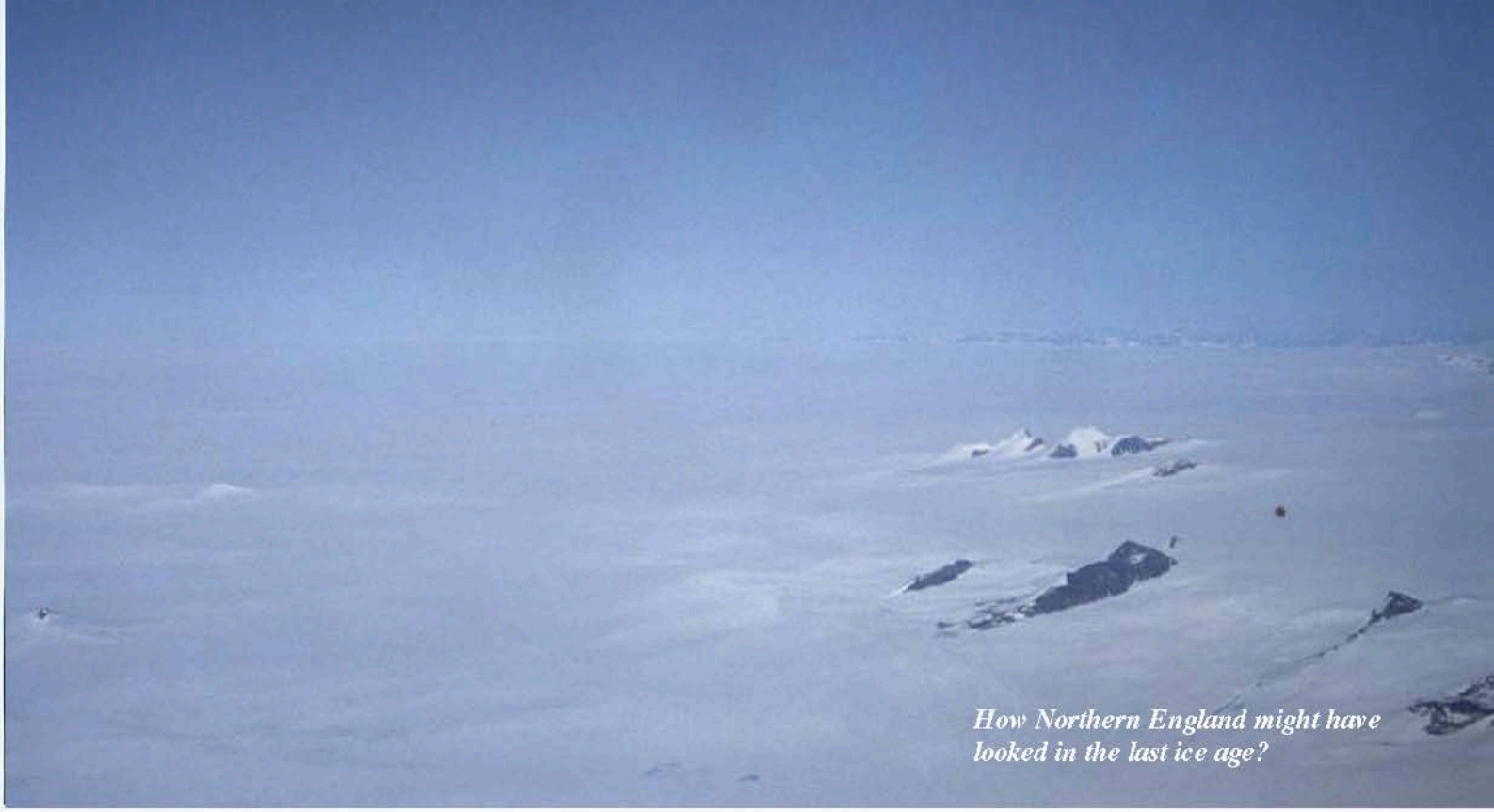


How Northern England might have looked in the last ice age?

