Class 12: Greenhouse to Icehouse, the last 50 million years

• What has climate done over the past 50 million years?
• What mechanisms explain the observed climate change?

Learning Objectives

1. Be able to describe the global temperature trend over the last ~50 million years
2. Describe the tools used to reconstruct this record and how each works
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4. Explain why information about climate over the last 50 million years is relevant to climate change today
Scientists endorse mass civil disobedience to force climate action
Stephen Leslie: A farmer on the frontline of climate action

By Commentary

Oct 15 2019 | 7 reader footnotes
Review: Paleoclimate – Pleistocene

Holocene = 11,700 years ago to present
**Review: Paleoclimate – Pleistocene**

<table>
<thead>
<tr>
<th>System/Subsystem/Epoch</th>
<th>Series/EPOCH</th>
<th>Age estimates of horizons in mega-ammon (Ma) unless otherwise noted</th>
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<td>Eocene</td>
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<td>65.5 ± 0.3</td>
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<td>Cenozoic (Cen)</td>
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<td>11,700 ± 99 yr*</td>
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Holocene = 11,700 years ago to present

Pleistocene = ~2.6 million to 11,700 years ago
Review: Paleoclimate – Pleistocene
Review: Paleoclimate – Pleistocene

Area of AMO Downwelling
Review: Paleoclimate – Pleistocene

1. Freshwater anomaly impedes ocean convection and heat transport to North.
2. Ocean warms around Antarctica

Northern sourced deep water shoals?
Southern sourced deep water shoals?

Antarctica
CO₂ release?
WINDS
North Atlantic
Review: Paleoclimate – Pleistocene

Figure from Shakun et al. (2012)
Last Glacial Maximum (~29-20 kyr)

- Big ice sheets
- Sea level ~130 m lower than today
- Global temp ~3.5°C lower than today

Figure from Spratt and Lisiecki (2015)
Last Glacial Maximum (~29-20 kyr)

- Melting Northern Hemisphere ice sheets suppress AMOC
- Less downwelling and CO$_2$ sequestration in ocean
- Warms southern hemisphere, causing more CO$_2$ release

Figure from Spratt and Lisiecki (2015)
The Last Interglacial (~125 kyr)

- Slightly warmer than today
- Sea level ~5 m higher than today
- Atmospheric CO$_2$ around 300 ppm

Figure from Spratt and Lisiecki (2015)
The Last Interglacial (~125 kyr)

- Increased absorption of solar energy due to Arctic sea-ice minimum
- Increased absorption of solar energy through vegetation changes and reduced snow cover
- Strong orbital forcing on northern hemisphere
- Reduced Greenland Ice Sheet area and volume
- West Antarctica: de-glaciated and largely below sea level
- East Antarctica: glaciated
- Meltwater
- Atmospheric CO₂: ~300 ppm

Illustration by JG for www.skepticalscience.com/LG3-1207.html
Source for Earth's topology: NASA/PL-Caltech
Last Interglacial (~125 kyr) – Present
• Slow, bumpy build-up of glaciers and ice sheets (~100 thousand years)

• **Fast** melting (~15 thousand years for biggest ice sheets)
• As ice sheets build up around North Atlantic, water becomes saltier

• Downwelling and CO$_2$ sequestration **increase**

Figure from Spratt and Lisiecki (2015)

Last Interglacial (~125 kyr) – Present
As ice sheets build up around North Atlantic, water becomes saltier.

Downwelling and CO$_2$ sequestration **increase**.
What causes the sawtooth pattern?

Partly due to orbital cycles

Arctic summer sunlight
What causes the sawtooth pattern?

Partly due to feedbacks that change the carbon cycle.
What causes the sawtooth pattern?

Partly due to ice sheets having a LOT of internal positive feedback loops!

