Plumpe Farm Section

Jon Merritt and Emrys Phillips

This exposure is situated behind a cowshed at Plumpe Farm [NY 3344 6813], Cumbria, 300 m east of the Scottish Border at Gretna (Figures 1, 2). The uppermost unit of diamicton (Table 1), the Plumpe Bridge Till Member [PBT], overlies a sequence of fine-grained sands and silts, the Plumpe Farm Sand Member [PFS]. The farmer reports that gravel occurs below to a depth of 7m. Borehole evidence suggests that the gravel is confined to a buried valley lying to the east of Gretna and Gretna Green, and that it rests on stiff, reddish brown clayey till (Chapelknowe Till Formation) (BGS, 2006). The lithostratigraphical framework adopted here follows McMillan et al. (2010a, b).

The site is of particular importance because it is situated close to where Trotter (1922, 1923) first deduced that there had been a significant readvance of Scottish ice into the Solway Lowlands. Further evidence was found subsequently in the Carlisle area, where the so-called 'tripartite sequence' was established and subsequently correlated widely across north-west England (Trotter and Hollingworth, 1932). These authors concluded that glaciofluvial and glaciolacustrine sediments laid down in the Solway Lowlands and elsewhere during an early, partial retreat of the last (Main Late Devensian) ice sheet had been glacially over-ridden during the subsequent 'Scottish Readvance'. Many have since concluded that evidence for any readvance, particularly a single, regionally significant one, is illusory, being devoid of sedimentological, stratigraphical and chronological foundation (Evans and Arthurton, 1973; Thomas, 1985). However, the Scottish Readvance has received renewed support (Huddart and Glasser, 2002, and references therein; Merritt and Auton, 2000) and now is more firmly established (Livingstone et al., 2010b).

The low-lying ground lying to the north of the Solway Firth is weakly drumlinized by low, elongated forms that arc south-eastwards and then eastwards towards the Tyne Gap (LT4 of Livingstone et al., 2008; 'Annan-Gretna suite' of McMillan et al., 2010b). They peter out eastwards towards the Brampton Kame Belt and are distinct from the better-developed, similarly orientated forms on the higher ground within the Tyne Gap. The section at Plumpe Farm lies at right angles to the eastward direction of ice flow as deduced from subtle W-E to WSW-ESE orientated drumlins observed in the vicinity on a hillshaded model derived from a 5 m resolution Digital Terrane Model produced by Interferometric Synthetic Aperture Radar (NEXTmap).

A set of 5 soft sediment block samples were collected across the boundary between units 2 and 3, down into the top of unit 4 (Phillips, 2002; Phillips et al., 2007). Blocks taken from near the base of the PBT (unit 1) are composed of a stratified, poorly sorted, sandy diamicton, containing layers of highly disrupted laminated silt and clay. The clay-rich layers within the till are lithologically similar to those within the underlying laminated sediments. Stratification within the diamicton becomes more pronounced and less diffuse towards its base. A block sample intersecting the gradational boundary between units 1 and 2 comprised alternating layers of laminated silt and clay, and sandy diamicton. The silt and clay layers are variably deformed and

disrupted. In the least deformed layers, the lamination is contorted by small-scale disharmonic folds, recumbent rootless folds and flame structures. These structures are cross-cut by thin veinlets and lenticles of clay cutan. The silt laminae are variably homogenised, with liquefaction leading to the overprinting of earlier developed structures. In more highly deformed layers, broken angular fragments of laminated clay occur within a homogenised silty or silty clay matrix. These disrupted layers also contain rounded to elongate till pebbles of similar composition to the adjacent layers of diamicton. Subsequent work at the site has demonstrated that the PBT has a weak W-E-orientated microfabric and that the diamicton may be interpreted as a subglacial traction till (*sensu* Evans et al., 2006).

Thin sections confirmed that unit 3 is composed of laminated fine-grained sand, silt and clay. Some of the thicker sand laminae are normally graded and preserve a low-angle cross lamination, but apart from some minor soft-sediment deformation and associated liquefaction structures, localised faulting and rare recumbent folding, the sediments are essentially undeformed. Although this unit was logged as a penetrative glacitectonite (*sensu* Benn and Evans, 1996), no micro-structures were observed proving this unambiguously, or indicating the former direction of ice movement. Subsequent work has determined that the sediments of unit 4 are glaciolacustrine in origin (Livingstone et al., 2010b), the silt/clay laminae having been formed by suspension rain-out and the sand layers as density underflows.