The Ribblehead drumlins

Wishart Mitchell

Drumlins are distinctive landforms associated with ice sheets that formed during the Pleistocene glaciations. Drumlins may be used to reconstruct ice sheet dynamics, as Wishart Mitchell explains using an example from northern England. This article will be of interest to all those studying glaciation at AS or A2.

Drumlins at Ribblehead looking towards Ribblehead viaduct with Whernside in the background. The drumlins here indicate southwest flow into Chapel-le-Dale

Ice sheets are one of the more obvious and dynamic parts of the **cryosphere** and are extremely sensitive to climatic change. They form when it is cold enough for precipitation falling as snow to accumulate and thicken to form an ice sheet thousands of metres in thickness. Gravity drives flow away from accumulation areas and the ice sheet advances and retreats in response to changing temperatures and precipitation.

It is extremely difficult to understand the mechanisms of present ice sheet flow since the important area of study is at the base, in the **subglacial** environment. The former beds of the last Pleistocene ice sheets are more accessible and can be studied to understand ice sheet dynamics – this is important given the sensitivity of the

present ice sheets to impending climate change.

Drumlins are a distinctive landform reflecting the former dynamics of ice flow in the subglacial environment. In profile, they present a smooth, elongate outline and in plan view they form discrete oval to elongate shapes (Figure 1). In both plan and profile the overall impression is of streamlining, with the long axis of the drumlin aligned to former ice flow direction. A field of drumlins is often referred to as 'basket of eggs' topography because of the way it appears in the landscape.

Drumlins in the UK formed under an ice sheet that completely submerged the landscape and may have been up to 1 km in thickness at its maximum extent about 20,000–25,000 years ago. Today, along with many other landforms in northern England, they are relict landforms, reflecting the deep chill that overcame this landscape during the last glaciation.

Drumlin formation

Although it has long been known that drumlins formed beneath ice sheets in the subglacial environment, the exact way in which they originated remains a matter of debate. Early explanations suggested that both erosional and depositional glacial processes were involved in their formation. Recent research has improved our understanding of the interaction between an ice sheet and the underlying bed. Here an interface is formed that can be thought of as a zone where the stress of the overlying ice influences the underlying material. This material may be either bedrock or previously deposited sediments, and these respond in different ways. Unconsolidated sediments are unable to resist the stress imposed by the ice, leading to **deformation** of the material to form drumlins.

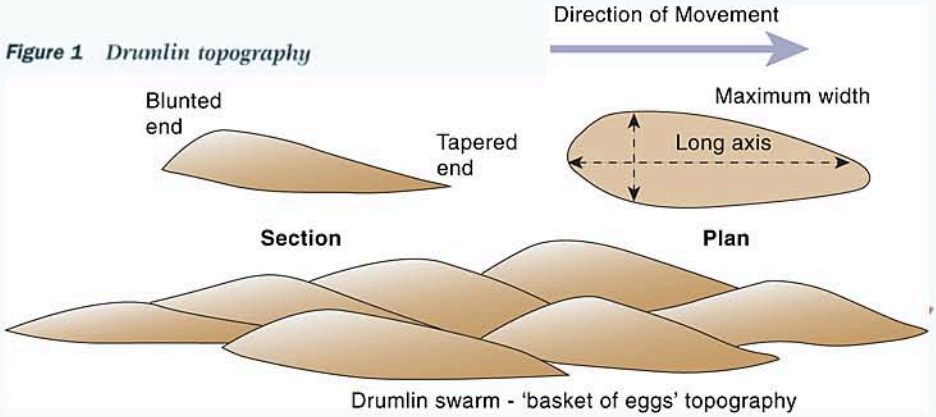
Mapping drumlins

Using these landforms to reconstruct the extent and flow directions of the former ice sheet requires detailed maps of their distribution. Mapping drumlins can be done easily in the field using either 1:25,000 or 1:10,000 scale Ordnance Survey (OS) maps. The key elements of a drumlin that are recorded are:

- the break of slope at the bottom of the drumlin defining its plan shape
- the orientation of the long axis
- the location of the highest point on the long axis

These are plotted directly on to a map using topographic features or a GPS for accurate location. Use of aerial photographs and digital elevation models (DEM) can allow rapid plotting of long-axis orientation over large areas.

