

3

3.1 Glaciers past and present

We start with a headline from *The Scotsman* newspaper that rocked Britain's scientific establishment on the morning of 7 October 1840:

Discovery of the Former Existence of Glaciers in Scotland, especially the Highlands, by Professor Agassiz

Reading this headline today prompts the same questions as a Victorian reader might have asked: What evidence is the discovery based on? How cold was it at the time of the glaciers? How long ago were there glaciers in Scotland? Why was this discovery newsworthy? Who was Professor Agassiz?

Jean Louis Agassiz was a professor of Natural History at the University of Neuchâtel in Switzerland, and he took a particular interest in the glaciers in his native Alps. On a visit to Britain in 1840, he convinced two contemporary British scientists, William Buckland and Charles Lyell, that many of the landscape features in Scotland matched the features being formed 'before his eyes' by the action of glaciers in the Alps of Europe. They agreed that this was evidence that northern Britain had recently been glaciated, but most other scientists at that time found this startling conclusion too revolutionary to accept — after all, there are no glaciers in Britain today. Prior to this glacial theory, most (including Buckland) had accepted the account in the Old Testament of a world-wide flood (Noah's flood) and believed that the sand, gravel and clay that blanket much of Britain were evidence of this great flood. By about 1860, however, most of those who had weighed up the evidence were of the opinion that glaciation had indeed produced many landscape features and also much of the sand, gravel and clay. In the face of actual physical evidence for the new glacial theory, the cherished connection with Noah's flood was abandoned by most scientists. This is an example of how one theory falls out of favour and is discarded when new evidence in support of another theory comes to light.

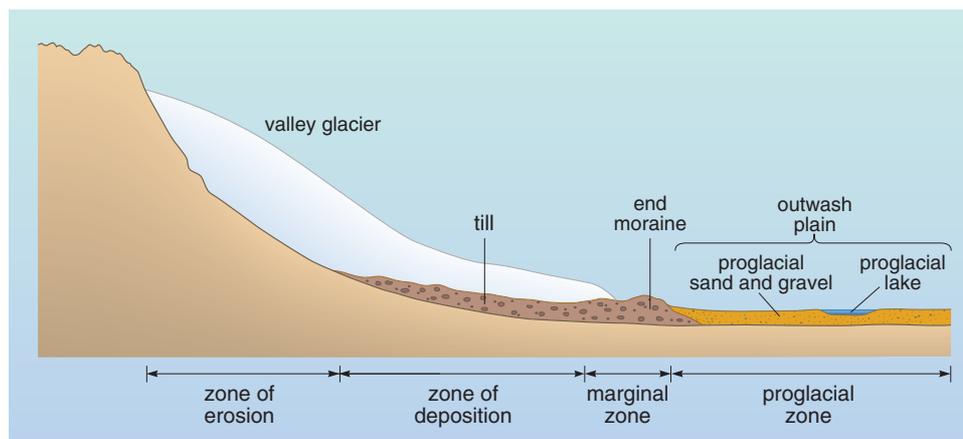
In the 150 years or so since the glacial theory was proposed (initially as a hypothesis), more evidence has been amassed and found to be consistent with it. To answer the first question inspired by the newspaper headline — what evidence is the discovery based on — we adopt the strategy of first studying the ways in which present-day ice-caps and glaciers determine landforms, and then show some examples of these characteristic landforms from Britain. Also bear in mind the questions we posed about the temperatures during the glaciation, and the age of the glaciation, for we'll address these too.

3.1.1 Glacial environments of the present day

A glacier can be thought of as a 'river' of ice but, unlike rivers of water, glaciers are typically hundreds of metres or more deep. Another difference is that glaciers flow extremely slowly; typical speeds of glaciers are just 0.3 metre per year to 600 metres per year.

In spite of these low speeds, ice-caps and glaciers erode the rock over which they flow, transport the eroded debris away and deposit it elsewhere. In some areas erosion is the predominant process, whereas in others deposition is more important. If we consider glaciated areas in terms of the relative importance of these effects it is possible to recognize the following four types of area, or zone, arranged in the way shown in Figure 3.1.

