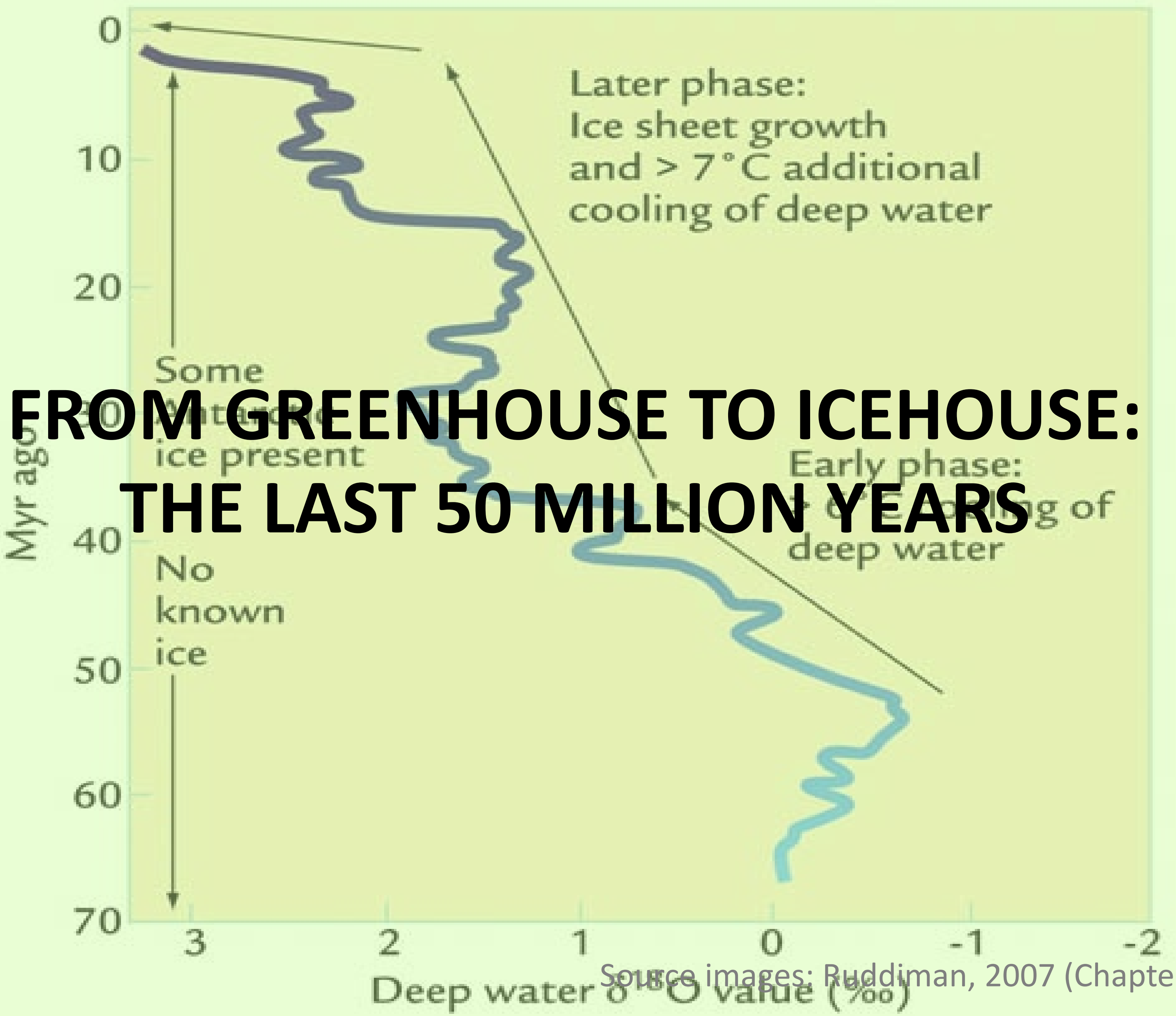
FROM GREENHOUSE TO ICEHOUSE: THE LAST 50 MILLION YEARS

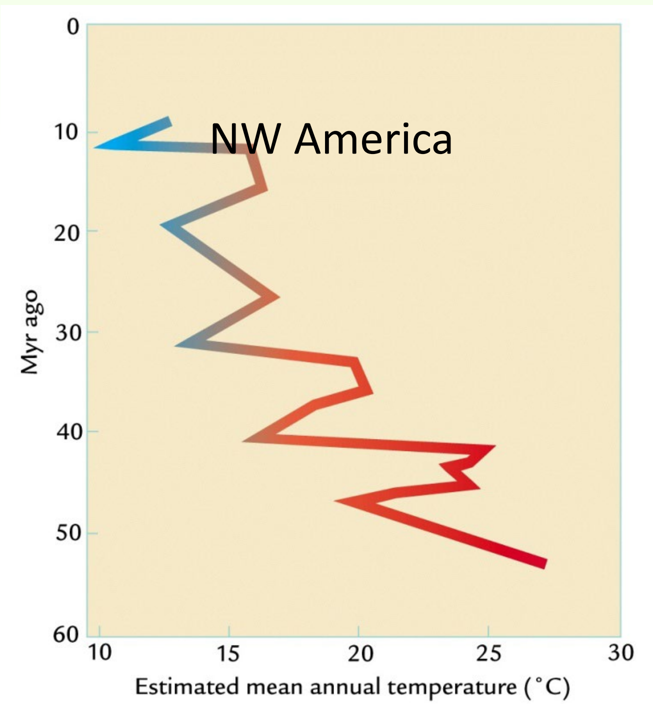


Source images: Ruddiman, 2007 (Chapter 6)

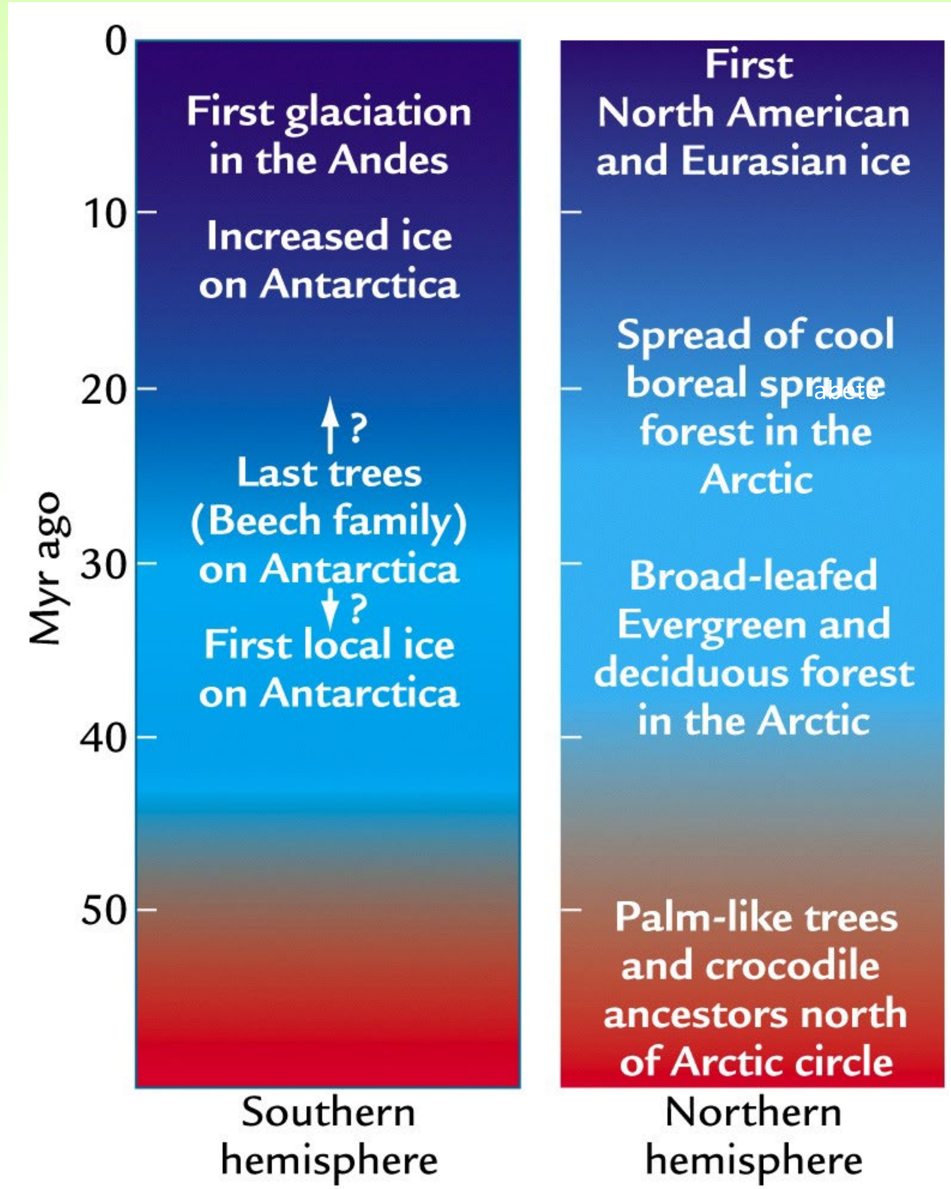
CLIMATIC EVOLUTION OF THE LAST 50 Myr

CONTINENTAL RECORD:

Cooling over the past 50 Myr is evidenced by ice and vegetation records in both the Southern and Northern Hemispheres.



Temperature estimate based on leaf margins in the last 50 Myr.



EVIDENCE FROM THE OXYGEN ISOTOPES

MARINE RECORD

Unlike the often incomplete continental record, the marine record provides long, continuous intervals ideal for paleoclimate studies.

