# Edexcel AS and A Level Geography

## Topic Guide for Landscape Systems, Processes and Change, Option 2A: Glaciated Landscapes and Change

### Practical support to help you deliver this Edexcel specification

This topic guide is aimed at teachers and should be seen as simply a guide to help teachers rather than a model to follow.

Our specifications offer an issues-based approach to studying geography, enabling students to explore and evaluate contemporary geographical questions and issues such as climate change and its impacts on cold environments. The specification content gives students the opportunity to develop an in-depth understanding of both the physical and human geography of glacial environments as well as the complexity of the interactions between these, with the aim of making students become critical, reflective and independent learners.

The AS and A levels in Geography are linear, and all assessments are at the end of the course. The AS Assessment will be at the end of the first year, and the A level Assessment will be at the end of the second year.

The specification has been designed so that the content is clear and so that it is manageable for centres to deliver within the guided learning hours over a one-year (AS level) or two-year (A level) period.

The guided learning hours are 180 for an AS level and 360, over two years, for an A level. This document provides a topic guide for teaching Glaciated Landscapes and Change, and can be adapted by centres to fit their own contexts and teaching styles. It has been produced as an example approach and is not intended to be prescriptive. The topic guides indicate resources that you can use to support your teaching. These are only suggestions, and you are encouraged to use a wide range of resources to suit your students' needs.

The advised teaching time for this topic is 26 guided learning hours, i.e. roughly 5 hours per enquiry question (EQ) and 6 hours for fieldwork development. This requires some blending together of the detailed content. In the guidance below, suggestions are made about contextualisation or stretch challenges that may be suitable for more able students, as well as expected lesson outcomes for those less able. Please note that these are suggestions only and not specific syllabus requirements.

Each EQ is broken down into lesson groups, each beginning with a quick overview of the breadth of the EQ, followed by a more detailed explanation of the key concepts and processes, examples of teaching strategies, guidance on integrating geographical skills, and a summary of the key terminology required. The structure is suggestive, not prescriptive.

**Synoptic linkages and case study nesting**

Our synoptic themes help students see 'the bigger picture', by encouraging them to make geographical links between topics and issues. To enable this, and to support exam preparations, we have continued to signpost 'Players' (P), 'Attitudes and Actions' (A) and 'Futures and Uncertainties' (F) throughout the specification content.

For Glaciated Landscapes and Change there are many areas where synopticity can be introduced, for instance there is a cross-over between glacier mass balance and the hydrological cycle; permafrost melting and the carbon cycle, as well as climate change and the impacts it presents for the future. (Topic 5: The Water Cycle and Water Insecurity. Key ideas: 5.1–5.3, 5.5 and 5.6)

On top of this there are areas for tectonics and fold mountains as well as the impacts glacial melt can have on volcanic eruptions (Topic 1: Tectonic Processes and Hazards. Key ideas: 1.1–1.3, 1.5 and 1.9) to be developed as well as regeneration of places and the issues associated with rurality. (Topic 4: Shaping Places. Option 4A: Regenerating Places. (Key ideas: 4A.4–4A.6, 4A.9)
There are other areas where tectonic landscapes can be used with other subject areas, but these are just a few ideas.

# EQ1: How has climate change influenced the formation of glaciated landscapes over time?

## Teaching approach over 5 hours

| | |
|---|---|
| Lesson 1 (1hr) | The causes of longer and shorter climate change. |
| Lesson 2 (1hr) | Present and past Pleistocene distribution of ice cover. |
| Lesson 3 (1.5 hrs) | The distribution of past and present periglacial landscapes and how periglacial processes produce distinctive landscapes. |
| Lesson 4 (1.5 hrs) | How periglacial processes produce distinctive landscapes and the formation of often unique periglacial landforms. |

## Lessons 1 & 2: The causes of longer and shorter climate change and present and past Pleistocene distribution of ice cover

**Overview**

These lessons are based on Key ideas 2A.1 and 2A.2 and will cover the chronology of past climate changes as well as the causes of these changes and the characteristics of past shorter-term events. Much of the information from the legacy specification (Topic 1 World at Risk 1:4 Climate change and its causes) can be applied here. Less able students, for whom this may be a new subject, may find there is much to get their heads around, and beginning slowly with the chronology will be important as new terms are being introduced. Diagrammatic representations and thorough groundwork into the long-term reasons are important here. Group work or group tasks might aid their appreciation of these factors, especially those related to the Milankovitch cycle.

For stronger students there is much information within this area, and many books and websites offer an excellent range of information, some of which are listed below.

### Key concepts and processes

Students will need to understand:

- the chronology of climate change throughout the Pleistocene:
  - there are many areas of change within our climate from the beginning of the Quaternary to the beginning of the Holocene
  - this period lasted from approximately 2,500,000 years to 11,500 years ago.
- the causes of the climate change that led to:
  - longer-term glacial and inter-glacial periods
  - shorter-term glacial and inter-glacial periods.
- the reasons and potential impacts of positive and negative feedback mechanisms.

### Guidance on teaching

There are plenty of good websites available for students to browse, including: http://www.livescience.com/40311-pleistocene-epoch.html – Livescience the Pleistocene epoch. This has many links within it that can be explored by both stronger and weaker students. For stronger students the University of California Museum of Palaeontology has a good article on the geologic time scales (http://www.ucmp.berkeley.edu/exhibit/histgeoscale.php).

The USGS website also has a significant online book on geological time by William L Newman that is an excellent resource; the link for this is below.
For climate history this site allows both more and less able students to develop further awareness of the importance of our climate history. It also has some multiple choice questions within it that could be a useful learning tool: http://serc.carleton.edu/eslabs/cryosphere/4a.html There are also excellent resources for teachers here.

The different reasons for longer-term climate change can be broken down into specifics and while less able students can struggle with the Milankovitch theory, it is important that this concept is fully developed and understood. This could be approached via a scenario-type questioning technique by drawing the orbital changes and getting students to consider the implications of this on the planet. The same can be done for the other two cycles.

The strengths and weaknesses of the theory can be developed for stronger students through a discussion of its authenticity.

Furthermore, the complication of feedback mechanisms will also need to be addressed, although this can be done later if necessary.Students may struggle with these concepts and might need some exemplification. A good example of feedback mechanisms can be found at http://www.metoffice.gov.uk/climate-change/guide/science/explained/feedbacks.

The final parts of the changes to climate are the shorter-term explanations. These can be broken down and described using exemplification, while the use of the Loch Lomond Stadial may need further development. Good examples for both more and less able students exist here: http://www.landforms.eu/cairngorms/Loch%20Lomond%20Stadial.htm.

Good information can be found in the further reading section for more able students, while less able ones may wish to be directed to: http://www.ncdc.noaa.gov/paleo/abrupt/data4.html (NOAA Paleoclimatology. Less able students may prefer to see more obvious visual representations. Some information can be found here: http://www.nap.edu/read/10136/chapter/4

Distribution of past and present ice cover can be explored through a variety of measures, including mapping data such as: http://higheredbcs.wiley.com/legacy/college/levin/0471697435/chap_tut/chaps/chapter15-05.html This is an excellent source of information on ice balance changes throughout time, dating from just before the Pleistocene, and other sites are listed in the further reading section.

At http://web.gccaz.edu/~lnewman/gph111/topic_units/glacial/glacial2.html there are supplementary lecture notes to Maricopa County Community College course, with excellent further links to help all students develop their interests. Includes questions that can be used by student and teachers.

## Lesson 3: The distribution of past and present periglacial landscapes and how periglacial processes produce distinctive landscapes

**Overview**

This lesson covers Key ideas 2A.3a and 2A3b, concentrating on the distribution of past and present periglacial landscapes as well as the processes within these environments. For those new to the topic there is an array of new vocabulary that is important for students to learn and they may be advised to have a vocabulary book to fill in to help memorise and learn these terms.

The aim is to be able to describe the past and present distribution of permafrost and periglacial areas across the world and the processes that exist within it.
For many teachers this will be an ideal time to bring in interpretation of maps and GIS, as well as being able to plot these areas on maps.

