Introduction
The physical landscape of the UK has evolved over billions of years. The oldest geology, the ancient metamorphic gneisses of north-west Scotland are at least 2.7 billion years old. There is evidence of an ancient destructive plate boundary in the Lake District and a constructive one on Arran.

Much of the UK landscape evolved much more recently, during the Quaternary geological period. It has been subtly modified by weathering and erosion since, but the well-loved upland landscapes of the Highlands, Lakes and Snowdonia are basically relict glacial landscapes. Even in lowland areas, glacial and periglacial processes are largely responsible for today’s landscape. The landscape legacy of the Quaternary is remarkably varied.

Keyword: Relict
Landslapes are described as relict when the physical processes which formed them ceased some time ago. They might be described as ‘fossil landscapes’. In the Lake District today there is a temperate climate and the dominant physical processes are fluvial (river action) not glacial, but the landscape is dominated by ancient glacial landforms like arêtes, corries and glacial troughs but these are no longer being actively formed.

Timescales
The Quaternary geological period spans the last 2.6 million years and is divided into two epochs, the Holocene and Pleistocene. The Holocene epoch began around 12,000 years ago and continues to this day. The Pleistocene epoch was characterised by regular climate fluctuations. The impact of this changing climate was to produce cold periods (glacial) and warmer periods (interglacials). Our current Holocene climate is one of these short, warm, interglacials called the Flandrian. During glacial periods ice developed in the UK’s uplands and advanced south across the land. This happened 10 or more times during the Pleistocene.

Keyword: Pleistocene
The geological epoch from 2.6 million years ago to 11,700 years ago (the end of the last glacial period, or ice age).

Many ways of sub-dividing the Quaternary have been proposed but the most universally used is the use of Marine Isotope Stages (MIS). These correlate, imperfectly, with British Stage names (see Figure 1) for glacial and interglacial periods during the Quaternary. The names, such as the Devensian and Anglian glacial periods, are named after sediment deposits typical of each period found in the UK. A major problem faced by anyone studying Quaternary landscapes is that the most recent physical evidence i.e. erosional landforms and sedimentary deposits, is the best preserved. Evidence for older stages, such as the Anglian and Cromerian is patchy. This is because later glaciations, periglacial activity and more recent weathering and erosion have modified and even destroyed evidence of glacial and interglacial periods in the distant past.

Oxygen isotope analysis
Sediments, continuously deposited on the ocean floor, preserve a record of the oxygen isotope composition of seawater within the small shells (called tests) of dead plankton.

In cold glacial periods (the even numbered stages in Figure 1) seawater had proportionately more O18 than O16 whereas in warmer interglacial periods (odd stage numbers) seawater had less O18.

The reason for this variation is that when seawater evaporated, water molecules containing O16 evaporate preferentially compared to those with O18. During cold glacial periods evaporated O16 rich sea water became locked in vast ice sheets, and did not return to the oceans. As a result, ocean water became enriched with O18. As warmer interglacial conditions took hold the O16 enriched ice melted and returned to the oceans.

Figure 1: Quaternary timeline for the last 0.5 million years
Landscape or landform?
- Landscapes consist of a number of different landforms, or a ‘suite’ of landforms.
- Geographers refer to glacial, volcanic or fluvial landscapes which were formed by different sets of processes.
- In the case of an upland glacial landscape, such as the Lake District, the dominant processes at work were those of glacial erosion, transport and deposition.
- Dig a little deeper, and we find that specific processes were responsible for different landforms within the landscape (Figure 2).

Table 1 The landscape-landform relationship

<table>
<thead>
<tr>
<th>Upland glacial landscape</th>
<th>Landform: Glacial trough / U-shaped valley</th>
<th>Landform: Roche moutonnée</th>
<th>Landform: terminal moraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrainment of rock particles at the base of glacial ice, followed by abrasion of the valley floor and sides</td>
<td>Abrasion on the upstream side combined with freeze-thaw and plucking on the steeper, craggier, downstream side.</td>
<td>Deposition during ablation (melting) from a glacier snout plus reworking by fluvio-glacial processes.</td>
<td></td>
</tr>
</tbody>
</table>

None of the landforms in Figure 2 are being formed in the UK today. Geographers have to interpret the relict landforms and landscapes using the principle of uniformitarianism.

Keyword: uniformitarianism
This principle can be summed up by the phrase “the present is the key to the past”. If we observe a modern day glacier depositing a landform such as a terminal moraine, we can assume that similar processes formed landforms of the same size, shape and composition in the past.

Across the UK, there are a number of different relict landscapes which reflect different dominant processes during the Quaternary (Figures 2 and 3). Most of today’s landscapes preserve evidence of glacial and periglacial landscapes from the Devensian, the last glacial period. In Southern England the picture is a little more complex because the Anglian ice sheet advanced much further south than the Devensian ice meaning that some areas which were glaciated around 450,000 years ago where not glaciated 20,000-40,000 years ago, but were subject to periglacial processes at that time.