MEMORANDUM ON THE OXYGEN
$\delta^{18}O$ sea surface waters = 0/+2 ‰
$\delta^{18}O$ deep waters = +3/+4 ‰
$\delta^{18}O$ ice caps= -30/-55 ‰

Foraminifera use HCO_3^- in H_2O to form their shells, with $\delta^{18}O$ reflecting two signals:

1. **Temperature change** => $\Delta\delta^{18}O$ = +1 ‰ = -4.2 ° C
2. **Ice caps Volume changes** => $\Delta\delta^{18}O$ = -1 ‰ = melting of ice caps currently present in Antarctica and Greenland

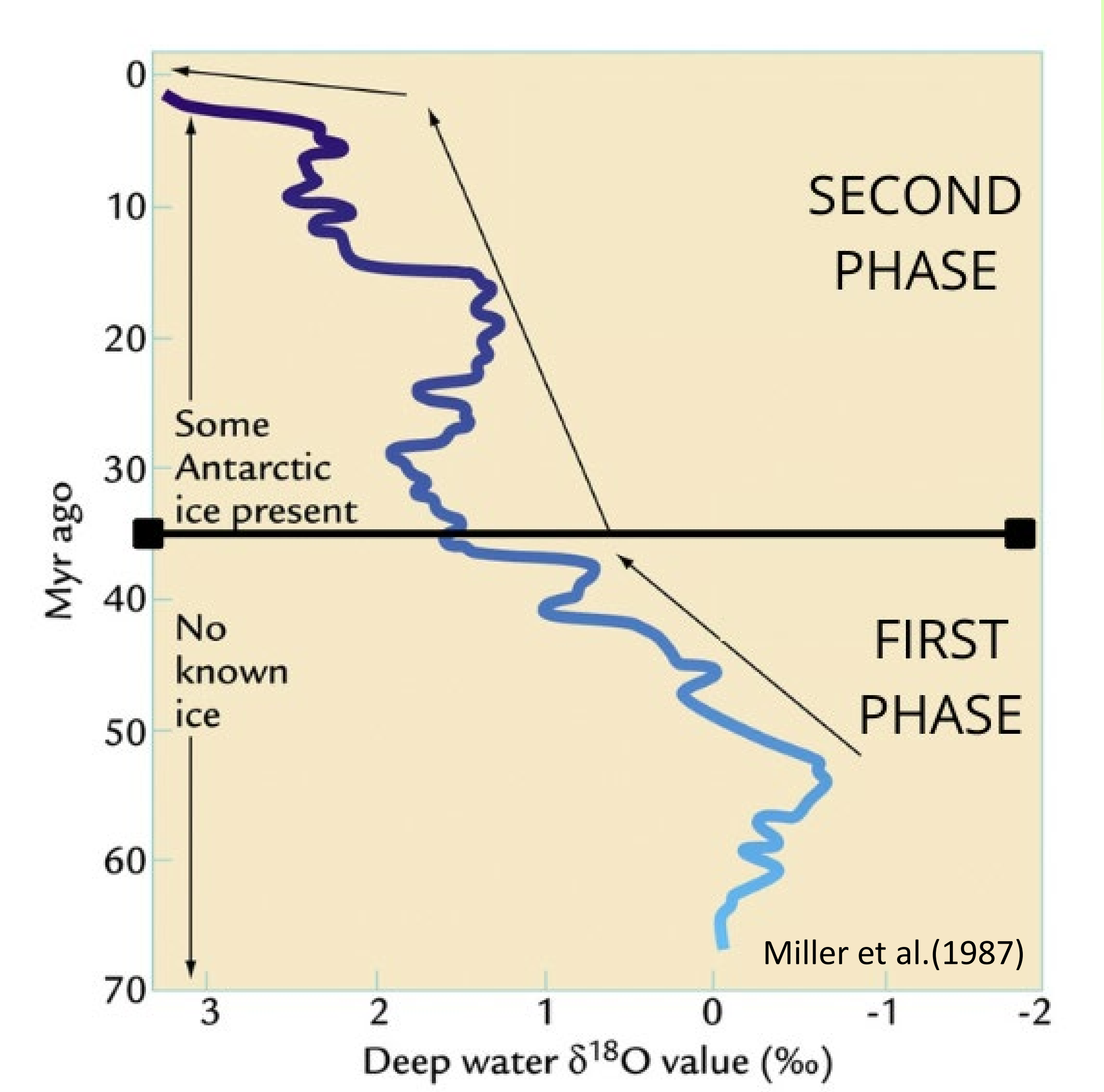
$$\Delta\delta^{18}O_{CARB} = \Delta\delta^{18}O_{WATER} \times 0.23\ \Delta T°C \qquad 0.23 = 1/4.2$$

CENOZOIC OXYGEN ISOTOPE CURVE

DISENTANGLE THE $\delta^{18}O$ SIGNAL:

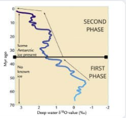
<u>From 50 to 35 Ma</u>:
no icesheet.
$\Delta\delta^{18}O$=1.5 ‰

<u>From 35 Ma to present</u>:
icesheet.
$\Delta\delta^{18}O$=2.75 ‰
$\Delta\delta^{18}O$ = 1.0 ‰ → ice caps



<u>PROBLEM</u>: Using the $\delta^{18}O$ data, calculate the temperature change for the intervals 50-35 Ma and 35-0 Ma.
Assume: 1) A change of +1‰ in $\delta^{18}O$ corresponds to a -4.2°C temperature decrease; 2) For the interval 35-0 Ma, account for ice volume, where -1‰ in $\delta^{18}O$ represents the melting of ice caps currently present in Antarctica and Greenland.

Exit



Using the $\delta^{18}O$ data, calculate the te
Assume:
A change of +1‰ in $\delta^{18}O$ correspor

1. Interval 50-35 Ma: -4.5°C; Interval 35-0 Ma: -6 — 0% 0
2. Interval 50-35 Ma: -6.3°C; Interval 35-0 Ma: -7.4°C — 0% 0
3. Interval 50-35 Ma: -5.2°C; Interval 35-0 Ma: -8.1°C — 0% 0
4. Interval 50-35 Ma: -7.0°C; Interval 35-0 Ma: -6.8°C — 0% 0

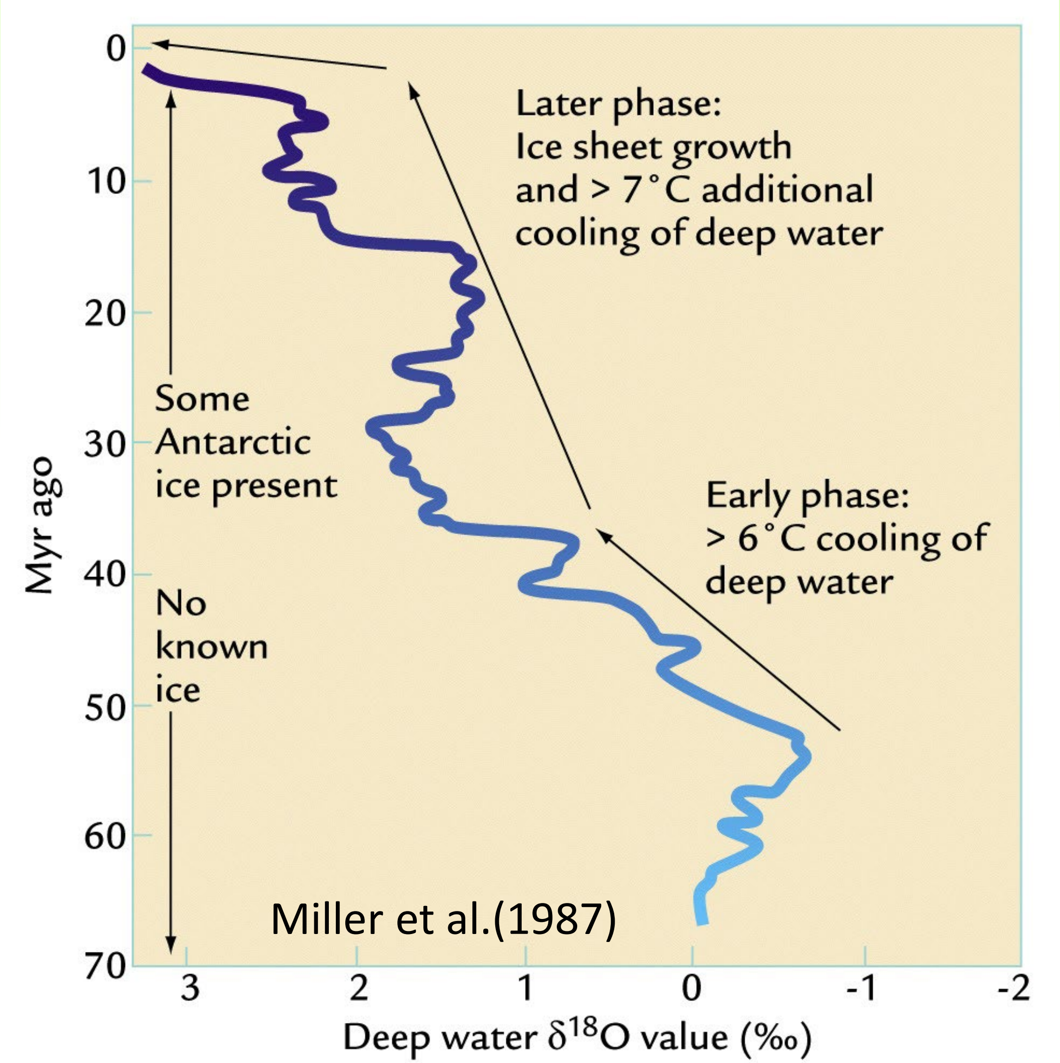
https://app.wooclap.com/events/PCCM24/0

CENOZOIC OXYGEN ISOTOPE CURVE

The results are as follows:

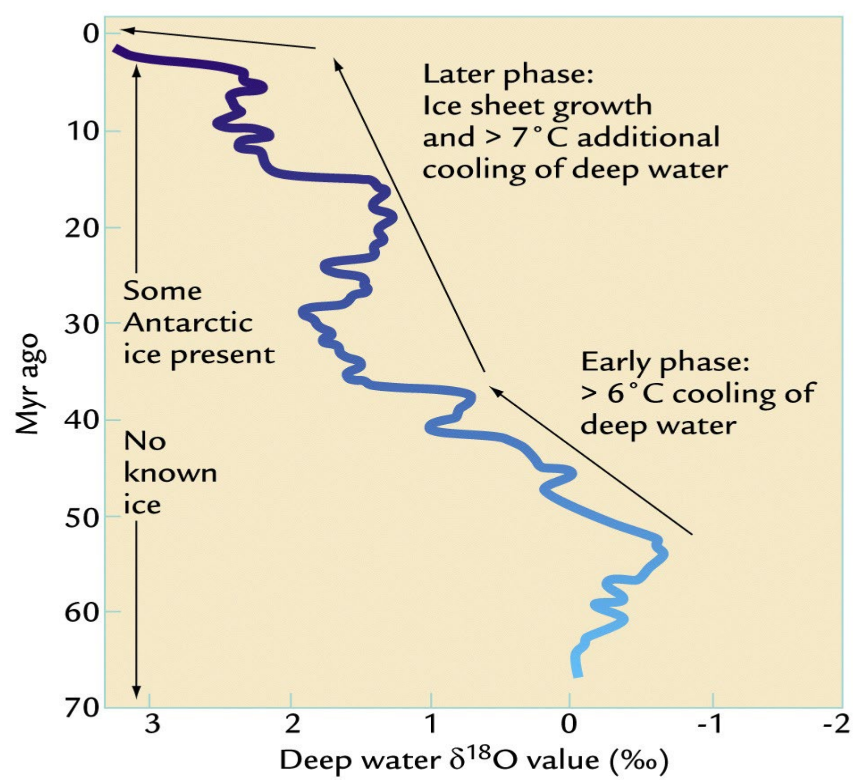
•**Interval 50-35 Ma**: The $\delta^{18}O$ change of 1.5‰ corresponds to a temperature decrease of approximately **-6.3°C**.

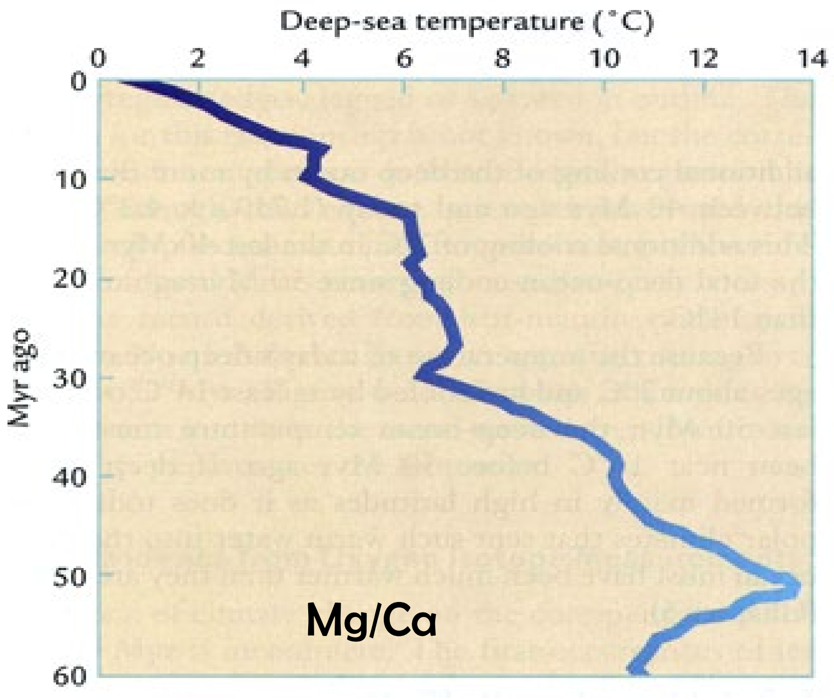
•**Interval 35-0 Ma**: After accounting for ice volume changes (1 ‰), the temperature component (1.75‰) corresponds to a temperature decrease of approximately **-7.35°C**.



EVIDENCE FROM THE Mg / Ca RATIO

The process of Mg replacing Ca in marine shells is temperature-dependent and nearly linear. The Mg/Ca record for the past 50 Myr closely aligns with oxygen isotope data, showing key shifts at 35, 13, and 3 Ma.





GREENHOUSE → ICEHOUSE TRANSITION

The transition from a greenhouse world to an icehouse world is supported by many proxies, but what is the cause of this cooling?

1. **SEA LEVEL DROP (no)**

2. **POLAR POSITION HYPOTHESIS**

3. **GATEWAY HYPOTHESIS**

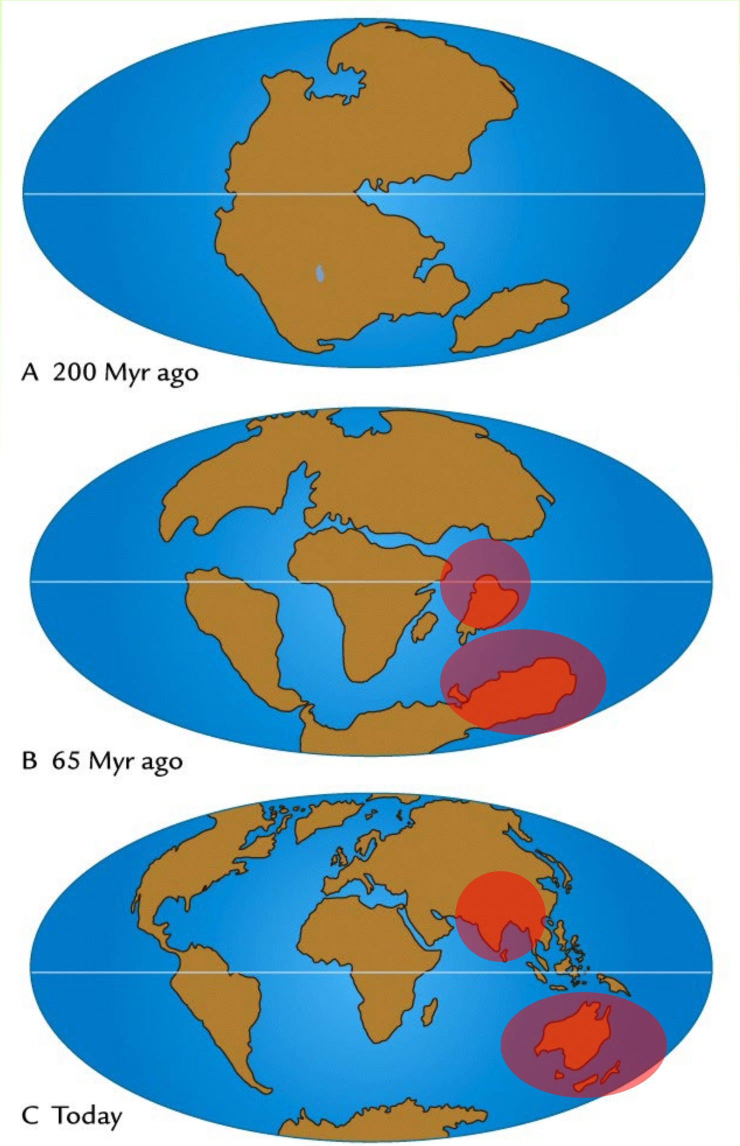
4. **TECTONIC HYPOTHESES**

BLAG HYPOTHESIS
UPLIFT-WEATHERING HYPOTHESIS

POLAR POSITION HYPOTHESIS

100 million years ago, Antarctica was already at the poles, yet glaciation had not occurred.

Over the past 50 million years, plate tectonics has shifted Australia and India northward toward tropical latitudes. This movement couldn't have triggered an ice age, as it removed land from the polar region.

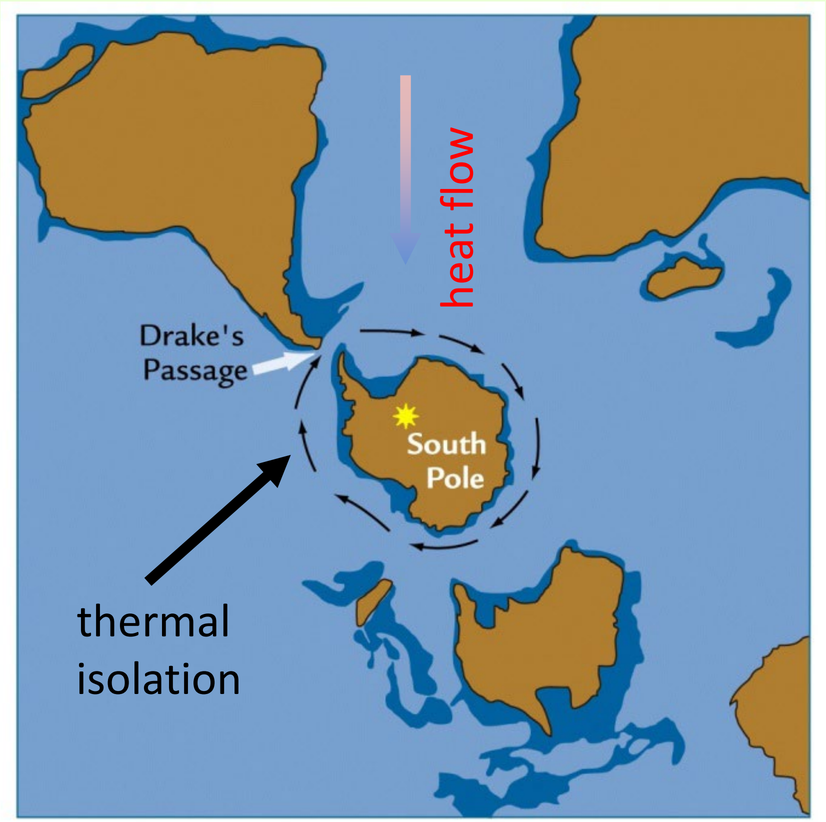


POLAR POSITION HYPOTHESIS

GATEWAY HYPOTHESIS -1

The opening and closing of passages affects ocean circulation, altering heat and salt transport to the poles and thereby promoting or discouraging glaciations.