Figure 3.1 A cross-section of a glaciated region and its surroundings. This diagram is a schematic slice through a part of the Earth affected by glaciation. Boundaries between zones are gradual ones. The labels on this figure are explained in the text.

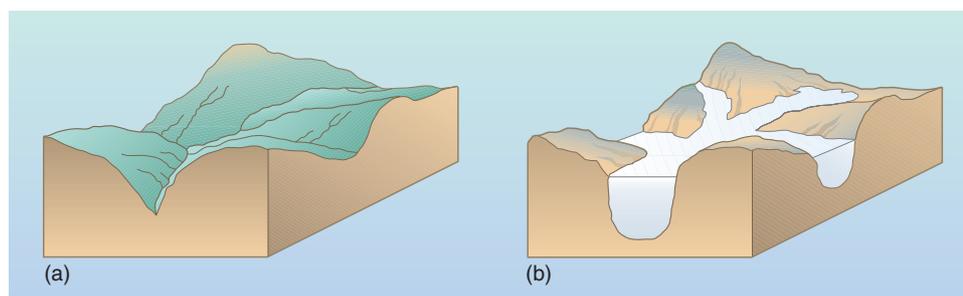


The zone of erosion

Where snow accumulation is greatest a thick layer of ice develops, establishing an ice-cap or glacier, which moves very slowly under its own weight. Large ice-caps are usually referred to as ice-sheets; an example is the Antarctic ice-sheet, which has a maximum depth of over 4 km and covers 12.5 million square kilometres ($12.5 \times 10^6 \text{ km}^2$) (units of area were discussed in Block 1, Box 4.2). Elsewhere, glaciers can be less than 1 km² in area. Some of the smallest are confined to valleys, although other valley glaciers spill out from the edges of ice-sheets (see title page).

Beneath the thickest parts of glaciers, the slowly moving ice scrapes against the bare rock, scouring debris away from the ground and carrying it along within the ice. The erosive power of a glacier moving slowly down a valley is enormous. Erosion acts over the floor and sides of the valley to carve a broad **U-shaped valley** (Figure 3.2b). A fast-flowing river, on the other hand, erodes the floor of a valley, resulting in a V-shaped valley (Figure 3.2a). The shapes of the valleys in Figure 3.2 are different because they formed in different ways — one by the action of flowing water, the other by the action of flowing ice.

Figure 3.2 A mountainous region that experiences erosion by fast-flowing rivers develops a landscape characterized by V-shaped valleys (a). This contrasts with the case in a much colder climate (b) where valley glaciers are present and erode U-shaped valleys.



The zone of deposition

Towards the end of glaciers, large amounts of rock debris, ranging in size from house-sized boulders to dust a few thousandths of a millimetre across, are dumped from the ice and accumulate beneath the active glacier. This muddled mixture of rock particles is called **till** and occurs as mounds, sheets or sinuous ridges called **moraines**, which are left behind when the ice eventually melts; Figure 3.3 shows an example.

The marginal zone

At the very end of glaciers the ice is melting, releasing water and rock debris. Some of the water that emerges from the glacier's front can also come from streams or



Figure 3.3 The moraine in the foreground of this picture was deposited when the valley was filled by a large glacier; the remnants of this Alpine glacier are seen in the background.

rivers that flow within or beneath the glacier. Although the escaping water may be travelling rapidly it does not have sufficient strength to carry away the larger fragments of rock so these remain near the front of the glacier, forming an end moraine.

The proglacial zone

This is the area extending outwards in front of the glaciated region. Here, fast-flowing meltwater carries particles of sand and gravel over an outwash plain, forming a complex area of shifting river channels (Figure 3.4). Small lakes can become established in local depressions, and many of the smaller rock particles may settle out from the water to form layers of mud, clay or silt on the bottom of these proglacial lakes.



Figure 3.4 A part of the expanse of gravel that has been deposited from rivers flowing rapidly from the melting glacier visible in the distance. This example of a proglacial zone is on the island of Svalbard (Spitzbergen) in the Arctic Ocean.