Although the PFS has been over-ridden by ice, the absence of significant glacitectonic deformation suggests that conditions at the ice-sediment interface were such as to impede the transmission of shear to any significant depth within these finely laminated sediments. The bulk of the deformation was concentrated within the gradational boundary between the PBT and the underlying PBS. The microstructures within the stratified base of the till, such as disharmonic folds and flame structures, coupled with the liquefaction and homogenisation of the silty laminae are consistent with the sediment having had high water content during its deposition and deformation (Phillips et al., 2007).

The lack of pervasive deformation in unit 3 may, at least in part, be related to the regional palaeogeography at the time of the Scottish Readvance. During the Readvance, glacier ice flowed over the flat-lying glaciofluvial and glaciolacustrine sediments and encountered ice-marginal lakes ponded against high ground to the east ('Lake Carlisle' of Trotter, 1929; Hollingworth, 1931: Livingstone et al., 2010b). The water-saturated nature of these sands and silts would have aided movement of the ice, dramatically reducing the amount of shear translated into the underlying sediments (Phillips et al., 2007).

Other localities in the vicinity

Two red tills separated by 5 m of dense gravel are seen in a section in the 'tripartite sequence' in the valley of the Logan Burn [NY 3110 7181], south of Chapelknowe. The lower till of the sequence is correlated with the Chapelknowe Till Formation [CT]. The gravel unit has been identified upstream in a section at [NY 296 734] and it also crops out in the valley of Closses Burn at [NY 3852 7610], where both the overlying and underlying tills are exposed (BGS, 2006).

The 'tripartite sequence' found in the Gretna area has been traced as far west as Annan and as far north as Langholm (McMillan et al., 2010b). It has been identified at

several localities in the valley of the River Esk downstream of Langholm and in boreholes drilled for the Canonbie by-pass (Figure 1). The northernmost known occurrence has been located in the valley of the Byre Burn, north of Claygate. Here, yellowish brown sand correlated with the PFS overlies very stiff reddish brown, stony diamicton (CT). The sand crops out on the western side of the valley in the vicinity of Greenburn, where a NNE-orientated drumlin has been partially dissected to expose the sequence. The sand unit extends into the drumlin, which therefore formed after deposition of the sand. Another north-east-orientated drumlin has been partially dissected by the River Esk in the vicinity of Brockwoodlees [NY 383 781], near Hollows, where boreholes record red sandy till overlying greyish brown, laminated silt and clay up to 7m thick. These laminated deposits rest on brown or reddish brown till and also pass into the drumlin beneath till.

The laminated deposits described above are assigned to the Great Easby Clay Formation by McMillan et al. (2010b). They include dark reddish brown clays, silts and very fine-grained sands that are generally thinly laminated and locally varved. These laminated deposits, which are more widespread around Carlisle, contain sparse dropstones, convolute bedding, slump and water-escape structures and are commonly disturbed glacitectonically and capped by red diamicton of the Gretna Till Formation (Dixon et al., 1926; Trotter, 1929; Livingstone et al., 2010a). The Great Easby Clay was probably laid down in proglacial lakes ('Glacial Lake Blackhall Wood' of Livingstone et al., 2010a) when ice occupied the Solway Firth and blocked drainage within the otherwise deglaciated Solway Lowlands (Stone et al., 2010).

It may be significant that the tripartite sequences recorded near Claygate and Brockwoodlees occur within NE-orientated drumlins, unlike at Plumpe Farm where the drumlins are aligned W-E. The NE-orientated drumlins probably belong to flow set LT6 of Livingstone et al. (2008), in which case the laminated clays they contain relate to the earlier 'Blackhall Wood Oscillation' of Livingstone et al. (2010a).

Conclusions

There can no longer be any doubt that discrete units of red till are separated by sequences of red silts, sands and gravels locally. The Plumpe Farm section demonstrates that the uppermost diamicton was deposited subglacially and that it results from an eastward glacial readvance of a wet-based glacier (Phillips et al., 2007; Livingstone et al., 2010b). The preservation of the Plumpe Farm Sand and Gravel Formation within major southward trending valleys such as the Esk probably results from the final flow of ice being directed at right angles, towards the east (Brookfield et al., this volume, fig.2).

It is apparent that 'tripartite' sequences are commonly preserved within drumlins, where units of silt, clay, sand and gravel have become attenuated through the process of 'extensional subglacial glacitectonism' (Hart and Boulton, 1991), leaving the upper and lower tills in contact on the flanks of the features. Between drumlins, the upper till commonly lies directly on bedrock as the rest of the sequence has been eroded away through the process of 'excavational subglacial glacitectonism'.