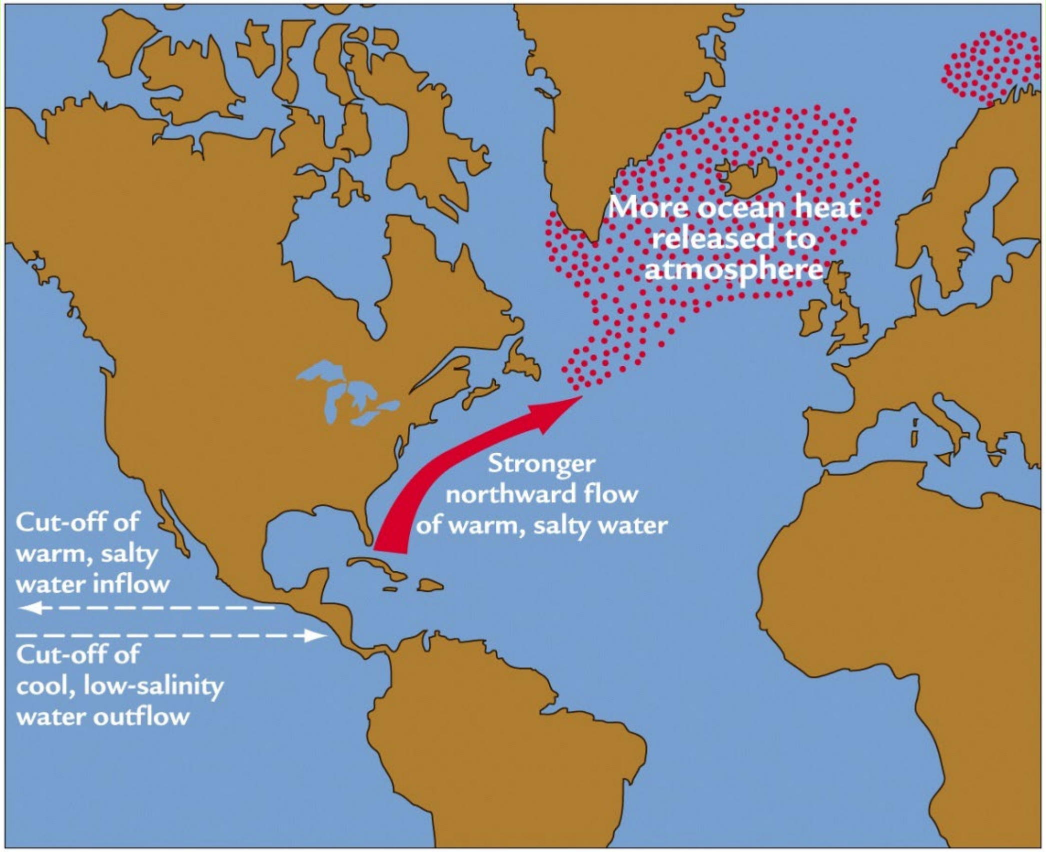
CASE HISTORY 1: ANTARCTICA (Passage Opening)



Kennett proposed that the opening of Drake's Passage between Antarctica and South America, about 40 Myr ago, reduced heat flow from low latitudes to the poles (thermal isolation). **This separation led to the establishment of the Antarctic Circumpolar Current (ACC).** However, using O-GCMs models with fixed boundary conditions, opening or closing the passage does not result in drastic changes in heat flow (see also De Conto and Pollard, 2003).

GATEWAY HYPOTHESIS - 2

Case History 2: FORMATION OF THE ISTHMUS OF PANAMA (Passage Closure)



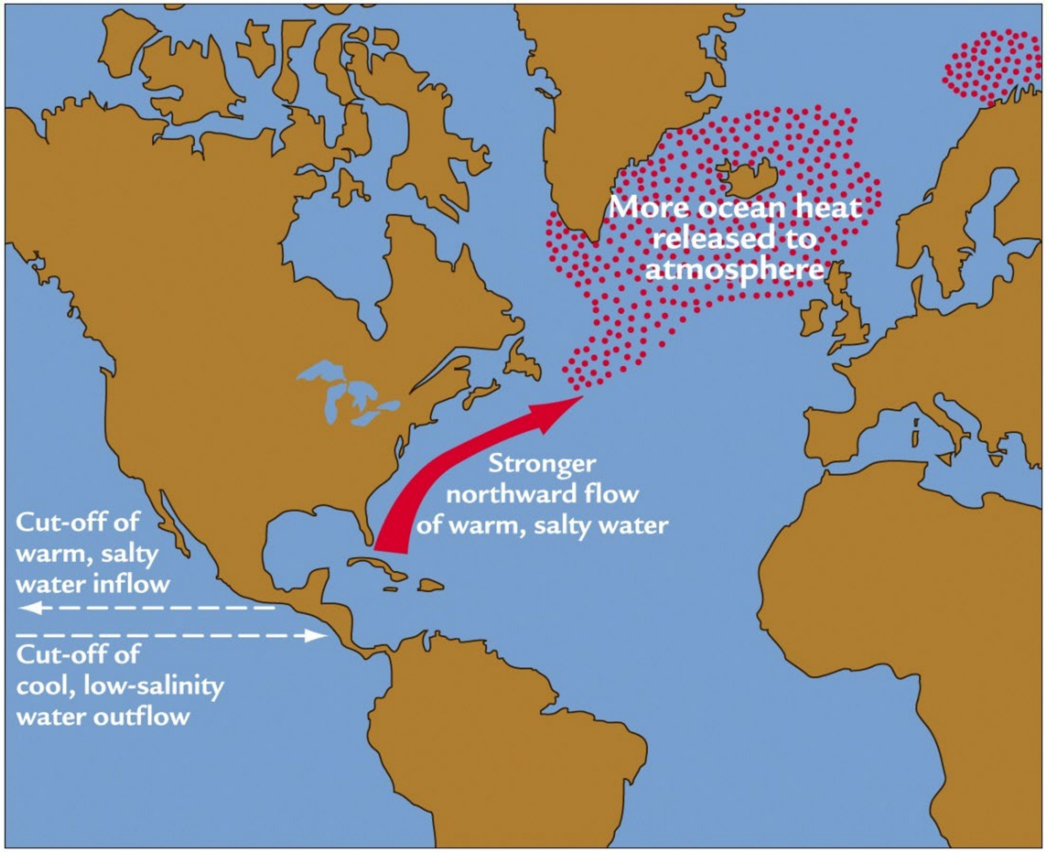
In the past 10 Myr, the uplift of Central America gradually reduced the passage between North and South America, closing around 4 Myr ago, just before North American glaciation (2.75 Ma).

The Isthmus of Panama's formation likely:

- Blocked warm, salty Atlantic waters from reaching the Pacific;
- Blocked cold, low-salt Pacific waters from entering the Atlantic;
- Initiated the Gulf Stream, carrying warm, salty waters northward, reducing sea ice formation (as salty water freezes at lower temperatures) and transporting heat to warm these regions.

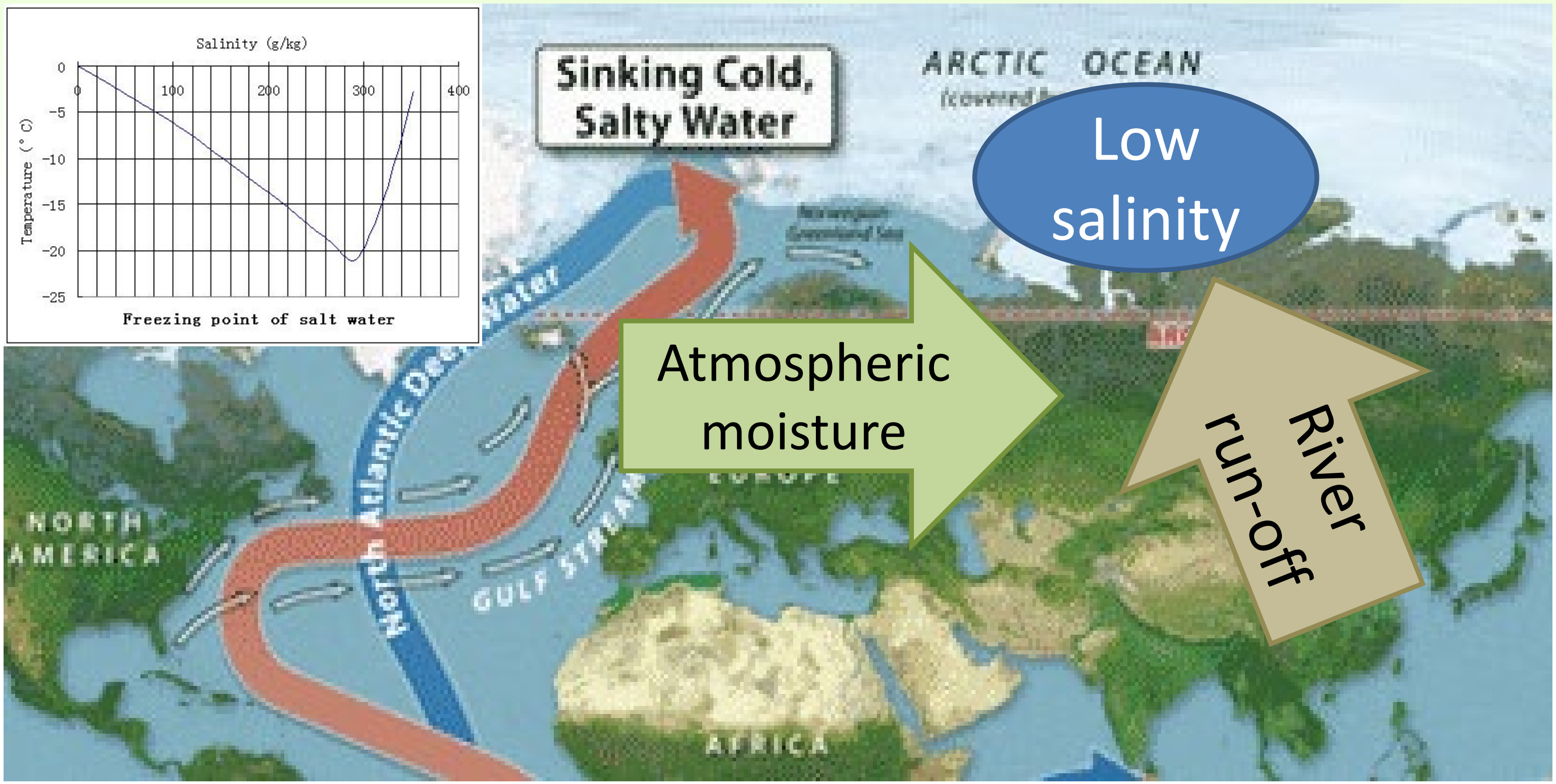
GATEWAY HYPOTHESIS - 3

Using O-GCMs with two configurations, with and without the Isthmus of Panama, confirmed the Gulf Stream's formation and a decrease in sea ice, though no significant changes in rainfall were observed.
Heat transport in the North Atlantic likely inhibited glaciation, promoting summer ice melt.