Figure 1 *Drumlin topography*



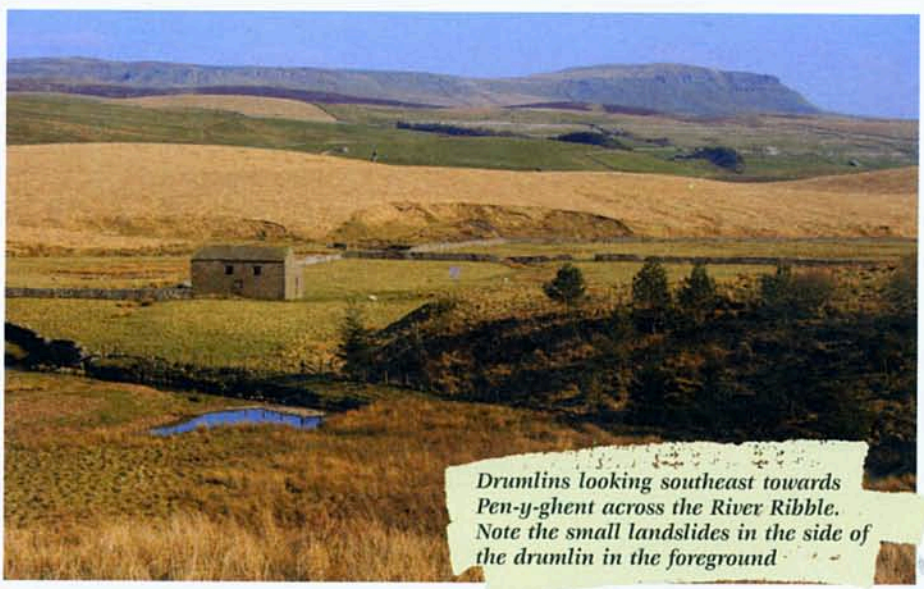
Accurate delimitation of the basal break of slope is important to allow meaningful measurements of the individual drumlin in terms of length, width and area. These basic measurements can be extended by calculation of the **elongation ratio** of the drumlin. This is the ratio of length (L) to width (W) (L/W) and defines a range from a near circle (~ 1) to a long but thin drumlin (>4). Elongation is an important parameter that can be related to the former stress field and velocity of the ice forming the drumlin. The derivation of topographic indices is known as **morphometric analysis.**

Ice sheet reconstruction

Measurements of individual drumlins can be used to reconstruct some of the characteristics of the former ice sheet. The orientation of the drumlin long axis indicates the former ice flow direction. This is usually used in conjunction with other indicators such as **erratics** and **striations**. Another important aspect of flow direction that has been seen through mapping is the existence of drumlins with multiple long axes. These have been defined as **superimposed drumlins** and record changes in ice flow direction during a glaciation – this has been shown to be important in identifying flow events reflecting changing significance of different flow centres.

Equally important is the overall size and elongation of the drumlins. Size is usually attributed to stability of flow over a long time, allowing deformation to continue increasing drumlin length. However, the size must be controlled by the deforming bed layer and there is probably an upper limit to drumlin dimensions. More apparent is the increased elongation of drumlins within certain parts of a drumlin field, suggesting that elongation reflects increases in stress and basal ice velocity away from ice accumulation areas and frictional effects associated with lateral ice margins. Velocity is found to increase along flow trajectories at right angles to the orientation of the ice divide.

Drumlins can be used to identify the location of a number of key components of former ice sheets. **Ice divides** are source areas where the ice accumulates. They are characterised by areas of low basal stress with the ice frozen to its bed, meaning that there was no bed deformation. In these accumulation areas there will, therefore, be no drumlins. However, the location of ice divides can be worked out by looking at the orientation of drumlin fields away from these areas.



