

Past climate and glaciation of the Drakensberg Mountains, southern Africa

Teachers' guidance notes

Although this resource has been designed as a full set of interrelated lesson plans, many of the activities can stand alone to support different aspects of the following topics:

- Studies of glaciation, periglaciation, and cold environments in general
- Studies of climate change where students need an example of long-term climate change and how scientists reconstruct climates of the past
- Studies of geographical skills, fieldwork, and the process of enquiry (including hypothesis testing, descriptive statistics, and correlation)

The rest of this document summarises each lesson, suggests how different activities might be taught, and provides answers to some of the student activities.

Lesson one: Case study

Aims: To learn about the LGM, review key terminology relating to glacial and periglacial environments, and build an A-level case study of a previously glaciated environment where climate was very different in the past compared to what it is today. To include:

- Information about the LGM with an overview of how different the world's climate was at the time
- A review of the main types of glacial and periglacial features
- The present-day location, climate and environment of the Drakensberg
- The climate of South Africa in general and relation to ocean currents
- An introduction into geographical research on past glaciation and past climates inspired by the research of Dr Stephanie Mills in the High Drakensberg

This lesson supports teaching of climate change over long timescales and the evidence for it, of how the distribution of cold environments has changed through time, and of the process of geographical research

Starter (*learning about the Last Glacial Maximum (LGM)*)

This activity would be best suited to a computer lab setting where students can browse the Powerpoint slide show about the LGM and the web links at their own pace while noting down answers to the questions. However, the slide show could also be presented by the teacher.

Use the links and PowerPoint slides to provide answers in note form to the following questions:

- What was the Last Glacial Maximum?
[The height of the last glacial phase, when ice sheets last reached their maximum extent and sea-level reached its lowest point during the last glacial cycle.](#)
- When did the LGM occur?
[In the academic literature a range of age estimates have been given for the Last Glacial Maximum, but the age range chosen for this presentation is that it represents a time of](#)

maximum ice sheet cover between 26,000 to 18,000 years ago. This has been chosen to be a relatively wide range that includes most estimates seen in the academic literature.

- How were the climate and environment different during the LGM?
Students will find plenty of detail in the slides and websites; but in general they should consider temperature (colder globally by about 6°C), precipitation (drier on average globally), and changed vegetation zones (e.g. tundra across mid-latitude Europe south of the ice sheet).
- What happened to the world's oceans during the LGM?
It was about 120m lower. Students should notice that lower sea-level meant that many places currently under water today were dry land, such as the English Channel.
- How do you think the Northern Hemisphere and Southern Hemisphere compared during the LGM and why?
Students should notice that ice sheets became much more extensive in the Northern Hemisphere because there is more land in this hemisphere at middle to high latitudes. Although the Antarctic Ice Sheet was bigger during the LGM, the change wasn't as large because of the Southern Ocean surrounding Antarctica.
- What has happened to the Earth's climate since the LGM?
The basic answer is that the Earth's climate warmed after the LGM and the ice sheets gradually became smaller. However, students should know that it took a long time for the ice sheets over Europe and North America to disappear completely (several thousand years). The actual warming during the Late Glacial was fast, but there were oscillations (including the Younger Dryas cold phase that brought glacial conditions back to Britain between about 12,900 and 11,700 years ago. Climate warmed rapidly around 11,700 years ago, ushering in the Holocene Interglacial. As the ice sheets wasted away, sea-level rose, reaching levels similar to today about 8,000 years ago.

Main

Activity 1: Review of glacial and periglacial terms and concepts

This activity can stand alone as a revision exercise for A-level, or even GCSE. The term/definitions matching exercise can be done by students individually or set as a homework assignment. The speed dating involves all students in the class.

The answer sheet showing correct matches between terms and definitions is on the last page of the 'Lesson 1 terms and definitions activity' download.

Activity 2: Overview of the present-day climate and environment of the High Drakensberg

Like the Starter activity, this activity would be best suited to a computer lab lesson where students can peruse the slides and associated web links at their own pace. Production of the summary document about the Drakensberg could be done in class or as a homework assignment.

Plenary

The aim here is for students to consolidate the knowledge gained so far in Lesson 1, and to consider what a geographical investigation based in the High Drakensberg could achieve and how it could be planned. They should also refer to the Researcher Q&A resource at the end of the lesson.

