Thurstaston

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Introduction

The coastal section at Thurstaston on the Wirral Peninsula is the only permanent exposure in Late Devensian glaciogenic deposits for approximately 200 km along the north-west coastline of England between Cumbria and North Wales. The site therefore is important not only for the evidence it contains about glacial events in this part of the Irish Sea basin, but also for regional correlation between Cumbria, North Wales and the Cheshire–Shropshire lowlands. The section provides an opportunity to reconstruct depositional environments and to test competing glaciomarine and glacio-terrestrial theories. Thurstaston also constitutes an excellent example of the tripartite lithological sequence ('Upper Boulder Clay', 'Middle Sands' and 'Lower Boulder Clay') favoured by early workers of the [British] Geological Survey.

The glaciogenic deposits at Thurstaston were first described by Slater (1929) and other accounts include those by Brenchley (1968), Pitts (1983) and Jones (1990). More recently, the section has been considered by Glasser *et al.* (2001).

Description

The underlying bedrock on the Wirral is Triassic Sherwood Sandstone, which forms a series of ridges trending NNW–SSE, separated by intervening depressions that often are below sea level (Gresswell, 1964). Evidence from the area was used as early as the 19th century to demonstrate that during the Pleistocene Epoch a large ice sheet flowed out of the Irish Sea basin across north-west England in a NNW–SSE direction (Tiddeman, 1872; Mackintosh, 1879; Morton, 1860, 1870). As it did so, the ice sheet deposited a spread of muds, sands and gravels (De Rance, 1870; Shone, 1878; Strahan, 1886). This regional pattern of ice flow is now firmly established (Gresswell, 1964), as are the limits of the ice sheet to the south in the Cheshire–Shropshire lowlands (Boulton and Worsley, 1965; Thomas, G.S.P, 1985a, 1989). During deglaciation the ice sheet in the area was relatively thin and deglaciation was achieved under temperate conditions with abundant meltwater (Sambrook Smith and Glasser, 1998; Glasser and Sambrook Smith, 1999).

The GCR site is located around Thurstaston Steps, where coastal erosion has created a 20 m section through a low NW–SE orientated mound. The succession comprises six main lithofacies (Glasser *et al.,* 2001). These are diamicton, gravel, sand, mud, laminite and cobble pavements (Figure 5.36). In general terms the northern part of the section is dominated by sand, gravel and minor mud, whereas the diamicton dominates the southern part. In the middle of the section, near Shore Cottages, mass movements obscure the cliff section.

Diamicton

Two diamicton lithofacies are identified: a lower (clast-rich) and an upper (clast-poor) diamicton. The lower diamicton comprises a red-brown, compacted, massive, clast-rich, sandy diamicton with a homogeneous texture. In places it shows a sub-horizontal structure defined by planar discontinuities (fissility). Locally derived Triassic sandstones and siltstones clasts dominate, but exotic lithologies include mudstone, limestone, quartzite, gypsum, gabbro, ignimbrite, tuff, basalt, granite and scattered shelly debris. Shear planes are present and there is evidence of poorly developed folding in the diamicton (see 'Deformation structures' section below).

The upper diamicton is a red-brown to light brown, clast-poor to very locally clast-rich, muddy diamicton. It is characterized by a relatively structureless, homogeneous texture and a uniform sediment composition. Some regular pebble-sized clast concentrations and shell fragments occur in discontinuous layers, especially near the base of the diamicton (TH2, (Figure 5.36)). Clast shapes range from angular to well rounded. Striated and faceted clasts are common, and the diamicton is dominated by Triassic lithologies with rare mudstone, limestone, basalt and granite clasts. There are occasional sand stringers and pods up to 3 cm thick and 30 cm across and generally a vertical joint pattern.

Sand

This lithofacies comprises well-sorted, light red-brown to yellow stratified sand consisting of layers of fine- to coarse-grained sand that generally are texturally homogeneous. The sand is composed mainly of subangular to rounded grains, with subrounded shapes dominating. In places, the sand contains isolated pods of gravel and occasional clay layers and lenses (e.g. TH4, (Figure 5.36)). Sedimentary structures are variable but include fining-upward sequences, parallel- and cross-laminated units, tabular cross-beds and erosional surfaces. In places, the sand fills erosional channels. Measurement of foresets in the cross-bedded layers indicates variable flow directions towards the south, southwest and north.

Mud

Mud is a minor lithofacies associated with sand horizons. Ranging from a grey clay to clay–silt–sand admixtures, it occurs as discontinuous beds a few centimetres thick within the sand. Contacts are commonly loaded or show convolute relationships. Occasional mud balls, several centimetres in diameter, are found within the sand bodies.