Arctic summer sunlight

Sea level (m)

Insolation (W/m²)

CO₂ (ppm)
Partly due to ice sheets having a LOT of internal positive feedback loops!
Holocene = 11,700 years ago to present
Pleistocene = ~2.6 million to 11,700 years ago
Today’s Class: Paleoclimate – The Last 50 Million Years

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How we know what we know → Big Picture: The last 50 million years → Causes of climate change in last 50 million years → Relevance to present climate change
How we know what we know
How we know what we know
How we know what we know

Tiny creatures build their skeletons using oxygen from ocean water

They inherit the oxygen isotope signature of the water
How we know what we know

**Oxygen Isotopes**

- $^{16}\text{O}$ (15.9949, 99.76%)
- $^{17}\text{O}$ (16.9991, 0.04%)
- $^{18}\text{O}$ (17.9991, 0.20%)

$\text{H}_2\text{O}^{16}$ and $\text{H}_2\text{O}^{18}$
I know... oxygen isotopes are confusing. Here’s what you need to know:

- Larger $\delta^{18}O = \text{Colder water and more ice volume}$
- Smaller $\delta^{18}O = \text{Warmer water and less ice volume}$
- Note: $\delta^{18}O$ is usually plotted upside down (the numbers increase as you go down) so that **up means warm**
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Big Picture: The last 50 million years

Causes of climate change in last 50 million years

Relevance to present climate change
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How we know what we know

Big Picture: The last 50 million years

Causes of climate change in last 50 million years

Relevance to present climate change
Big Picture Observations: The last 50 million years

Figure from Zachos et al. (2008)
Big Picture Observations: The last 50 million years

- First glaciation in the Andes
- Increased ice on Antarctica
- ? Last trees (beech family) on Antarctica
- ? First local ice on Antarctica
- Spread of cool boreal spruce forest in the Arctic
- Broad-leaved evergreen and deciduous forest in the Arctic
- Palm-like trees and crocodile ancestors north of Arctic Circle
- First glaciation in the Andes
- Increased ice on Antarctica
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What explains the cooling?

Multiple Hypotheses:

- Gateway Hypothesis
- Changes in CO$_2$
- Increased Volcanism
- Uplift Weathering Hypothesis
What explains the cooling?

Gateway Hypothesis:

• Continents moved in last 50 million years
What explains the cooling?

Gateway Hypothesis:

- Continents moved in last 50 million years
- This changed ocean currents!
What explains the cooling?

Gateway Hypothesis:

- Continents moved in last 50 million years
- This changed ocean currents!
- Hypothesis states that these changes (1) isolated and cooled Antarctica, and (2) started the AMOC
What explains the cooling?

Gateway Hypothesis:

However, data and models don’t support these changes alone causing the cooling.
What explains the cooling?

Changes in CO$_2$:

• Did CO$_2$ lower?
• Harder to test!
• Ice cores only go back 800,000 years
• No direct measurements of CO$_2$ concentrations past that
What explains the cooling?

Changes in CO$_2$:

- Some proxies exist to *estimate* CO$_2$ concentrations from ocean sediment cores
- Larger uncertainty in estimations the further back you go
- Overall, though, looks valid!
What explains the cooling?

Spreading Rate Hypothesis:

• Ok, so why did CO$_2$ levels drop?
What explains the cooling?

Spreading Rate Hypothesis:

• Ok, so why did CO$_2$ levels drop?
• Increased volcanism?
What explains the cooling?
What explains the cooling?

Spreading Rate Hypothesis:

- Ok, so why did CO₂ levels drop?
- Increased volcanism?
- Can explain some of the reduction, but not after ~15 million years ago
What explains the cooling?

Uplift Weathering Hypothesis:

- Ok, so why did CO$_2$ levels drop until the Pleistocene?
- Building the Himalayan Mountain, caused a global increase in chemical weathering
- Started around 55 million years ago
What explains the cooling?

It was most likely due to a combination of reduced volcanism and increased weathering that led to a reduction in atmospheric CO$_2$.
Dr. Maureen Raymo is the Director of the Lamont-Doherty Core Repository at Columbia University. The work she has done over her career has vastly improved our understanding of ice ages, rapid climate change, the uplift-weathering hypothesis, and the long-term oxygen-isotope record. In 2014, she became the first woman to win the Wollaston Medal for geology in its 183-year history.
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Why is this relevant?

1. Gives us time periods to observe with higher CO₂ levels
2. Gives us a better understanding of how CO₂ and temperature are linked
3. Shows us how the climate system is different in a warmer world