For less able students the use of:

- climatic maps
- blank maps for annotation
- annotated diagrams

may all help in developing an understanding of these areas and their distribution around the world. For stronger students there is a wealth of information available to look at and develop both analytical as well as evaluative judgements based on evidence from these often complex environments.

## Key concepts and processes

Students will need to understand:

- what is meant by periglacial environments
- distribution of past and present periglacial landscapes
- the extent to which these covered the globe and where, over different timescales
- permafrost and what is meant by the active layer
- what is understood by the idea of continuous and discontinuous permafrost
- the processes of periglaciation, to include a clear understanding of the following terms:
    - nivation
    - frost heave
    - freezethaw weathering
    - solifluction
    - high winds
    - meltwater erosion.

## Guidance on teaching

The term 'periglacial' refers to the climatic conditions and landscape characterised by being at the margins of glacier ice or those non-glacial cold climate areas found at high latitudes and high altitudes that may or may not contain glaciers.
Understanding the past extent of periglacial environments as well as the present can be done with maps such as the one at http://www.geo41.com/periglacial-environments/, which shows present periglacial cover.

These maps can be found online and in textbooks, and teachers should concentrate on explaining to students that at the present day approximately 20% of the earth's surface is covered by periglacial conditions, and that this has previously grown and shrunk, with an estimated 33% having been covered in the past and reaching much lower latitudes.

Strong students could visit http://www.physicalgeography.net/fundamentals/10ag.html to look at this in greater detail, as well as the processes within these environments.

 

Most students easily identify and understand the concept of permafrost, but need to appreciate how it can influence the geomorphological processes acting within these regions.

Understanding that permafrost has an active layer can be done via diagrammatical presentation and annotation with the active layer highlighted for less able students to understand.

Stronger students may wish to research this in more depth, and could look at the localised layers of unfrozen ground called taliks, which can be seen here.

The different types of permafrost are also important and these can again be looked at via pictorial evidence.

There are many factors that influence the distribution of permafrost, and students must appreciate these and apply them to given environments. These can be ranked by students to allow them to think about their importance in determining how much influence they have on permafrost distribution.

(There are more resources for this area and Key idea 2A.3 Periglacial processes in the next lesson.)

## Lesson 4: How periglacial processes produce distinctive landscapes and the formation of often unique periglacial landforms

### Overview

This lesson covers Key idea 2A.3b and c, looking at processes involved in periglacial landform development. This could be introduced via a video such as those presented by WizScience.com

For less able students there are plenty of diagrammatical representations and websites that teachers and students can make use of. These are noted below. More able students could strengthen their knowledge by beginning to identify periglacial landforms in unfamiliar landscapes.

Other useful learning activities include bingo and dominoes, as well as vocabulary books to help students remember and revise key terms and apply them to given places. Another good activity is to put students in pairs in mixed differentiated groups: one describes the feature they are looking at and the other tries to work out what it is. Other examples could include glacial Pictionary, crosswords or similar word games, which get both strong and weaker students to develop an understanding of the processes and features involved.

### Key concepts and processes

Students will need to understand the processes of glaciation, including:

- the role of snow (nivation)
- frost heave

- freezethaw weathering, including the role of frost shattering
- the role of mass movement – solifluction, frost heave and asymmetric valleys
- the role of winds and meltwater erosion, including loess
- relict periglacial features.

They must also understand and appreciate the following landforms:
- ice wedges
- patterned ground
- pingos
- loess (fine sediment made up of accumulation of silt).

## Guidance on teaching

Students must be aware of many different landforms and the processes that create them. St Andrews university has some excellent resources for teachers to adapt http://www.st-andrews.ac.uk/itsold/papers/public/miscellaneous/printingproblems/GE2011L21.pdf. The US Army corps of engineers also has useful information: http://permafrosttunnel.crrel.usace.army.mil/permafrost/patterned_ground.html.

For less able students, continual testing and annotation diagrams as well as videos from well known video sites are important learning tools, while stronger students may also wish to discuss articles such as this one: http://news.nationalpost.com/news/canada/timelapse-video-shows-lake-falling-off-a-cliff-in-northwest-territories-creating-a-large-temporary-waterfall
Other good places for information and starting points could include: http://www.physicalgeography.net/fundamentals/10ag.html , which goes through a range of features and processes and is an excellent place for stronger students to research for further understanding.

Videos by Wiz Science™ can help less able students. These can be found online. Less able students will benefit from case-study orientated approaches looking at the tundra environments of northern Canada and northern Russia.

Quizzes and tests using unlabelled diagrams that students complete, as well as games, templates and ideas can all be found here: www.teachitscience.co.uk/attachments/22499.pdf . Other examples are available online or can be created using Word or Excel.

For case-study information the Canadian Ministry of the Environment has a fact sheet for the tundra region, which also has excellent links to other areas: http://www.hww.ca/assets/pdfs/factsheets/tundra-en.pdf . Further information on both Canada and Russia can be found below.

Students in groups may wish to research and provide presentations on all or part of these areas.

## Key vocabulary for EQ1

| Term | Definition | Term | Definition |
|---|---|---|---|
| Glacial period | Period of time during an ice age when glaciers advance because of colder temperatures. | Thermohaline circulation | The ocean consists almost entirely of water and salt. The density of water depends on its temperature and salinity. Any changes to this causes the water to flow (currents). Also known as ocean conveyer. |
| Interglacial period | Period of time during an ice age when glaciers retreat because of milder temperatures. | Ablation | Surface removal of ice or snow from a glacier or snowfield by melting, sublimation, and/or calving. |
| Icehouse conditions | Very cold glacial conditions. | Cirque | Landform created by glaciers, grinding an existing valley into a rounded shape with steep sides, often called a corrie or cwm. |
| Greenhouse conditions | Warmer interglacial conditions. | Ice field | Large level area of glacial ice found covering a large expanse of land. Similar in size to an ice cap but does not have a dome shape. |
| Pleistocene | Period of time from about 2 million years ago to 11,700 years ago. During this period areas of land at higher and middle latitudes where covered with glacial ice. | Cryosphere | The frozen water part of the Earth system. |
| Milankovitch cycle | A theory that suggests that changes in the | Nivation | Process where snow patches initiate erosion |

| | | | |
|---|---|---|---|
| | Earth's climate are caused by variations in solar radiation received at the Earth's surface. These variations are due to cyclical changes in the geometric relationship between the Earth and the Sun. It comes in three parts: orbit eccentricity, axial tilt and earth wobble. | | through physical weathering, meltwater flow and gelifluction. |
| Stadials | Short-term changes to conditions that lead to ice re-advances. | Solifluction | Form of mass movement in environments that experience freeze-thaw action. It is characterised by the slow movement of soil material downslope and the formation of lobe-shaped features. |
| Interstadials | Short-term changes to conditions that lead to ice. | Permafrost active layer | The top level of soil of permafrost that thaws and freezes during summer and winter. |
| Orbital / astronomical forcing | A process which can change the amount of energy from the Sun reaching the Earth and forces climate to change as a response. | Continuous permafrost | Form of permafrost that exists across a landscape as an unbroken layer. |
| Albedo | The amount of light or radiation that is reflected by a surface such as ice. | Discontinuou s permafrost | Form of permafrost that contains numerous scattered pockets of unfrozen ground. |
| Calving | The breaking up of the ice sheet at the glacier snout which then forms icebergs. | Sporadic permafrost | Form of permafrost that exists as small islands of frozen ground in otherwise unfrozen soil and sediments. |

