Stratigraphy and sedimentology of Devensian (Dimlington Stadial) glacial deposits, east Yorkshire, England

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ABSTRACT: The stratigraphy and sedimentology of the glacial deposits exposed along the coast of east Yorkshire are reviewed. Critical sections at Filey Brigg, Barmston and Skipsea are examined to reassess the stratigraphy of Devensian Dimlington Stadial glacial deposits in the light of recent developments in glacial sedimentology. Sedimentary and glaciectectonic structures studied in the field and by using scanning electron microscopy are emphasised. Two hypotheses are considered for the genesis of the interbedded diamictons and stratified sediments. The first involves the deposition of lodgement till and/or deformation till followed by meltout till, which was overridden to produce more deformation till, reflecting periods of ice stagnation punctuated by glacier thickening. The second hypothesis, which is favoured on the basis of field evidence and micromorphology, involves the vertical accretion of a deforming till layer associated with cavity/channel or tunnel valley fills, beneath active ice. At Barmston the upper part of the diamicton contains elongate pendant structures containing gravels, indicating that the diamicton was saturated and able to flow. The diamictons, therefore, represent a complex sequence of tills deposited and deformed by active ice during the Dimlington Stadial. Previously published stratigraphical schemes involving classifications of multiple tills in east Yorkshire should be simplified and it is more appropriate to assign these to a single formation, the Skipsea Till Formation. Rhythmic glaciolacustrine and proglacial glaciofluvial sediments overlie the tills at Barmston and Skipsea. These were deposited in sag basins during deglaciation as the tills settled and deformed under thickening sediment and as buried ice melted out. Extensive sands and gravels cap the succession and were deposited on a sandur during the later stages of deglaciation.

KEYWORDS: Stratigraphy; sedimentology; micromorphology; Skipsea Till Formation; Dimlington Stadial; Devensian.

Introduction

The coastal cliffs cut in Quaternary sediments along the east Yorkshire coast are ideal for investigations into glacial depositional environments, because the rapid rate of marine erosion provides extensive fresh exposures which aid in the reconstruction of the three-dimensional sedimentary structures. This paper discusses the stratigraphical and sedimentological investigations undertaken on the cliffs of Filey and Bridlington Bays in order to elucidate the genesis and depositional environments of the Quaternary sediments present (Fig. 1).

A considerable amount of stratigraphical work was undertaken on the coast of east Yorkshire in the late nineteenth and early twentieth centuries and this is reviewed by Catt (1879, 1891, 1897). Much of the early work on the coastal stratigraphy in Filey and Bridlington Bays was undertaken by Lamplugh (1879, 1891) and Bisat (1939, 1940) respectively. Several refinements of these early lithostratigraphies have been offered by Catt (1963), Catt and Penny (1966) and Madgett and Catt (1978) for the Holderness area which has become the UK type site for the Late Devensian 'Dimlington' Stadial/ Chronoszone (Rose, 1985). Comprehensive discussions of the regional lithostratigraphical correlations are available in Catt and Madgett (1981), Edwards (1981) and Catt (1987, 1991). This paper will refine the stratigraphy of the late Quaternary sediments along the east Yorkshire coast by investigating the environments of deposition of the glacial sediments.
Previous research on the east Yorkshire coastal stratigraphy

The Late Devensian glacial sediments in east Yorkshire are varied in their lithoclast content, colour and structure and this has resulted in a complex nomenclature (Edwards, 1981; Catt and Madgett, 1981). Madgett and Catt’s (1978) dual subdivision of the Devensian glaciogenic sediments into the Skipsea and Withersea Tills has become the accepted lithostratigraphic nomenclature, but this conceals considerable internal diversity.

The tills of the east Yorkshire coast are divided into three units, the Basement, Skipsea and Withersea Tills. The diamictons exposed in Bridlington Bay are regarded as part of the Skipsea Till, except where Basement Till is occasionally exposed by beach erosion (Bisat, 1939, 1940; Catt and Madgett, 1981). In Filey Bay, Edwards (1981) identifies two tills and, despite the lithological and structural complexities created by glaciotectonics, correlates them with the Skipsea and Withersea Tills although the latter till does not crop out in Holderness north of Hornsea (Catt, 1991). A summary of the till nomenclature for the east Yorkshire coast is presented in Table 1. The deposition of the Skipsea and Withersea Tills or their equivalents (Table 1) during one glacial advance is suggested by Catt and Penny (1966), Madgett and Catt (1978) and Edwards (1981). They envisage the deposition of the Skipsea Till by an ice lobe originating in southern Scotland and flowing southwards along the east Yorkshire coast. The Withersea Till was deposited by an ice lobe originating in the Tees Valley, which overrode the Skipsea Till ice lobe and was transported on its back to southern Holderness (Carruthers, 1953). Glaciotectonic disturbance was responsible for folding of the Basement Till and overlying Dimlington Silts during the late Devensian ice advance. In addition, rafts of Skipsea Till are found included within basal Withersea Till (Catt, 1991).

Late Devensian sediments overlying the tills in Filey and Bridlington Bays have received little attention with respect to reconstructions of glacial depositional history. Varley (1968) and Bridger (1977) present general stratigraphical sequence and depositional history for Barmston. At this site Skipsea Till is overlain by discontinuous gravels, laminated silts and clays (varves), sands and gravels, shelly clays and then Flandrian peats and clays. Although considerable palaeoecological and archaeological work has been undertaken on the Flandrian succession, only provisional interpretations are available for the post-Skipsea Till pre-Flandrian deposits. The discontinuous gravels are regarded as glacial outwash, which has been cryoturbated, explaining 2-m-deep intrusions and pendant structures into the Skipsea Till. An undulating surface on the Skipsea Till and the discontinuity of the gravels are related to subaerial erosion. Catt and Penny (1966) report extensive gravels overlying the Skipsea Till, which they relate to outwash emerging from the boundary of the two-tiered Late Devensian ice sheet. These deposits presumably correlate with the ‘Gravels’ of Lamplugh (1879), Mitchell et al. (1973) and Edwards (1981), the ‘Interstratified Series’ of Lamplugh (1891) and the ‘Sand, Silt and Gravel’ of Bisat (1939, 1940; cf. Table 1).

