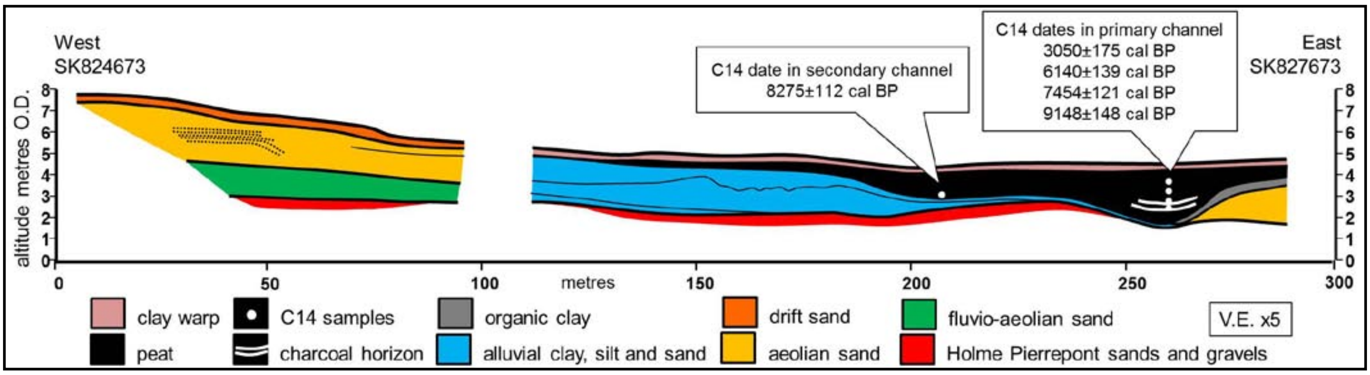

***Figure 15**. Reversed section of Holocene palaeochannel at Waycar Pasture exposed in June 1990 (after Grattan, 1990).*

pollen sites in Holderness (Tweddle & Edwards, 2010). So this suggests that the Girton evidence may be highly localised, confined to vulnerable sandlands more sensitive to short term drought and fire damage, but with perhaps no wider regional significance.

## Luminescence dating

Three Girton samples were analysed in August 1998 using quartz-based TL (Table 4). Thermoluminescence (TL) dating methodology is outlined in Bateman (1995). In the 1990s the use of TL for dating sediments was largely superseded by quartz-based OSL (optically-stimulated luminescence) and feldspar-based IRSL (infra-red stimulated luminescence) affording improved precision and accuracy (Wintle, 2008). For the North Lincolnshire coversands, however, Bateman (1998) employed the older TL methodology, but analysed quartz and feldspar components separately, as previous attempts with OSL and IRSL had resulted in gross underestimates of age. These quartz and feldspar splits gave consistent results and fitted well with the radiocarbon chronology, thus placing coversands confidently within the Younger Dryas stadial, and justifying the continued use of TL for dating purposes.

TL results for Girton are both internally consistent and compatible with the North Lincolnshire chronology. Initial coversand sheet and dune construction in unit 1 include an age estimate of 11.25±2.0 ka, suggesting their start late in the Younger Dryas. Later modification under easterly palaeowinds dates to around or just before 9.30±1.1 ka (unit 3), and reactivation of drift sand in unit 4 dates to 7.71±0.8 ka.

Three samples of horizontally-bedded aeolian sand at the interface with Holme Pierrepont sands and gravels at Besthorpe and Girton yielded somewhat older OSL dates of between 25 ka and 18 ka (Schwenninger *et al.,* 2007; White *et al.,* 2007). If these samples are truly Spalford Sands rather than older sand horizons within the terrace sequence, they appear to fall problematically within the Dimlington Stadial. Problems of low quartz sensitivity, high feldspar contamination and extreme moisture variation were acknowledged as likely sources of error.

## Holocene reactivation of the sand

At both 9.3 ka (Fleitmann *et al.,* 2008) and 8.2 ka (Baker, 2012) significant cold, dry climatic anomalies may have reactivated sand at Girton, though the overlapping TL error margins (10.4-8.2 ka and 8.51-6.91 ka) mean that any climatic oscillation within the Later Mesolithic might be implicated. This dating points to an episode of major soil erosion in the 9th millennium, after the climatic shifts of the Younger Dryas and pre-boreal oscillations, but before Neolithic woodland clearance, as is recorded by reactivated coversand in East Kent (Baker & Bateman, 2010).

