3D Architecture and evidence of multiphase sediment fill within drumlins formed between a palaeo ice stream.

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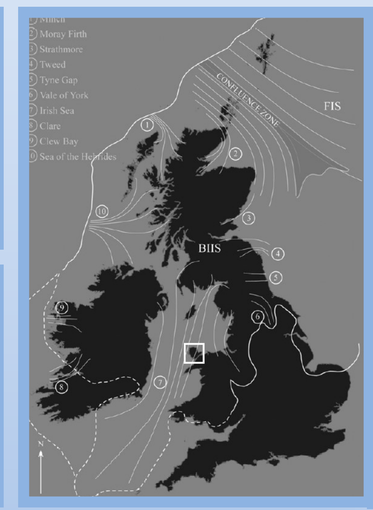
1. Introduction

Ice streams have an important capacity in determining the behaviour of ice sheets, taking the form of channels of fast-flowing ice. Areas of fast moving ice have also been recognised draining the margins of the Late Devensian British and Irish Ice Sheet. One of the largest of these palaeo ice streams, the Irish Sea Ice Stream (ISIS) (fig 1), fed ice from its source in southern Scotland, south through the Irish Sea Basin where it merged with ice issuing from the ice caps formed over Ireland, Wales and the Lake District, reaching as far south as the Isles of Scilly. Part of the distinctive 'footprint' left by this palaeo ice stream are the drumlins and related bedforms found near Cemlyn Bay, NW Anglesey, NW Wales.

2. Location and appearance

Two lengthwise coastal sections (15-20 m high x 200 m long) and one cross-section (25 m high x 30 m wide) through three drumlins exposed on the of north west coast Anglesey (fig 2) have allowed the detailed internal 3D architecture of these landforms to be investigated. The internal sedimentary architecture of the drumlins, coupled with the variation in till upward through the sequence has been used here to suggest that the landforms developed as a result of several phases of sediment-fill. This multiphase or pulsed model of drumlin development is thought to record the fluxing of sediment down-ice beneath this part of the (ISIS).



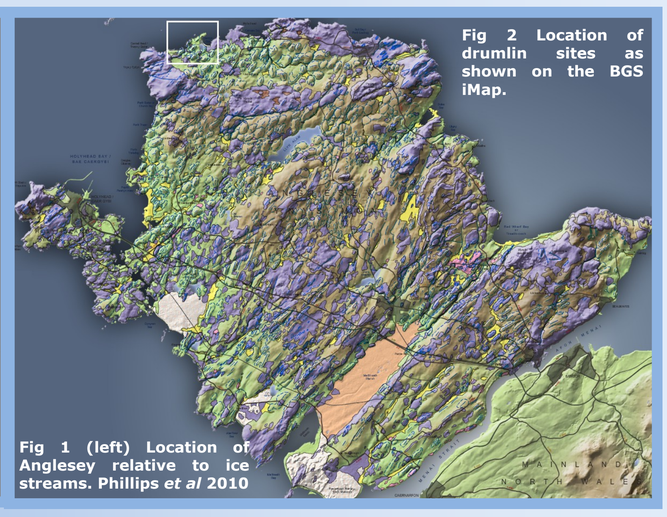


Fig 2 Location of drumlin sites as shown on the BGS iMap.

Fig 1 (left) Location of Anglesey relative to ice streams. Phillips *et al* 2010

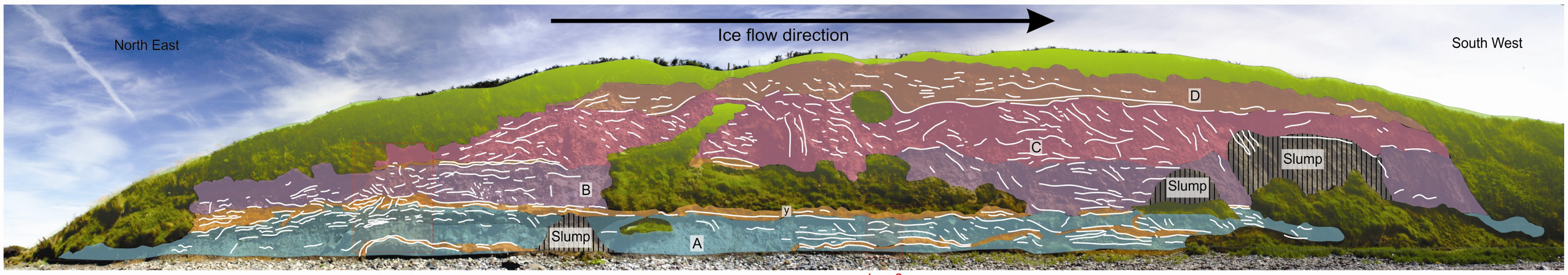
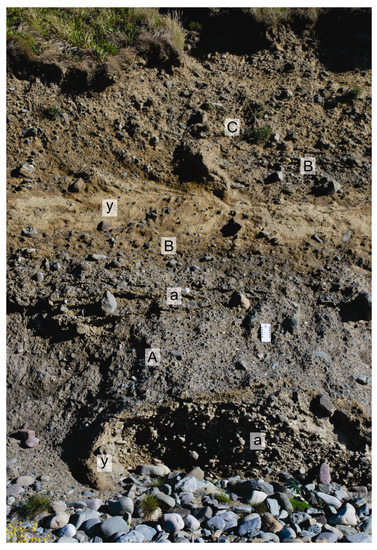
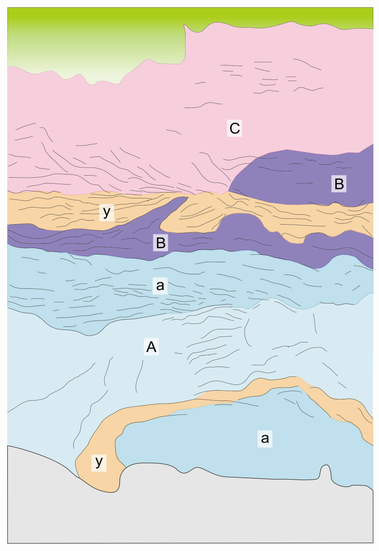