3.1.2 Glaciers in Britain's past

Glaciers, and glaciers alone, are responsible for forming landscape features such as U-shaped valleys, moraines, and the types of sand, gravel and clay deposits found in proglacial zones. It follows that an area where such features are observed, but where no glaciers presently exist, must once have been affected by the action of glacial ice. It was this train of thought which Buckland, Lyell and Agassiz followed some 150 years ago when they proposed that Scotland had once been covered by ice. The next step of logic is that the climate must have been considerably colder than at present for glaciation to have been possible. Let's look at the evidence for ourselves.

Figure 3.5 Glen Rosa, Isle of Arran, western Scotland.



Look at Figure 3.5, which shows a view of Glen Rosa on the Isle of Arran.

- What is the evidence that the valley in Figure 3.5 was *not* carved by the stream currently flowing down the valley floor?
- Glen Rosa is a U-shaped valley (Figure 3.2b) and must, therefore, have been cut by a valley glacier, perhaps not too dissimilar from those on the title page.

You may have seen other examples of U-shaped valleys in the Scottish Highlands, and elsewhere in the UK, for example the English Lake District or Snowdonia. In all cases the distinctive shape of these valleys indicates that these upland areas were once covered by slowly moving ice. Deposits of till are also common across these areas and other regions of Britain, again implying the former presence of glaciers. But was the whole country under ice?

Only southernmost Britain is free from deposits of till, and this is taken as evidence that glaciation did not reach that far south. Another set of observations that bears on this is shown in Figure 3.6. Ailsa Craig is a distinctively shaped island in the Firth of Clyde (Figure 3.6a). The rock that forms Ailsa Craig is also distinctive, being a particularly decorative type of granite that is unique to the island. However, boulders of this unusual granite are found in many places far to the south of Ailsa Craig (Figure 3.6b). Why these rocks come to be more than 300 km away from their source can be explained by the action of ice transport, because only ice is capable of carrying large boulders over long distances. Such boulders, which have been

transported (by natural processes) far from their site of origin, are called **erratics**. The distribution of Ailsa Craig erratics shown in Figure 3.6b implies that the ice that transported them moved southwards, but apparently it did not reach much farther than South Wales. This fits reassuringly with the southern limit of till; it is always satisfying when more than one line of evidence leads to the same conclusion.