The silt-clay laminae overlying the discontinuous gravels are regarded by Varley (1968) and Bridger (1977) as proglacial lake deposits and their coarsening upwards to sand-silt laminae and then sands and gravels are thought to indicate infilling of the lake basin. Ice wedge pseudomorphs in the sands and gravels indicate that permafrost existed after lake drainage. Further incision by proglacial outwash is indicated by cut and fills in the whole sequence (Varley, 1968; Bridger, 1977).
Table 1  Summary of east Yorkshire coast till nomenclature compared with the tripartite scheme of Madgett and Catt (1978)

<table>
<thead>
<tr>
<th>Dimlington Silts/Basement Till</th>
<th>Skipsea Till</th>
<th>Withernsea Till</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basement Till</td>
<td></td>
<td>Hessle Till</td>
<td>Lamplugh (1879)</td>
</tr>
<tr>
<td>Chalk rubble</td>
<td></td>
<td>Brown Till</td>
<td></td>
</tr>
<tr>
<td>Greenish-purple Till</td>
<td></td>
<td>Gravel</td>
<td></td>
</tr>
<tr>
<td>Upper Till</td>
<td></td>
<td>Upper Purple Clays (2 beds)</td>
<td>Bisat (1939, 1940)</td>
</tr>
<tr>
<td>Interstratified series</td>
<td></td>
<td>Gravels</td>
<td></td>
</tr>
<tr>
<td>Sand, silt and gravel</td>
<td></td>
<td>Lower Purple Clays (3 beds)</td>
<td></td>
</tr>
<tr>
<td>Upper Drab Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Drab Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalk rafts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Drab Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub Drab Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement Drab Clay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basement Clay</td>
<td></td>
<td>Hessle Till</td>
<td>Catt (1963)</td>
</tr>
<tr>
<td>Sub Basement Clay</td>
<td></td>
<td>Purple Till</td>
<td>Catt and Penny (1966)</td>
</tr>
<tr>
<td>Drab Till</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimlington Silts</td>
<td></td>
<td>Upper Till</td>
<td>Mitchell et al. (1973)</td>
</tr>
<tr>
<td>Basement Till (Series)</td>
<td></td>
<td>Unnamed Till</td>
<td></td>
</tr>
<tr>
<td>Chalk rubble</td>
<td></td>
<td>Gravel</td>
<td></td>
</tr>
<tr>
<td>Basement Till</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speeton Shell Bed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Till</td>
<td></td>
<td>Upper Till Series</td>
<td>Edwards (1981)</td>
</tr>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalk rubble</td>
<td></td>
<td>Lower Till Series</td>
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<tr>
<td>Basement Till</td>
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<tr>
<td>Speeton Shell Bed</td>
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</tbody>
</table>

Surficial geology and glacial geomorphology

The surficial geology of the study area is reproduced in Fig. 2, which has been extracted from the Geological Survey Drift Geology sheets 54, 55, 64 and 65 of 1881–1884. Summary sections for the Dimlington Stadial glacial deposits along the east Yorkshire coast and a comparison with Bisat's (1939, 1940) work is shown in Fig. 3. Two units relate to glacial depositional environments. First, the Dimlington Stadial ice margin is clearly defined by the edge of the till cover; the Yorkshire Wolds restricted penetration of the glacier inland (Fig. 1). Second, large pockets of sand and gravel with laminated silts and clays overlie the till. These glaciofluvial accumulations are interpreted by the authors as ice-marginal kames where they occur at altitudes of > 20 m OD along the north and south slopes of Flamborough Head (specifically the Speeton Hills and north of Bridlington). Elsewhere they occur below 20 m, forming discontinuous chains, which, in the Wansford–North Frodingham area, may represent beaded eskers or ice-marginal subaqueous forms. A quarry section in a bed at Gransmoor (National grid reference TA 127/395) to the northwest of North Frodingham, which was examined by the authors, reveals steeply dipping, cross-stratified sands and gravels with a general palaeocurrent from the northeast. Some flat areas of sands and gravels probably document the burying of subglacial features by proglacial lake sediments during the later stages of ice retreat.
Figure 2 Surficial geology of Filey and Bridlington Bay areas. After Geological Survey Drift Geology sheets 54, 55, 64, 65.

General stratigraphy and sedimentology

Methodology

Sediments were examined in coastal sections at Filey, Skipsea and Barmston on the North Yorkshire coast. Scale sections were constructed and vertical graphic sedimentary logs were measured by climbing the cliffs along gullies. These comprise highly variable diamictons, gravels and sands, and fine-grained laminated sediments. There is considerable lateral variation within individual sections and throughout the whole of the coastal exposures. Sediments are grouped into lithofacies associations (LFAs) based upon stratigraphical and sedimentological differentiation at each of the sites investigated. Samples were collected from each of the lithofacies to examine the characteristics and variation within individual LFAs. Pebble fabric of diamictons and the structure of deformed sediments were studied. Particle size distribution of sediments was determined by a combination of wet sieving and SediGraph methods, and particle shape (Rittenhouse, 1943; Powers, 1953) and lithology were also noted. Microfabrics of selected samples were examined using scanning electron microscopy.

Preparation of samples for scanning electron microscopy was quick and simple using the methods of Derbyshire (1978). Qualitative and quantitative guides, as well as the nomenclature of Owen (1989, 1994), were used to characterise the anisotropy and porosity of the microfabric (Table 2).

Filey Brigg

A section 46 m thick was examined in the cliffs of Filey Brigg (TA 126816). The section contains diamictons (LFA 1a and b) with highly variable characteristics and intervening beds of sands and gravels (LFA 2) (Fig. 4).

Two distinct diamictons can be distinguished within the section on the basis of sedimentological characteristics, although colour, grain size and lithological content vary (LFA1a and LFA1b Figs 4–6). A massive, matrix-supported diamicton (LFA 1a) lies unconformably on Jurassic Limestone and in some places partially fills fissures within the bedrock. Towards the eastern end of Filey Brigg the bedrock is deformed into complex overfolds and sheath folds that verge
Figure 3  Summary logs for the sediments recorded along the east Yorkshire coast compared with a reproduction of the sections recorded by Bisat during the early 1930s and 1940s (Bisat, 1939 and 1940).
Table 2 Micromorphology indexes

<table>
<thead>
<tr>
<th>Visual porosity index</th>
<th>Percentage of particles aligned subparallel to one another within the sediment matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Low</td>
<td>5–15</td>
</tr>
<tr>
<td>Medium</td>
<td>15–30</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>