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Figures

Figure 1. Evidence for the pattern of deglaciation following readvances of Scottish ice into the Solway Lowlands, also showing localities revealing a 'tripartite sequence' (after McMillan et al., 2010b). BKB, Brampton Kame Belt; DG, Dalston Gap; DM, Dumfries Moraine of Charlesworth (1926a); GE, Great Easby site; GM, Gretna Moraine of Charlesworth (1926a); HS, Holme St Cuthbert fan; PL, Plumpe Farm site; PM, Powfoot Moraine of Charlesworth (1926a); W, Wizza Beck channels; WB, Wreay-Buckabank limit. NEXTmap Britain elevation data from Intermap Technologies.

Figure 2. Section behind cowshed at Plumpe Farm [NY 3344 6813]

Tables

Table 1. Plumpe Farm section log

Acknowledgements

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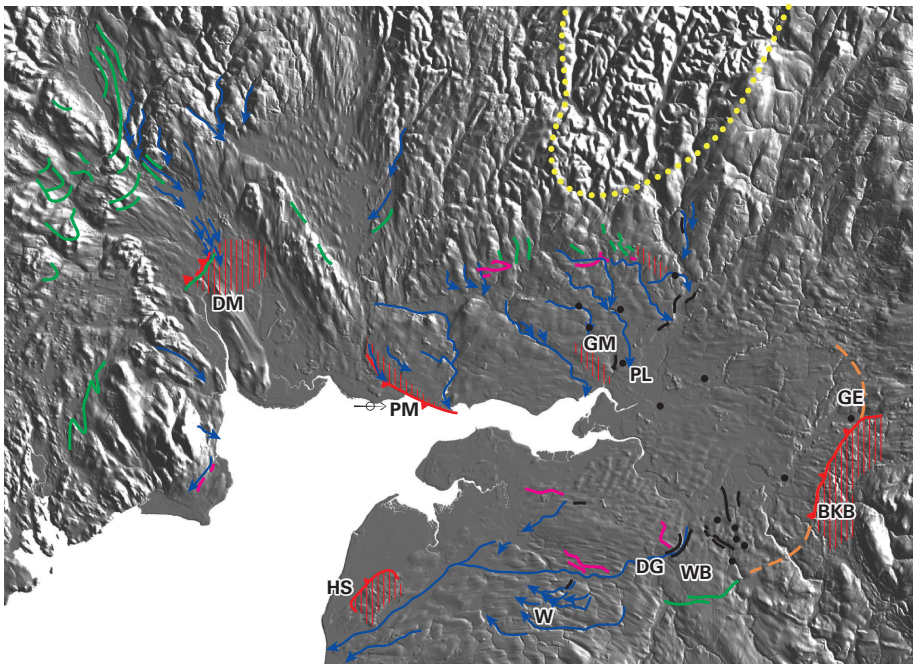
Table 1 Plumpe Farm section log

Unit	Thickness	Description *{interpretation}*	Lithostratigraphy
1	0.2 m	Soil	Soil
2	<1.5 m	Hard, friable, reddish brown, gravelly sandy clay diamicton, matrix-supported, massive. Well dispersed, sub-rounded to well rounded clasts of wacke sandstone and siltstone, and angular fragments (<0.4 m) of pale red and grey sandstone. Poor fabric, some stone clusters, poorly developed lamination/fissility towards base. Basal contact generally gradational over 10 cm, but locally represented by a 10 cm lens (boudan) of dark yellowish brown, sandy clay diamicton containing granules of coal and yellow sandstone. *{subglacial traction till}*	**Plumpe Bridge Till Member [PBT]**of the Gretna Till Formation
3	0.5 m	Very compact to hard, reddish brown, planar interlaminated sandy silt, silty sandy clay and fine-grained sand. Lamination is parallel to the gently undulating contact with unit 2 above. Most laminae 1-5 mm thick, but some 4-5 cm beds are composed of wavy to ripple cross-laminated, very fine-grained sand. Most laminae have gradational boundaries and fine upwards. Gradational basal contact. *{penetrative glacitectonite}*	**Plumpe Farm Sand Member [PFS]** of the Plumpe Sand and Gravel Formation
4	>2.5 m	Compact, reddish brown, silty fine-grained sand, becoming medium to fine grained and yellowish brown downwards. *{glaciolacustrine}*. Uppermost 50 cm is crudely laminated and interpreted as a *non-penetrative glacitectonite*.	



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Esker

Glaciofluvial complex with ice-contact slope shown by ticks

Major ice-marginal drainage

Minimal glacial erosion and deposition of till

Moraine ridge

Occurrence of 'Tripartite' sequence

Striae on boulder pavement

Speculative glacial limit