The Girton sand dune entered a stable phase within the mid-Holocene, when it gained Bronze Age and Iron Age plough marks, middens and beaker burials (Kinsley, 1998; Kinsley & Jones, 1999). Above these, up to 2 m of structureless drift sand is present (Fig.16). Sand reactivation took place in two further phases, with features of probable Iron Age date between. The second phase was in turn cut by Late Saxon or medieval ridge and furrow. The later drift sand at Girton thus formed in or after the Iron Age, but probably no later than Late Saxon; reactivation was probably associated with Roman clearance on fragile sandy soils.

There were numerous phases of Holocene sand reactivation in the East Midlands (Table 5). Most of these polycyclic events were short-lived and probably had little or no lasting impact. However, the Later Mesolithic, Neolithic and Iron Age/Roman events redistributed sand on a larger scale. While the Neolithic Revolution seems to have initiated these repeating cycles, sand reactivation within the Mesolithic period is not so easily explained (Knight & Howard, 2004).

| Sediment unit | TPAT code | SCIDR code | Depth (m) | K % | U ppm | Th ppm | Water % | Dose (quartz) (Gy/a) | Equivalent dose (Gy) | TL age (ka± 1σ) |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit 3 (laminated sands, west of slipface) | ES110 QS5.7 | Shfd 98034 | 1.1 | 1.10 | 0.90 | 2.05 | 3.6 | 1.56±0.04 | 14.48±1.6 | 9.30±1.1 |
| Unit 4 (superficial sand, west of slipface) | ES109 QS5.7 | Shfd 98035 | 0.5 | 1.23 | 1.00 | 2.50 | 3.1 | 1.77±0.04 | 13.67±1.4 | 7.71±0.8 |
| Unit 1 (laminated sands, east of slipface) | ES111 QS5.6 | Shfd 98036 | 1.6 | 1.59 | 1.09 | 3.10 | 7.9 | 2.05±0.05 | 23.0±3.9 | 11.25±2.0 |

***Table 4**. Luminescence dates for the three TL samples from Girton.*

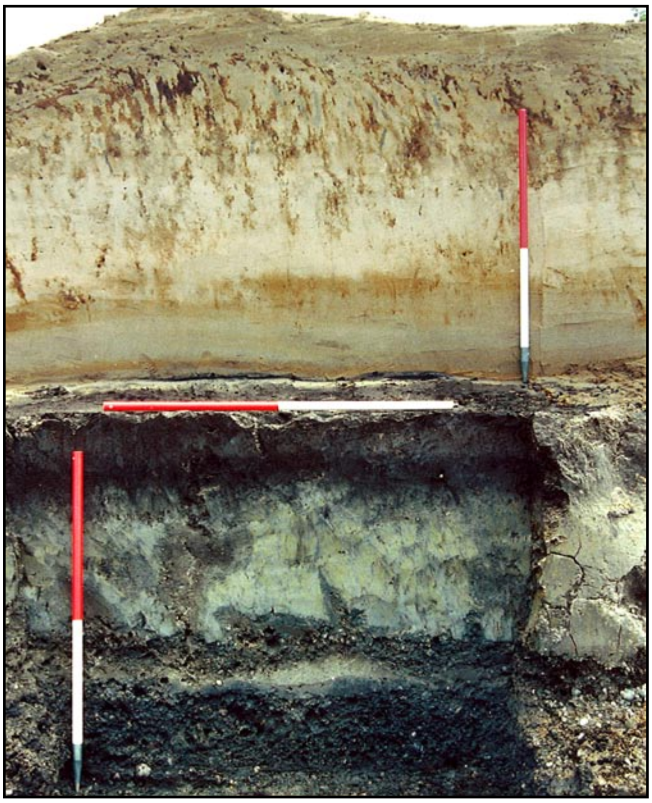

***Figure 16**. Structureless, manganese-stained drift sand, probably of Iron Age or later, overlying and terminating the palaeochannel sequence at Girton [826665] (photo: TPA).*

