

The Palaeoclimates of Antarctica

Palaeoclimates are ancient climates

Antarctica 'greenhouse to icehouse'

Prior to 35 million years ago Antarctica had a much warmer "greenhouse" climate, but twenty million years later the cold had set in producing an "icehouse" world with permanent, large ice sheets. This cooling was not a smooth and continuous process, but made up of many variations in ice sheet size and sea level. The evidence of these changes is of two types, direct and indirect evidence.

1. Direct or 'natural' evidence are the measurements taken since the first polar explorers a century ago. This include weather data and other physical measurements such as ice cover.

2. Indirect evidence provides most of the clues about the past because some factors, such as temperature, simply cannot be fossilised. This indirect or "proxy" evidence can take many forms including

- fossil plants (flora) and animals (fauna). These are useful because we know the conditions they needed to survive.
- trapped bubbles of ancient air within the ice
- the types of sediments deposited, such as those shown in the table below

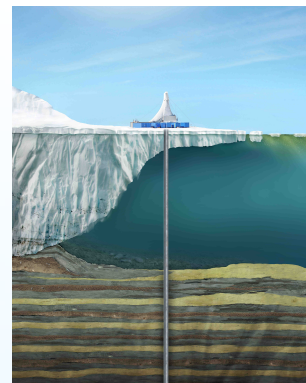
Ice (Glaciers, ice shelves, icebergs)	Rivers (Fluvial)	Seas (Marine)
Thick poorly sorted deposits of angular (sharp) boulders mixed with finer sediment	Sediments are often rounded and sorted into different sizes, depending on the water speed	Fine (small) sediments with marine fossils indicates deposition in the ocean

Besides the rock types themselves, changes between in the type show whether the climate was warming or cooling.

Fossils within these sedimentary rocks provide excellent proxies for past climates and are divided into two types:

- Macrofossils: these are visible to the naked eye and include wood, leaves, animal or fish bones and shellfish
- Microfossils: these require a microscope to be seen and include pollen grains, foraminifera and phytoplankton (diatoms).

Another example of indirect evidence is the ratio of isotopes of oxygen (^{16}O and ^{18}O) in the carbonate shells of microscopic marine creatures known as foraminifera. The ratio of these isotopes in sea water changes with the temperature of the water, and since foraminifera form their shells in sea water, the temperature is indirectly recorded within their shells.



*Extracting rock samples from beneath an ice shelf.
"The farther backward you can look the farther forward you can see" -Winston Churchill.*

Drill cores from Antarctica

The extensive ice cover of Antarctica means there are few rock outcrops, so most of the clues to Antarctica's past come from drilling into layers of offshore sedimentary rock. These drill cores provide a wealth of climate data about the past.

Other important drill cores are those into glacial ice as they reveal the annual snowfalls, which as they are compressed into ice, include air samples trapped as bubbles within the ice. As these bubbles are completely undisturbed they provide accurate samples of the ancient atmosphere including the levels of greenhouse gases, dust and volcanic material. From these tiny samples even the extent of the surrounding sea ice can be estimated.

The changes in climate over the last 35 million years are particularly well-recorded in the sedimentary rocks of the Ross Sea, and show a repeated cycle of

- glacialiation (coarse-grained, poorly-sorted sediment known as 'diamictite')
- shallow-water coastal environments (marine fossils in sandstone) with some evidence of ice nearby
- warmer, deeper oceans (marine fossils in mudstone)

This repeating pattern indicates Antarctica's early ice sheets expanded and contracted through warm (interglacial) and cold (glacial) climate periods. This in turn resulted in repeated changes in the volume of ice, along with rises and falls in sea level.

Dating the changes

Dating of these changes is possible using microfossils and the magnetic fields (palaeomagnetism) recorded in rocks and volcanic ash layers. The pattern revealed shows the Earth's climate varied on both a

- 40 000 year cycle, due to variation in its tilt
- 100 000 year cycle, due to variation in its orbit around the sun

Known as Milankovitch cycles, they caused the total amount of solar radiation (and where it falls) to vary, triggering the climate to change between glacial (ice age) and interglacial (warm) conditions. In this way Ross Sea sediments showed for the first time that Antarctica's ice sheets are sensitive to changes in Earth's motion.