Laminites

This lithofacies comprises a sequence of finely laminated (millimetre scale) clay and silt, in places immediately overlying the lower diamicton. There is no obvious grading in the laminae. The average thickness of this laminated unit is 10–15 cm, although it reaches a maximum of 20 cm near site TH1.

Cobble pavements

A well-developed cobble pavement is sometimes exposed within the clast-rich (lower) diamicton towards the southern end of the section (TH9, (Figure 5.36)). Where cobbles are absent, there is a clear planar discontinuity in the diamicton. The pavement has a maximum thickness of 20 cm and clasts show a strong NNW–SSE preferred orientation, with planed and smoothed upper surfaces and striations. The cobbles that comprise the pavement are a variety of lithologies but are mainly igneous and Lower Palaeozoic rock-types.

Deformation structures

The clast-rich diamicton is characterized by two groups of deformation structures. First is a group of surfaces that resemble listric faults. These have cross-sectional traces around 10 m in length and are spaced over tens of metres. They flatten into a bedding-parallel orientation in the lower horizons. Nowhere are they seen to cut below the cobble pavement or penetrate upwards into the overlying units. Their curviplanar form appears concave towards the north-west. It is difficult to define the sense of displacement but vertical separation of beds in the fault is up to 4.5 m. The fault zone itself, *c.* 5 cm in thickness, is relatively indurated, probably arising from the preferential introduction of a carbonate cement within this localized zone. Occasional, approximately bedding-parallel, slickensided and slickenlined surfaces also indicate localized shearing.

The second group of structures in the diamicton is a set of roughly orthogonal joints, crossed obliquely by the listric faults. These are distributed sporadically, but are best developed towards the base of the unit. They are typically closely spaced (10–15 cm apart) in an orthogonal set, approximately at right angles to the stratification. These joints are mainly near-vertical, although they are inclined in places.

Two contrasting suites of small-scale deformation structures occur in the sand. First is a range of asymmetric load and flame structures, convolutions and attenuated isoclinal folds. These are developed on a centimetre scale and are most prominent in the laminated sands. The second type, developed in close proximity, are numerous, very sharp faults, again developed on the centimetre scale. These are a series of curvilinear, normal faults with cross-sectional traces tens of centimetres in length and, more commonly, straight, steep to vertical, very narrow faults with traces typically on the scale of centimetres.

Interpretation

Slater (1929) recognized a tripartite sequence consisting of 'Upper Boulder Clay' and 'Lower Boulder Clay' separated by sands and gravels ('Middle Sands'). Slater's tripartite sequence mirrored that reported from other locations on the eastern fringes of the Irish Sea Basin (e.g. Jehu, 1909) and is now known as the 'Stockport Formation' (Bowen, 1999). Jones (1912) studied the erratic content of the glacial deposits of the Wirral and identified a variety of clast lithologies, the majority of which are derived from the Lake District and the Southern Uplands of Scotland. This confirms that the ice in Wirral flowed out of the Irish Sea basin in a NNW–SSE direction (Morton, 1860, 1870; Mackintosh, 1879). In a more recent study of the sediments at Thurstaston, Glasser *et al.* (2001) have interpreted the section in terms of terrestrial glacial deposition beneath an Irish Sea ice sheet. They attached the following interpretations to the six lithofacies based on the sedimentary properties described above.

Diamicton

Massive diamictons are known to form in the glaciogenic environment by: (i) terrestrial lodgement and meltout of basal glacial debris (Andrews and Shimuzi, 1966; Boulton, 1970; Lindsay, 1970; Mark, 1974; Lawson, 1979a; Shaw, 1982; Haldorsen and Shaw, 1982; Dreimanis, 1989; Hart, 1994; Benn, 1995); (ii) deposition from ice at, or seawards of a grounding line (Powell and Molnia, 1989; Powell *et al.,* 1996); (iii) from a high density of icebergs (Domack and Lawson, 1985; Dowdeswell *et al.*, 1994); (iv) from the formation of deformation tills produced by the deformation and *en masse* transport of subsole sediments as a slurry layer beneath the ice base (Boulton and Hindmarsh, 1987; Hicock and Dreimanis, 1992; Eyles *et al.,* 1994, Hart and Roberts, 1994; Evans *et al.,* 1995; Hart, 1995, 1998; Benn and Evans, 1996; Boulton, 1996; Alley *et al.,* 1997); and (v) from sediment gravity flows in both subaerial and sub-aquatic contexts (Boulton, 1968, 1971, 1976; Marcussen, 1973, 1975; Lawson, 1979b; 1982; van der Meer, 1987, 1993).