## Further reading

http://www.ucmp.berkeley.edu/quaternary/pleistocene.php – University of California Museum of Palaeontology – The Pleistocene Epoch.
http://www.indiana.edu/~geol105b/1425chap6.htm – an article that discusses the relevance of measuring geological time (good for more able students). Chapter 6: Geologic Time, Geologic Processes Past and Present – Uniformitarianism.
http://pubs.usgs.gov/gip/geotime/ – USGS Geologic Time (online edition).
http://www.cru.uea.ac.uk/documents/421974/1295957/Info+sheet+%237.pdf/320eba6e-d384-497d-b4fc-2d2c187f805e – The Thermohaline Circulation by T. Osborn and T. Kleinen.
http://www.geos.ed.ac.uk/homes/s0350775/Golledge_2007_SGJ.pdf – Academic paper by N. Golledge from *Scottish Geographical Journal* Vol. 122 No.4 Dec 2006.
http://geology.gsapubs.org/content/38/4/383.short?rss=1&ssource=mfr – The Geological Society of America.
http://www.bgs.ac.uk/research/highlights/2012/lakeWindermere.html – BGS on Windermere glacial history.
http://www.natice.noaa.gov/ims/ NOAA Ice Centre (ice extent charts).
http://web.gccaz.edu/~lnewman/gph111/topic_units/glacial/glacial2.html – excellent teacher and strong student information.
http://web.gccaz.edu/~lnewman/gph111/topic_units/glacial/glacial2.html – Glaciers and landform systems.
Wyckoff, Jerome. 2003. *Reading the Earth: Landforms in the Making*. A good book that examines processes that create the earth's various landforms with lots of good pictures. (Can be purchased cheaply from Amazon.co.uk)
http://www.blueplanetbiomes.org/tundra_climate.htm – Canadian climate with links to other areas.
http://www.ucmp.berkeley.edu/exhibits/biomes/tundra.php – Arctic tundra biome, University of California.
http://www.blueplanetbiomes.org/siberian_tundra.htm – Siberian Tundra
http://www.pri.org/stories/2014-07-30/huge-mysterious-holes-emerge-russian-tundra – interesting story on the holes appearing in the Russian tundra.
http://northerrussitundra.weebly.com/plants.html – Siberian plants found in northern tundra.
http://www.bbc.co.uk/nature/places/Russia – BBC: life in the Russian tundra.
http://www.iflscience.com/environment/underground-methane-is-making-the-russian-tundra-wobble-like-jello/ – interesting talking point for students.
https://www.theguardian.com/environment/2009/oct/20/arctic-tundra – *Guardian* article on Siberian tundra and climate change.

 

# EQ2: What processes operate within glacier systems?

## Teaching approach over 5 hours

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|---|---|
| Lesson 5 (1hr) | Glacial mass balance system and the relationship between accumulation and ablation. |
| Lesson 6 (1hr) | The reasons for variations in the rates of accumulation and ablation, and the impact these variations have on the mass balance over different timescales. |
| Lesson 7 (1.5hr) | Different processes explain glacial movement and variations in rates. |
| Lesson 8 (1.5hr) | The different processes that are important in the movement of glaciers and the factors that control the rate of movement. |
| Lesson 9 (1hr) | How glaciers alter landscapes and glacial landforms at a macro/meso and micro scale and how these create distinctive landscapes. |

## Lessons 5 & 6: The Glacier System

### Overview

In these lessons students will be investigating the ideas behind the glacial mass balance system, covering Key idea 2A.4.

This will include understanding the formation of glacier ice and its timescales, as well as the inputs and outputs within the system and appreciating that the glacier mass balance is a system which is dynamic as the ratio of the inputs and outputs varies continually in the short term as well as the long term.

For less able students it may be wise to:

- make sure all key words are defined where necessary
- use diagrammatic representations and annotations to explain the complex nature of the formation of glacier ice
- run a chronology of the timescale to help develop an awareness of the time it takes for the transition from snowflake to glacier ice
- develop an awareness of the importance of the dynamic nature of the glacier mass balance system.

Students will use numerical data (3) to calculate simple mass balance and equilibrium line position. They will also use GIS to identify the main features of glacier types and assess glacier health.

## Key concepts and processes

Students will need to understand:

- how ice forms
    - appreciate the compaction of snow and other factors that develop into ice
- the timescale for the process of glacier ice formation

    - that the timescale varies depending on temperature and can take a few days or thousands of years
- inputs and outputs of the glacier system
    - that inputs into the system consist of energy from the sun and the mass it creates in terms of snowfall to create accumulation and outputs being the ablation, sublimation, calving and meltwater/sediment leaving the system
    - glacial mass balance as a system that is dynamic and changing constantly.

## Guidance on teaching

Ice formation is generally well understood by most students. This development can be shown via a timeline as snowflakes develop into glacier ice as shown here.

What students may find harder to understand is the differing timescales that the process may take. It is important that less able students appreciate this, and they may need time to develop this awareness, while stronger students may wish to develop and research ideas such as the ones found here: http://www.iceandclimate.nbi.ku.dk/research/drill_analysing/cutting_and_analysing_ice_cores/analysing_gasses/firn_zone/

Another good site for information with some video information is Earth Labs Climate History & the Cryosphere – these also have questions for students to answer.

The information at http://serc.carleton.edu/eslabs/cryosphere/4b.html) will aid stronger students with the idea of changes in outputs and inputs and their impacts on the system. Many other videos exist, some of which are included below and in the further reading section: http://study.com/academy/lesson/what-are-glaciers-types-facts-pictures.html

For an introduction to the glacier mass balance, Antarctic Glacier.org offer an excellent website illustrating the changes between the seasons: http://www.antarcticglaciers.org/modern-glaciers/introduction-glacier-mass-balance/

## Lessons 7 & 8: The different processes that explain glacial movement and variations in rates and the different processes that are important in the movement of glaciers and the factors that control the rate of movement

### Overview

These two lessons cover much of Key ideas 2A.5a, b and c, glacial movements, and towards the end may introduce the glacial landform system.

The movement of ice often only seems difficult because of the vocabulary involved, and while there are ways to make sure that clarity is important, it is imperative that all students understand the underlying concepts that polar and temperate glaciers have different rates of movement and that there are different processes that are important in the movement of glaciers.

 

For less able students, annotated pictures, diagrams and use of PowerPoint will help in this area. Also useful are students' presentations on the processes and factors involved in glacial movement. Several videos are available online to help less able students, and university websites offer more developed resources to help stronger students develop a deeper understanding of the processes involved. Many of these will be mentioned in the further reading section.

## Key concepts and processes

Students will need to understand:

- that there are both temperate and cold climate glaciers
- that the rates of movement between these differ
- that there are different processes that are important in the movement of glaciers, including:
    - basal slip
    - regelation creep
    - internal deformation.
- that a number of factors control the rate of movement, including:
    - altitude
    - slope
    - lithology
    - size
    - variations in mass balance.
- that the factors which control the rates of movement can have both positive and negative feedback in the system.

## Guidance on teaching

Appreciating how glacial movement occurs is key to developing a full knowledge of the topic area. Students need to understand that temperate glaciers tend to be warm and wet, and generally have greater snowfall in winter and more rapid ablation in summer. This causes them to have a greater imbalance between accumulation and ablation, and leads to the ice moving more quickly down the slope in order to maintain equilibrium with the slope angle. In colder polar glaciers this movement is reduced as accumulation is slower and ablation has an even slower rate. This is shown in the diagram found at http://www.antarcticglaciers.org/modern-glaciers/introduction-glacier-mass-balance/.

More information can be found at http://www.antarcticglaciers.org/modern-glaciers/glacier-flow/, which is a great teaching resource for all students.

Students need to appreciate that the zone of ablation and accumulation determines the movement of the glacier and the mass balance gradient is the key control in factors such as the glacier's response time (i.e. the time it takes for a glacier's geometry to adjust to a new steady state after a change in the mass balance).

Once they understand this, students can focus on the processes such as basal sliding, where ice melts under pressure. This can be shown via an excellent video: http://www.antarcticglaciers.org/modern-glaciers/glacier-flow/#SECTION_4

However, where the base is cold the ice will remain frozen and unable to slide along the base, creating stresses elsewhere and potentially cracking as the upper layer is less fluid than the bottom. Students should be aware that with basal sliding there are two processes (enhanced basal creep and regelation basal creep); the differences will need clarifying and more able students may wish to consider the impacts this has on temperate glaciers as opposed to polar glaciers.

Less able students will benefit from an all-round understanding of the types of flows and the reasons – for instance, the type of geology of the rock, as soft rock will deform more easily and therefore flow will accelerate (subglacial bed deformation). The velocity of glacier ice depends on the following factors:

- altitude
- slope
- lithology
- size
- variations in mass balance.

Each of these can be reviewed in turn and assessed for the importance students believe them to have. For instance, is altitude a more important factor than gradient of slope?

Finally, within these lessons students will need to appreciate the glacier landform system and the glacial processes at work, namely:

- erosion
- deposition.