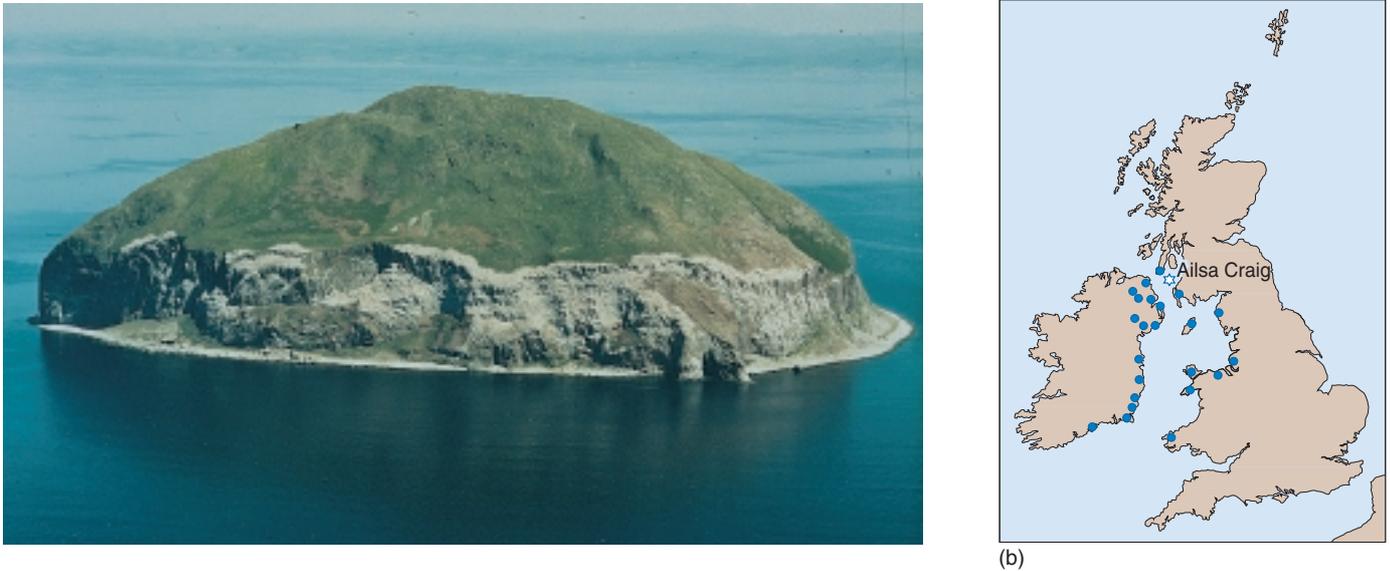


Figure 3.6 (a) The granite island of Ailsa Craig in the Firth of Clyde is about 1.3 km across and 340 m high. (b) Erratics of Ailsa Craig granite have been found far from their place of origin as shown by the blue dots.

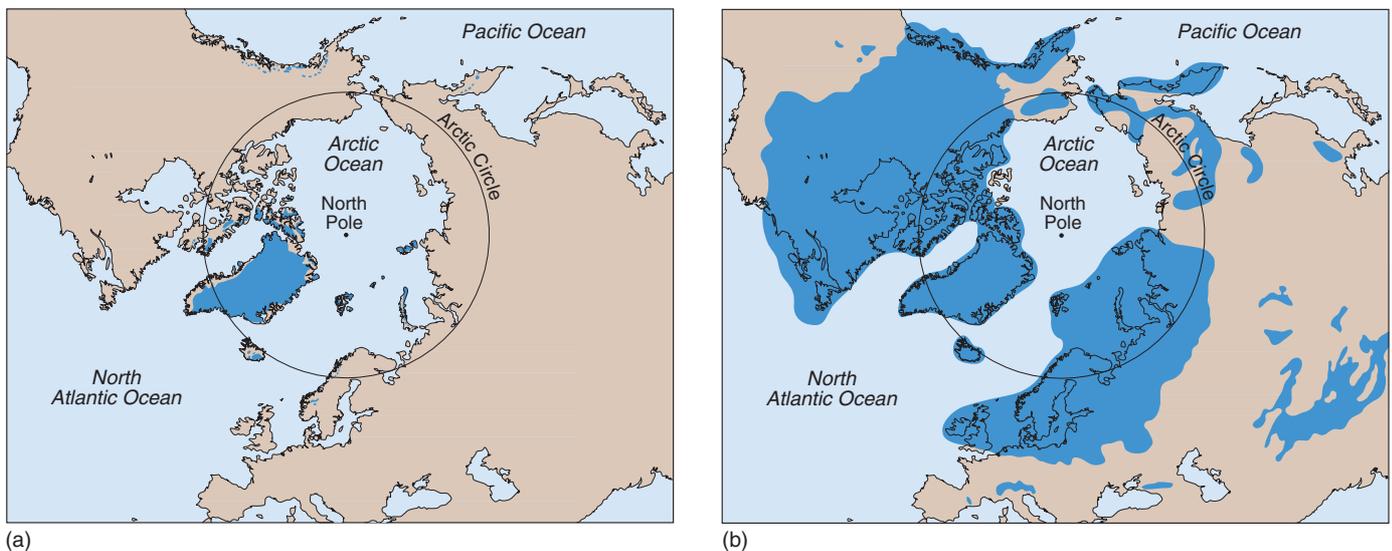


Figure 3.7 The deep blue areas on these maps show (a) the present-day extent of northern hemisphere ice-sheets and (b) the greatest extent of ice in the past (about 18 000 years ago).

Using the sorts of evidence we have been looking at, it is possible to recognize signs of glaciation over an area that extends far beyond the present-day limit of ice-sheets (Figure 3.7). This indicates that the Earth's climate was once significantly different, with colder conditions prevailing in Britain and elsewhere. During that time, Britain was cold enough to be mostly covered by permanent ice, and its landscape must have looked similar to that found today in arctic Norway and eastern Greenland (title page). But you may have started to wonder what the temperatures were in those ancient times, or how they changed over time. These topics can be addressed by studying fossils, as the next section will reveal.