The clast-rich (lower) diamicton is interpreted as a basal deformation till deposited beneath temperate, terrestrially based ice. Evidence for this interpretation includes the inclusions of unlithified sediments into the diamicton, the structures indicating deformation and the weak clast macrofabric, which are similar to those described from deformation tills (Hart and Roberts, 1994; Benn and Evans, 1998). Clast-surface features, including striations and facets, and clast shape are indicative of basal transport beneath temperate, sliding glacier ice (Boulton, 1978; Bennett *et al.,* 1997). External boundary relationships, such as the presence of the cobble pavements within the diamictons are also strong evidence that it is a deformation till (Clark, 1991; Hicock, 1991; Boulton, 1996). The sub-horizontal fissility noted at Thurstaston is formed by shear along numerous discontinuous slip planes and their position has been noted at the base of the deforming layer (Boulton and Hindmarsh, 1987; Benn, 1994).

The origin of the predominately clast-poor (upper) diamicton is less clear. Possible origins include a readvance till, a glaciogenic sediment gravity flow, or a deformation till. The similarity in the lithological assemblage between the upper and lower diamictons, the lack of unequivocally pro-glacial sand and gravel between the two diamicton units and the continuity in the sediment deposition sequence suggests that it is not the product of a readvance. A second possible origin is a series of glaciogenic sediment gravity flows deposited from debris-bearing glacier ice. Evidence for this interpretation is the weakly consolidated nature of the matrix and the variable textural composition.

The nature of the clasts in this lithofacies, including the proportion of striated and faceted clasts and their degree of rounding, indicates that if this facies was formed by sediment flows then the sediment was sourced from material originally transported in the basal layers of the ice sheet. However, the thickness of this deposit (up to 6 m thick), its homogeneous nature and the absence of stacked sequences that can be differentiated on the basis of texture, basal clast concentrations, washed tops and interbedding between the diamictons and glaciofluvial sediment of exposures argue against this origin. The upper diamicton also could be interpreted as a deformation till, which built up incrementally through time. Evidence for this interpretation includes the weak clast macrofabric, which is similar to those described from other deformation tills (Hart and Roberts, 1994; Benn and Evans, 1998). Clast surface features, including striations and facets, and clast shape are also indicative of basal transport beneath temperate, sliding glacier ice (Boulton, 1978; Bennett *et al.,* 1997). External boundary relationships, such as the presence of the cobble pavements within the diamicton, are also strong evidence that it may represent a deformation till (Clark, 1991; Hicock, 1991; Boulton, 1996).

Gravel

The thickest gravel-dominated lithofacies at the base of the sequence at the north-western end of the succession probably indicates a fluvial regime characterized by major, short-lived floods (Williams and Rust, 1969; Rust, 1972, 1975; Bluck, 1974, 1979; Boothroyd and Ashley, 1975; Church and Gilbert, 1975; Hein and Walker, 1977; Macklin and Hunt, 1988; Aitken, 1998). The simplest interpretation of this lithofacies is the product of deposition in a pro-glacial braided river. The presence of Triassic sandstone and siltstone clasts in similar proportions to the two diamicton lithofacies suggests that this river may have been reworking and transporting sediment originally released directly from glacier ice. The majority of clasts fall within the rounded class, which is consistent with this interpretation. However, it is also possible the gravel lithofacies was deposited in a subglacial channel. Many of the thinner gravel and sand sequences can be demonstrated to lie between diamicton units and therefore are likely to have formed in this way.

Sand

The sand lithofacies occurs in close association with the gravel lithofacies, and the two lithofacies commonly are interbedded. These lithofacies associations are typical of a glaciofluvial environment with fluctuating discharge levels and sediment supply (Aitken, 1998). The alternation of sand with the gravel lithofacies would indicate frequent channel migration during ice recession. Sedimentary structures such as load and flame structures indicate that the sediment may have been deposited rapidly, inducing deformation and remobilization of water-saturated layers

Mud

This minor facies represents the waning flow stage of fluvial deposition or the effects of channel migration. Deformation structures in the mud are interpreted as the effect of loading of the sediment by later influxes of sand. Most mud horizons formed in ponded water.

Laminite

The clay–silt and silt–fine-sand laminite is interpreted as the product of material settling from suspension into a series of subglacial ponds on the irregular topography of the deformation till. The lateral impersistence of the laminated unit and its limited thickness indicates that these water bodies were small and that their existence was relatively short-lived.

Cobble pavements

Boulder pavements at the base of massive diamictons have previously been interpreted as evidence for subglacial deformation in a terrestrial environment (Clark, 1991; Hicock, 1991; Boulton, 1996). Similar pavements have been reported to form during stick-slip motion in a stable–deforming bed mosaic by Piotrowski and Kraus (1997) and by Fischer and Clarke (1997). Pavements also may form by current winnowing in a glaciomarine setting, with subsequent abrasion of upper surfaces by partly grounded basal ice (Eyles, 1988), a floating ice margin (Eyles and Lagoe, 1990) or floating icebergs (McCabe and Haynes, 1996). A glaciomarine origin for the cobble pavements at Thurstaston appears unlikely because of the setting of the pavement within a diamicton sequence that displays many of the properties of direct deposition from a sub-glacial deforming layer. The Thurstaston cobble pavements are probably products of terrestrial subglacial deformation, formed as large clasts in a deforming layer sink through the till to a level where the matrix is able to support their weight (Clark, 1991).