Within erosion, as with other areas they have studied, students need to learn a set number of key terms and understand the impact of each one.
Simple videos such as 'How do glaciers shape the landscape?' (an animation from geog.1 Kerboodle) can be used for less able students. More able stronger students may wish to read https://nsidc.org/cryosphere/glaciers/questions/land.html or http://www.physicalgeography.net/fundamentals/10af.html to help develop understanding.

Images are important here and many can be found on the internet to show the impacts of abrasion or plucking as well as fracturing and traction, dilation and meltwater erosion. Teachers may wish to combine these areas with landforms along with deposition.

## Lesson 9: How glaciers alter landscapes and glacial landforms at a macro/meso and micro scale and how these create distinctive landscapes

### Overview

This lesson covers Key ideas 2A.6a, b, c and begins to look at how glaciers alter the landscape at three different levels: micro, meso and macro. For less able students the idea of scale should be developed, while stronger students may wish to research these and look into the differences.

The erosional processes should be covered carefully, using diagrams, annotated pictures, videos and other methods that may benefit less able students as well as the more able. This is important as it helps students to recognise these processes and interpret the landscapes around them.

The same is true for landforms developed by different processes, such as ice scouring, where students with a good knowledge may be able to develop a clear understanding and with minimal help can begin to pick out features such as those seen in valleys such as Borrowdale, Newlands and Buttermere in the Lake District, as well as large areas of Snowdonia and northern Scotland.

Several videos of these developments are available online and can help less able students; an internet search for 'Landforms formed by Glacial Erosion' or 'Glacial Erosion and Transportation Processes' will locate material that can help students to visualise the development of landforms.

## Key concepts and processes

Students will need to understand:

- the relative importance of the glacial erosion processes of entrainment, transport and deposition. Entrainment comes in two forms:
    - supraglacial – debris transported on the surface of the glacier (erosion caused by debris from above glacier level including rockfalls, volcanic ash)
    - subglacial – debris transported beneath the glacier (erosion from valley walls and glacier beds).
- features at the following levels:
    - macro
    - meso
    - micro.
- how these have distinctive morphologies within different environments, such as subglacial, marginal, proglacial and periglacial.
- that these landforms create distinctive landscapes in both upland and lowland areas.

## Guidance on teaching

Less able students need to understand that erosion rates are more intense where glaciers are warm based, thick and faster moving and the bedrock relatively weak, and that many of the landforms that exist today are a product of this.

More able students should understand that this has relevance for the present day, since there have been several ice ages, several ice advances and retreats in the past and the landforms we see today are the product of all of these.

The mountains in the UK offer a clear indication of these landforms, especially those of the Cairngorms and north west Scotland, the Lake District and North Wales. All of these are excellent for case study information and mapping to help students identify features on an OS map.

- For the Cairngorms the maps available are: OL50–OL62
- For the Lake District the maps are: OL4–OL7
- For North Wales the maps available are: (Snowdonia) OL17, OL18 and OL23.

Mapping tools are available elsewhere, and though there is often a charge, some can be found online, such as OS Getamap (https://www.ordnancesurvey.co.uk/shop/os-maps-online2.html)
Digimaps charges a small yearly fee (http://digimapforschools.edina.ac.uk/), while ArcGIS online allows free accounts, and can be an excellent resource.
In terms of the scale of features, students need to appreciate what the following mean:

- macro-scale (around 1km or greater, e.g. cirques)
- meso-scale (within macro features and between 10m and 1km roughly, e.g. roches moutonnées)
- micro-scale (< a few metres in size, e.g. striations).

To help students understand this, the context of size is important and can be explained using the diagram in Figure 1; many landforms fit into the macro category and to a large extent the numbers get progressively less the smaller the landform.

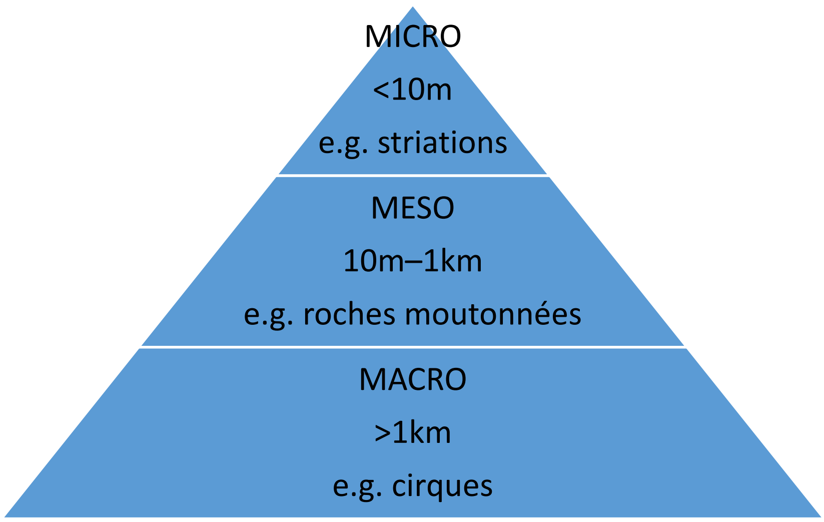


**Figure 1 – Selected Landforms by Scale (J. Foster)**

Less able students may prefer to see these in a table such as Figure 2.

| Scale | Landform |
|---|---|
| **MACRO** | cirque |
| | arête |
| | pyramidal peak |
| | trough |
| | truncated spur |
| | hanging valley |
| **MESO** | roche moutonnée |
| | |
| **MICRO** | striation |
| | chatter marks |
| | grooves |

**Figure 2 – Landforms of glacial erosion**

Students could add to this by drawing each feature and adding a short description of how they are formed as a homework or extension task in the forthcoming lessons.

These landforms and their scale are important to geographers in terms of interpreting landscapes. As these assemblages of landforms appear as a result of glaciation, they help us to reconstruct the exact position and extent of ice sheets and ice cover.
There are several models and theories surrounding this area and this is an ideal time to get students to research this and present their findings as a short radio newsflash, Q&A interview or similar.
These ideas and theories include:

- Hutton's principle of uniformitarianism
- the principle of equifinality (Drumlin formation – covered in later lessons).

By this point students should be ready to begin looking at erosion, transportation and deposition.

## Key vocabulary for EQ2

| Term | Definition | Term | Definition |
|---|---|---|---|
| Névé or firn | Partially melted and compacted snow that survives the year's ablation season (it can become glacier ice). | Plucking | Erosive process of particle detachment by moving glacial ice. In this process, basal ice freezes in rock surface cracks. As the main body of the glacial ice moves material around, the ice in the cracks is pulled and plucked out. Also called *quarrying*. |
| Extrusion flow | The theory that glacier ice flows faster at a greater depth. | Fracture and traction | Results from the crushing effect of the weight of ice passing over rock and any variations in pressure resulting in freeze-thaw action (can aid the plucking process). |
| Equilibrium point | Ablation losses and accumulation gains are balanced within a glacier. | Dilation | Happens when overlying material is moved, causing fractures in the rock that are parallel to erosion surfaces as the bedrock adjusts. |

 

| | | | |
|---|---|---|---|
| Benchmark glacier | A glacier chosen to be monitored annually for ablation and accumulation. | Meltwater erosion | Similar to fluvial erosion except meltwater is under hydrostatic pressure and chemical weathering. |
| Basal sliding | The sliding of a glacier over the surface it rests on. Caused by the gradient of the slope and the weight of the glacier's mass. Comes in two forms: relegation slip and enhanced basal creep. | Supraglacial | Situated or occurring at the surface of the glacier. |
| Internal deformation | A 'creep' method found generally in cold-based glaciers where the ice crystals orientate themselves in the direction of ice movement. This allows ice crystals to slide past one another. | Subglacial | Situated or occurring underneath a glacier or ice sheet. |
| Intergranular flow | When individual ice crystals deform and begin to move in relation to each other. | Englacial | Situated, occurring, or formed inside a glacier. |
| Laminar flow | Where individual layers of the glacier move. | Macro-scale | Landform above 1km in size. |
| Glacial surge | Occurs where instabilities in flow result in a rapid forward movement of the snout of a glacier. | Meso-scale | Landform between 10m and 1km. |
| Abrasion | Physical wearing and grinding of a surface through friction and impact by material carried in water or ice. | Micro-scale | Landform roughly less than 5m in size. |