Discuss the following questions in your groups of three, and report back your answers to the rest of the class.

- What do you think the climate of the High Drakensberg would have been like during the LGM compared with today?
All that's needed here is awareness that the climate of the High Drakensberg would probably have been much colder during the LGM than it is today. Students might also comment on a change in precipitation. The actual change in precipitation that occurred in the High Drakensberg during the LGM remains contentious and a subject of research; but it seems likely that summer precipitation decreased while winter precipitation increased.
- What evidence would you look for in the Drakensberg to test your views about the climate there during the LGM?
Evidence for a once colder climate in the form of glacial and periglacial landforms. Any glacial or periglacial landforms identified would also need to be dated in some way to test whether or not they originated during the LGM.
- The extent of past glaciation in the Drakensberg is neither as well studied nor as well known as past glaciation in the British Isles. Can you suggest any reasons why?
One reason is that the British Isles were much more heavily glaciated, so the evidence is much more visible and abundant. Another reason is that due to the lower latitude of the Drakensberg (about 30°S as opposed to over 50°N) scientists have not expected to find much (if any) evidence there, and so the area has not attracted the same amount of research. Students might also suggest that there has been less research done there because the area is less accessible and less economically developed compared with Europe.
- Why do you think it would be useful to investigate evidence for glacial and periglacial activity in the Drakensberg?
It would increase our knowledge about the climate of southern Africa and how it has changed over long periods of time.
- What is the wider relevance of such research to our understanding of climate change in general? (*Hint*: think of links between other parts of the world's climate system, such as oceans.) Studying past climate changes gives us a better perspective with which to assess recent climate changes related to human activity. Reconstructing past climate change over a land area, and comparing this with changes that occurred to ocean temperatures and currents offshore helps climatologists to better understand the way the ocean affects the atmosphere. Complex general circulation models (GCMs) are used to predict future climates, and one way of testing the predictive capability of a GCM is to try to simulate climates that existed in the past. Many climate models have attempted to reproduce the world's climate during the LGM, and these tests can be improved if scientists can reconstruct the actual LGM climate in more detail. Southern Africa is one of the places where more research is needed to add to our global picture of climate conditions during the LGM.

Lesson two: Data analysis

Aims: To gain experience of how images and sketch maps can be interpreted to identify previously glaciated areas, and to work with some data linking glaciers and climate. To include:

- Comparing the Leqooa area of Lesotho with the Mount Enterprise area of the Eastern Cape
- Reviewing the concept of the equilibrium line altitude (ELA) of a glacier
- Setting a hypothesis and undertaking correlation analysis of data linking ELA with climate
- Applying the ELA/climate relationship to reconstructing past climate of the High Drakensberg

This lesson supports teaching of practical aspects of studying past glaciation and reconstructing past climates. It also provides a geographical skills exercise on correlation.

Starter (*practice with image interpretation*)

This activity is well suited to pair work, and the Lesson 2 Starter slides could either be viewed on computer or printed out in colour. Students can check their answers by clicking on the link to view or download the answer sheet.

Main

This activity relies on students understanding what the equilibrium line altitude (ELA) of a glacier is. This could be reviewed during the lesson by pointing students towards the relevant web links.

To complete the ELA-climate relationship data analysis task, students will need to manipulate the data provided in the Excel spreadsheet individually. They also need to have the 'Lesson 2 ELA data analysis task sheet'. It would be easiest for students to have a printed copy so that they can easily refer to it, and write in the answers, as they work with the spreadsheet.

Answers to questions on the Lesson 2 Data analysis task

The hypothesis could be phrased as:

- There is a positive correlation between temperature and precipitation at the ELA of glaciers. This is because under warmer conditions (primarily summer temperatures) more snowfall needs to occur for a glacier to form.

For the describe question, the correlation should be described as:

- A positive correlation that appears to be a strong one

For the R-squared question:

- Should be 0.81

For the final question on the worksheet:

- The hypothesis is supported by the data. There is a strong correlation between summer temperature and precipitation at the ELA of glaciers. Eighty per cent of the variation in precipitation is explained by the variation in summer temperature. This is a high R-squared

value, so we can have high confidence that this correlation could not have occurred by chance.

Following the task, students could be pointed towards the web links on the task sheet to learn more about how significance testing of correlations works.