| *Period* | *Location* | *Dates* | |
|---|---|---|---|
| Mesolithic<br>(11500-6000 BP) | Twigmoor Woods | (Preboreal)<br>10.32±0.8 | Pollen<br>TL |
| | Tiln (Bellmoor) | 8.51±0.8 | TL |
| | Tiln (Bellmoor) | 7.7±0.7, 7.91±0.7<br>8.3±0.8 | TL |
| | Westwoodside | 7.9±1.6 | OSL |
| | Girton | 7.7±0.8, 9.3±1.1 | TL |
| | Yarborough | 6.7±2.1 | TL |
| | Farndon | 7.98±0.69 | OSL |
| Neolithic<br>(6000-4500 BP) | Kelsey (Caistor) | 6.46±0.6 | TL |
| | Twigmoor Woods | 5.66±0.6 | TL |
| | Misterton Carr | 4958±332 cal BP | C14 |
| | Bagmoor | 4.56±0.5 | TL |
| Bronze Age<br>(4500-2700 BP) | Risby Warren | (undated) | Arch |
| | Girton | (undated) | Arch |
| | Farndon | 2.87±1.29 | OSL |
| Iron Age/ Roman<br>(700 BC-400 AD) | Crosby Warren | 2394±276 cal BP<br>2094±194 cal BP | C14 |
| | Besthorpe | (undated) | Arch |
| | Torksey | 2563±196 cal BP<br>1869±171 cal BP | C14 |
| Anglo-Saxon<br>(400-1000 AD) | Twigmoor Woods | 1.31±0.2 | TL |
| | Fonaby House | (undated) | Arch |
| Medieval Warm<br>(1000-1400 AD) | "West Lincs" | 11th century | Doc |
| Little Ice Age<br>(1400-1800 AD) | Torksey | (undated) | Arch |
| | Torksey Lock | 1700s | Arch |
| | Nettleton | 1675-1695, 1698 | Doc |
| | Santon, Roxby | 1695, 1699 | Doc |
| | Tiln | 0.3±0.3 | TL |
| Present<br>(post 1800 AD) | Market Rasen | 1888 | Obs |
| | Risby | 1900-1910 | Obs |
| | Marston | March 1968 | Doc |
| | Caistor | 1972 | Doc |
| | Naylor's Hill | 1973 | Obs |
| | Tiln | 1996 | Obs |

***Table 5**. Periods of Holocene reactivation of aeolian drift sand in Nottinghamshire and Lincolnshire. Luminescence dates are in ka; C14 in years cal BP; and recent sources in years AD; Arch = archaeological, Doc = documented, Obs = observed. Compiled from multiple sources.*

| *Location* | *Reference* | *Lab codes* | *Age, ka* |
|---|---|---|---|
| Bellmoor Quarry<br>(Tiln) | Bateman *et al.* 1997<br>Howard *et al.* 1999 | Shfd96046 | 8.51±0.8 |
| | | Shfd96044 | 8.30±0.8 |
| | | Shfd96043 | 7.91±0.7 |
| | | Shfd96003 | 7.70±0.7 |
| Cove Farm | Bateman *et al.* 2001b | Shfd97078 | 7.90±1.6 |
| Girton | This study | Shfd98034 | 9.30±1.1 |
| | | Shfd98035 | 7.71±0.8 |
| Farndon | Harding *et al.* 2013 | X3738 | 7.98±0.7 |

***Table 6**. TL and OSL dating of sand mobility in the Trent valley in and around the 8200 BP anomaly.*

Rapid climate change within the Early Holocene, associated with natural fire and woodland dieback, might explain these earlier episodes. The case for climate-driven regional sand mobility within the 8200 BP event is strengthened by the new Girton TL dating (Table 6). Ninth millennium reactivation in the Trent valley may be just one local expression of a more widespread climate oscillation detected in aeolian studies throughout Britain and the near-continent (Janotta *et al.*, 1997; Gilbertson *et al.*, 1999; Dalsgaard and Vad Odgaard, 2001; Wilson, 2002; Hitchens, 2009; Baker and Bateman, 2010).

## Palaeowind reconstruction

The wind regime throughout the Last Glacial Maximum and Late Glacial is generally recognised as being similar to that of the present, with a prevailing westerly source. Dune ridge alignment in the Lower Trent, and inferred palaeowind directions within the coversands (Fig. 17), are broadly consistent with this view. Local dunes are arranged in lines or *en échelon*, with long axes aligned east to west, with steeper slopes facing north (Lamplugh *et al.,* 1911). Dunes in the Messingham area, near Scunthorpe, have 78% trending W-E and 22% N-S (George, 1992). Among a sample of 197 dunes, there is a preference for W-E alignment in the Ancholme valley, whereas the Trent valley has equal numbers of W-E and N-S ridges (Bateman, 1998). Whether these are longitudinal or transverse dictates whether perpendicular or parallel palaeowinds may be inferred. The Girton evidence points to asymmetrical transverse ridges, with strong easterly gales driving north-south dunes westwards. By contrast, chaotic dune orientation at Twigmoor Woods reveals compound wind directions, reflecting both bio-topographic origin and deflation in inter-dune blowouts (Bateman *et al.,* 2001a).