## Further reading

http://www.iceandclimate.nbi.ku.dk/research/drill_analysing/cutting_and_analysing_ice_cores/analysing_gasses/firn_zone/ – The Firn Zone: transforming snow to ice.
http://study.com/academy/lesson/what-are-glaciers-types-facts-pictures.html – What Are Glaciers? – Definition, Types & Processes (good for less able students).
https://www.aber.ac.uk/greenland/Petermann.html – Petermann Glacier, NW Greenland.
http://www.eea.europa.eu/data-and-maps/indicators/glaciers-1/assessment – glacier assessment.

http://www.antarcticglaciers.org/modern-glaciers/introduction-glacier-mass-balance/ – Antarctic glaciers.org.
https://www.studyblue.com/notes/note/n/chapter-13/deck/4808118 – great site for the key terms and meanings.
http://geomorphology.org.uk/sites/default/files/ice_movement.pdf – excellent pdf on Ice movement and glacier flow from the BGS.
http://www.physicalgeography.net/fundamentals/10ae.html – more information on glacier processes from physical Geography.net
http://www.glaciers.pdx.edu/Projects/LearnAboutGlaciers/Skagit/Basics00.html – great for less able students Questions about Glaciers, Climate and Streamflow.
http://www.geology.um.maine.edu/geodynamics/AnalogWebsite/UndergradProjects2010/BrittanyGilman/Pages/Introduction.html – glaciers and glacial movement, good for less able students.
http://people.ee.ethz.ch/~luethim/pdf/script/pdg/chapter1-2.pdf – good for more able students and teachers.
http://www.puzzle-maker.com/CW/ – crossword maker.
https://worksheets.theteacherscorner.net/make-your-own/crossword/ – crossword maker.
http://tools.atozteacherstuff.com/word-search-maker/wordsearch.php – wordsearch creator.
http://www.geol.umd.edu/~piccoli/100/CH14.htm – moraines and good information on many different landforms and erosion types.
I.S. Evans, Durham University wrote an excellent article on 'Cirques and Moraines of the Helvellyn range, Cumbria: Grisdale and Ullswater' in the British Geomorphological Research Group Spring Field Meeting 16–18 May 1997, called *Geomorphology of the Lake District: A Field Guide*, edited by John Boardman
https://web.viu.ca/earle/geol305/glacial-entrainment.pdf – excellent presentation with great diagrams students could label.
https://www.geo.umass.edu/courses/geo563/Geo563-7.SubglErosion.pdf – excellent presentation with lots of great diagrams.

## EQ3: How do glacial processes contribute to the formation of glacial landforms and landscapes?

### Teaching approach over 5 hours

| | |
|---|---|
| Lesson 10 (2hr) | The processes of glacial erosion and the processes leading to the formation of landforms associated with cirque and valley glaciers. |
| Lesson 11 (1hr) | The formation of landforms due to ice-sheet scouring. |
| Lesson 12 (1hr) | The formation of ice contact depositional features and those of lowland depositional features. The assemblage of landforms can be used to reconstruct former ice extent and movement and for provenance. |
| Lesson 13 (1hr) | The processes of water movement within the glacial system and the fluvial glacial deposits and their different characteristics. |
| Lesson 14 (1hr) | The formation of fluvioglacial landforms; ice contact features and proglacial features. |

 

## Lessons 10, 11 & 12: Processes, landforms and features of glacial landscapes

**Overview**

This group of lessons covers Key ideas 2A.7 a, b, c and lesson 12 Key idea 2A.8a, b, c. Students will be introduced to the processes leading to the formation of landforms at different scales. The concept of scale from previous lessons can now be revisited to help explain and reinforce these ideas and built upon now by an explanation of the processes within our landscape.

In these lessons it's important to cover highland erosional landforms and lowland ones. Less able students may find it hard to distinguish these, so it may be wise to break them down into those created in mountainous areas and those created in areas where deposition and transportation are more prominent.

The final part of these lessons develops and builds on what students already know in terms of methods and ways of creating, interpreting and identifying provenance.

### Key concepts and processes

Students will need to understand:

- the processes of glacial erosion:
  - abrasion
  - quarrying
  - plucking
  - crushing
  - basal melting.

- their combined impact with:
  - subaerial freeze-thaw
  - mass movement.

- the processes that lead to the formation of landforms associated with cirques and valley glaciers:
  - cirques/corries
  - arêtes
  - pyramidal peaks
  - glacial troughs
  - truncated spurs
  - hanging valleys
  - ribbon lakes.

- the formation of landforms due to ice-sheet scouring:
  - roches moutonnées
  - knock and lochan
  - crag and tail.

- the impacts and influence of different geology, including:
  - hard rock such as granite
  - soft rock such as shale.

 

## Guidance on teaching

Students could produce annotated sketches of these landforms or find them on maps (macro scale only). Alternatively, use known examples such as those listed below.

| Landform | Example in UK |
|---|---|
| Cirque | Red Tarn (Helvellyn) or Easedale Tarn (Grasmere) |
| Arête | Striding Edge (Helvellyn) or Sharp Edge (Blencathra) |
| Pyramidal peak | Ben Lui (Argyll Scotland) |
| Trough | Buttermere Valley in the Lake District |
| Truncated spur | Langdale Valley in the Lake District |
| Hanging valley<br>Ribbon Lake | Borrowdale Valley the Lake District<br>Windermere in the Lake District |

In the field or using photographic evidence it may be possible to consider other features such as roche moutonnée. Furthermore, it may be beneficial to use both UK and global examples (the USA has many good examples).

Using OS maps, students could analyse the direction of ice flow through the location and interpret cirques within a given area. Examples from several areas of the UK could be passed around the class for students to consider and discuss. This will improve their understanding of both OS maps and glacier movements and the processes of erosion.

In a similar way, students could look at the landforms of glacial deposition. The main processes of deposition are:

- lodgement – when subglacial debris becomes lodged or stuck beneath the glacier (more common in very large glaciers)
- ablation – debris being deposited as a glacier thaws
- deformation – less obvious but where weak underlying rock can cause sediment to be moved downwards
- flow – where high water removes and deposits material elsewhere

Some good video material can be found by carrying out an internet search for 'Glacial landforms OSUECampus video'. This helps to show students how to interpret maps and then explains this via pictorial evidence, a really good tool for less able students and covers a great deal of information.
Again for students it might be wise to develop a range of features and how they are made, like Figure 3 (some cells have been left blank for students to fill in).

| Landform | Appearance | Description | Example |
|---|---|---|---|
| Braided streams | | | Ennerdale (R. Liza) |
| Drumlins | | | Swindale Valley or Esk Valley |
| Erratics | | Long twisting ridges of sand and gravel. Created when the deposits of subsurface glacial streams are placed | Easedale |

 

| | | | |
|---|---|---|---|
| | | on the ground after glacial melting. | |
| Moraine | | | |
| Outwash plain | | A flat or gently sloping surface of glaciofluvial sediments deposited by meltwater streams at the edge of a glacier. Usually found in close spatial association with moraines. | |
| Rock flour | | | |

**Figure 3**

(Any variation of this table many be useful with teachers altering where applicable depending on students' level.)

It is important to note that moraines exist in a variety of types, many of which can be shown via diagrammatical or pictorial evidence like this. Many of these features are available for viewing in the UK – Borrowdale Valley in the Lake District offers excellent examples of both meso- and micro-scale features as well as the grander macro features.

The other types of moraine are also important to remember. There are several videos available online, including: http://study.com/academy/lesson/glacial-deposition-definition-results.html , which looks at USA glacial deposition; it is good for less able students. For more able students, several academic papers are available such as the excellent article by D.J. Graham (Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales) on 'The formation and significance of a moraine-mound complex ("hummocky moraine") of Younger Dryas age in Ennerdale, English Lake District'.

