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How to use this book

This is one of two books in this series, written for the AQA GCE in Geography. This particular book (Physical geography) has been written to meet the content requirements of the A Level course, but can equally well be used for the separate AS course.

Skills questions indicated by the icon are aimed at meeting the geographical and statistical skills requirements for both AS and A Level.

Practice questions have been included for both AS and A Level, with marks allocated. Please note that the Practice questions used in this book allow students a genuine attempt at practising exam skills, but are not intended to replicate the exact nature of final exam questions.

At appropriate points, chapters focus on providing fieldwork opportunities. These, plus associated questions, will help to prepare you for the fieldwork requirements for both AS and A Level.
Fieldwork opportunities

In the UK, fieldwork investigating glaciated landscapes necessarily involves fossil landforms – there aren’t any glaciers in the UK today. Fossil landforms are likely to have been shaped by ice during the last glacial period, referred to in Britain as the Devensian glaciation. This glacial period was at its maximum extent about 20,000 years ago (see 4.2).

1. Observation in the field: evidence of past climate
Identifying erosional or depositional features of a glaciated landscape, for example, in the Lake District, creates a good opportunity to develop your field-sketching skills (take care with scale). Use photography to compliment your drawings; you can use photo-editing software to crop, enhance and label your photographs later. Keep a notebook to hand to make a detailed record of where the features are located in the landscape and map them on your return to the classroom, or use GIS software on a hand-held device in the field. From your evidence can you estimate the direction of flow or identify different periods of advance and retreat?

2. The impact of subsequent physical processes on glaciated landscapes and beyond
Geomorphological processes don’t take place in isolation, and over several thousand years fluvial processes have shaped and reshaped glacial deposits. Before that, fluvioglacial processes associated with the action of meltwater, eroded, transported and deposited material beyond those areas of Britain that were ice covered. Observations about the way more recent processes may have altered or removed clues about glaciation is as relevant a focus for investigation. Sediment analysis, for example, comparing sediment in glacial till against fluvial or fluvioglacial deposits, may take the form of the classification of sediment samples by texture, roundness, size and stone orientation as well as the respective level of sorting of material.

Your key skills in this chapter

In order to become a good geographer you need to develop key geographical skills. In this chapter, whenever you see the skills icon you will practise a range of quantitative and relevant qualitative skills, within the theme of ‘Glacial systems and landscapes’. Examples of these skills are:

- Interpreting photographs and remotely-sensed images 4.1, 4.6, 4.8
- Using atlases and other map sources 4.2, 4.8, 4.10, 4.15
- Using electronic databases 4.4
- Drawing and annotating sketch maps 4.8
- Measurement and geospatial mapping 4.3, 4.4, 4.10, 4.14
- Data manipulation, including applying statistical skills to data 4.13
- Understanding and calculating mass balance or glacial budget 4.13
- Drawing and annotating diagrams 4.2, 4.4, 4.5, 4.7, 4.11

Your exam

You must answer one question in Section B of Paper 1: Physical geography, from a choice of three: Hot desert systems and landscapes or Coastal systems and landscapes or Glacial systems and landscapes. Paper 1 makes up 40% of your A Level.

You must answer one question in Section A of Paper 1: Physical geography and people and the environment, from a choice of three: Water and carbon cycles or Coastal systems and landscapes or Glacial systems and landscapes. Paper 1 makes up 50% of your AS Level.

Specification key ideas

3.1.4.1 Glaciers as natural systems 4.1
3.1.4.2 The nature and distribution of cold environments 4.2
3.1.4.3 Systems and processes 4.3–4.7
   Gulkana Glacier, Alaska 4.3
   Mer de Glace 4.4
3.1.4.4 Glaciated landscape development 4.8–4.11
3.1.4.5 Human impacts on cold environments 4.12–4.14
   Oil exploration in Alaska, USA 4.14
   Climate change in the European Alps 4.14
3.1.4.7 Case studies
   Local scale: Gulkana Glacier, Alaska 4.3
   Mer de Glace 4.4
   Challenges and opportunities for development:
   Oil exploration in Alaska, USA 4.14
   Climate change in the European Alps 4.14
   Svalbard, Norway 4.15

The Perito Moreno Glacier in Argentina is one of the most accessible glaciers in the world and is a UNESCO World Heritage site – look at how it towers above the tourists on the viewing platform.
Glaciated landscapes and the glacial system

In this section you will learn about glaciated landscapes and the glacial system.

What is a glaciated landscape?
Look at Figure 1. It shows a glaciated landscape in the French Alps close to Mont Blanc, Europe’s highest mountain. In common with all landscapes, it comprises many colours, textures and features. Yet, it is a landscape that is very distinctive in that its characteristics are exclusively linked to glaciation. In the foreground is an active glacier, the Mer de Glace, set amid magnificent peaks, known locally as aiguilles (meaning ‘needles’ in French), that have been carved and shattered by ice processes. In places the mountainsides are strewn with rocks, dumped by the melting ice or piled up beneath frost-shattered cliffs. Elsewhere, exposed rock surfaces bear evidence of glacial erosion, with deep scratches or polished surfaces. There are trees in the foreground and also some traces of vegetation beginning to take hold on the valley sides. There is no evidence of human activity, yet it is possible to infer that such a landscape would be popular with climbers and walkers. With its glaciers, snowfields, steep mountainsides and deep valleys, this is a distinctive glaciated landscape.