Anisotropy index

<table>
<thead>
<tr>
<th>Anisotropy index</th>
<th>Percentage of particles aligned subparallel to one another within the sediment matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Medium</td>
<td>20–60</td>
</tr>
<tr>
<td>High</td>
<td>&gt; 60</td>
</tr>
</tbody>
</table>

southwest. Angular rip-up clasts of limestone are present within the lower 0.5–1 m of the basal diamicton. Diamicton LFA 1a occurs throughout the section but changes colour from dark brown (7.5YR 3/2) to very dark grey (5YR 3/1) (on dry samples) at 39 m above the base of the section (Fig. 4) after being interrupted by an outcrop of sand and gravel lenses of dark reddish brown (5YR 3/2) (LFA 2, see below). A thin bed of dark reddish brown (5YR 3/2) diamicton occurs at 19 m above the base of the section and is characterised by more subangular clasts than the other samples from LFA 1a (Fig. 4). Pebble fabrics in the massive diamictons reveal a northeast dipping trend (Fig. 7), although clustering is not strong (Fig. 8). Clasts within LFA 1a are mainly subrounded to subangular (Table 3) and many are striated. Some sandstone clasts are smeared within the matrix of LFA 1a. Particle size curves for four massive diamicton samples at 10 m, 16 m, 30 m and 45 m above the base of the section reveal a gradual coarsening upwards, demonstrating that the lithofacies' variability in LFA 1a is gradual (Figs 4 and 5).

A diamicton (LFA 1b) characterised by discontinuous laminae (DML) crops out between 17 m and 18.5 m and between 24 m and 28 m above the base of the section. In the lower exposure the laminae constitute anastomosing, irregular clay partings which are less than 1 mm thick but spaced every 5–10 cm between diamicton beds. The upper exposure is a banded diamicton with abrupt colour changes between beds centimetres to decimetres thick. In both laminated diamictons the contacts between beds are both depositional and erosional. A pebble fabric in the lower exposure reveals a strong bi-modal fabric aligned NE-SW (Fig. 7).

The microstructures of four massive matrix supported diamictons from within LFA 1a (sample numbers 3.7.6, 12.7.6, 2.7.6 and 8.7.6) and a laminated diamicton from within LFA 1b (5.7.6; Fig. 4) were examined. The massive diamictons comprise mainly fine-silt-sized platey grains which support the occasional sand grain and have a low porosity and a medium to high anisotropy. In sample 3.7.6 some of the larger sand grains (100–1000 μm) are coated with a layer of platy fine silts. Some of the silts form bridge-like structures to produce a honeycomb lattice work (Fig. 9a). Discontinuous microsills (Fig. 9b) are also present, dipping in a westerly direction; and in other areas the diamicton comprises coarser silts with a higher porosity (> 10%). Sample 8.7.6. comprises a more variable matrix characterised by platy silts with a high anisotropy and low porosity. However, some parts of
LITHOLOGY

- Silt
- Sand
- Pebbles & Cobbles
- Boudery Diamicton
- Silty Diamicton
- Sandy Diamicton
- Silty Pebbley Sediment
- Sandy Pebbley Sediment
- Bedrock

SEDIMENTARY STRUCTURES & BEDDING CONTACTS

- Massive bed
- Planar bedding plane
- Cross stratification
- Erosional contact
- Laminations
- Ripples
- Irregular contact
- Contorted bed
- Gradational contact
- Imbricated clast support cobbles
- Poorly defined stratification

Figure 4 Graphic sedimentary log for Filey Brigg. Fabrics F1 to F5 are shown on Fig. 7.

between and variability within each lithofacies association are complex and each is described in turn (Figs 11 and 12).

Lithofacies association 0 comprises matrix-supported diamictites with large numbers of edge rounded and striated clasts. The diamictites are highly consolidated and contain well-developed subvertical dilation joints. In some places a crude subhorizontal stratification or laminations can be recognised where wave action has differentially eroded the diamictite (Figs 11 and 12). Steep localised zones of shear can be recognised also by such weathering and where LFA 0 has been overthrust on to LFA 1 (Fig. 12). In addition, LFA 0 and LFA 1 are complexly folded at some locations.

Lithofacies association 1 comprises beds of at least 1.5 m of planar cross-bedded sands and gravels. These infill depressions and also form scours within LFA 0. More commonly LFA 1 forms veneers decimetres thick on the irregular surface of LFA 0 and is composed of poorly sorted, polymictic and matrix-supported conglomerates. Where LFA 1 is thicker, the lower units comprise decimetre-thick beds of planar cross-stratified and poorly sorted medium- to coarse-grained sands containing a few suspended pebbles and decimetre-thick beds of pebbly gravels. These units coarsen upwards into poorly sorted, polymictic and matrix-supported gravels. Small pebbles are the dominant clast within the gravels but large cobbles are present. The clasts are subrounded to rounded with a moderately high sphericity.

Lithofacies association 2 comprises centimetre- and decimetre-thick beds of sand, silt and clay (Figs 10-12). This LFA coarsens upwards and can be subdivided into two units on the basis of the percentage of clay beds present. Lithofacies association 2a has more than 30% clay beds, whereas the upper LFA 2b has less than 30% clay beds. The upper two units possess gradational contacts with each other and it is therefore difficult to draw an accurate contact between them.

Lithofacies association 2a is made up of centimetre-thick beds of laminated clays interbedded with centimetre-thick beds of rippled sands or starved sand ripples. Dropstones deforming clay laminae and clusters of fine pebbles and sand are present throughout the unit. Rare centimetre-thick beds of fine gravel also are present. Towards the top of LFA 2a some of the silts and sands display convolute bedding and have loaded underlying clays. Some of the silt-rich beds grade upwards into clays. Lithofacies association 2a overlies LFA 1 and LFA 0, infilling depressions and draping mounds of the diamictite. The bedding in the lower part of LFA 2a mimics the surface of the underlying LFA s and may dip as much as 20°. The bedding becomes less steep up section and it becomes subhorizontal to horizontal within 1–2 m of the top of LFA 2a. The sediment is faulted in places by centimetre-long non-persistent normal faults dipping in the direction of the slope of the upper contact of LFA 0 and 1.

Lithofacies association 2b is composed of centimetre-thick beds of climbing and planar rippled sands over which clays are draped, preserving the ripple morphologies. Towards the bottom of this association, however, some of the sand beds grade upwards into silts and clays. Towards the top of the association some of the sand beds display reverse grading. Large-scale convolutions are present along some of the horizons and many of these have become detached from their beds to form isolated pillow structures.