GATEWAY HYPOTHESIS - 3

Despite these "adverse" conditions, the movement of humid air masses toward Siberia may have increased rainfall and runoff, leading to extensive freshwater patches in the Arctic Ocean.



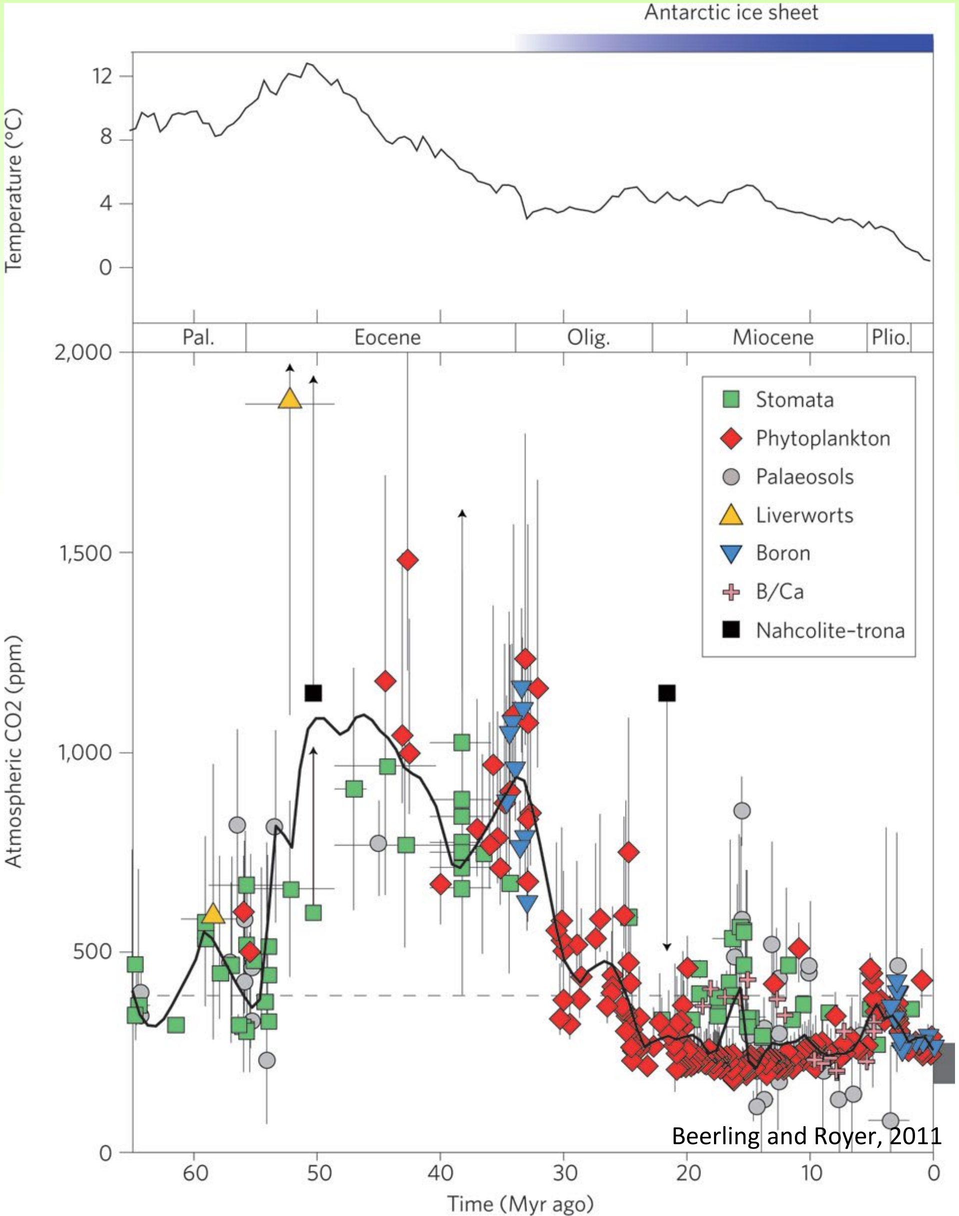
CO_2 (TECTONIC) HYPOTHESIS

All proxies indicate a gradual decrease in atmospheric CO_2 over the past 50 Myr.

Starting from this premise, we examine whether tectonic CO_2 variation hypotheses can explain Southern Hemisphere glaciation:

1. **BLAG Spreading Rate Hypothesis**

2. **Uplift-Weathering Hypothesis**



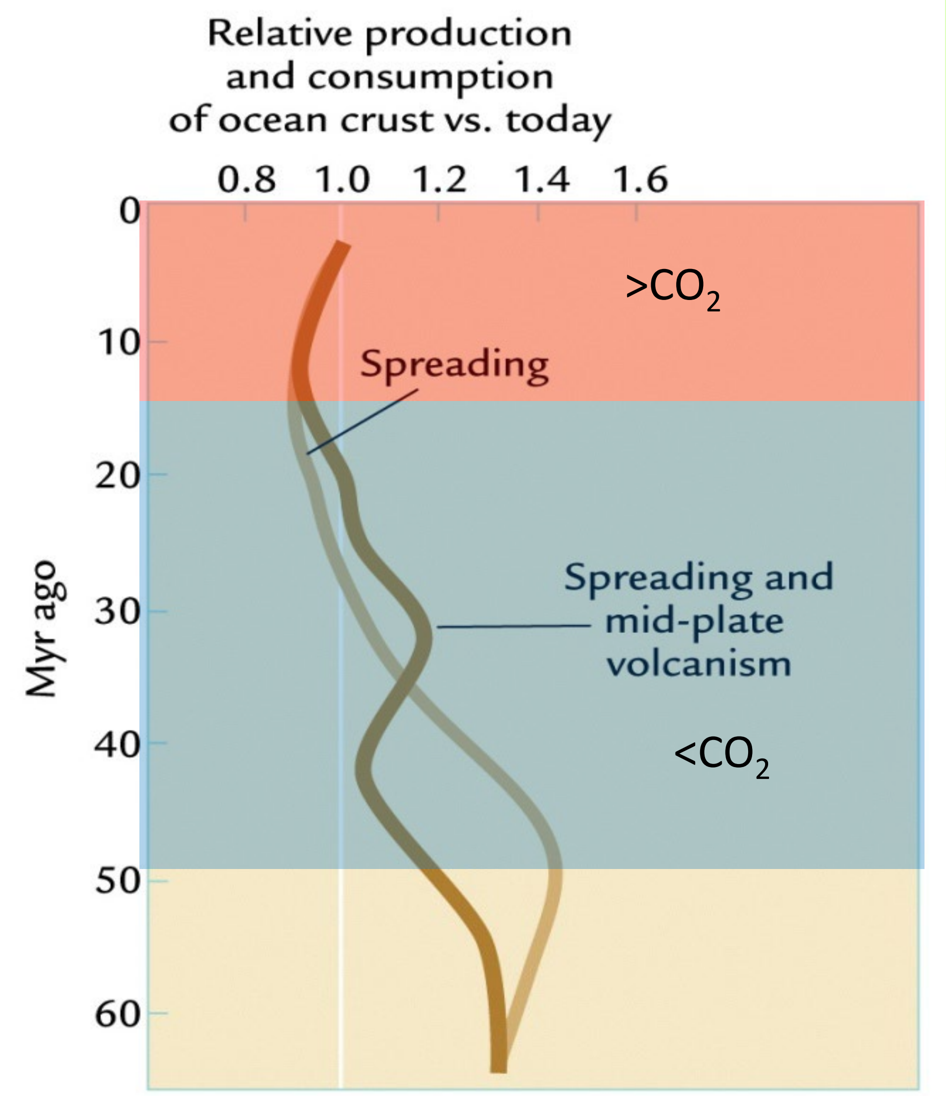
Beerling and Royer, 2011

BLAG - SPREADING RATE HYPOTHESIS

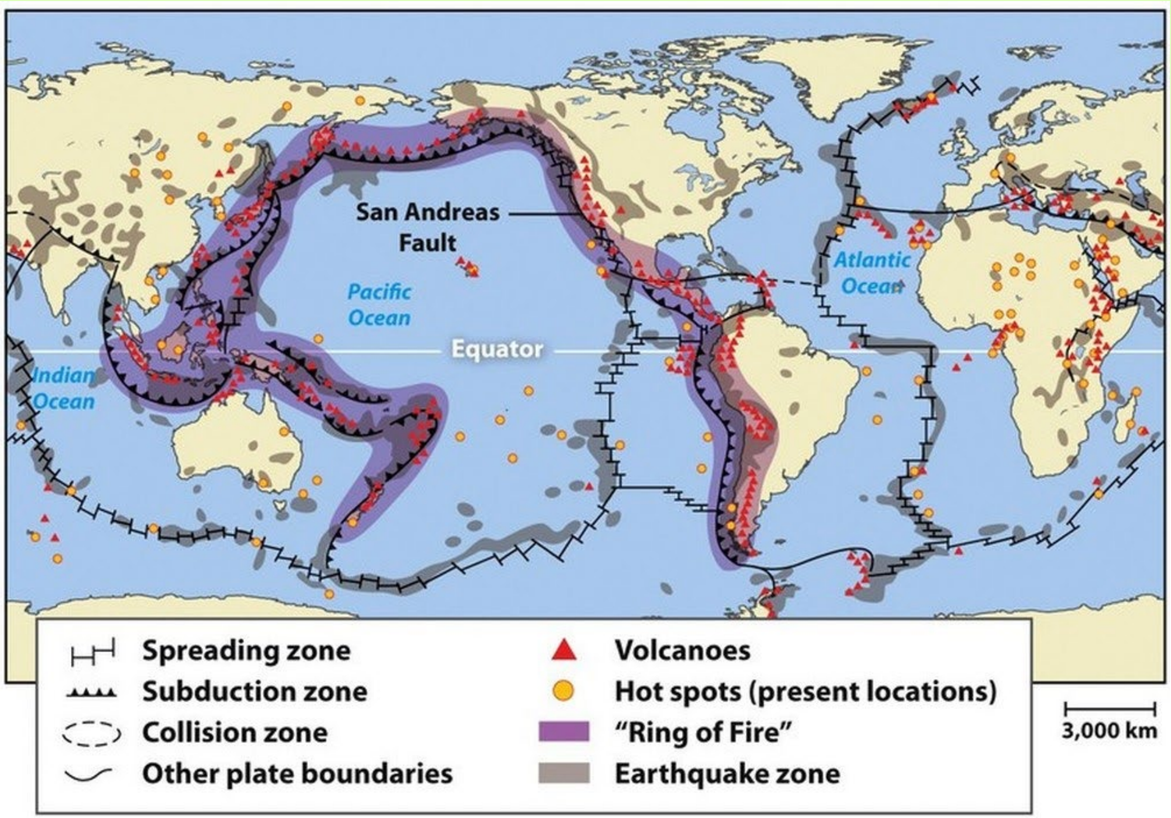
A necessary condition is a **global decrease in spreading** and subduction rates to reduce atmospheric CO_2 emissions.

Up to 15 Ma, the spreading rate decreases but then begins to rise.

This increase would raise CO_2 levels and cause warming, which contradicts the geological record.



BLAG - SPREADING RATE HYPOTHESIS



SEDIMENT TYPE VS. SPREADING RATES

An extended BLAG model considers the type of sediments subducted. Carbonate-rich sediments release more CO_2, while carbonate-poor sediments, like those in the Pacific (where most subduction occur), release less CO_2. This could explain a CO_2 decrease even with constant or slightly increased spreading rates.

UPLIFT-WEATHERING HYPOTHESIS

To validate the uplift-weathering hypothesis for global cooling over the last 50 million years, three conditions must be met:

1. **The current extent of erodible "high terrain" must be greater than in the past.**

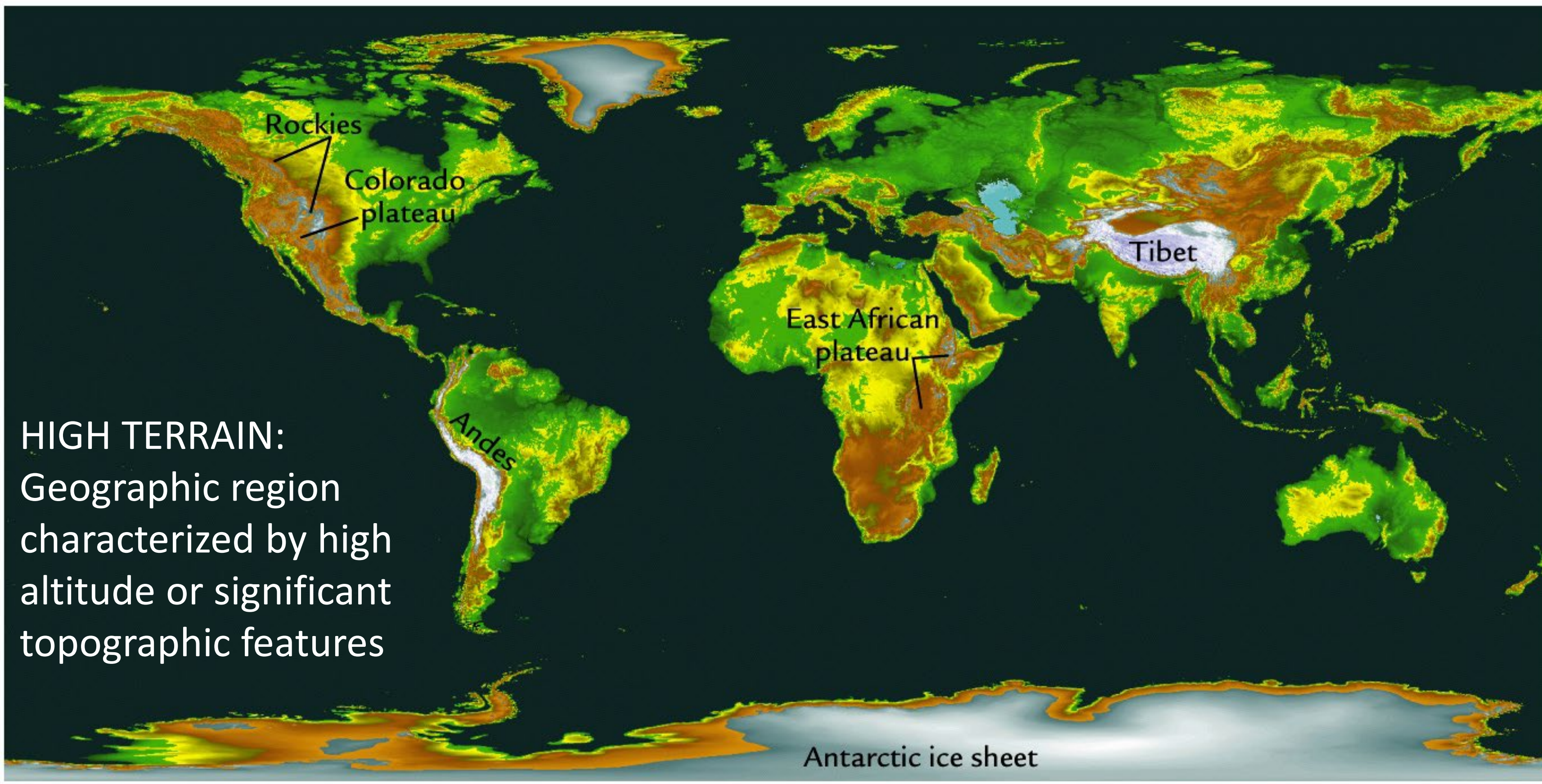
2. **Active, vigorous physical weathering must occur in these regions.**

3. **Fresh rock exposure must lead to exceptionally high rates of chemical weathering.**

A comparison will be made with the Cretaceous period, an ideal benchmark due to its well-documented geological record and greenhouse conditions.

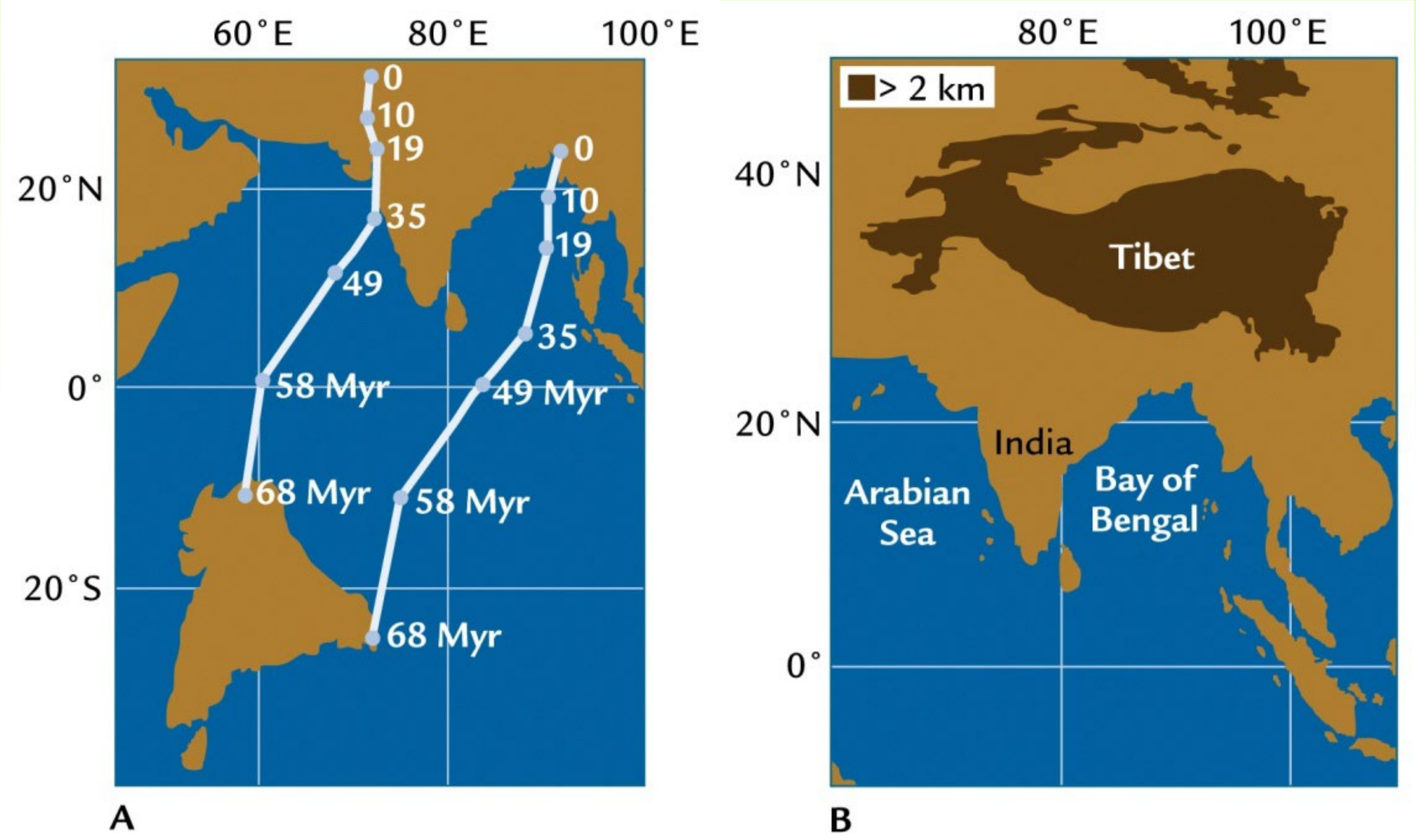
EXTENSIVE HIGH TERRAINS -1

Sediments deposited between 100 and 65 million years ago are now at high altitudes, indicating uplift over the last 70 million years. While most existing "high terrains" are relatively young, this does not guarantee they are more extensive or taller than in other periods.