What is the glacial system?
In common with many aspects of geography, systems concepts can be applied to glaciers to assist in understanding how they operate. A glacier can be viewed as an open system – with inputs from and outputs to external systems, such as atmospheric and fluvial processes promoting rapid change. There are examples of both positive and negative feedbacks in glacial systems, as you will see during this chapter (see 4.13).

The main input is of course snow. As it becomes increasingly compacted over many years, it gradually turns from low-density ‘fluffy’ white ice crystals (snowflakes) to high-density clear glacial ice. Avalanches from mountain sides can also be an input to the glacial system. The main output from a glacial system is liquid water resulting from the melting of ice close to the snout, where temperatures are higher. Where the ice extends over water, such as the ice shelves in Antarctica, huge chunks of ice may break off to form icebergs. This process is called calving (Figures 3 and 4). The processes of evaporation and sublimation also act as outputs from the glacial system. A glacier’s mass combines with the force of gravity to generate potential energy. As the glacier moves, this potential energy is converted into kinetic energy, enabling the glacier to carry out the processes of erosion, transportation and ultimately deposition. The presence of meltwater facilitates this conversion of potential energy to kinetic energy (work).

Many physical systems move towards a state of dynamic equilibrium, where landforms and processes are in a state of balance. In a glacial system, an equilibrium line can be drawn to mark the boundary between the accumulation zone (glacial inputs) and the ablation zone (glacial outputs). If the glacier is in a state of balance where inputs equal outputs, the equilibrium line will remain in the same place. As this balance shifts, the equilibrium line will move up or down the glacier, hence the term ‘dynamic’ equilibrium.

Figure 1 A glaciated landscape – the Mer de Glace, France

Figure 2 Braided river, Hopkins River, South Island, New Zealand

Figure 3 The glacial system

ACTIVITIES

1. Obtain a photo of a glaciated landscape, such as in South America, New Zealand or the Himalayas. Write a description of your chosen landscape in the form of detailed annotations. Consider physical landforms and processes, vegetation and human activity.
2. Using a copy of the same photo or selecting a different one, use Figure 2 to help you identify and label systems concepts such as inputs, outputs and flows. Try to identify or infer as many concepts as possible in your photo.
3. Explain why a glacier can be considered to be an open system.
What was the past distribution of cold environments?

The distribution of cold environments has changed significantly over time. During the last two million years – a blink of the eye in geological terms – temperatures have fluctuated considerably. This period of time is known as the Pleistocene, a geological period that lasted from about 1.8 million years ago until about 11700 years ago (Figure 1). During this time there was a pattern of alternating cold periods (glacial) and warm periods (interglacial); in the last one million years there may have been as many as ten glacial periods.

During the cold glacial periods, the climate cooled sufficiently for precipitation to fall as snow rather than rain. This resulted in the formation and growth of huge ice masses, which in the northern hemisphere spread south over large parts of Europe, Asia and North America. During the warmer interglacial periods – some being considerably warmer than the conditions we experience today – much of the ice melted and the ice sheets and glaciers retreated.

Look at Figure 2. It shows the approximate distribution of ice at its maximum extent about 20000 years ago. Notice that vast ice sheets covered much of North America and Europe. There were also extensive glaciers and ice caps in South America and in mountainous regions. With so much water locked up as ice on the land, the water cycle was significantly distorted and sea levels fell by 130 m.

What is the present-day distribution of cold environments?

At this small scale, the finer detail of the actual ice extent needs to be treated with caution as evidence may be absent or unclear. For example, Figure 2 shows the entire land mass of the UK to be covered by ice. Yet Figure 3 shows this was not the case. Ice extended over much of the UK but the southern-most regions stayed ice-free despite being frozen and experiencing periglacial conditions.

What is the present-day distribution of cold environments?

Look at Figure 4. It shows the present-day distribution of cold environments. Notice that, with the exception of Antarctica and the far south of South America and the Andes, the world’s cold environments are located in the far north. This is a reflection of the latitudinal position of the land masses – in the southern hemisphere, the equivalent latitudes coincide with ocean rather than land.

It is possible to identify four types of cold environment:

- Polar – areas of permanent ice. Essentially the vast ice sheets of Antarctica and Greenland.
- Periglacial (tundra) – literally-speaking, at the ‘edge’ of permanent ice. Periglacial environments are characterised by permanently frozen ground (permafrost) and include large tracts of northern Canada, Alaska, Scandinavia and Russia.
- Alpine – mountain areas. For example the European Alps and the Southern Alps in New Zealand, where the high altitudes result in cold conditions particularly in winter.
- Glacial – glaciers are found at the edges of the ice sheets and, in particular, in mountainous regions such as the Himalayas and Andes.