Lithofacies association 3 contains cross-bedded decimetre-thick beds of poorly sorted, matrix-supported polymictic gravels interbedded with centimetre-thick beds of poorly sorted, coarse sands and clayey sands. The association coarsens upwards into poorly stratified, matrix-supported cobbly gravels. Lithofacies association 3 fills scours within LFA 2, LFA1 and LFA 0 and locally it is overlaid by and

Bridlington Bay

Three main coastal sections along Bridlington Bay, two at the road end at Barmston (referred to as Barmston north and Barmston south) and one at Skipsea were examined.

Barmston north

At Barmston north (TA 17 1597) four main lithofacies associations were recognised and these comprise a basal diamictite (LFA 0), overlain by sands and gravels (LFA 1), in turn overlaid by thinly bedded laminated sands, silts and clays (LFA 2a and b). The sections are capped by a thick unit of gravels and coarse sands (LFA 3; Fig. 10). The contacts

...
interdigitates with LFA 2. Where LFA 2 overlies LFA 3 its bedding mimics the surface expression of the cross-bedded sands and gravels of LFA 3.

Barmston south

The same four lithofacies associations identified at Barmston north can be differentiated at Barmston south (TA 173593). However, the sections are more complexly deformed in many places (Fig. 13). Lithofacies association 0 is represented by matrix-supported diamicton which is at least 4 m thick.

Several distinct diamicton units can be differentiated within this association, which are not apparent at Barmston north, on the basis of colour, stratified sediments and apparent bedding. Metre-thick beds of massive diamicton are separated by crudely stratified diamicton or centimetre-thick beds of coarse sand and gravel. Contacts dip from 45° to horizontal with no preferred orientation. Several of the contacts are marked by boulder pavements (Clark, 1991). Chalk clasts are common within the diamicton and often form irregular clusters. Pebble fabrics display weak bimodal orientations in ESE–SE and WNW–NW directions (Figs 8, 13 and 14). Numerous complex fold structures occur in the diamicton.
Figure 6 Ternary diagrams for the particle size characteristics for selective diamictons from east Yorkshire.

near the base of the cliffs and are recognisable due to
differential weathering of coarser laminations.

The microfabrics of three samples from the massive matrix
supported diamicton (LFA 0) were examined (TS2, TS3 and
5.8.6.: Figs 13 and 15). The matrix comprises platy silts
which support subangular to subrounded sand grains.
The sediment has a low porosity and is partially overconsolidated
where silts and clays have been squeezed and sheared.
Anisotropy is high and in TS2 well-defined shear zones are
present (Fig. 15a). The main shear zones dip to the east, and
are characterised by strongly aligned platy silts, trending
subparallel to the main shear zones. Within the shear zones,
silt grains align symmetrically around sand grains to form
augen-like structures (Fig. 15c and 16). Sample TS3 has no
distinct shear zones, but in places silts are squeezed around
sand grains (Fig. 15b). Although the matrix in sample 5.8.6
has a rather homogeneous texture, an augen structure and a
chevron fold are present, clearly showing that it has been
deformed (Fig. 15c).

As at Barmston north, LFA 1 comprises massive polymictic
pebbly gravels and sands. The pebbles and occasional cobbles
are rounded to well rounded with moderately high sphericity.
Lithofacies association 1 infills the irregular surface of LFA 0
and forms regularly shaped elongate pendant structures that
penetrate several tens of centimetres to several metres into
the underlying diamicton (LFA 0) (Figs 13 and 17). Some of
these pendant structures have become detached from their
beds on the surface of LFA 0 and constitute isolated pods
within the upper 3 m of the diamicton. The corresponding
diamicton necks lying between the gravel pendant structures
have not penetrated into LFA 1 but in some places LFA 1
has been reduced to a bed only one clast thick due to sinking
of the pendant structures. At some locations the vertical axes
of the pendant structures dip northwards at angles of between
60° and 80° (Fig. 17). Where pendant structures are absent,
sands and gravels are cross-bedded.

The exposures of LFA 2, like those at Barmston north, can
be subdivided based upon clay content and are represented
by centimetre-thick beds of laminated rippled sands and
laminated silts and clays containing dropstones. Bedding
again mimics the topography of the underlying sediments
and may dip by as much as 30°. This bedding becomes less
steep up section as progressively younger beds onlap each
other.

Exposures of LFA 3 are far more restricted than at Barmston
north, constituting a wide channel-fill cut into LFA(s 0, 1 and
2 at the north end of the section. Here LFA 3 comprises
cross-bedded, matrix-supported cobble gravels interbedded
with pebbly sands and poorly sorted coarse- to medium-grained
sands.

Skipsea

Sections at Skipsea (TA 176573) exhibit predominantly diamictons
containing intrabeds of stratified sands and gravels which
have undergone various degrees of deformation (Fig. 18). A
composite stratigraphical log for Skipsea is presented in
Fig. 3. At the base of the sections exposed is < 2.5 m
thick, massive to laminated, matrix-supported diamicton,
which contains deformed sand lenses in its upper 1 m and
very thin sand and silt wisps towards the base. The sand/silt
wisps are essentially beds of only a few grains thickness that
can be identified by differential weathering of the exposure.
It is this apparent bedding that prompts the classification laminated diamicton. The intense folds that are identifiable through these laminae occur in the basal diamicton (Fig. 18). The axis alignments of the folds trend from 100° to 280° and the limbs dip at various angles towards the north and northeast.

This lower diamicton is separated from an upper diamicton by 1.5 m of interbedded sheared diamictons and heavily folded and faulted sand lenses with recognisable planar and trough cross-stratification and ripples (Figs 18 and 19a–c). The diamictons in this zone possess unconformable, or intercalated internal contacts and exhibit highly attenuated chalk fragments or smears. They are separated from the lower diamicton by a sharp unconformable contact. The intercalated contacts appear to have been produced by shear fault displacement at the boundaries between sand and diamicton beds. The interbedded sands and diamictons are separated from the upper diamicton by a thin shear zone less than 20 cm thick, which is marked by a massive diamicton possessing chalk and sand smears (Fig. 19c) and a gradational contact with the upper diamicton.