Drumlins looking southeast towards Pen-y-ghent across the River Ribble. Note the small landslides in the side of the drumlin in the foreground

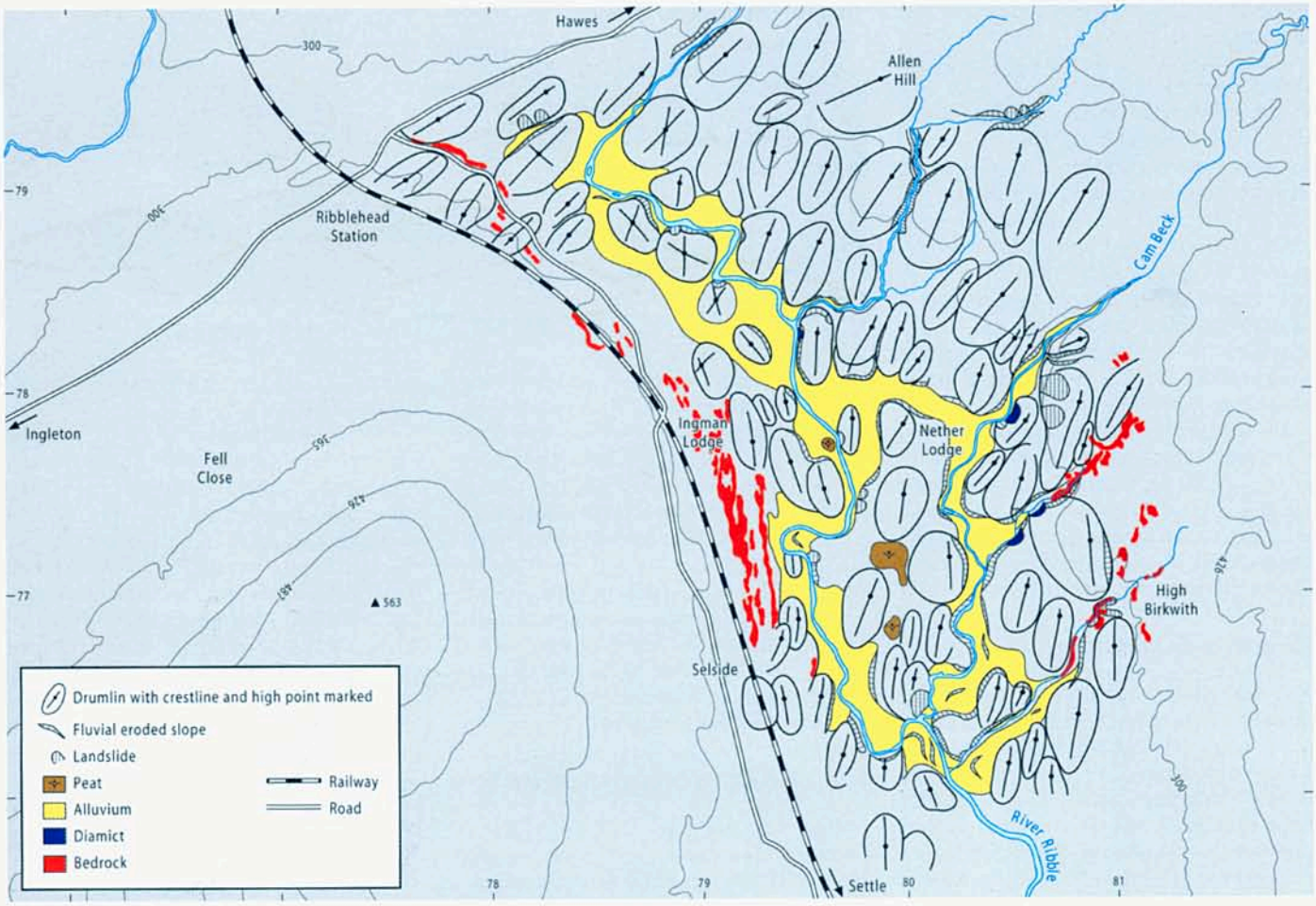


Figure 2 *Geomorphological map of the glacial landforms around Ribblehead*

Source: Original field mapping completed at 1:25,000 scale, based on a 1:25,000 First series OS map. OS National Grid coordinates. © Crown copyright AM94/07.