Figure 2 UK glacial and periglacial landscapes map
Case Study 1 Glaciated uplands: the Lake District

The Lake District and Snowdonia represent the classic ‘alpine’ glaciated upland landscape dominated by glacial erosion. This is a landscape of cirques, arêtes and glacial troughs. There are over 200 cirques in the Lake District. Their average orientation is 49° i.e. facing north-east. This orientation faces away from the sun, so encouraging the build up of snow and ice.

Addacombe Hole cirque, with Wandope to the left and Crag Hill to the right.

Addacombe Hole (Photograph 1) is a good example. It lies between the mountains on Wanhope and Crag Hill and faces east. Photograph 1 shows the bowl shaped cirque backed by a steeply eroded, scree covered craggy headwall. Addacombe Hole does not have a tarn (small lake) because the cirque lacks a distinct lip to dam the water. Glaciers originated at these cirques and flowed down into glacial troughs.

Photograph 2 shows Bassenthwaite Lake, just north of Keswick. Bassenthwaite Lake is a classic ribbon lake, occupying the flat bottom of a broad glacial trough (U-shaped valley). Originally, the lake was probably joined to Derwent Water to the south. Alluvial deposits have split the two lakes in two. These can be seen as the flat farmland and marsh in the right middle-ground in Photograph 2. Bassenthwaite’s glacial trough is very broad because numerous glaciers merged into the valley as they flowed north.
Reactivated glacial landscapes
Not all glaciations have been long and widespread. At the end of the last glacial, the Devensian, most of the UK was free of ice by 15,000 years ago. Around 12,800 years ago, glaciers advanced briefly, and small glaciers and ice caps returned to Scotland (Figure 3). This period, a stadial, is referred to as the Loch Lomond re-advance or Younger Dryas. The UK was on average 5°C colder than today.

Ice cover existed for only about 1300 years, and was gone by 11,500 years ago. This short timescale was enough to generate small glaciers, but not major ice sheet cover. Many glacial features such as corries were ‘reactivated’ during this period. In western Scotland and the Lake District, many terminal moraines and push moraines appear to date from this brief re-advance.

Photograph 3 shows the hanging valley of Greenburn Bottom, just north of Grasmere, in the Lake District. In the valley bottom there is hummocky moraine and some small push moraines, with a larger terminal moraine across the end of the valley. These features, which are ‘fresh’ i.e. not modified very much by post-glacial erosion and weathering, probably represent the brief valley glacier Loch Lomond re-advance.

Keyword: stadial
A short period of colder temperatures during a warm interglacial, lasting a few thousand years. Cold temperatures may allow ice to form, and glaciers to advance. The opposite term is interstadial: a short, warmer period during a longer glacial.

Case Study 2 Cold based ice: the Cairngorms
Glacial erosion in the Devensian was intense in the Lake District because the glaciers here were warm-based. Elsewhere, there is evidence of cold-based ice and less intense erosion.

Warm- and cold-based ice
In intensely cold, high latitude and high altitude locations, the basal layer of ice is frozen to bedrock. This cold-based ice actually protects the land surface, rather than erodes it because the ice is not moving.

Warm-based ice has a thin layer of water between the ice base and the land surface. At the ice-bedrock interface, ice is above its pressure melting point. Warm-based glaciers and ice caps move by basal sliding, which promotes erosion by abrasion. Plucking erosion may also as basal water freezes in fissures and joints in the bedrock.

The Cairngorms of north-east Scotland were a centre for ice formation during the Devensian and earlier glaciations. This is a landscape of selective linear erosion. There are deep glacial troughs, but on the mountain summits and high plateaux there are many granite tors. Tors are not glacial in origin. This has led many geographers to believe that the glacial ice in the Cairngorms was cold based – therefore not moving and erosive - and that this preserved these landforms on the summits. Although of higher altitude, the Cairngorms generally lack the steep-faced aretes and ridges so characteristic of the Lake District (e.g. Striding Edge and Swirral Edge). The most probable explanation for this is that for much of the time during quaternary glaciations Cairngorm was covered with a thick ice cap, with ice movement only occurring selectively in troughs. Conversely, the Lake District summits and high rock slopes may have been ice-free for much of the time, with ice confined to valley glaciers (so-called Alpine glaciation). On the summits and slopes, intense freeze-thaw weathering predominated.

Keyword: Tor
A tor is a large, free-standing rock formation often on a rounded hill top. Tors often appear in landscapes which lack other rock outcrops. Most commonly granite, tors have the appearance of numerous large boulders stacked one on top of another. They form through weathering, not erosion.

Case Study 3 Ice sheet erosion
In the west of Scotland, in the northwest Highlands and Isle of Lewis, is a very irregular lowland landscape of small, bare-rock, ice-sculpted hills (knocks – similar to roche moutonnées) and small lakes (lochans). This is called ‘knock and lochan’ topography. It is rough, but low relief. Similar landscapes can be found in Canada, the Vestfold Hills of East Antarctica and parts of Scandinavia. This landscape is a result of:
- Resistant bedrock, over an extensive area; metamorphic gneiss in the west of Scotland.
- Widespread abrasion and plucking by and ice sheet moving in one direction for a long period of time: called areal scouring.
- Selective deeper erosion of faults, master joints and weaker areas of rock to form lochans.
- Areas of more resistant rock form the higher knobs.