Figure 20 illustrates the pebble fabrics for diamictons at Skipsea shown in Figure 18. These fabrics are moderately strong and are bimodal, with pebbles dipping toward the west-northwest and east-southeast. These fabrics contrast sharply with the high anisotropy in the microfabrics (see below), which suggests that the pebbles have been orientated with the folded channel fills, whereas the microfabrics have retained the strong structures induced by ice shearing. Alternatively, they may have been realigned by the low pressure field set up by a subhorizontal channel in the deforming layer, similar to the mechanisms proposed by Alley (1991).

The microstructures of a massive matrix-supported diamicton (3.22.6: Fig. 18E), a laminated diamicton (4.22.6: Fig. 18A) and a laminated chalky diamicton (2.22.6: Fig. 18E) were examined. The microstructure is highly variable between samples. Sample 3.22.6 has a low porosity and a high anisotropy, with microshears dipping 45°–50° towards the east (Fig. 21a). Sample 4.22.6 has a platy silty matrix, with occasional subangular to subrounded sand grains. The matrix has a medium anisotropy and a low porosity, with some areas of the matrix being coarser in texture. A honeycomb lattice network of silts is present (Fig. 21b). Sample 2.22.6
is highly distinctive, characterised by subhorizontal discontinuous laminae varying from 100 \( \mu \)m to several millimetres in thickness, comprising diamicton and disintegrated chalk. The upper and lower contacts of the chalk laminations are generally sharp, with no interdigitation of laminations. The chalk laminations comprise moderately sorted, subrounded silt-sized carbonate grains. No grading is present and the fabric is essentially isotropic (Fig. 21c and d). Thin non-calcareous layers are present within some of the carbonate layers and comprise platy silts which have a high degree of anisotropy. The grains frequently align subparallel to the contacts of the chalk laminations and they commonly form anastomosing systems of interconnecting laminations (Fig. 22). Channel fills of cross-stratified coarse sands and gravels are present within the diamictons. These range from a few centimetres to several metres across and are up to 2 m deep. Undefomed fills have convex downwards lower contacts and planar upper contacts. Deformed fills are complexly folded with normal and reverse faulting displacing planar and rippled laminae. Centimetre- to decimetre-thick beds of stratified diamicton are also present within these channel fills.
Lamination within the diamictons is a result of attenuated chalk fragments. However, both streaked and undeformed chalk fragments exist in juxtaposition within the diamictons. The diamictons are folded parallel with the edges of the sand and gravel fills and small isolated pods of sand are present within the diamictons immediately adjacent to the channel fills.

Above the thin shear zone the upper diamicton passes from >1 m of laminated material, possessing wisps of sand and silt whose attitudes pick out highly attenuated sheared lenses and sheath folds, into >3.5 m of massive diamicton. The complete sequence at Skipsea probably correlates to LFA 0 at Barmston but correlation with LFAs 1 and 2 at Filey Brigg is made here only tentatively.

**Glacial depositional environments of the Dimlington Stadial**

Interpretation of LFAs 1a, 1b and 2 (Filey) and lower LFA 0 (Barmston and Skipsea)

Interbedded diamictons and discontinuous bodies of stratified sediments have been interpreted in various ways in the glacial sedimentological literature. Based upon these interpretations two hypotheses are proposed for the genesis of the east Yorkshire coast diamictons and stratified intrabeds.

Hypothesis 1 involves the deposition of lodgement and/or deformation till (Eson, 1962, 1989) followed by melt-out till production (Haldorsen and Shaw, 1982; Shaw, 1982). This sequence then can be further disturbed, perhaps before melt-out is complete, by glacial overriding or thickening to produce more deformed till (e.g. Evans, 1994).

Hypothesis 2 involves the vertical accretion of a deforming till layer associated with cavity/channel or pipe fills (Boulton and Hindmarsh, 1987; Clark and Walder, 1994). Migration of subglacial channels during accretion of deforming till layers produces internally disturbed intratill lenses of stratified sediments (Eyles et al., 1982; Alley, 1991).

Hypothesis 1 implies a period or periods of glacial activity punctuated by stagnation whereas hypothesis 2 is thought to reflect the normal drainage conditions beneath low-profile ice-sheet margins overlaying deformable beds (Boulton and Hindmarsh, 1987). In hypothesis 1 the diamictons are produced by lodgement and passive melt-out and therefore the resulting meltout tills largely retain the internal fabric of the former glacier (Shaw, 1979, 1982; Lawson, 1979). This fabric, as well as the stratified intrabeds produced by the melting of relatively clean ice layers, may be disturbed if the melt-out sequence is overridden (cf. MacClintock and Dreimanis, 1964; Evans, 1994). Alternatively, in hypothesis 2 the diamictons are produced by deformation of a subglacial till due to pervasive shear (Boulton, 1976, 1979; Humphrey et al., 1993) and meltwater evacuation can occur in pipes (Boulton and Hindmarsh, 1987; Alley, 1991) or in a system of braided 'canals'; the latter are broad, shallow streams incised into the deforming bed but possessing flat roofs of glacier ice (Walder and Fowler, 1994). Canal drainage occurs over soft sediments characterised by high clay content and where the associated ice-sheet margin possesses a shallow surface slope. If the ice margin is undergoing retreat and is thinning then tunnels or pipes can open up for short periods during the summer to produce stratified sediment ('minieskers': Alley, 1991). Although these pipes close during the winter due to sediment creep, the stratified sediments are preserved within the deformation till.

Therefore, the principal difference between the two hypotheses is that stratified intrabeds are taken to reflect stagnation in hypothesis 1 but active ice in hypothesis 2. The emplacement of stratified sediment within till units is common to both hypotheses but, based upon the deformation of the stratified intrabeds, hypothesis 2 is the most appropriate for the Filey and Bridlington Bay diamictons (Figs 13 and 18). The most important elements of the diamictons are the moderately strong fabrics and well-developed shear structures, laminations and smeared inclusions or wisps, and the deformation of the stratified intrabeds. In addition, the boulder pavements marking contacts within the diamictons at Barmston south may represent layers of high strain within the deforming till similar to those described by Clark (1991). Clearly, the channel fills were being deposited and being deformed during the accretion of the till.