Notice in Figure 4 that there is a clear latitudinal sequence of cold environments – polar environments in the far north are followed by discontinuous and then continuous permafrost as conditions become warmer further south. Alpine cold environments and most glacial environments exist in the mountainous areas.
Physical characteristics of cold environments

Cold environments include some of the world’s last great wilderness areas. The vast expanses of ice and snow, combined with freezing temperatures and strong penetrating winds, make these some of the most inhospitable places on Earth.

Soil development

Soil is a mixture of weathered rock, rotted organic matter, living organisms (biota), gases (particularly oxygen) and water. In cold environments, weathering is limited due to the lack of liquid water; the lack of vegetation means there is little organic matter and there are few decomposers – fungi and bacteria thrive in warm and humid conditions. Soil formation is, therefore, extremely slow, and any soils that do develop will be thin, acidic, sometimes waterlogged and mostly frozen.

Look at Figure 5. It shows deep permafrost in northern Alaska. Notice that there is a thin layer of light grey unfrozen soil above the permafrost. This is called the active layer. With downward drainage prevented by the permafrost, the active layer will often become saturated and boggy.

Climate

All cold environments experience significant periods of time when temperatures are close to or significantly below freezing (Figure 6). Liquid water is limited to certain times of year and, in the most extreme environments, totally absent. Snowfall amounts vary enormously, from very little in polar environments to potentially huge amounts in coastal and mountain areas. Frequent strong winds add to the wind chill and also absorb precious moisture from plants. These extreme climatic conditions have a severely limiting effect on the development of soils and vegetation.

Svalbard is an archipelago (group of islands) in the northern Arctic. Most of Svalbard experiences a polar climate, although some stretches of coastline experience slightly less severe periglacial conditions. Its capital, Longyearbyen, is home to about 2000 people and is one of the most northerly permanent settlements in the world.

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### What is the glacial budget?

Just as a financial budget involves credits (payments in) and debits (withdrawals), a glacier also has a budget – the glacial budget. Essentially, the glacial budget considers the balance between the inputs and outputs – the term mass balance may also be used in glacial studies to effectively mean the same thing, although technically the term mass balance considers the balance between the inputs and outputs – the credits (payments in) and debits (withdrawals), a glacier also has a budget. Just as a financial budget involves credits (payments in) and debits (withdrawals), a glacier also has a budget.

### The Gulkana Glacier, Alaska

The Gulkana Glacier is one of two ‘benchmark’ glaciers in Alaska that have been studied by the United States Geological Survey (USGS) since the 1960s. The purpose of this study has been to understand glacier dynamics and hydrology, and assess the glaciers’ response to climate change.

#### Key
- Colored dots indicate additional index sites and weather stations.
- The green line indicates the annual (net) mass balance.
- The black line indicates the monthly mass balance.
- The gray line indicates the cumulative mass balance.

#### ACTIVITIES

1. Why do you think the Gulkana Glacier was chosen as a ‘benchmark’ glacier?

2. How was data collected for the study of the glacier’s mass balance?

3. a) Study Figure 2. Describe how the extent of the glacier changed between 1974 and 2013.
b) Why might inferences based on evidence from Figure 2 alone possibly lead to inaccurate conclusions about the glacier’s changing mass balance?

4. a) Study Figure 3. How can you explain the positive mass balance values in the winter and negative mass balance values in the summer?
b) Complete the two blank columns. The first few calculations have been done for you.
c) Represent the cumulative balance data in the form of a line graph. Be careful to choose an appropriate vertical scale. Describe the trends.

5. a) Use the data for 1990–1999 in Figure 3 to complete your own graph in the same style as that in Figure 4.
b) Use your graph together with Figure 4 to describe the changes in mass balance between 1966 and 2014.

6. With reference to all the evidence gathered and using your answers to the earlier activities, consider to what extent the Gulkana Glacier is showing signs of decline.

#### Figure 3

Net mass balance (mmw) for the Gulkana Glacier, 1980–2005 (USGS). This chart indicates the balance between the inputs and outputs – the credits (snowfall and limited melting) and debits (meltwater, calving, etc.) during the winter. The losses (meltwater, calving, etc.) exceed the gains.

#### Table

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<th>Summer balance (mwe)</th>
<th>Net balance (mwe)</th>
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#### Figure 4

Gulkana Glacier mass balance 1966–2014 (USGS). This chart shows the trends in mass balance for the Gulkana Glacier between 1966 and 2014. Notice that the green shading indicates the annual (net) mass balance. The data for the 1990s are missing.

#### Case study

In this section you will learn about the glacial budget. The boundary where gains and losses are balanced is called the equilibrium line. Over a period of several years, variations in mass balance (glacial budget) may result in the equilibrium line moving either up or down the glacier. This can often be linked to the advance or retreat of the glacier snout. Mass balance varies during the course of a year (Figure 1). In the summer, ablation will be at its highest due to rapid melting of the ice. During the winter, higher amounts of snowfall and limited melting will result in accumulation being greater than ablation.