Another way to help students would be through the use of such teaching aids as crosswords or wordsearches. These are especially helpful for less able students who may be struggling with the terminology.
Crosswords can be created easily using sites such as:
http://puzzlemaker.discoveryeducation.com/CrissCrossSetupForm.asp

The final part of these lessons should concentrate on provenance and how these erosional and depositional features allow us to interpret landscapes and understand the way glaciers flowed and where they flowed to. If students have a clear understanding of the features and can appreciate and evaluate the types of landforms via OS maps and shape, the concepts should be understandable and a good area for fieldwork if applicable.

A good way for students of glaciology to begin to detect these origins is to have access to a range of evidence and to come up with their own conclusions.
Good examples are the Cairngorms, North Wales and the Lake District. Students would need maps, photographs, satellite images such as Google Maps or similar, and they can begin to analyse these to help understand where and why the ice flowed the way it did.

The Helvellyn and Fairfield range offer excellent exemplification to help students develop their understanding through mapping. Using OS map OL5 and the area roughly between Thirlmere Reservoir and Ullswater (the Helvellyn and Fairfield Ranges), it is possible to isolate and interpret the direction of ice flows via the cirques that have been created. There are over 15 cirques (see I.S. Evans). More able students may wish to delve further into this paper and plot and evaluate the movement of ice within these regions, while less able students must understand the concepts surrounding provenance in upland areas.

## Lessons 13 & 14: Glacier hydrology and the formation of fluvioglacial landforms

**Overview**
As already considered in previous lessons, glacial meltwater plays an intrinsic part within the processes of erosion. These two lessons aim to cover Key ideas 2A.9 a, b, c. There are many areas within this to consider, and teachers or students may well have already touched on several of these within the lessons so far.

## Key concepts and processes

Students will need to understand that:

- meltwater plays a key role in erosion:
    - in the movement of sediment
    - (indirectly) in plucking and glacial abrasion.
- meltwater and water movement can be subglacial, englacial or supraglacial:
    - surface melting – occurs during the ablation period towards late summer and melts the top of the glacier, creating streams (in ablation zone) which then enter the glacier through moulins or crevasses and become englacial streams
    - basal melting – in warm glaciers the base can be at the pressure of melting point and thus flows under hydrostatic pressure and flows subglacially until it reaches the snout of the glacier and flows from it.
- the processes of fluvio-glacial erosion:
    - these streams tend not to operate like normal streams as they act under pressure and have different velocities. This can cause erosion via abrasion, cavitation and chemical means. Many streams have high discharge during deglaciation which can also lead to powerful erosion.
- the characteristics of fluvio-glacial deposition:
    - deposits tend to be smaller in size as they carry finer material
    - deposits are generally smoother and rounder due to contact with water and the moulding methods of attrition
    - larger material is found higher up the valley
    - deposits are stratified vertically due to seasonal sediment accumulation.
- the landforms created from fluvio-glacial deposition can be broken down into:
    - ice contact features: any material that is deposited subglacially, englacially or supraglacially
    - proglacial features: deposited after the meltwater has left the glacier snout.

## Guidance on teaching

After covering a lot of land features and processes, it might be difficult to maintain the momentum of less able students. One way to introduce this topic is to have students annotate a glacier from its beginning to its snout, then question them about what happens next. Some may get the link between sea-level rise and increased ablation, but stronger students may consider the impacts of fluvial erosion downstream of the snout.

Students need to understand the processes and role of meltwater. This can be seen in several videos found online, such as 'Rivers of meltwater on Greenland's ice sheet contribute to rising sea levels' by UCLA. There are also other documentaries that can be found for students who express a further interest, e.g. Greenland Ice Sheet: 'Starting to Slip' – YaleClimateConnections. Other search headings can be found below.

Once students appreciate the importance of the hydrology within glaciers and the role of meltwater in both erosion and transportation, it is important that they recognise the depositional features these can present. These can be separated into those features created by constant ice, and those that are created beyond the ice sheet where the glacier snout has receded (proglacial features) – see Figure 4.

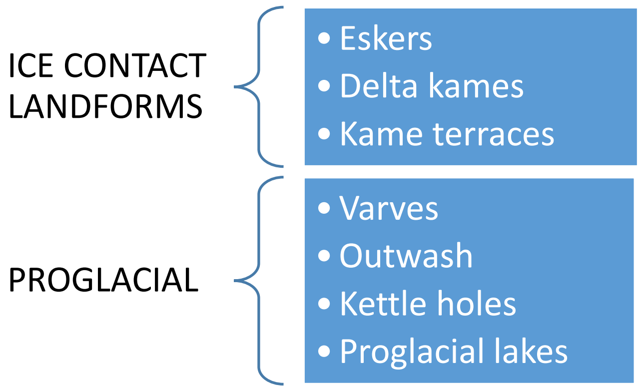


**Figure 4: Landforms of fluvio-glacial deposition**

Case studies are an excellent way to get this material across, while student t-tests can be used to analyse changes in sediment size and shape in outwash plains. Central tendency analysis of both glacial and fluvioglacial deposits (comparison of size, shape and degree of sorting of clasts) could be carried out as part of fieldwork. There is the possibility of using data such as this on glacial and fluvioglacial deposits in the Boyne Valley, Ireland.

These landforms can create difficulties for less able students, and different methods could be used such as dominoes, vocabulary testing, crosswords, or more inventive methods where students have to stand in a corner designated as a feature of deposition, erosion, ice contact or proglacial. All these methods should help to develop understanding, whilst for more able students a wealth of extra study and research methods exist, many of which are listed in the further reading sections in this guide.

## Key vocabulary for EQ3

| Term | Definition | Term | Definition |
|---|---|---|---|
| Fluvio-glacial | Erosion or deposition caused by flowing meltwater from glaciers or ice sheets. | Kame | Small mounds left on a valley floor. |
| Proglacial | Occurring beyond the snout of a glacier. | Esker | A long sinuous ridge left by a retreating glacier on a valley floor. |
| Moulin | A vertical shaft in a glacier, often round like a pot hole, formed by surface water percolating through cracks in the ice. | Proglacial lake | A lake that forms behind a moraine or ice dam. |
| Crevasse | A deep fracture or break on the brittle surface of a glacier. Caused by the differential movement of parts of the glacier at different depths. | Kettle holes | Small, often circular, lake left on the valley floor by detached ice block melt. |
| Hydrostatic pressure | An increase in pressure in proportion to depth measured from the surface due to the increasing weight of ice exerting a downward force. | Varve | A thin yearly deposit of sediment on the bottom of a lake. Within each varve there are variations in the colour and texture of the material deposited. The thickness and its associated layers can be used to reconstruct past environmental conditions influencing the lake. |
| Cavitation | A process of intense erosion due to the surface collapse of air bubbles found in constricted rapid flows of water. | Outwash plain | Also called a sandur; a plain formed of glacial sediments deposited by meltwater outwash at the terminus of a glacier. |
| Kame terrace | Ridges of material left behind and running along the edge of a valley floor. | Overflow channels | Often called meltwater channels; these form as the original course followed by a river before glaciation become blocked or as an overflow of a proglacial lake. They have considerable energy and can gouge out a new channel, e.g. Ironbridge Gorge. |

## Further reading

http://thebritishgeographer.weebly.com/the-physical-characteristics-of-extreme-environments.html – British Geographer on glacial environments – good for pictures, definitions and other information.
http://www.swisseduc.ch/glaciers/glossary/index-en.html – photo glossary, excellent teaching resource.
http://geo.msu.edu/extra/geogmich/outwash_plains.html – outwash plains information from MSU.
http://nsidc.org/data/glacier_inventory/index.html – World Glacier inventory (contains information for over 130,000 glaciers. Inventory parameters include geographic location, area, length, orientation, elevation, and classification) – contains huge amounts of free datasets.
http://www.bgs.ac.uk/research/tomography/permafrostCRI.html – permafrost research.
https://www.nrcan.gc.ca/the-north/resources/maps/10725 – an excellent resource for teachers and more able students, this has huge amounts of free data and academic papers and is easy to navigate.