Fig 3

Log 1

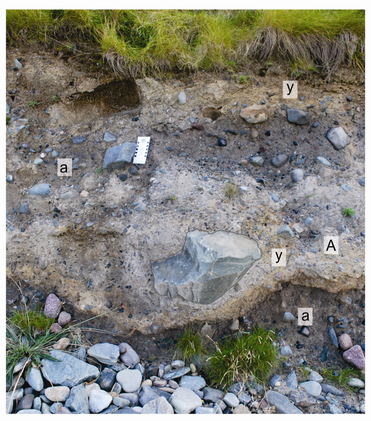


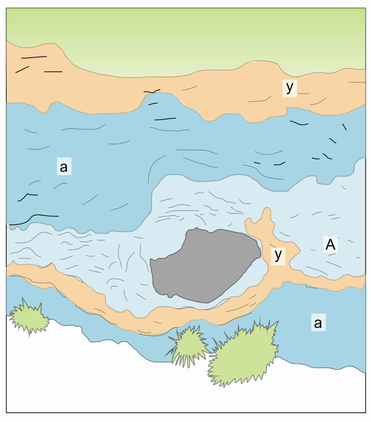


Matrix rich bluish grey till (A)
Hydrofractured bluish grey till (a)
Clast rich bluish brown till (B)
Matrix rich redish brown till (C)
Sand rich hydrofractures (y)
Till fabric
1 m

Fig 4

Log 2





Matrix rich bluish grey till (A)
Hydrofractured bluish grey till (a)
Sand rich hydrofractures (y)
Till fabric
1 m

Fig 5

3. Sediments and structure

The sediments and structures contained within these subglacial landforms provide a comprehensive record of the phases and processes occurring beneath the ISIS. The drumlin examined in Cemlyn Bay (fig 3) has a till sequence which comprises at least four layers, each one representing a different accretionary phase. The initial deposition occurred onto the blue-green metasedimentary rocks of the New Harbour Group (NHG). The pervasive tectonic foliation (schistosity) developed within these rocks occurs at approximately 90 to the ice flow direction.

- **Unit A** is a weakly stratified diamicton and contains mainly locally-derived striated angular clasts. It is supported by a stiff grey-blue silty matrix. (fig 5)
- **Unit B** silty blue grey as above but with a lower proportion of matrix creating a clast-supported unit towards the top of the layer. (See fig 4 & 5.)
- **Unit C** is composed of a sandy, red-brown stratified, matrix-supported till containing a higher proportion of far-travelled striated clasts than the lower two units.
- **Unit D** contains sub-rounded, far travelled striated clasts and a red-brown sandy matrix as above, but there are again fewer fines towards the top.