Plenary

The aim here is for students to apply their data analysis work from the main part of the lesson to understand how such a data set can be used to make specific inferences about past climate. They do not need access to a computer to answer these plenary questions, but they will need to have printed out their scatter graph from the previous activity.

Referring to your scatter graph, try to answer the following questions which could be followed up in a group discussion.

- The scatter graph suggests that when the summer temperature is higher at the ELA of a glacier, the total precipitation (accumulation) must also be higher. Why do you think this is the case?
Because higher summer temperatures cause higher rates of 'ablation', and therefore more snow accumulation must occur over the course of the year to compensate for this. Otherwise the glacier will shrink, moving the ELA upwards in altitude to where it is colder and a balance between ablation and accumulation is reached.
- If precipitation is low, then we see that the summer temperature must also be low. Why does this relationship have to exist for a glacier to form?
Since temperature controls ablation rates, if there is little snow to begin with, then snow will only survive from one year to the next if summer temperatures are low, so that ablation rates are also low.
- It's not difficult to identify the ELA on an existing glacier. How do you think the appearance of the glacier's surface will be different above and below the equilibrium line?
Since there is net accumulation above the ELA and net ablation below, the area of the glacier above the equilibrium line is likely to look 'cleaner' with any rock debris covered by recent snowfall; whereas down slope of the ELA, the glacier will look dirtier as ablation is causing overlying snow to melt revealing debris at the glacier's surface.
- What evidence would we need, and what assumptions do you think we would have to make, to estimate the altitude of the equilibrium line for a glacier that existed in the past, but no longer exists today?
First, we would need evidence for the former size and dimensions of a glacier. Such evidence would include the positions of lateral and end moraines, as well as glacial 'trim lines' from which the elevation of a former glacier against a valley side can sometimes be estimated. From studies of existing glaciers a rule of thumb is that, on average, between 60 and 65% of a glacier's area is in the accumulation zone. So provided that a former glacier's surface area and contours can be estimated, then an estimate can also be made of the altitude of the former ELA as being located where at least 60% of the former glacier's area lies above it.

- Provided we are confident about the former location of a glacier, why would an error in our exact estimate of the ELA for a former glacier make less difference to our palaeoclimatic inferences if the former glacier was relatively small?

This is because small glaciers tend not to span a great difference in altitude. Therefore, different estimates of the elevation of the ELA in the way described above wouldn't vary as much in comparison with such estimates for a glacier that spanned a large altitudinal range.

- At Leqooa, it's estimated that the ELA of the former glacier was at approximately 3,140m above sea level. The precipitation at this location today is about 850mm per year. If precipitation was the same as this during the LGM, use your scatter graph to estimate what the average summer temperature must have been.

Reading off the trend line, the answer should be about 0.5°C.

- The current average summer temperature at this altitude is about 8°C. Other evidence (for example from studies of periglacial features) suggest that summer temperature in this region during the LGM was 6°C colder than today. Some scientists have suggested that precipitation was about 30% lower (around 600mm) in the Drakensberg during the LGM. Assuming that the estimate of 6°C colder than today during the LGM is about right, why do those who claim the Drakensberg was drier during the LGM have to be wrong?

For this question students need to look at the trend line to find out what the corresponding precipitation level is at 2°C. The corresponding value is about 1,300mm. This indicates that precipitation must have been considerably *higher* than its present day value for this glacier to have existed.

- The Mount Enterprise area is about 1,000m lower altitude than Leqooa. Because air temperature decreases on average by about 6°C for every 1,000m elevation gain, the Mount Enterprise area has an average summer temperature of around 15°C. Assuming that the total precipitation at Mount Enterprise was 850mm during the LGM, how much of a temperature drop would have to have occurred there for a glacier to have formed during the LGM?

From a previous question, students will know that summer temperature would have to have been about 0.5°C to allow a glacier to form with just 850mm of precipitation. This would therefore require a 14.5°C temperature drop during the LGM at Mount Enterprise – which is unrealistic.

- Finding out the ELA of former glaciers provides useful information about the climate at the time the glacier existed. However, it's also necessary to find other types of evidence when reconstructing past climate. Why?