Drumlins can also be used to work out the linear zones of fast ice flow called **ice streams** that are responsible for most of the transfer of mass through the ice sheet. From the study of present-day ice streams in Antarctica and Greenland, it can be shown that conditions under ice streams would have created enough basal stress to allow deformation of the ice sheet bed and the formation of drumlins.

Drumlin fields often stop abruptly at well-defined lateral margins – this can be explained as the point where the side of a fast-moving ice stream slipping over its bed met ice frozen to the bed that was moving much more slowly. The drumlin limit therefore indicates where bed deformation stopped. Changes in stress levels down-glacier may also mean that drumlins are not formed towards the ice margin.

Detail of drumlins looking southeast towards High Birkwith showing that the drift cover that makes up the drumlins is relatively thin. This allows exposure of the limestone bedrock

The Ribblehead drumlins

In northern England, drumlins are a characteristic landform associated with the last ice sheet. There are extensive fields or swarms of drumlins in many of the valleys in the Pennines and surrounding lowlands. One of the better-known drumlin fields occurs in the upper part of the Ribble valley, from Horton-in-Ribbledale upstream towards Ribblehead. Although this drumlin field has been known since the early days of geological mapping and has been mentioned in numerous papers and illustrated by aerial photographs, there has been no attempt to produce a detailed geomorphological map of the landforms. This would allow an evaluation of their potential in reconstructing former flow lines for the ice and the establishment of former ice divides in this part of the Yorkshire Dales

Ribblehead is an outstanding area to illustrate drumlins and their significance in