# EQ4: How are glaciated landscapes used and managed today?

### Teaching approach over 6 hours

(*break down into lesson groups – doesn't need to be individual lessons*)

| | |
|---|---|
| Lesson 15 (1hr) | Relict and active glaciated landscapes have environmental and cultural value and why these landscapes are important economically as well as environmentally. |
| Lesson 16 (1hr) | Glaciated landscapes face varying degrees of threat from both natural hazards and human activities. |
| Lesson 17 (1hr) | Human activity can degrade the landscape and fragile ecology of glaciated landscapes. |
| Lesson 18 (1hr) | Global warming is having a major impact on glacial mass balances, which in turn risks disruption of the hydrological cycle. |
| Lesson 19 (1hr) | Different stakeholders are involved in managing the challenges posed by glaciated landscapes, using a spectrum of approaches. The use of legislative frameworks to protect and conserve landscapes by conservation and management at a variety of scales. |
| Lesson 20 (1hr) | The challenges faced in successfully managing these unique and fragile landscapes against the context risk of climate change. |

 

## Lesson 15: Relict and active glaciated landscapes have environmental and cultural value and why these landscapes are important economically as well as environmentally

**Overview**

This lesson covers Key ideas 2A.10a, b, c and is a good introduction to the human element of this topic. It looks at the value that we put on these environments in cultural, economic and environmental terms.

For the cultural aspect, students should look at the scientific research that is occurring, especially in polar regions, and the growth in wilderness recreation and the spiritual and religious associations some of these areas have.

For many more able students there is plenty of information on these areas, many of which are listed below, beneficial both in the development of case studies as well as research tasks. Other good methods for less able students to be able to evaluate these areas would be cost-benefit analysis and SWOT analysis.

There are also possible synoptic links to topics such as the carbon and water cycles (permafrost melt and glacial ablation) as well as tectonics (fold mountains). (Topic 5: The Water Cycle and Water Insecurity. Key ideas: 5.1–5.3, 5.5, 5.6)

### Key concepts and processes

Students will need to understand that:

- relict and glacial landscapes experience both opportunities and threats from economic factors
- there are several economic benefits of these areas:
  - farming
  - mining
  - forestry
  - tourism
  - hydroelectric power.
- relict and active glacial areas also offer both ecological and environmental value:
  - 75% of all freshwater is confined to ice
  - glacial features such as ribbon lakes can easily be dammed
  - upland areas and glacial summer melt are a valuable source of water for many people around the world.
- tundra plants and animals have adapted to very low temperatures, often making them unique.

### Guidance on teaching

For research, a good place to start would be http://www.polarresearch.net/index.php/polar, an up-to-date research site that is good for teachers and more able students. The Scott Polar research institute (http://www.spri.cam.ac.uk/) is full of good examples and academic work from the University of Cambridge. Less able students will benefit from developing a clear understanding of the research that is carried out into climate change, ecology and marine life.

The Antarctic and Arctic regions are the fastest-warming on the planet, and scientists are trying to appreciate the impact this will have not only on climate but also on ocean circulation, sea level and the maintenance of ecosystems that help support life. For less able students it is easy to develop this reasoning through an appreciation of the impacts that could result from the warming of the polar regions, and getting them to list the potential issues should develop their reasoning as to the importance of the areas.

For their wilderness value in active glacial areas it is possible to go back to the legacy specification and look at the development of Arctic National Wildlife Refuge (ANWR) both as an example of the pristine environment that exists and for the potential economic value of the area. Examples of attitudes to development and preservation can be discussed with various views accounted for, e.g. in favour of preservation: http://anwr.org/ or for a balanced view: http://arcticcircle.uconn.edu/ANWR/anwrindex.html from an environmental perspective: http://www.defenders.org/arctic-national-wildlife-refuge, while there is also a view that the local indigenous tribes such as the Gwich'in see the Arctic from a religious perspective. This allows a case study such as this to cover a variety of perspectives, and may help less able students to develop their understanding. This site looks at why the Gwich'in consider it a sacred area – a great resource for teachers and students alike: http://sites.coloradocollege.edu/indigenoustraditions/sacred-lands/arctic-national-wildlife-refuge/

There are a variety of uses for these environments that should also be considered whether they are relict or active. Hydroelectric power (HEP), sources of water, timber and recreation are all important around the globe. HEP can be looked at in terms of the Alps. The Grande Dixence Dam in Switzerland is a good example, as is http://www.swissinfo.ch/eng/hydropower_swiss-alps-proposed-as-powerhouse-of-europe/32762310 a balanced view looking at different aspects. Other areas to focus on include forestry. A good example that can be a combined case study is the Ennerdale Valley in the Lake District, which offers an excellent view of forestry in the past and the concept of re-wilding the valley to help secure its future. Tourism is another area that students can look at. Several sites are listed below.
Mining and quarrying can be developed through several relict and active environments including sand and gravel in Wales. These are found mainly in river valleys where they were deposited directly at the margins of glaciers.
Tourism (walking, climbing, recreation) is important both in the relict areas of the UK and in active places such as the Alps, Canada and Nepal. These subjects lend themselves to the development of discussion and research where differentiation is possible and encouraged.

 

## Lessons 16 & 17: Glaciated landscapes face varying degrees of threat from both natural hazards and human activities, which can degrade the landscape and fragile ecology of these areas

### Overview

These lessons look at Key ideas 2A.11a and b. These two lessons build on what was taught in the previous lesson. Understanding the value of these areas will allow students to understand the potential threats. For less able students, SWOT analysis and cost-benefit analysis will be excellent tools to develop focus on the threats and problems that are present.

More able students can investigate links to climate change and hazards as well as a wealth of research which is available both online and in textbooks.

### Key concepts and processes

Students will need to understand:

- that there are several threats to glacial environments and that these can be broken down into 'natural' and 'human'
- that humans can degrade this landscape as they look for economic gain
- that there is a constant battle between the elements and human activity in using these wilderness environments.

### Guidance on teaching

For some students it may be best to state the factors that are human and those that are natural:

| NATURAL | HUMAN |
|---|---|
| Avalanches:<br>• Slab<br>• Powder<br>• Dry flow<br>• Wet flow | Tourism:<br>• Wildlife and environmental degradation<br>• Disruption to ecosystems<br>• Litter and waste<br>• Noise<br>• Trampling |
| Lahars | Deforestation |
| Glacial outbursts | Soil erosion and landslides |

Though the environmental factors appear to outweigh the human in number, the human factors are far more complex in terms of the impacts and factors that cause them. An excellent resource for the tourism impacts is GRID Arendal, which is a centre collaborating with the UNEP. It has a huge photograph collection which covers both the Arctic and Antarctic regions and Prudhoe Bay, Arctic Tundra wilderness (ANWR). It has an excellent report on tourism in polar regions, useful for both teachers and students: http://www.grida.no/publications/tourism-polar/page/1417.aspx. There is also a report on cruising in the Arctic: http://www.arctictourismandclimate.lakeheadu.ca/sites/default/files/CTAC_Final-Report_FINAL_REDUCED.pdf , which consists of case-study examples and is a great resource for less able students. The following site looks at the costs and benefits of this type of tourism: http://www.worldpolicy.org/blog/2014/09/17/price-discovering%E2%80%9D-arctic-%E2%80%93-part-i

For natural threats there are definite areas where students can develop a clear appreciation and link to other topics such as Tectonics. Avalanches kill over 150 people each year, most of whom are skiers and other recreationalists. Information can be found below.

For some natural events there is a human factor to consider. For more able students, a graph such as this could be the start of a good debate on tourism vs natural threats.

For different types of avalanches and the problems they present, http://www.digitaljournal.com/news/world/avalanches-an-alpine-menace/article/455234 allows students to read up on these. The USGS has excellent resources for lahars (see below) and for glacial outburst many videos can be found with the aid of search criteria such as 'Volcano in Iceland - flash flood from Eyjafjallajökull glacier'. This will help to give students an appreciation of the amount of water that can be released by such events as jökulhlaups.

## Lessons 18, 19 & 20: Global warming is having a major impact on glacial mass balances and the hydrological cycle. There are different stakeholders involved in managing the challenges posed by glaciated landscapes at a variety of scales and there are challenges in successfully managing these fragile landscapes from the risk of climate change.

### Overview

These final three lessons cover the Key ideas of 2A.11c as well as Key idea 2A.12,b,c. These lessons help tie together the previous lessons in terms of the management of these environments and the complex nature of climate change and its impacts. This can be done via first discussion as to the issues and the solutions or alternatively via research and organised debate. Students may wish to break into different groups such as Governments, Environmentalists, TNCs and locals. They could look at a named environment such as ANWR, Snowdonia or the Alps and begin to look at the impacts and the best way to manage these environments.