Drilling projects in the Ross Sea

There have been a number of remarkable drilling projects in the Ross Sea and on the adjoining land but three recent and important projects have been

- The Cape Roberts Project
- ANDRILL* 2006, from the McMurdo Ice Shelf
- ANDRILL* 2007, from the sea ice of McMurdo Sound

The ANDRILL drill cores are particularly remarkable for being over 95% complete, 1200m long and providing a window into the past 18 million years, right up to the last million years. The sediments in these cores showed repeated swings between extensive glaciation with floating ice shelves and warm open ocean conditions. These swings followed well the 40 000 year variation in Earth's tilt from 22 to 24 degrees.

Perhaps the most striking revelation of this pattern was that the Ross Ice Shelf (and possibly the whole West Antarctic Ice Sheet) had disappeared repeatedly and quickly in the past - requiring only a temperature only 2 - 3°C higher than at present.

It is important to remind ourselves here that Milankovitch cycles do not directly change climate, instead they provide the trigger or tempo for changes to our atmosphere - especially changes to the greenhouse gases that do result in climate change.

Ice and sediments agree

When comparing the air trapped in ice cores and the sediments from the Ross Sea over the last 800 000 years a pattern emerges, one that links the atmosphere and the sediments on the sea floor.

This pattern shows that repeatedly :

- that the composition of the atmosphere and type of sediment vary together
- there is a gradual decrease in carbon dioxide concentration and average temperature
- there is a slow (tens of thousands of years) fall in global sea level, as the volume of ice increases
- there is a rapid (thousands of years) increase in carbon dioxide concentration and average temperature. At the same time the global ice volume drops and sea level rises.

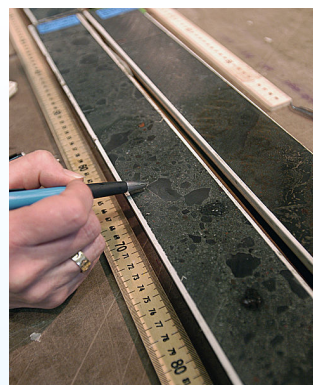
The future

Over the last thirty years, using Antarctic palaeoclimate records and other data computer models have attempted to simulate parts of the complex climate system, such as:

- ocean temperature
- extent of sea ice
- ice sheet size
- reflection from land and sea
- greenhouse gas concentrations
- variation in the sun's output
- changes in the earth's orbit.

So far the extensive, international field work carried out Antarctica has confirmed what the computer models predict, namely that due mainly to increasing carbon dioxide levels, the Ross Ice Shelf (the world's largest) may take only a few thousand years to completely collapse.

In conclusion the study of Antarctic palaeoclimates has greatly improved our understanding of how Earth's climate system works and highlighted the importance of Antarctica role in this process. "



Examining a section of the ANDRILL drill core from the Ross Sea

Practical activity: Ross Island model.

Introduction

The sea sediments surrounding Ross Island provide a wealth of information about Antarctica's past. This activity allows you to build a paper model and then use it to answer questions that will guide you through the process of how evidence about ancient climates (palaeoclimates) is both gathered and interpreted.

What to do

1. Simply assemble the 3D model using scissors and paper glue.
2. Answer the attached questions

Relevance

- The Ross Sea (which includes McMurdo Sound and Ross Island) holds a unique set of clues about Antarctica's previous climates.
- Understanding previous climate changes allows us to better predict future climate change and its effects.