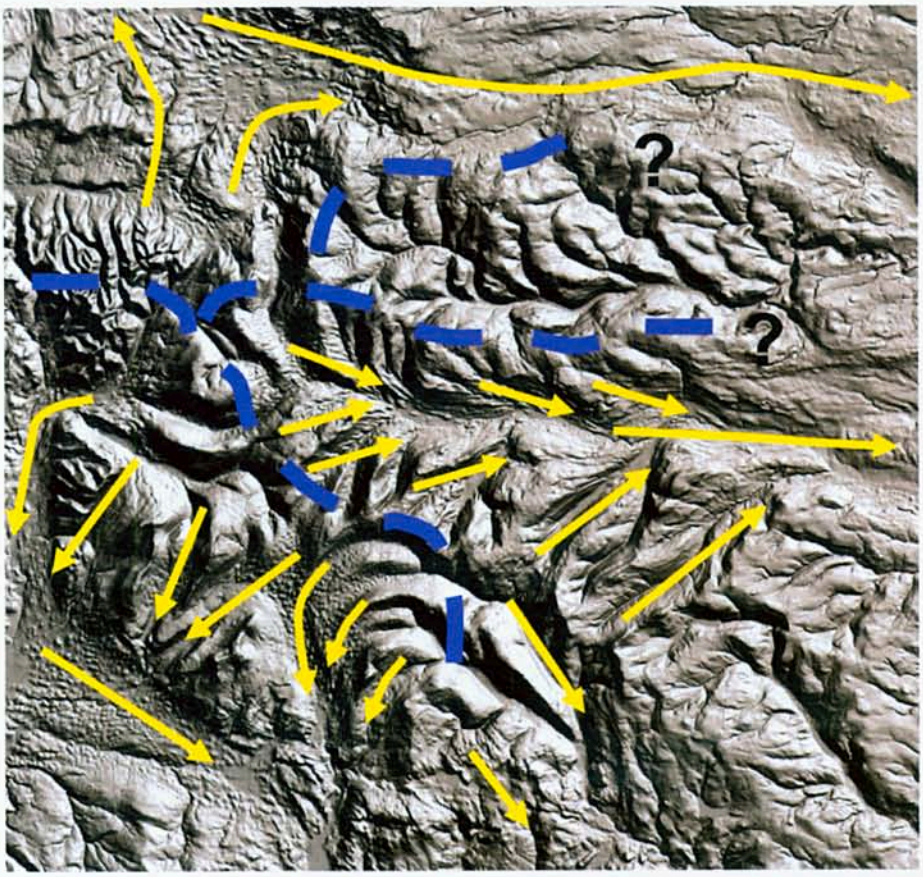


***Figure 3** Ice flow directions (yellow) derived from drumlin orientation and former ice divide (blue) in the Yorkshire Dales. The base map is a digital elevation model (DEM) which is a hill shaded image illuminated from the northeast*

Source: Generated from the Land-Form PANORAMATM with illumination from NE. © Crown copyright AM94/07.

ice sheet reconstruction. Drumlins are well developed from the present interfluve area to the north between Wensleydale and Dentdale. From here drumlins extend southwards across Blea Moor to the northern edge of Ingleborough where they bifurcate, with one former ice flow southwest down Chapel-le-Dale towards Ingleton, and a second former direction into the present Ribble valley towards Settle (Figure 2). It is important to appreciate that the drumlins do not only occupy the valley floor but also form a continuous cover across slopes to elevations greater than 500 m OD. This shows that the ice sheet was flowing independently of topography. For example, drumlins occur over most of the ground of Gayle Moor, on either side of the Ingleton–Hawes road, indicating former southwards ice flow from Wold Fell that formed part of the ice divide and dispersal zone along the southern side of the Wensleydale ice stream.

In the area of the upper River Ribble from Ribblehead towards Horton-in-Ribblesdale, drumlins are well developed on the eastern side of the river. They create a number of distinct forms, many of them, such as High Rigg and Ling Gill Rigg, quite large and individually named on the 1:25,000 OS map. Smaller drumlins are found nearer the river, such as the drumlins that surround Selside Moss. A number of drumlins have been modified by the river eroding the basal slopes, steepening the sides that have then often failed as small landslides.

At Ribblehead, interesting changes in flow direction are recorded by the drumlin long axes. First, there is a clear southwestwards trend in the drumlins nearest Ribblehead, indicating former ice flow into Chapel-le-Dale that can be clearly seen by the drumlins at the road junction. A second major flow set records flow convergence into the Ribble with a south-southwesterly flow becoming dominantly southerly towards Selside and High Birkwith (Figure 3). However, there are superimposed drumlins near the sharp northeastern turn of the River Ribble that reflect changes in the relative importance of ice flow into these two valleys at different times during the last glaciation.

Glossary

Cryosphere The parts of the Earth where temperatures are so cold that all water is in its solid form as ice.

Deformation When material begins to change its shape due to the application of an overlying stress exceeding material resistance.

Erratics Rocks within glacial sediments or on a surface that are different from underlying bedrock. They can be used to reconstruct former flow paths if their source area is known.

Ice divide A linear dispersal centre within an ice sheet from which the ice flows. Ice velocity at an ice divide is zero. Equivalent to a watershed in a river basin.

Ice streams Linear channels of fast-flowing ice between zones of slower-moving ice. They are related to bed conditions where the basal ice is melting, leading to slippage and bed deformation.

Morphometric analysis The measurement of key characteristics of landforms such as size and shape to generate numerical data allowing statistical investigations of geometric relationships.

Pleistocene glaciations Period of geological time from 1.8 million years to 10,000 years ago characterised by expanded glaciations when ice sheets covered large areas of the Earth's surface due to the cold climate.

Striations Scratches on a boulder or rock surface caused by abrasion by particles carried by the overlying ice.