Deformation structures

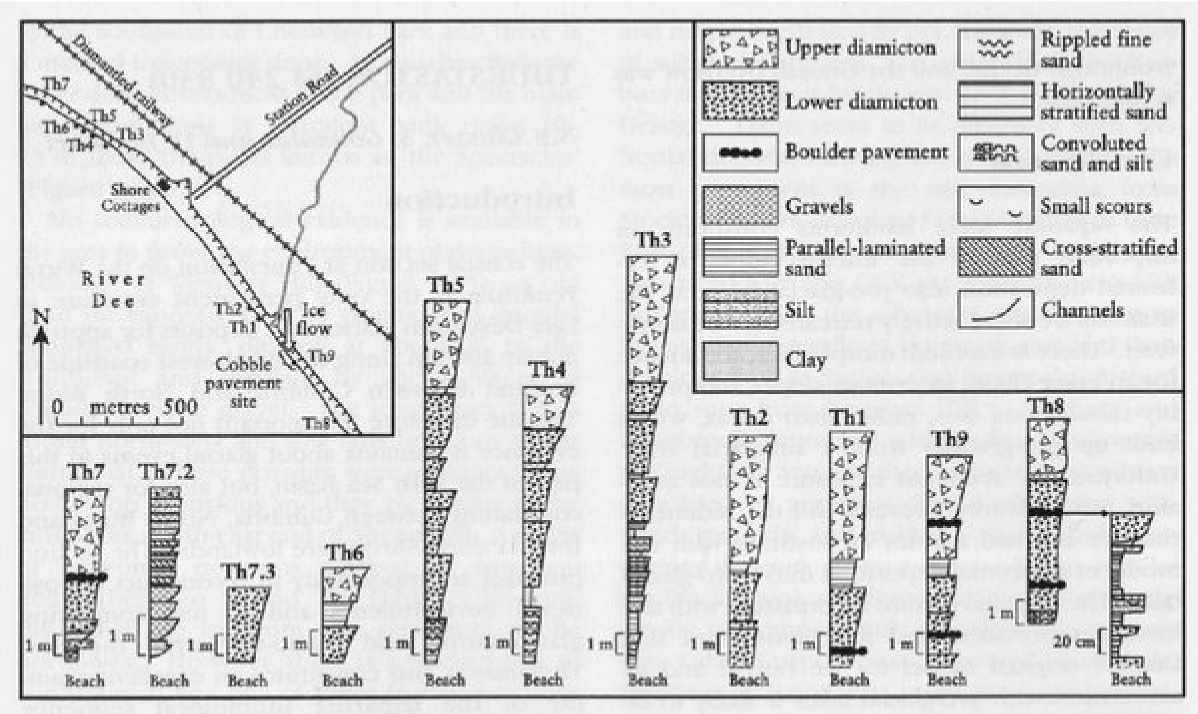
The listric faults in the clast-rich (lower) diamicton may represent thrust faults, developed in response to the movement of ice across the area (Boyce and Eyles, 2000). The induration of the zones presumably records enhanced fluid flow along them (Maltman, 1994). The orthogonal joints with a polygonal upper surface are most suggestive of a desiccation origin, formed at a time when the diamicton was exposed subaerially. The deformation may represent the thrusting and shearing of sub-sole sediments as a result of ploughing and frictional drag at the ice–bed interface.

The ductile deformation structures in the sand lithofacies probably formed when the sediment was temporarily reduced in strength, perhaps as a result of sediment or ice overburden. Accompanying temporary variations in the density and viscosity of the different layers would prompt Raleigh–Taylor instabilities and hence the formation of the flames and lobes. During their transient loss of strength, the sands would be sensitive to even a slight slope, which, together with shear imposed by the ice or sediment, helps explain the asymmetry of many of the structures.

Conclusions

The section at Thurstaston shows evidence for sedimentation in a range of different glacial environments. The dominant lithofacies are interpreted as deformation tills and glaciofluvial and subglacial interbeds. The laminites suggest the presence of ephemeral water bodies, possibly silting ponds in a subglacial position. The cobble pavements are interpreted as an integral product of deformation till formation. Collectively, these sediments appear to record deposition by a terrestrially based Irish Sea glacier and there is little evidence for glaciomarine sedimentation at Thurstaston.

[References](#)



(Figure 5.36) Stratigraphical logs of nine sections (TH1–TH9) at Thurstaston showing the major lithofacies identified at the site. Inset shows location of logs.