Strong fabrics have been documented in lodgement, deformation and melt-out tills and often cannot be used exclusively in differentiating the various origins (cf. Lawson, 1979; Shaw, 1982, 1985; Dowdeswell and Sharp, 1986; Hart, 1994). Other evidence of intense shear during deposition, such as streaks or wisps, variants of cherts, and sand intratills and sand intratills, shear faults within stratified intrabeds, and laminations are all incompatible with a passive melt-out origin (Boulton, 1976; Kruger, 1979; Eyles et al., 1982; Dreimanis, 1989, 1993; Hart et al., 1990; Hart and Boulton, 1991), although
Figure 10: Graphic sedimentary log for sediments exposed at the southern end of the Burmaston north section.
Figure 11  View looking west at coastal sections north of the road end at Barmston showing the geometries and structures in the four main lithofacies associations.
Figure 12 View looking west at coastal sections approximately 100 m north of the road end at Barmston.

Figure 13 View looking west at the coastal section at South Barmston. Clast fabrics were taken at positions BF1 to BF6. Lithofacies codes shown in Fig. 18: a. Polymeric well-rounded gravels with planar low-angle cross-stratification decimetres to centimetres thick; b. planar beds of silt and clay centimetres thick — the bedding dips parallel to upper surface of the underlying diamicton and becomes less steeply dipping up-section, eventually becoming horizontally bedded; c. elongated gravel involutions within the upper part of the underlying diamicton — these dip northwards at an angle of about 60°; d. subtle partings in massive diamicton picked out by differential weathering; e. irregular pods of polymeric well-rounded pebbles and gravel, incorporated within the massive diamicton; f. coarse sands and clayey sands which become more clay-rich up-section — these are rippled with occasional flame structures; g. unstratified polymeric rounded to well-rounded cobbles and pebbles; h. cross-stratified carbonaceous clayey sands and poorly sorted matrix-supported gravels; i. box folds in clay and silt beds.
increased shear during a later phase of ice-marginal thickening/advance could create such features (Dreimanis, 1989; Evans, 1994).

The micromorphology of the sediment supports hypothesis 2. In the Filey Brigg section samples 2.7.6 (45 m up section) and 8.7.6 (19 m up section) are remarkably similar despite their different positions within the section. This suggests that they were formed by similar processes. Both of these have a high degree of anisotropy, low porosity and high consolidation, which suggests that the sediment was deposited subglacially and was subject to high strain. The sand grains in sample 3.7.6 (30 m up section) are coated with silt and are similar to augen structures, which suggests that the sediment has undergone intense shearing, although dewatering and rotational intergranular pervasive shear can also cause concentrically coated grains to develop. The lowest diamicton sample 12.7.6. (11 m up section) has a lower anisotropy within the microfabric and no shears, yet it has a strong macrofabric. This suggests that differential deformation has occurred in the sediment pile as it has been progressively deformed.

The laminated diamicton (5.7.6) within the middle of the Filey Brigg section has a variable anisotropy, which suggests that it underwent differential consolidation and disruption due to dewatering associated with meltout and deformation processes. The fine silts infilling spaces between grains of coarse silt and sand may represent areas of dewatering where fines accumulated in spaces after being translocated by high pore-fluid pressures. Alternatively, the zones of differential consolidation may be due to differential strain within the sediment as it deformed.

On the basis of microstructure the diamictons at Filey Brigg were deposited by active ice and were probably progressively deformed as ice flowed NE–SW over the sediment. The evidence for variable strains within the tills is probably a function of varying rates of deposition and deformation, and locally contrasting bed rheological conditions.
At Barnston, the high anisotropy, the shear and augen structures, and the high degree of consolidation within samples TS2 and 5.8.6 clearly show that these sediments have undergone glaciotectonic deformation, with the shearing mechanism being discrete and brittle. This helps support hypothesis 2, with efficient pore-water evacuation and drainage through the canal systems effectively ‘drying out’ the deforming layer, reducing saturation levels. Sample TS3, which is beneath TS2 has also been glaciotectonised although the deformation was less intense, producing a high anisotropy but no well-defined shears. Sample TS3 probably underwent less strain because of its lower position within the deforming sediment pile (Fig. 13).

The diamictons at Skipssea also have a variety of structures that are compatible with hypothesis 2. These vary from diamictons that have no unequivocal deformation structures and a medium anisotropy (e.g. sample 4.22.6), to diamictons with moderate shearing (e.g. sample 3.22.6), to tightly folded laminated diamictons with anastomosing shear systems (e.g. 2.22.6).

Sample 3.22.6 (LFA 0) is characteristic of the deformed stratified diamictons. Micromorphologically it comprises mixed matrices with easterly dipping microshears and a low to high anisotropy, with no volume reduction structures and no dewatering structures (indicative of meltout). This suggests that the sediment was possibly deformed under low strains, probably after it was deposited by ice and after it had dewatered. Zones of stratified chalky diamicton are common throughout the lower parts of the section. The origin of the chalky laminae and the stringers may be attributed to one of three depositional processes.

1. Deformation origin. Soft-sediment clasts are smeared within a deforming matrix, to produce stringers and boudins. Such laminae or stringers will show variable sorting depending on source material and will lack sedimentary grading and sedimentary structures. The contacts between laminae will be sharp, but interdigitation may be present due to differential deformation, thrusting or squeezing of one sediment type into the other.

2. Fluvial/subaqueous origin. Where primary sedimentary laminae are formed by subaqueous deposition. Laminae exhibit varying degrees of sorting and grading depending
on depositional mechanisms. Contacts may be erosional, depositional or gradational, and are more often laterally continuous, although discontinuous laminae also can be found and sedimentary structures also may be common. 3. A combination of 1 and 2 where deformation of pre-existing subglacial stratified or laminated sediment takes place as ice overrides the sediment soon after its deposition. The third explanation is favoured, the subglacial glaciofluvial and glaciolacustrine sediments being deposited in association with the diamictons in subglacial channels. This is consistent with hypothesis 2 because the sediments were englacially and subglacially deposited then deformed by overriding ice.

The microstructural work supports this explanation as well as the association of these diamictons with the sandy channel fills (see below). In sample 2.22.6, for example, the calcareous laminae are discontinuous and ungraded with no internal sedimentary structures, and have sharp upper and lower contacts. Non-calcareous laminae (diamictic) have a high anisotropy, often with particles in the matrix orientated subparallel to adjacent lamina contacts. These ‘diamictic’ laminae form anastomosing systems of discrete microsheets, derived from the lateral attenuation of the sediment matrix and soft-sediment clasts, and resulting from multiple, discrete brittle shear events. However, the internal structure of the chalky laminae did not show a high degree of anisotropy or any deformational structures, such as microsheets, possibly indicating that originally they were primary sedimentary structures. Nevertheless, this does not necessarily support a primary submarine origin for the laminae, as neither the diamicton nor chalky horizons display any form of grading; although this may be because the sediment source was uniformly sorted. Juxtaposition of underformed chalk clasts with streaked out chalk masses also supports differential shear within the deforming layer, which may be controlled by pre-existing subaqueous strata. Therefore, this sediment probably represents a stratified diamicton originally deposited in or associated with an aqueous subglacial environment that later underwent deformation due to ice overriding and shearing.