### Guidance on teaching

First, students can research the known impacts of climate change on glaciers. Less able students could be directed to https://www3.epa.gov/climatechange/kids/impacts/signs/glaciers.html in order to introduce the main ideas; issues such as snowpack and permafrost melt can also be investigated on this site. The antarcticglaciers.org website again has much to offer as well as the reduction in the size of the Greenland ice sheet.

Stronger students may wish to research and counter the argument for which some links exist below. These links should be a good starting point from which to develop a clear understanding of the impacts and an evaluative view of future problems. Showing impacts to the hydrological cycle such as meltwater, river discharge, sediment yield and quality could be given to scientists to report on and disputed by others to help the assessment process, while numerical analysis can be done to look at rates of recession in different areas. The world glacier monitoring service offers data and statistics that can be sourced, and some other links are also listed below.

The legislative frameworks and management can be considered much as they were in the legacy specification in terms of methods, e.g. see Figure 5:

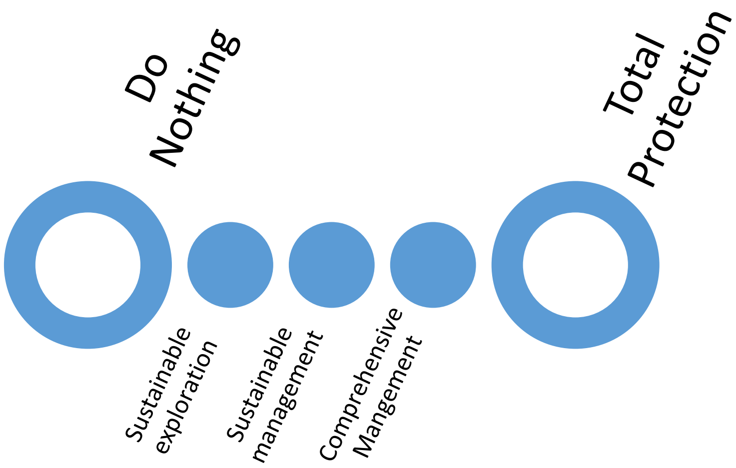


**Figure 5**

Students will benefit from having examples of each specific to a cold environment. It is important that all students recognise that sustainability relies on three factors, shown in Figure 6:

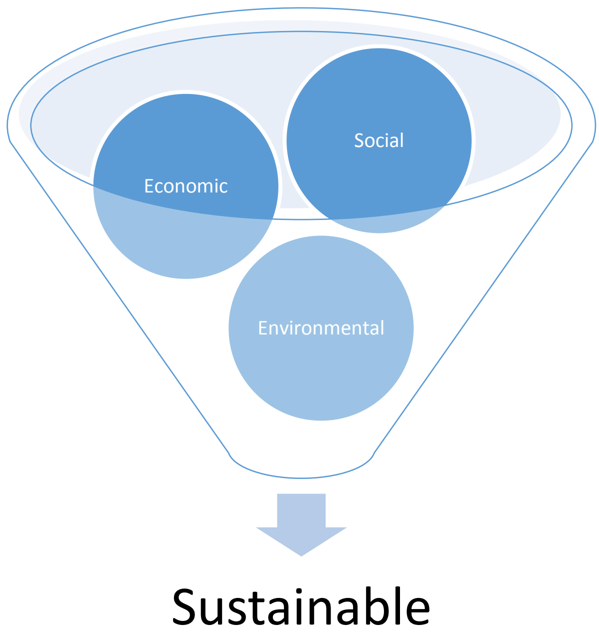


**Figure 6 – factors in sustainability**

 

If these factors are maintained, the approach can be considered sustainable for the future, as shown in Figure 7:

| Social | Economic | Environmental |
|---|---|---|
| Working conditions<br>Cultural and religious awareness<br>Community<br>Health and well-being | Good jobs<br>Fair wage<br>Security<br>Infrastructure | No pollution<br>Renewable<br>Conservation<br>Restoration<br>Consideration |

**Figure 7 – some conditions of sustainability**

The legislative framework should be considered on three scales: International, National and Local. Examples of these should be known.

The final area considers the futures for these regions. These increasingly fragile landscapes need a coordinated approach at the levels mentioned and these need to be acted upon now. Students may wish to develop their awareness of the different types of mitigation and adaptation policies. For example, investigation into such conservation techniques as CITES, UNESCO World Heritage sites, lifestyle changes, taxation and international agreements such as those aimed at emission reductions. Many of these were covered in the legacy specification under World at Risk: climate change and biodiversity under threat.

## Further reading

http://www.polarresearch.net/index.php/polar – *Polar Research* is the international, peer-reviewed journal of the Norwegian Polar Institute, Norway's central institution for research into polar regions.
http://www.spri.cam.ac.uk/ – Cambridge University research department.
http://sites.coloradocollege.edu/indigenoustraditions/sacred-lands/arctic-national-wildlife-refuge/ – Colorado College article looking at indigenous religious traditions in ANWR.
http://wwf.panda.org/what_we_do/where_we_work/alps/problems/freshwater/hydropower.cfm – WWF review of issues with Alpine HEP (good for less able students).
http://www.wildennerdale.co.uk/managing/forest/ – Wild Ennerdale Forestry.
http://www.rewildingbritain.org.uk/rewilding/rewilding-projects/wild-ennerdale – Rewilding Britain, Wild Ennerdale.
http://www.countryfile.com/countryside/ennerdale-wildest-corner-cumbria – Countryfile article on re-wilding of Ennerdale.
http://www.wildennerdale.co.uk/resources/library/ – resources available from Wild Ennerdale website.
http://environment.nationalgeographic.com/environment/natural-disasters/avalanche-profile/ – *National Geographic* article on avalanches.
https://www.dosomething.org/facts/11-facts-about-avalanches – 11 facts about avalanches.
http://www.digitaljournal.com/news/world/avalanches-an-alpine-menace/article/455234 – Avalanches: an Alpine Menace.
https://volcanoes.usgs.gov/vhp/lahars.html – USGS Lahars
http://glaciers.uoregon.edu/hazards.html – Glacier Hazards, University of Oregon, has excellent links and resources for both teachers and students.

http://www.icimod.org/dvds/201104_GLOF/reports/final_report.pdf – Long report on glacial lakes and glacial outburst in Nepal.
http://www.antarcticglaciers.org/glaciers-and-climate/glacier-recession/glaciers-and-climate-change/ – Antarctic glaciers and impacts of climate change.
http://www.skepticalscience.com/Global-Warming-in-a-Nutshell.html – sea ice melt.
http://www.eea.europa.eu/data-and-maps/figures/area-of-greenland-ice-sheet-melting-1979-2007
https://yougov.co.uk/news/2012/09/04/melting-greenlands-ice-sheet-natural-phenomenon-ma/ – melting of Greenland's ice sheet – natural phenomenon, manmade, or both?
http://www.nasa.gov/feature/goddard/nasa-study-mass-gains-of-antarctic-ice-sheet-greater-than-losses – NASA Study: Mass Gains of Antarctic Ice Sheet Greater than Losses.
https://www.wunderground.com/climate/SeaIce.asp – sea ice and the climate system.
http://geogenetics.ku.dk/latest-news/alle_nyheder/2015/nature-ice-sheet/ – the Greenland Ice Sheet during the 20th century – a missing link in IPCC’s climate report.
https://nsidc.org/glims/glaciermelt/#data – global glacier recession data.
https://www.epa.gov/climate-indicators/glaciers – EPA climate change indicators – glaciers.
http://www.grid.unep.ch/glaciers/pdfs/glaciers.pdf – large directory of facts and figures – good for teachers and more able students.
http://instaar.colorado.edu/other/download/OP55_glaciers.pdf – Colorado University data Glacier Mass Balance and Regime: Data of Measurements and Analysis by M. Dyurgerov (268 pages).
http://nsidc.org/data/g10002 – Glacier Mass Balance and Regime Measurements and Analysis, 1945–2003, Version 1.

 