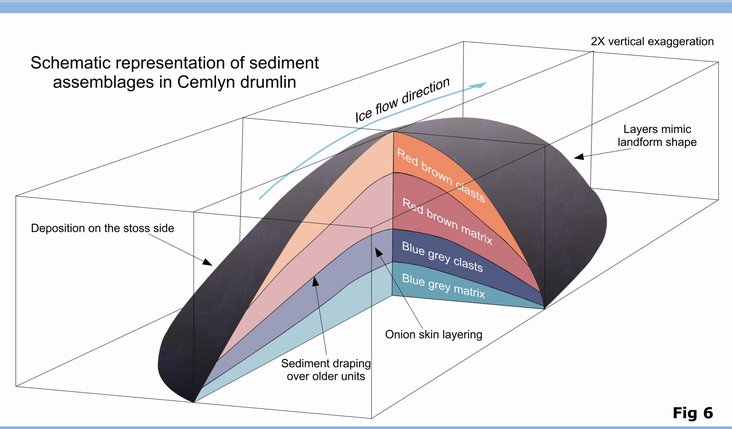


Fig 6

Throughout the whole section, but more prolific towards the base, there are laterally extensive sub-horizontal and inclined fractures infilled by laminated sand and silt. These sand and silt fractures cut through parts of the till sequence and are interpreted as sediment-filled hydrofractures. These may have formed as the weight of the overlying ice decreased and sediment was injected during the thinning of the ice sheet and therefore are a feature of deglaciation. The sediments within the hydrofractures are more highly cemented (carbonate) than the adjacent till and contain variably deformed clasts and stringers of this diamicton. There appear to be several phases of hydrofracturing as thinner older fractures are truncated by newer often larger features. At Cemlyn there is a large sandy hydrofracture between the grey till units and the browner younger ones.

Field evidence suggests that the internal structure of the drumlins comprises several curved shell-like layers which taper off at both the stoss- and lee-side of the feature (see fig 6 and 8). These onion skin type layers indicate that material is being deposited over the whole landform at once rather than just down-ice of the feature.

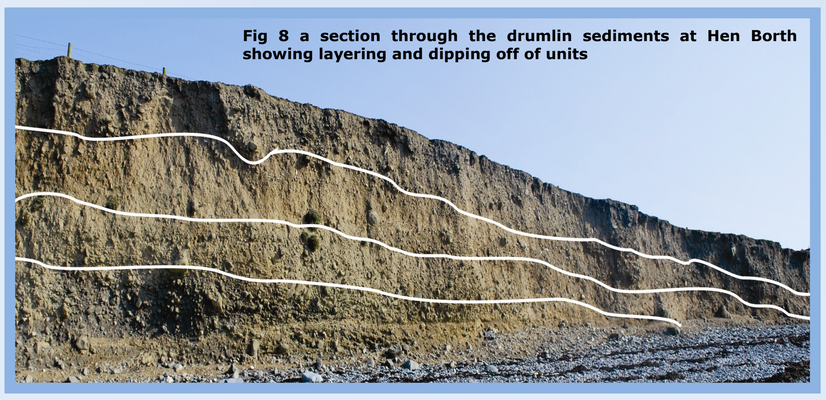


Fig 8 a section through the drumlin sediments at Hen Borth showing layering and dipping off of units

4. Phases of growth and deglaciation

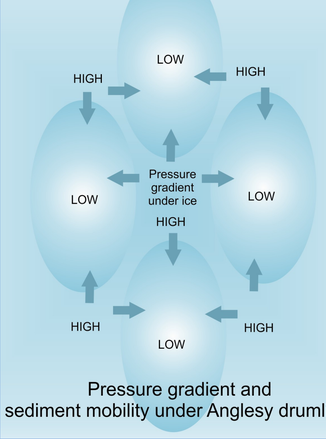
This island of Anglesey is a topographic high in relation to the Irish Sea to the north which may have caused a loss of energy and sediment deposition at the base of the ice stream as it moved over this high. The structural 'roughness' of the NHG could have acted as a preferential zone for sediment deposition. In areas of differential pressure beneath an ice stream sediment is likely to be displaced from areas of high pressure to areas of low pressure (fig 7). Accretion across the whole of the landform would then be possible and would allow for a smaller amount of sediment mobility than had been previously assumed. If the whole drumlin was mobile then this preservation of till structure would not be possible, it is likely that only the very top layer would have been lubricating the base of the ice.

A clast-rich or boulder pavement is locally developed at the top of the individual layers of diamicton. These may have formed due to the removal (winnowing) of the finer grained matrix by meltwater flowing along the ice-sediment interface. This suggests that there may have been marked breaks in subglacial sedimentation and therefore the development/growth of the drumlin.

The mimicking of the landform by the layers of till suggest that the units were deposited in several phases as opposed to a single event. These layers may have formed as different amounts of sediment were fluxed down glacier and deposited over the previous one.

The hydrofracturing occurred during the later stages of landform development possibly due to decompression associated with thinning of the overlying ice sheet during the early stages of deglaciation or shutdown of the ice stream. During this time, pressurised meltwater migrated upwards through the till pile and as a result hydrofracturing occurred.

Fig 7



Pressure gradient and sediment mobility under Anglesy drumlins

5. Conclusion

- Drumlins are likely to form by a range of sub-glacial mechanisms and the geomorphology may occur through a variety of processes resulting in the same overall form.
- The different till layers in the sedimentary record indicates phased stages of deposition.
- Hydrofracturing occurred in the latter stages of landform development suggesting that the ISIS was thinning prior to deglaciation.