The main reason is because the effects of temperature and precipitation cannot be isolated from each other when looking at the ELA of a former glacier by itself. If other forms of evidence can be found to pin down either past temperature or precipitation, then the ELA-climate relationship can be used to estimate the other variable.

Lesson three: Methods of fieldwork and concluding

Aims: To learn about some field and laboratory methods, to interpret a set of surface exposure dates, and to compare these with evidence from Indian Ocean marine sediments.

This lesson supports teaching of field techniques in cold environments and provides a skills exercise on descriptive statistics using surface exposure dates.

Starter (*learning about the field and laboratory methods*)

For this starter activity there is a noting sheet that can be downloaded and given to students to help them summarise the main methods of the research project from the “Ask the researcher” information.

Main

Activity 1: Geological time lines

Some of the tasks for this activity require that students visit the websites shown on the worksheet. Students could complete the worksheet individually or in pairs.

The first question is descriptive, and all of the information required is on the BGS website.

Question 2 is: [2.6 million years ago](#).

Question 3: [Pleistocene Epoch and Holocene Epoch](#)

For question 4, students draw a straight vertical line through the whole EPICA Dome C data set from -400 on the horizontal axis. This represents the mean annual temperature at present.

Question 5: [the arrow should be drawn to indicate the time of *the most recent* abrupt shift from colder to warmer temperatures.](#)

Question 6: [The other interglacial times when temperatures were around today’s level occurred at about 125,000 years ago, 240,000 years ago, 330,000 years ago, 410,000 years ago, and 620,000 years ago.](#)

Question 7: [There are four interglacials represented in the graph that saw higher temperatures.](#)

Question 8: [From about 450,000 years ago onwards, the climate cycles appear to become more pronounced with larger temperature variation.](#)

Question 9: [The arrow should be drawn at about 20,000 years ago on the graph.](#)

Question 10: [The time span of the LGM is from about 26,000 to 18,000 years ago.](#)

Activity 2: Descriptive statistics exercise with surface exposure dates

This activity gives students practice with descriptive statistics of central tendency and range, and introduces the idea that there is always an uncertainty range around the age of a landform when it is dated using scientific means.

As with the Main activity for Lesson 2, students will need access to a computer to manipulate the Excel spreadsheet and answer the questions. Students could be reminded that ‘kyr’ means thousand years.

Answer the following questions (either by hand or in Excel):

- From column A, work out the **average** date of the 11 age estimates (the mean) and work out the **median** date. (Remember that the median is simply the middle value.)
Average = 22.2 kyr BP and Median = 21.1 kyr BP
- Taking into account all the dates, which of these two ‘measures of central tendency’ do you think is likely to be the better approximation of the true age of this moraine and why?
The median is likely to be the better estimate, as the age estimate of 35 kyr BP looks like an anomaly compared with the rest of the data. This anomalously high value skews the average (arithmetic mean) to make it higher (older) than the median. It is possible that the anomaly occurred due to a problem with the sampling or the laboratory methods.
- Why do you think each surface exposure date includes its own error range (standard deviation)?
Because the scientific procedures associated with the surface exposure dating method have their own errors. This limits the degree of precision of the method, so scientists always give both the best estimate age and the likely range (in which the true age may lie) above and below this best estimate. Since the error range is usually given as a ‘standard deviation’ above and below (+/-) the best estimate, scientists know that there is a 68% probability that the true age of the sample represented by the age estimate lies within this range. For example, for the date of 17.8 ± 1.8 kyr BP, we can say that there is a 68% chance that the age calculated for this sample lies between 19.6 and 16 kyr BP.
- This time taking account of all the standard deviations, work out the **full age range** likely for the moraine according to this data set.
By taking account of the standard deviations on the youngest sample age and the oldest sample age, the full age range for the moraine is very likely to be between 38.5 and 16 kyr BP.
- Looking at the distribution of the dates, what do you think would be a best estimate of the age range of the moraine and why? (*Hint*: you might disregard any apparent anomalies, and double the ‘average standard deviation’ around your chosen mean or median value so you have 95% confidence of the time span during which the moraine was formed.)
There is not a single correct answer to this question, but a logical way to go about it would be to take the median date as the best estimate (because the average is skewed by an anomalously old date) and to double the error range. This gives a plausible range for the age of the moraine between 25.3 and 16.9 kyr BP.
- Did the formation of this moraine occur during the LGM? And how confident can you be?
Our best estimate age range calculated above overlaps well with the timing of the LGM (between about 26,000 and 18,000 years ago), so we can have high confidence that this moraine did form during the LGM. It is highly unlikely (though not impossible from the surface exposure dates) that the moraine formed after the LGM.