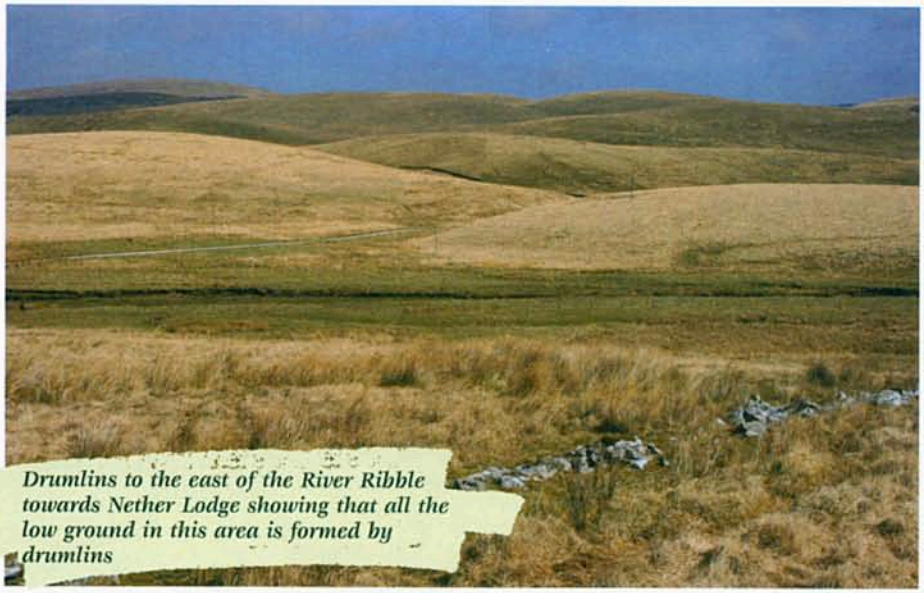
Subglacial Underneath a glacier or ice sheet.

Superimposed drumlins Drumlins with multiple crest-lines at different orientations indicating modification of the original drumlin by changing flow directions during glaciation.

Reconstructing the last British ice sheet

The present landscape of the north of England cannot be understood without considering the legacy of the last ice sheet that covered much of northern Britain and Ireland (Figure 4). The Ribblehead drumlins form part of a much wider distribution of drumlins in northern England. From the distribution of drumlins and other evidence such as erratics, it can be shown that the Lake District and Yorkshire Dales formed an important linear ice divide that was a major source area within the last ice sheet. The distribution of drumlins shows that this ice sheet was independent of topography — flow occurred across and up some valleys.

Reconstructed flow lines indicate that, in the Yorkshire Dales, there was a major ice stream occupying Wensleydale, flowing eastwards towards the Vale of York and the North Sea. Northwards flow across the topography was part of a composite flow



Drumlins to the east of the River Ribble towards Nether Lodge showing that all the low ground in this area is formed by drumlins