Website simulation

For an excellent, interactive simulation which clearly demonstrates the links between temperature, ice and sediments, visit:

www.andrill.org/system/files/web/images/edu/iceshelfadvanceretreat.swf

Adapted from material by *Dr Cliff Atkins, Victoria University of Wellington.*

Produced by *Donald Reid, iMatters.co.nz* in association with *Gateway Antarctica, University Of Canterbury*
Images: Andrill

Ross island Questions

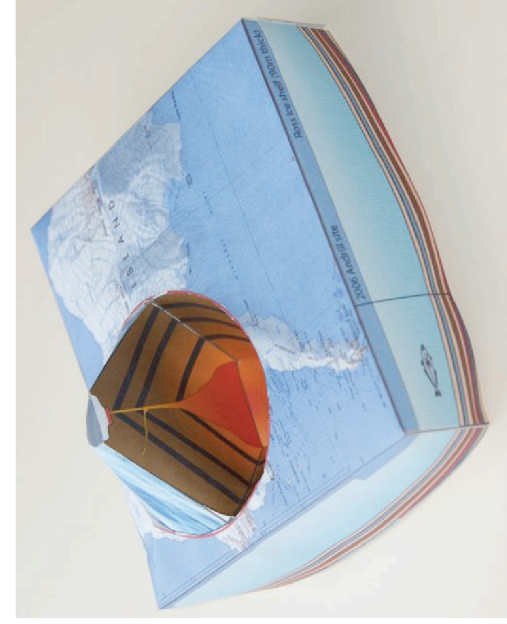
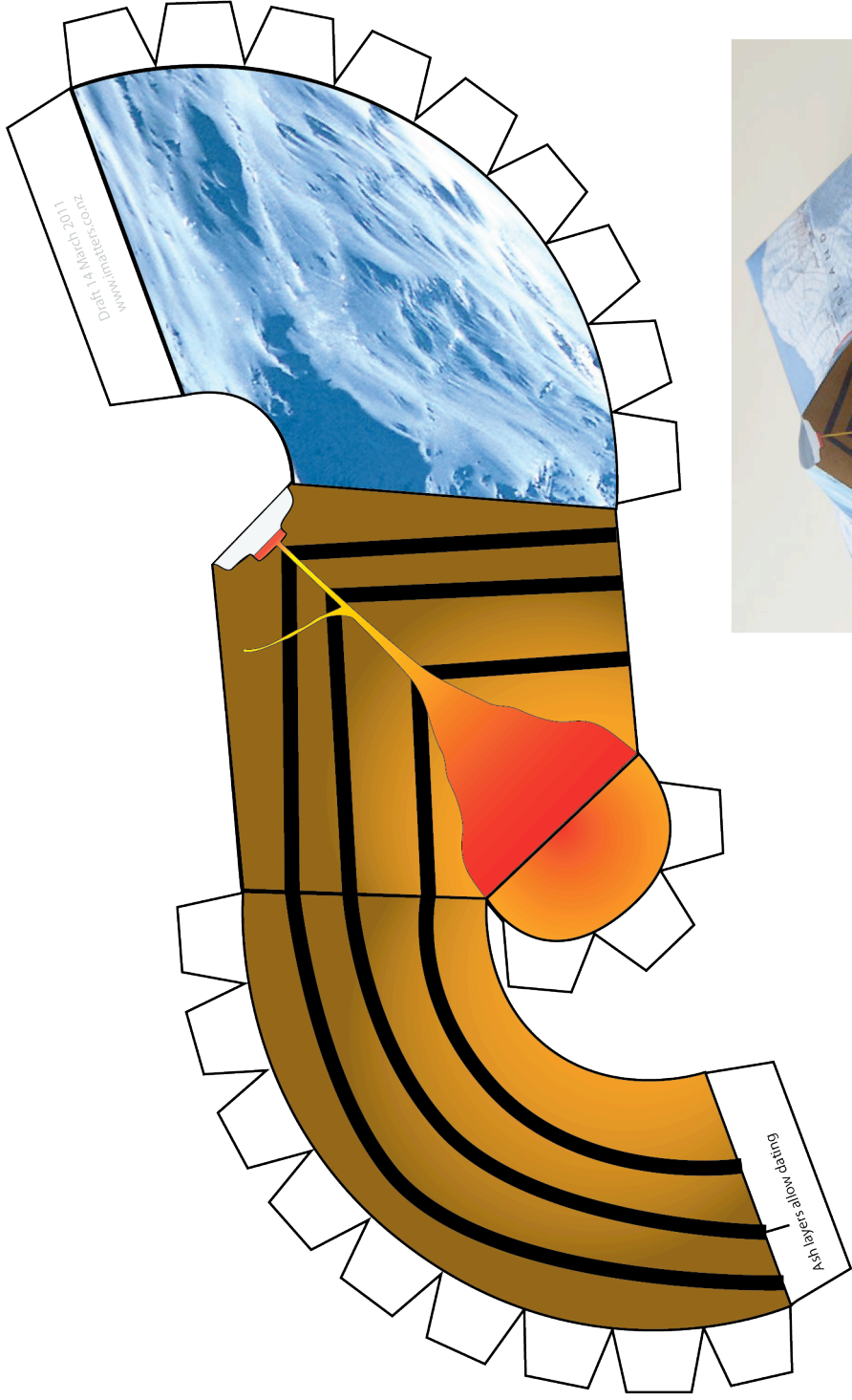
After constructing your 3D paper model of Mt Erebus and Ross Island use it to answer the following questions