Plenary

This plenary activity helps students to see how the dating of a moraine can fit into a bigger picture of reconstructing past climate and comparing different types of evidence. It also asks students to consider the links between the ocean and the atmosphere over different timescales.

As the plenary slide show only consists of three slides, the teacher could present the slides from the front, and students could work in pairs or small groups to answer the plenary questions.

Using your interpretation of the surface exposure dates from *Activity 2*, answer the following questions:

- How does your cold climate evidence (formation of a moraine) from the High Drakensberg relate to the SST reconstruction shown in Slide 1?
The age range estimate for the moraine appears to correlate in time with the phase of minimum sea surface temperatures (SSTs) for the Indian Ocean off the Mozambique coast. (Slide 1).
- Looking at Slide 1, give an estimate of the SST at the time of formation of the moraine. How much colder is this than the present SST in this graph?
The SST reaches a minimum of almost 24°C, and this represents an LGM SST depression of about 3°C compared with the present.
- Looking at Slides 2 and 3, describe the differences you can identify between the Indian Ocean SSTs today and the SSTs during the LGM.
During the LGM, SSTs in the Indian Ocean off the coast of southeast Africa were around 4°C cooler than today. Students might also notice that the SST reconstruction shown in slide 1 is for a lower latitude than the seas due east of the Drakensberg. The mean annual LGM SST off the east coast of South Africa was between 16 and 20°C.

In small groups discuss the following ideas:

- Why might you expect a correlation between colder seas off the coast of southern Africa and a colder mean annual temperature in the Drakensberg?
First, during the LGM one would expect both the land and the sea to be cooler because the average temperature of the whole planet was cooler. Secondly, a colder sea surface causes cooling of the overlying air. The surface of the ocean is both slower to heat up and slower to cool down compared with a land surface, so seas have a moderating influence on climate, and their influence is more strongly felt in coastal locations compared with inland locations.
- In what ways do you think oceans affect the climate experienced over land? (*Think of both temperature and precipitation.*)
As above, the atmosphere will be cooled where air is in contact with a cool sea surface. In addition, as air cools it becomes denser, and therefore convection is less likely. (Convection is the rising of air because it is heated – this leads to the formation of clouds and precipitation.) Conversely, warm seas both warm overlying air and increase the chances of precipitation.

During the LGM, the zones of mid-latitude westerly winds in both hemispheres occurred at lower latitudes than today. This was related to the fact that the 'polar front' (boundary between warmer and colder waters in the oceans) was also located at lower latitudes during the LGM.

- Can you guess why this difference in winds, and ocean temperature off the coast, might have caused the Drakensberg during the LGM to experience relatively **more winter precipitation**, and **less summer precipitation**, than occurs today?
Summer precipitation in the Drakensberg today is often convective, and with cooler SSTs off the coast and a colder climate in general during the LGM convection was less frequent – this accounts for the diminished summer precipitation. However, with an expanded polar cell

and an equatorward movement of the zone of mid-latitude westerlies during the LGM, mid-latitude storm systems would have tracked from west to east across the Drakensberg (approximately 30°S latitude) more frequently than today. This would have enhanced winter precipitation.

- Can you summarise why researching past glaciation in the High Drakensberg provides an important test of what we think the climate in South Africa was like during the LGM? From what we know about the ELA-climate relationship (see Lesson 2), for glaciers to have existed in the High Drakensberg during the LGM precipitation must have been higher than it is today – because otherwise the amount of temperature depression required would be unrealistically large for a region that is not at a high latitude. Since the seas were cooler off the coast during the LGM (and the land was cooler), the extra precipitation needed to form glaciers could not have come from increased convective storms. Therefore, it's likely that the winter precipitation zone of southern Africa extended further north and east during the LGM. The presence of glaciers during the LGM in the Drakensberg provides strong evidence for enhanced winter precipitation. Put another way, it provides a test for a hypothesis about how the southern African climate was different during the LGM; and even more broadly, this is an example of how theoretical ideas about the way the climate system works can be tested against actual field evidence.