HIGH TERRAIN: Geographic region characterized by high altitude or significant topographic features

EXTENSIVE HIGH TERRAINS -2



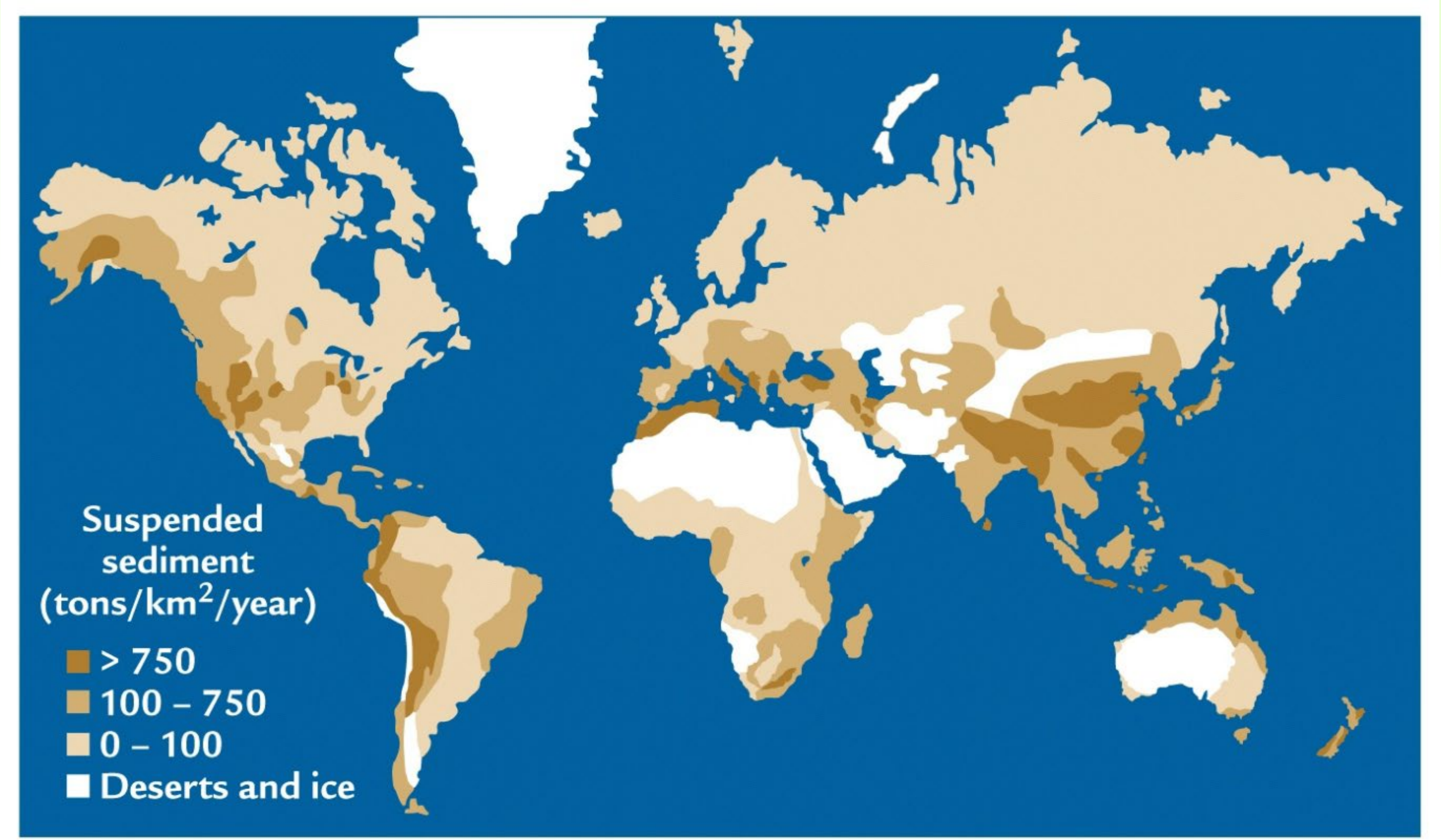
The main evidence supporting the expanded "high terrains" over the last 65 million years is the India-Asia continental collision, forming the Tibetan Plateau around 55 million years ago. There is no evidence of other continental collisions between 65–100 million years ago or before 150 million years ago.

EXTENSIVE HIGH TERRAINS -3

Other elements of elevated topography resulted from oceanic subduction. Given the ongoing nature of subduction, it is probable that analogous elements were present even in more ancient periods.
The same rationale applies to the African Plateau, formed by deep heating, which could have had a counterpart in geological history.

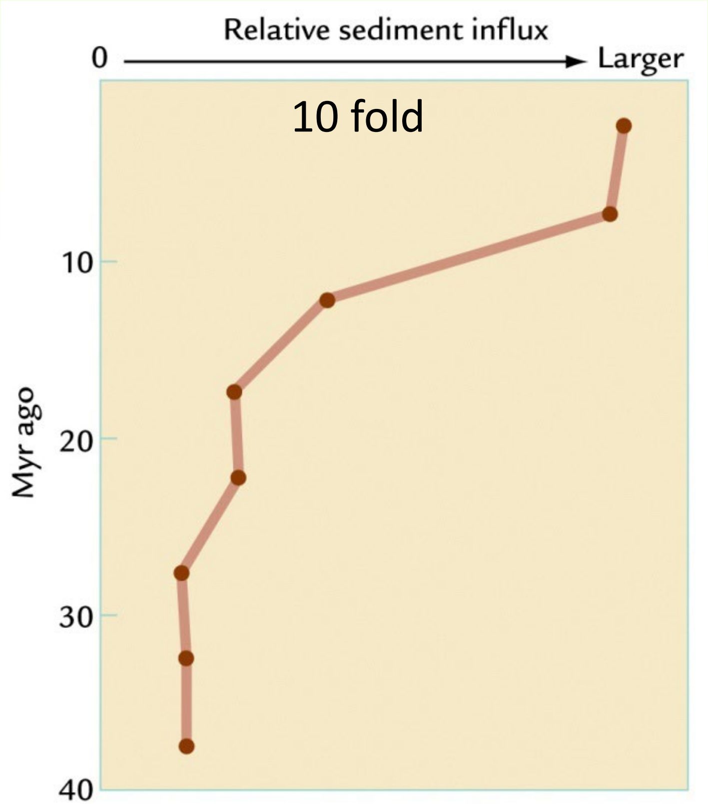
VIGOROUS PHYSICAL WEATHERING-1

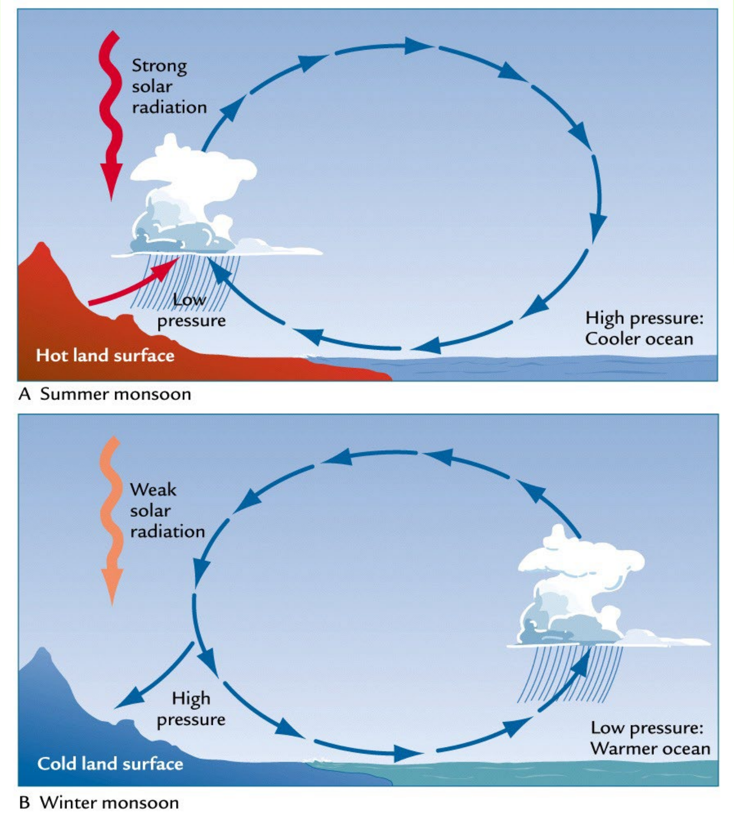
High rates of physical weathering are particularly notable in the Himalayas and Andes.



VIGOROUS PHYSICAL WEATHERING-2

TIBET AND HIMALAYA: Sediment flow into the Indian Ocean is influenced by the steep slopes along the southern Himalayas and Tibet and by the the monsoon regime.





Despite sediment loss from subduction, evidence shows increased physical weathering, with rates in the Himalayas rising tenfold over the past 40 Myr.