Considerable use has been made of stratified intrabeds or lenses in previous studies of diamictons (cf. Eyles et al., 1982; Shaw, 1982; Leven and Rutter, 1986, 1988; Alley, 1991) and both their primary and secondary features are critical to interpretations of diamicton genesis. Although the stratified intrabeds on the east Yorkshire coast have been folded and sheared, evidence that indicates considerable post-depositional disturbance, their shape can still be determined. They are convexo-planar, convexo-concave or irregular. The predominance of convexo-planar forms, with their flat upper surfaces, large width/depth ratios and inclusions of diamicton, suggests deposition in subglacial drainage pathways similar to the subglacioluvial cut-and-fill channels of Eyles et al. (1982), the canals of Clark and Walder (1994) and the mini-eskers of Alley (1991). Folding and shear faulting in the stratified sediments represent disturbance during the accretion of the overlying massive and laminated diamictons or deformation tills. The accretion of several till layers separated by stratified units may have been the product of lateral displacement of ice streams, as suggested by Eyles et al. (1982).

Although the intratill pipe fills (or mini-eskers) envisaged by Alley (1991) are subject to deformation induced by till creep after their deposition, they also may be disturbed by further incremental deposition of deformation till if the overlying glacier is re-activated. Such disturbance would involve lateral shearing and attenuation, as observed in the intratill lenses in this study. The intratill lenses at Skipsea contain intercalated beds of diamicton and sand lending support to Alley’s (1991, 1992) notion of till creep into the drainage pipes during low water flow. The creep of subglacial deforming sediment into subglacial channels or pipes has been modelled also by Boulton and Hindmarsh (1987), who envisage the formation of channels wherever sediment squeezing into the cavities/pipes is effectively removed by meltwater discharge.

The intratill stratified lenses within the diamictons on the east Yorkshire coast possess many of the attributes of the canal fills of Clark and Walder (1994) and the mini-eskers of Alley (1991). They are also very similar to the lenticular channel fillings of Eyles et al. (1982) from northeastern England. Given that the clay-rich tills of the eastern English coast were prone to intense deformation and that the attributes of strong fabrics, shear structures, truncated and shear faulted stratified lenses, laminations and smeared inclusions all indicate a depositional environment of high shear stresses, it is suggested that LFA 0 at Bridlington Bay and LFAs 1a and 1b at Filey Bay are tills deposited by an ice-sheet margin.
Figure 18 (A). View looking westward at coastal sections at Skipsea and (B)–(F) showing details of structures. Clast fabrics were taken at the positions F1 to F5. a, Deformed stratified poorly sorted coarse sands and pebbly sands; b, concentrations of chalk clasts; c, concentrations of rounded pebbles within the diamicton; d, deformed lenses comprising sand within a massive diamicton; e, massive diamicton with crude lamination picked out by subtle grain size variations; f, major discontinuity within the massive diamicton — this marks the upper zone of deformed sand lenses; g, strongly developed vertical joints; h, interdigitation of diamicton and sand; i, crudely planar stratified sands; j, laminated diamicton comprising streaks of red, grey brown and buff (2.5Y5/2, 10YR4/3, 2.5YR4/4); k, chalk stringers; l, laminated diamict on (10YR3/2); m, laminated diamicton (2.5Y5/2) with chalk stringers; n, chevron fold; o, stratified sand with thin 5–10-mm-thick interstratified diamicton; p, diamicton with a weak stratification at the base and chalk stringers subparallel to the lower contact; q, dark brown diamicton with chalk stringers, r, sand with stratification parallel to the overlying diamicton; s, cross-stratified sands; t, normal faulted sands; u, gentle folds dipping towards the base of the depression; v, light brown stratified diamict with sandy intercalations; w, folded stratified diamicton; x, concentrations of subrounded chalk pebbles, some of which are deformed into stringers within the diamicton; y, sand stringers within the diamicton; z, sandy diamicton interstratified with centimetre-thick beds of clayey sand folded into a recumbent fold; aa, deformed stratified clayey sands; ab, decimetre-wide stratified sand lenses with convex tops and flat bases; ac, deformed diamicton which are lined with sand 2–5 mm thick; ad, laminated diamicton grades into massive diamicton; ae, moderately to well-sorted coarse to fine sands; af, rippled medium sands; ag, deformed lenses of irregularly rippled sands; ah, fine to very coarse, poorly sorted clayey sands which contain pebbles towards the top of the unit; ai, stratified diamict interdigitated with sandy clay; aj, chalk stringer deformed by a diapir; ak, coarse to fine sands, low-angled cross-stratification deformed by small normal faults; al, smooth base of laminated diamicton parallel to the laminations of the underlying sands; am, massive to moderately to well-sorted coarse sands; an, faulted, stratified, poor–moderately sorted medium to fine sands.

Facies codes

Diamict, D:
DM : matrix supported
DC : clast supported
D-m : massive
D-s : stratified
D-g : graded
D-l : laminated

Sands, S:
St : rippled
St : trough cross-bedded
Sh : horizontal laminated
mg : graded
Sd : soft sediment deformation

Fine-grained (mud), F:
F1 : laminated
F-m : massive
F-d : with dropstones

Adapted from Eyles et al. (1983)
that was accreting and deforming the sediment. The intratill layers in LFA 0 at Bridlington Bay and LFA 2 layered sediments at Filey Bay probably represent sedimentation by meltwater draining through a system of braided canals or mini-eskers (diameters < 10 m) within the deforming substrate, as envisaged by Clark and Walder (1994) and Alley (1991).