The main argument for westerly provenance of local coversands is sandsheet geometry, with aeolian sand banked against the windward west-facing slopes of the Isle of Axholme and the Lincolnshire ridges (Straw, 1963, 1979; Gaunt, 1981; Buckland, 1982; Bateman, 1998). Sandsheet thickness decreases eastwards, with little or no sand found east of the Wolds, though the coversand distribution in Figure 1 may be an under-estimate (Sumbler, 1993, and Berridge, 1999).

A westerly sand source is compatible with Atmospheric General Circulation Modelling for the Younger Dryas; the net result on the atmosphere of the relocation of the Icelandic low and compressed

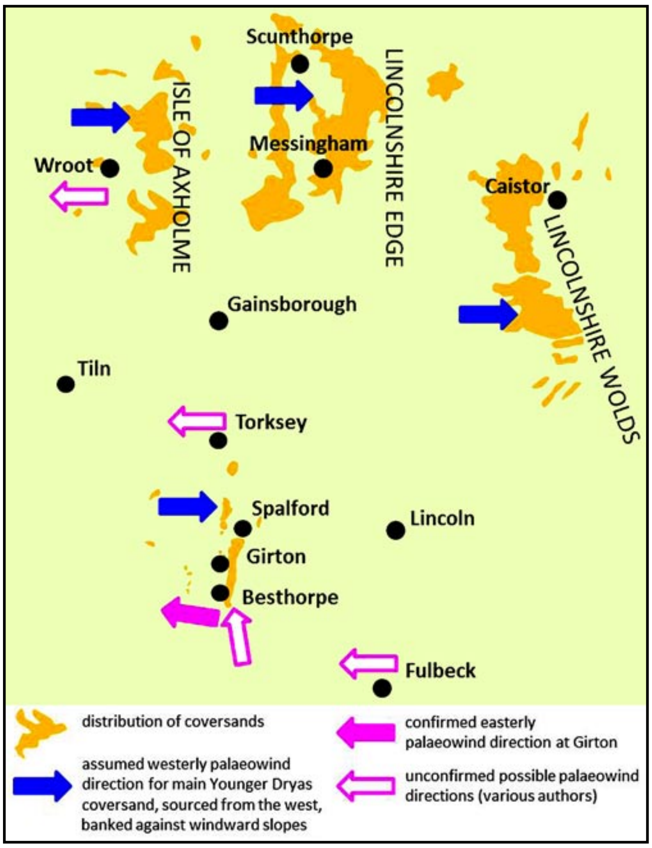

***Figure 17****. Palaeowind directions within the East Midlands coversand sequence (part after Bateman, 1998; Bateman et al., 2001a; Gaunt, 1994; Sumbler, 1993; Lamplugh et al., 1911).*

***Table 7****. The Girton palaeoenvironmental reconstruction.*

| *ka BP* | *Pollen zones* | *Archaeology* | *Climate trends* | *Climate events* | *Coversand TL dates* | *Channel C14 dates* | *Environments* |
|---|---|---|---|---|---|---|---|
| 1 | sub-atlantic | | warming | Little Ice Age | | | |
| 2 | | Anglo-Saxon<br>Romano-British | cooling | | | | Major reactivation of drift sand due to woodland clearance and intensive land use during the Iron Age. Palaeochannel is overridden, terminating the infill. Zone G/F shows reversion to reed swamp with heath, disturbed species and weeds of cultivation |
| 3 | sub-boreal | Iron Age | | | | | |
| 4 | | Bronze Age | | | | 3050±175 | Dune stability, its weathered sand surface studded with archaeological features. Cutoff continues to infill, zones G/D and G/E recording mature diverse woodland dominated by alder carr, with reed-fringed fenland around the closing palaeochannel. Burnt mound debris and sand lenses interbed with the peat. Recovery of water and woodland-dependent beetles. |
| 5 | | Later Neolithic | | | | | |
| 6 | atlantic | Earlier Neolithic | thermal maximum | | | | |
| 7 | | Later Mesolithic | | | | 6140±139 | Palaeochannel zone G/C records a period of environmental stress (hazel nearly eliminated, restricted water beetles, severely abraded terrestrial beetles, and abundant macro-charcoal). Natural fire damage inferred. A further phase of sand reactivation deposits drift sand across the dune surface, possibly related to a second climatic reversal (at 8.2ka). |
| 8 | boreal | | warming | 8.2 ka | 7.71±0.8ka | 7454±121 | |
| 9 | | | | 9.3 ka | | | |
| 10 | | | | | 9.30±1.1ka | 9148±148 | After initial period of postglacial warming and woodland development, a brief climatic reversal (at 9.3ka) intervenes with cold dry winter easterlies reactivating sand. Dune topography is formed, with multiple asymmetric transverse ridges. Eutrophic fen is established around the palaeochannel, away from the main river, and surrounded by hazel shrubland. |
| 11 | pre-boreal | Earlier Mesolithic | | 11.4 ka | | | |
| 12 | younger dryas | Late Upper Palaeolithic | GS-1 cooling | | 11.25±2ka | | |
| 13 | | | | | | | Active channel in the periglacial Trent valley sandur. Westerly winds cross the cold arid mammoth steppe, depositing coversand sheet on the east side of valley. |