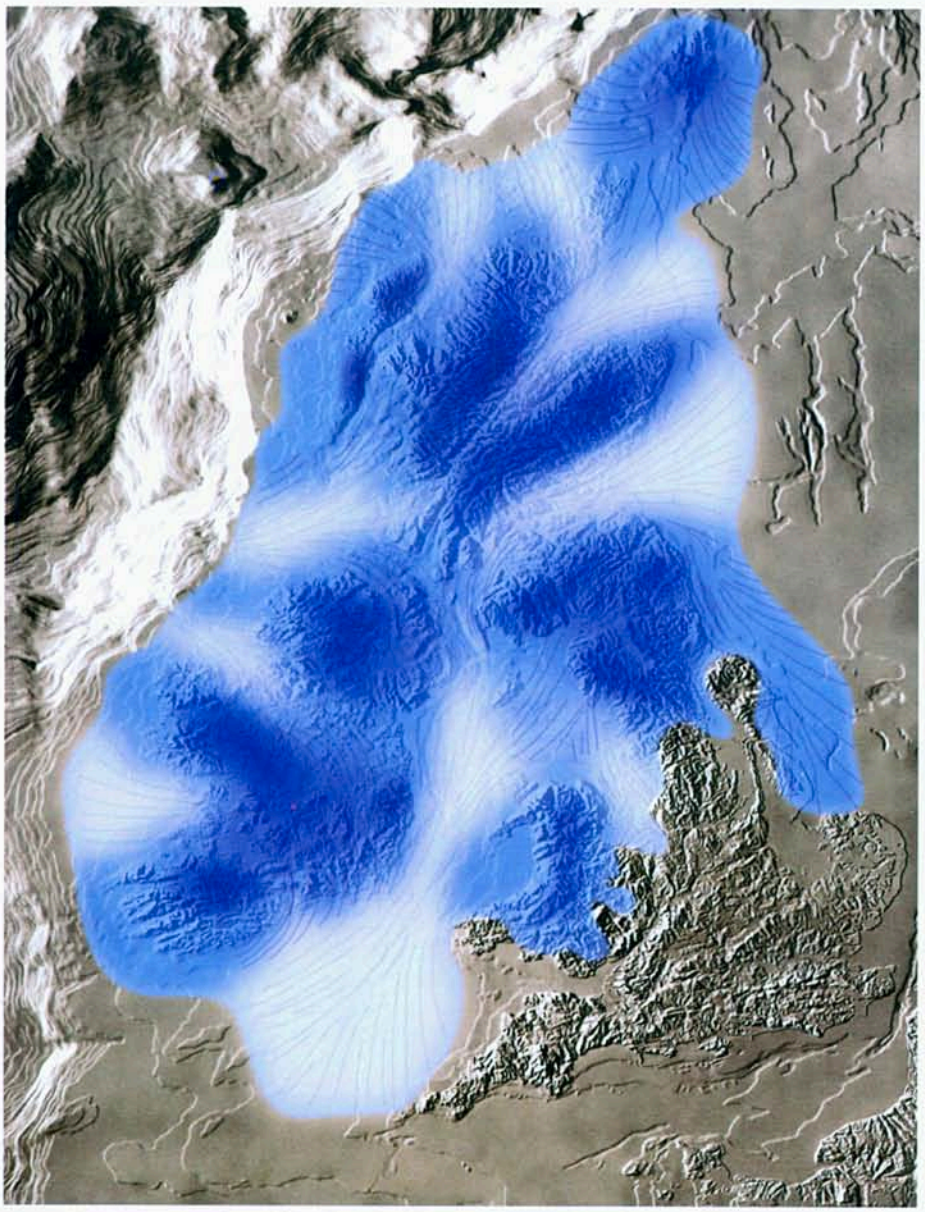


Figure 4 *Reconstruction of the last British ice sheet, derived from many sources. The main source areas appear dark blue and ice streams are white*

through Stainmore. The southern flow pattern from this ice divide, of which the Ribblehead drumlins are part, occupied the southern part of the Yorkshire Dales before leaving the uplands and forming a complex flow pattern in the surrounding lowlands as part of the eastern sector of the Irish Sea ice stream.

Points for discussion

(1) Research the idea of 'ice streams'. Consider their importance in ice sheet dynamics with respect to the present Antarctic ice sheets.

(2) Consider why studying the bed conditions of former ice sheets may be important in understanding the flow dynamics of current ice sheets.

(3) Think about the role of past glaciation in the formation of the present landscape.

Further information

The BRITICE website is a record of the known distribution of landforms associated with the last British ice sheet: **www.sheffield.ac.uk/geography/staff/clark_chris/britice.html**

Further information on Antarctic ice streams can be found at: **www.antarctica.ac.uk/about_antarctica/geography/ice/streams.php**

www.sciencenews.org/articles/20070331/bob9.asp

Further information on drumlins can be found at: **www.physicalgeography.net/fundamentals/10af.html**

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Key points

- Drumlins reflect the interaction between bed material and the stress of the overlying ice leading to deformation of the bed material and the formation of bedforms across large areas of the subglacial environment.
- The distribution of drumlins can be used to reconstruct the flow directions of former ice sheets and allow the identification of the location of ice streams and source areas.
- The drumlin fields in the north of England indicate that the area was an important source area of the last British ice sheet. Ice from the Lake District and Pennines flowed from this area southwards into the Irish Sea basin, towards Birmingham, down the Vale of York and into the North Sea.