If hypothesis 2 is the most appropriate to the east Yorkshire tills then aspects of the local glacial geomorphology must be taken into account with respect to the observations made by Clark and Walder (1994). Based upon the predictions of Walder and Fowler (1994), Clark and Walder (1994) have shown that eskers (diameters > 10 m) are largely absent in areas where intense bed deformation occurred during the last glaciation. Immediately inland from Bridlington Bay, in the Wansford–North Frodingham area, a large linear beaded form, which is probably an esker, together with the Kelsey Hill esker on Holderness (TA 236253; Catt, 1977) indicate that drainage did occur in a system of large subglacial R-channels at some time during glacier stagnation. Such an arborescent network of tunnels is regarded by Clark and Walder (1994) and Walder and Fowler (1994) to be more typical of a rigid substrate than a deformable one. That eskers and subglacial deforming tills are juxtaposed has been proved at the margin of Breidamerkurjökull, where Boulton (1979) monitored subglacial deformation in an area where several eskers are being uncovered by snout retreat (Price, 1969).
Figure 19  (c) Massive to laminated diamicton (LFA 0) possessing chalk smears and attenuated sand bodies, Skipsea.

Figure 20  Lower hemisphere stereographs of pebble fabrics for diamictons at Skipsea. The location of each pebble fabric is shown in Fig. 18.
In the Breidamerkurjokull situation it is apparent that the eskers have been deposited over ice, because their surface profiles have lowered considerably since deposition (Price, 1969). The corollary is that large eskers can form englacially but their internal structure may be considerably disturbed by melt-out. At Gransmoor the internal structures of the sediments in the possible Wansford-North Frodingham esker remain relatively intact, suggesting that if they did originate subglacially they were deposited on a non-deforming till. Clark and Walder (1994) suggest that R-channels and canals cannot exist simultaneously and, therefore, the occurrence of eskers in these situations may reflect large discharges in N-channels developed after a deformable till becomes overconsolidated or has been eroded down to the local bedrock. Intratill channels or mini-eskers do not develop into eskers wherever the substrate is still deforming and where accretion of till leads to canal switching. The Wansford-North Frodingham and Kelsey Hill eskers most probably represent a later period during deglaciation when large amounts of surface meltwater were reaching the glacier bed and when the substrate was more cohesive, perhaps overconsolidated. Alternatively, the esker represents deposition within a subglacial tunnel valley being excavated in the deforming layer (Boulton and Hindmarsh, 1987); evidence for tunnel valleys in this area of east Yorkshire has been presented by Valentín (1957).

Relationships between subglacial deforming layers and meltwater tunnel formation have been modelled by Boulton and Dobbie (1993) who suggest that the thickness of the deformable layer increases as till permeability decreases and drainage deteriorates. This initiates tunnel development in order to drain the till and maintain stable deformation, and relates well to the discrete microshear systems present within the diamictons. This model was tested by Boulton and Dobbie (1993) on tills on the Holderness coast, immediately to the south of the field area, where they found variability in the stiffness of tills between sites which was associated with variability in drainage path efficiency through the Chalk. Similarly, Alley (1991) predicts localized overconsolidation wherever meltwater channels occur, because they lower the water pressure in their vicinity. It is apparent from these theoretical considerations that an accreting till with an associated meltwater system of canals and/or mini-eskers will
produce an increasingly less permeable and more poorly drained substrate, leading to multiple stacked deformed tills and stratified intrabeds. This is particularly effective in east Yorkshire where an abundant source of clay-rich sediment exists offshore, or in an up-ice direction, so that deformable sediment was in constant supply at the ice margin where compressive flow led to net thickening of the deforming till after excavation offshore (e.g. excavational and constructional glaciotectonics; Hart et al., 1990).

The upper part of LFA 0 at Barnton south probably originated as an underconsolidated subglacial till during ice wastage, which then formed a debris flow diamicton loaded by outwash (LFA 1). This loaded mass advanced down the underlying slopes of the consolidated LFA 0 deformation till and, as the upper LFA 0 diamicton dewatered, it produced folds in LFA 1 which mimic the surface of LFA 0, and produced the dips in the pendant structures. The pendant structures possess none of the characteristics of ice wedge pseudomorphs and therefore are not indicative of permafrost conditions.

Meltwaters filled the depressions within the dewatering and gravitationally deforming upper LFA 0 to form either small ponds or a network of basins within a more extensive proglacial lake. These became infilled with rhythmites and cross-bedded sands and gravels. The rhythmites have steeper bed dips towards the base of LFA 2 because they were deposited within sag basins, which became less deep and


**EVANS, D. J. A.** 1994. The stratigraphy and sedimentary structures associated with complex subglacial thermal regimes at the south-

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**Conclusions**

Glacial sediments deposited during the Dimlington Stadial on the east Yorkshire coast form a complex sequence representing deposition during glaciation and stages of deglaciation (Fig. 23). On the basis of the sedimentology, the diamictons within the sequence are considered to represent deposition by active ice by vertical accretion of a deforming till layer with associated cavity/channel and pipe fills. At Barnston south the upper diamicton represents a debris flow of unconsolidated till associated with the stagnation of the ice margin. Rhythmic silts and clays, and cross-beded sands and gravels represent proglacial deposition in sag basins beneath deep water and a sandur associated with ice retreat.

The interpretation of these sediments in terms of their depositional environments questions the validity of previously published complex stratigraphies for the Dimlington Stadial sediments. This complexity is partially a function of the variability of colours and clast lithologies due to the reworking of pre-existing sediments. It is therefore proposed that the diamictons examined in this study are attributed to one formation and should be called the 'Skipsia Till Formation'.

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References


**BENN, D. I.** 1994. Fluted moraine formation and till genesis below steep as the tills settled, eventually producing an inverted topography. Meltout of buried ice also may have contributed to the setting although it is not necessary and there is little evidence for the large-scale faulting normally associated with meltout. Today, the highest parts of the cliffs have the thickest rhythmite sections.

The rhythmtes coarsen upwards indicating a shallowing and increasing energy within the sag basins as they began to fill and as the till settled. The presence of dropstones throughout LFA 2 indicates that the ponds or lake developed near the ice margin, where sufficient icebergs were available for ice rafting of sediments. Lithofacies association 3 represents proglacial channels that continued to change position throughout the depositional sequence. Where LFA 3 occurs within the rhythmite sequence, it comprises steeply dipping cross-bedded sands and gravels representing small Gilbert-type deltas.

The upper part of LFA3 comprises low-angled cross-beded sands and gravels representing sediments that were deposited on an extensive sandur. It is this sandur surface that is represented by the flat glacial sand and gravel areas on the surficial geology map in Fig. 2. A large ice wedge pseudomorph at Barnston north (Fig. 11) provides evidence of permafrost conditions during sandur deposition.