A useful analogy is to think of this lowland landscape as having been roughly ‘sand-papered’. Knock and Lochan landscapes often have a distinct regional alignment of small hills and lakes which follow lines of weakness e.g. master joints or weaker rock strata.

Case Study 4 Lowland ice sheets
In lowland areas away from the centres of ice formation during the Devensian, the landscape is blanketed by glacial till (boulder clay). Much of this material is lodgement till that formed between the ice sheet above and the bedrock below. In some areas, the till has been shaped into a landscape of drumlins. A drumlin is a small, rounded hill – shaped rather like half an egg (hence the term ‘basket of eggs topography’). Drumlins usually occur together in ‘swarms’ or ‘fields’. Figure 4 shows a swarm of drumlins to the south of Loch Lomond in Scotland.

Figure 4 Drumlins in cross-section and plan

<table>
<thead>
<tr>
<th>Blunt end</th>
<th>Tapered end</th>
</tr>
</thead>
<tbody>
<tr>
<td>500m</td>
<td></td>
</tr>
<tr>
<td>Blunt end</td>
<td>Tapered end</td>
</tr>
<tr>
<td>Individual drumlins</td>
<td>Loch Lomond</td>
</tr>
</tbody>
</table>

Drumlin swarm

Ice flow direction

End of Loch Lomond

Drumlin water

Endrick water

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Quaternary glacial landscapes of the UK
Drumlins are:
- Lined up parallel to the direction of ice flow
- Their ‘blunt’ end faces into the ice flow direction, and their tapered end is downstream of ice flow direction
- Typically 100-2000m long and 50-600m wide
- Usually under 50m high
- Made of glacially deposited sediments, although some have a rock core.

Drumlins are believed to have formed by deposition under moving ice sheets. As such, they are a sub-glacial bed-form. Most are made of lodgement till but some have fluvo-glacial deposits suggesting flowing water might play a role in their formation. There are a number of theories of drumlin formation, but because they form under ice, they have never been observed forming.

A process involving deformation (moulding and ‘streamlining’) of lodgement till by relatively fast moving ice sheets is one possibility. Shaping by melt water between ice and till could be responsible for some of the fluvo-glacial sediments found in some drumlins. In some lowland locations eskers accompany drumlins. Eskers are long, ridge like landforms consisting of gravel and sand. They can extend to several kilometres. Eskers from as sediment is transported in ice channels either within ice sheets (englacial) or beneath the ice (subglacial). As the ice walled channels melt, the sediment is deposited – preserving the basic channel form as a sediment ridge. The limit of the UK ice sheet extent in the Devensian is generally preserved on the basic channel form as a sediment ridge. The lowland ice sheet landscape that remains today can be seen in Google Earth. Search for Clew Bay in Ireland (53°50’37.44"N, 9°36’24.41"W) and Strangford Lough in Northern Ireland (54°27’54.55"N, 5°37’30.69"W). At both locations drumlin swarms can be easily seen.

Post-glacial modification
When investigating the UK’s glacial landscapes it is important to remember that all of them have been modified by physical processes (and in some cases human activities) since they formed.
- River processes have modified glacial valleys, both further erosion of valley floors and deposition of river terraces and other landforms
- Mass movement has altered slopes and valley sides
- Weathering has continued since the last glacial period, so processes such as freeze-thaw have continued in upland areas
- Soil development has taken place, and vegetation grown over most glacial landscapes

All of these processes have ‘softened’ glacial landscapes in the UK, compared to active landscape such as the Alps.

Ideas for further research
1. Use the BRITICE maps (see references, below) to investigate the glacial landforms in a small area such as the Lake District or Snowdonia. Print out a small part of the map at a high resolution and examine landform patterns. These could include the orientation of drumlins and eskers (which can be used to see ice flow direction) and the sources of erratics.

2. Use a copy of a 1:25000 Explorer Ordnance Survey map, such as a part of the Lake District. Mark on the locations of cirques (corries) and shade in glacial trough valleys – this will allow you to get an idea of the complex network of valley glaciers that existed in upland glaciated areas.

3. The lowland ice sheet landscape that remains today can be viewed in Google Earth. Search for Clew Bay in Ireland (53°50’37.44"N, 9°36’24.41"W) and Strangford Lough in Northern Ireland (54°27’54.55"N, 5°37’30.69"W). At both locations drumlin swarms can be easily seen.

4. Research the formation of tors and their significance in glaciated landscapes. The Cairngorms website is a good place to start; you could use a physical geography textbook and draw a labelled diagram of tor formation.

References
- The Cairngorm Landscapes website, www.landforms.eu/cairngorms/tors.htm; you could use a physical geography textbook and draw a labelled diagram of tor formation.

Acknowledgements:
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