*This fumarole, formed as hot volcanic vapours become a chimney of ice, still continues to grow.
(Mt Erebus. B.A.E. 1907- 09)*

1. In the model which layer is probably the oldest?
2. Which layer is the most recent?
3. High on Mt Erebus there are fumaroles which look like smoking chimneys.
Where on your model might they appear and how might they form?
4. What evidence is there that the weight of Ross Island has created a bowl shaped depression around it?
5. Why is this depression useful for studying palaeoclimates?
6. On the model what differences between sea ice and ice shelf are shown?
7. On the model (or elsewhere) complete the cross section of Mount Terror (east face of model).
8. On the model (or elsewhere) complete the cross section of Mt Erebus's (north face of model)?
9. Why is the sea ice - ice shelf boundary not clearly shown on the map?
10. The model includes an iceberg. Where is it?
11. The sediments drifting down from melting sea ice, or open water contains microfossils. How will the sediments from ice bergs or ice shelves differ?
12. What evidence is there of the Ross Ice Shelf having disappeared in the past?
13. On 16 December 2006 ANDRILL set a new record depth for Antarctic drilling at 1285m (13 million years). How far was this below the drillers feet?
14. Does the ANDRILL drill stem (pipe) touch the ice shelf? Why?
15. The ANDRILL drill stem is drawn as being vertical but it seldom was. Why?
16. As drilling depth increases what happens to the size of the drill pipes used?
17. Why were layers of volcanic ash (with minerals that could be dated) a great advantage?
18. Could sediments be dated if there were no ash layers?

Answers
1. Bottom sediment in the sea. 2. Ash or lava from Mt Erebus. 3. Near side vent. Hot spot melts ice, water dissolves minerals, water vapour (or steam) escapes into cold air and freezes. 4. Sediments on all four faces are curved downwards / synclines. 5. Has long, continuous, record of sediments since Ross Island formed. 6. Ice Shelf is thicker (x30). Sea ice is to the north. Sea ice is seasonal. 7. As per Erebus, cone shaped alternating layers of rock and ash. May include thermal metamorphosis of sediments. 8. As per Erebus or Terror but cuts sediments. 9. Varies, drifting snow. 10. NW corner. 11. Few fossils, mainly rocks. Any fossils from remote locations. 12. Sediment sequence has cyclic, open water sediments beneath ice shelf. Volcanic ash is a uniform layer across model. 13. 1285 + 90+1000 is about 2370m. 14. No ice shelf moves with tide. 15. Ice shelf moved horizontally. 16. Is reduced, three sizes. 17. Marker beds for comparison between drill cores. Minerals allow absolute aging, rather than relative aging (deeper is older). 18. Yes by comparison with fossils from elsewhere (relative aging)



Depth not to scale

Sea ice
(3m thick)

volcanic ash allows dating
McMurdo Sound
(deep 1000m)



RIS, 90m thick

Sea depth = 1000m

volcanic ash allows dating

McMurdo Ice shelf

2006 Andrill site



iceshelf
open ocean
glacier
iceshelf
open ocean
iceshelf