UNUSUAL CHEMICAL WEATHERING

Estimating chemical weathering efficiency is challenging due to several factors:

1. **Differentiating ions from hydrolysis (which affect CO_2 balance) versus dissolution is difficult.**
2. **The vast number of rivers makes it hard to establish a reliable balance.**
3. **Estimating past weathering rates adds further complexity.**

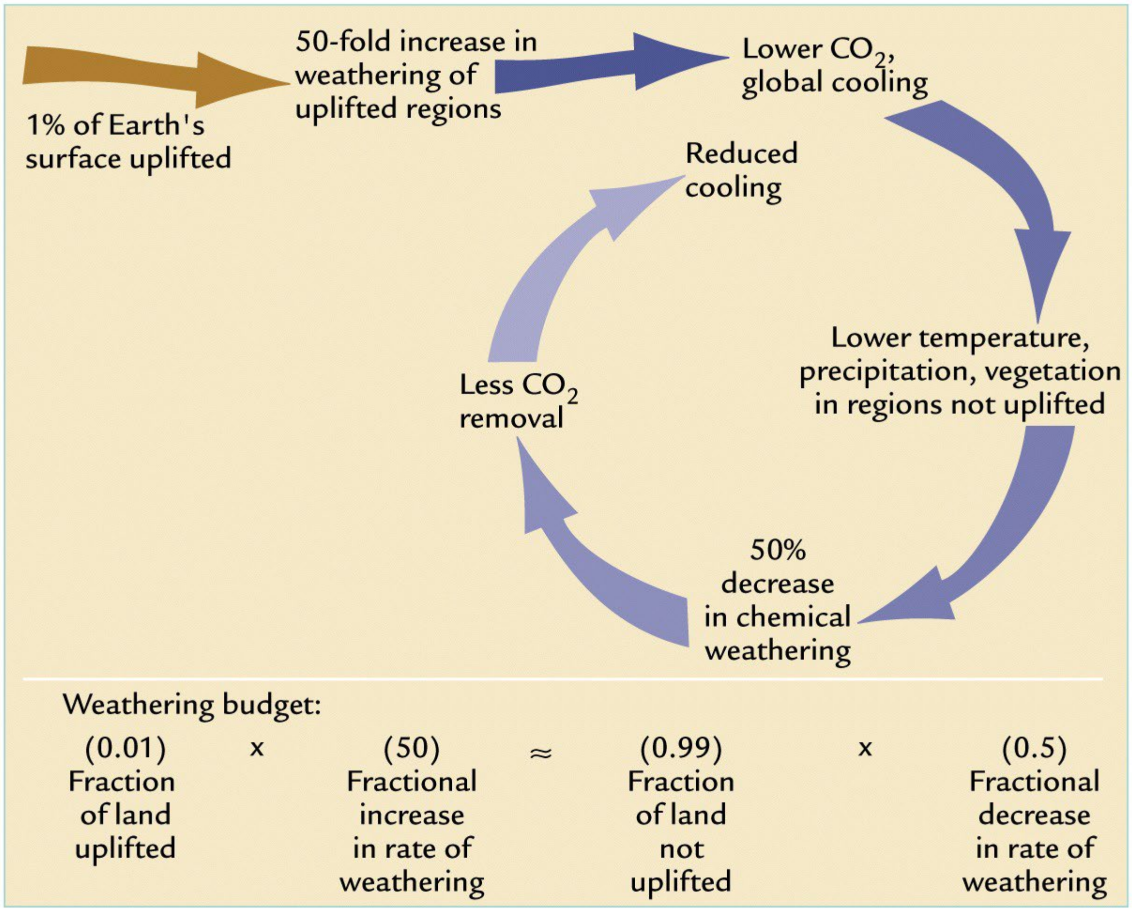
Thus, the idea that chemical weathering rates have been higher in the last 50 million years remains plausible but unproven..

CONCLUSION

The cause of global cooling therefore remains uncertain, even if the main suspect is CO_2, it is still difficult to define whether the mechanism to justify the decrease in CO_2 is linked to the spreading of ocean floors or to the increase in chemical weathering or ....

CHEMICAL WEATHERING : net balance equal to zero?

A rough estimate illustrates the complexity of chemical weathering over the past 50 Myr. Weathering increased significantly in the Himalayan area (+50%), which represents about 1% of the land surface. Assuming a decrease (0.5%) in the remaining 99% due to cooling from uplift, these effects would balance each other, producing no net effect on climate.



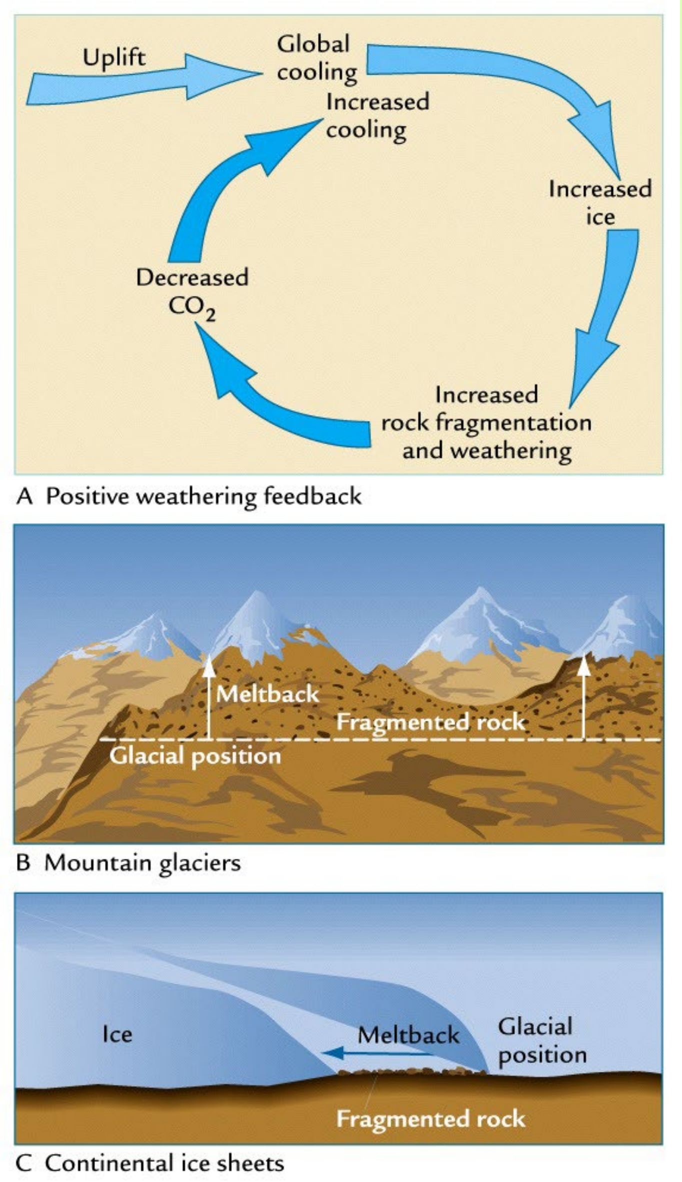
ICE VOLUME (POSITIVE) FEEDBACK VARIATIONS

The cooling trend can create positive feedback, amplifying initial changes.

POSITIVE FEEDBACK

•Initial cooling increases ice, which expands mountain glaciers, fragmenting rocks and boosting weathering rates, especially with glacial advance and retreat (orbital pacing).

•Expanding and retreating ice caps produce a similar effect; however, if bedrock remains fully covered by ice, weathering is minimal, limited to the ice front.



FEEDBACKS & CONCLUSION

The cooling trend over the last 50 Myr is poorly understood, complicating future forecasts.

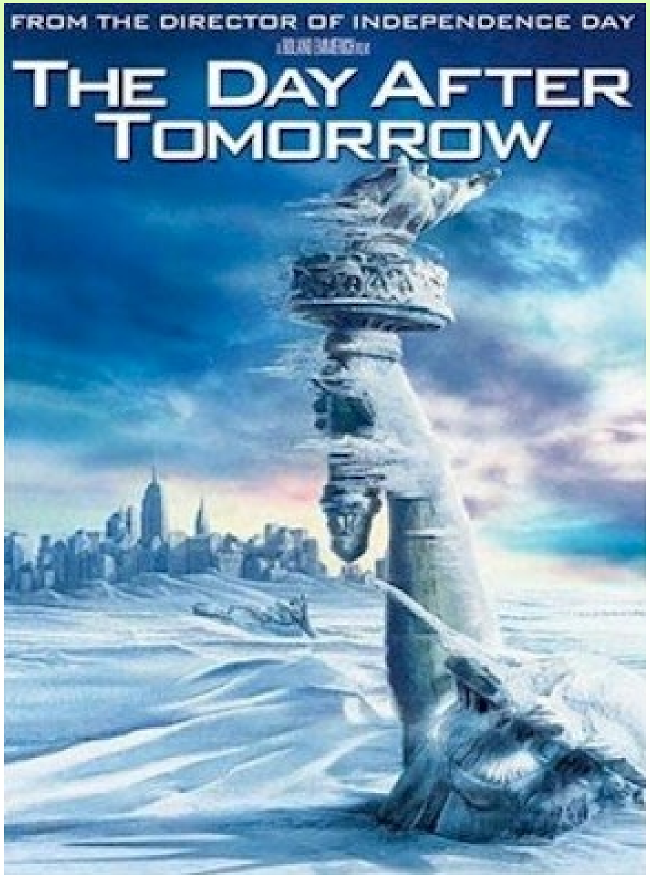
Tectonic processes are shaped by positive and negative feedbacks: for instance, BLAG suggests negative feedback from chemical weathering.

Understanding these feedbacks is crucial to interpreting past events and anticipating future changes.

CONCLUSION

The cause of global cooling remains uncertain. While **CO_2 is the main suspect**, it is unclear whether the decrease in CO_2 is due to **ocean floor spreading**, **increased chemical weathering**, or other factors.
The **Gateway Hypothesis** remains a possible contributing factor.

THE CLIMATE OF THE FUTURE



Long-term predictions based on **tectonic activity suggest a gradual cooling** of Earth's climate, but this process is extremely slow and not an immediate concern.

In the meantime, faster processes can drive climate change in the opposite direction, influenced by **(1) orbital parameters and (2) human activity.**