pressure gradient over the ice-covered North Atlantic would have been greatly to increase the speed of westerly winds over Europe (Isarin *et al*, 1997). Van Huissteden *et al.* (2001) identify mainly westerly winds for the Dutch Older Coversands, and prevalence of westerly winds over the whole European Sand Belt is generally agreed (Schwan, 1988; Kasse, 2002; Renssen *et al*., 2007; Koster, 2009). This would have been applicable throughout the Last Glacial Maximum to Early Holocene periods.

There are local exceptions, such as at Vrijdijk (van Huissteden *et al.,* 2001) which has an easterly component, while wind polish on Younger Dryas boulders in the Scottish Highlands indicates dominant winds from both north and south (Christiansen, 2004). Palaeowinds were not unidirectional, partly due to Atlantic depressions sweeping across Britain (Williams, 1975), but easterly winds may have been due to a blocking anticyclone over Scandinavia (Isarin *et al.,* 1997; Lamb, 1977; Gaunt, 1981; van Huissteden *et al.,* 2001), or they may have been generated by katabatic flow across those areas closest to the Scandinavian ice margin (Kasse, 2002; Renssen *et al.,* 2007).

This demonstrable variability in wind direction questions whether an easterly palaeowind can be convincingly recognised in the East Midlands. The case for easterly winds has been made by Gaunt (1981, 1994) (Fig. 17). The Humberhead dunes are barchan-like with westward-facing horns, but Bateman (1998) questions whether these are not perhaps parabolic, and thus could be interpreted in exactly the opposite way. By contrast, most dunes within Lincolnshire are indistinct, providing little or no evidence of wind direction (Bateman, 1998; Bateman *et al,* 2001a). Cases of easterly provenance have also been suggested at Fulbeck Heath (Sumbler, 1993) and Torksey (Samantha Stein, *pers. com.*). The Girton evidence supports temporarily reversed palaeowinds, with an incursion of strong winter easterlies driven by intensified anticyclonic circulation over the dwindling Scandinavian ice sheet. Although Younger Dryas westerly winds certainly activated coversands, strong easterly airflows must also have been experienced, albeit briefly, in the Early Holocene. With the southern North Sea as yet unformed, cold Siberian winds must have blown unhindered into eastern Britain across Doggerland during the Later Mesolithic period.

## The Trent Valley palaeo-environment

Although the Spalford Sands at Girton constitute only a small outlier of the East Midlands coversand sheet, they have yielded significant new insights into Late Pleistocene and Early Holocene conditions (Table 7). Sourced from the Trent sandur, these sediments fit a framework of Younger Dryas deposition, post-dating the Holme Pierrepont terrace, and correlating with the continental Younger Coversand II. Involutions and ice-wedge casts exist in the former active layer in a few places prior to the coversand sheet, but are absent at Girton. Complex dune structures with unusually clear ridges, slipfaces and high-angle cross-bedding indicate reversed easterly winds probably driven by a strong blocking anticyclone over Scandinavia in the Early Holocene. This conforms with the standard palaeoclimatic model of prevailing westerly airflow; coversands were initially sourced from the west during the Younger Dryas, but were modified in the final stages of dune stabilisation possibly linked to climatic anomalies at 9.3 ka and 8.2 ka. Multiple phases of reactivation in polycyclic drift sands include three at Girton, at around 9.3 and 7.7 ka and then during the Iron Age or Roman period. Palaeochannel sediments indicate a period of environmental stress in the 10th and 9th millennia, overlapping in time with the aeolian events. A scenario of interrelated drought, natural fire, woodland dieback and soil erosion, driven climatically, is thus envisaged for Girton, but this may be confined to the fragile sandy soils of the Lower Trent area.

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