

# The Paleocene-Eocene Thermal Maximum

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Mathematics of Climate Seminar

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# What was the PETM?

- Event 55 million years ago, lasting 100,000 years
- Increase in temperatures by 6° C over 20,000 years
- Huge spike in atmospheric carbon dioxide

# What was the Paleocene like?

- “Subtropical and moist” throughout North America and Europe.
- Thick tropical and deciduous forests covering most of Earth
- Coniferous forests near the poles

# What was the Paleocene like?

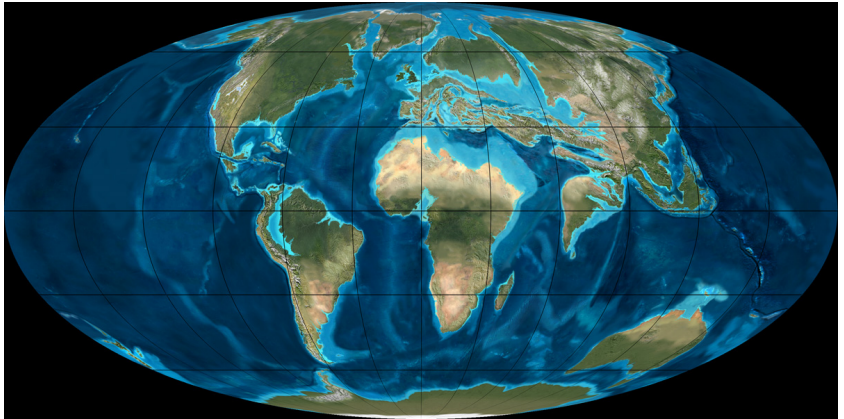
- Crocodiles in Greenland



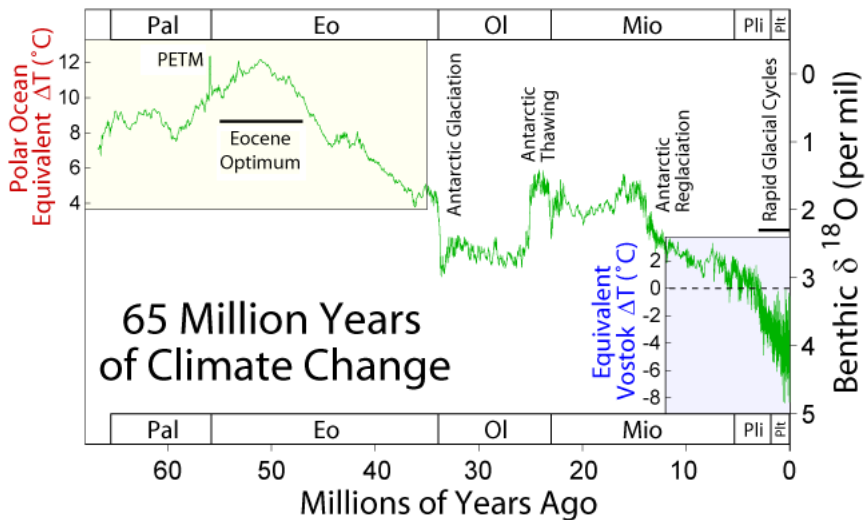
- Primates in tropical forests of Wyoming

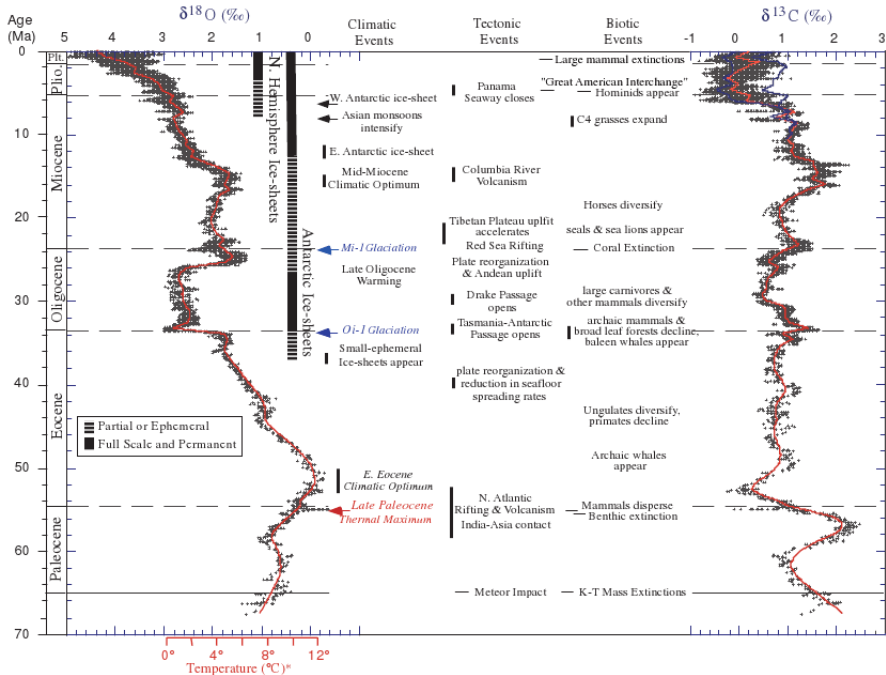


# What was the Paleocene like?



50 Ma





## Effects of the PETM

- Rising ocean levels

$$\frac{\Delta V}{V} = \alpha_v \Delta T$$

For liquid water,

$$-.7 \times 10^{-4} / ^\circ C < \alpha_v < 7.07 \times 10^{-4} / ^\circ C \text{ for } 0^\circ C < T < 100^\circ C$$

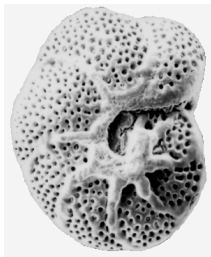
Thermal expansion of  $6^\circ C$  would expand water by at most  
 $6(7.07 \times 10^{-4}) = 0.42\%$



# Effects of the PETM

- Ocean circulation reversal
- Carbon Compensation Depth is shallower

## Effects of the PETM



- Extinction of benthic foraminifera
- Other species thrived, including mammals

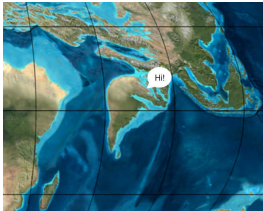
## Proposed causes

- Massive release of  $CO_2$  into atmosphere
- Release of methane into atmosphere - “Clathrate Gun”
- Ocean circulation and deepwater formation
- Positive feedbacks after initial warming

# Carbon Dioxide

Zeebe et. al. estimated 3000 Gt of carbon released into atmosphere. Where did it come from?

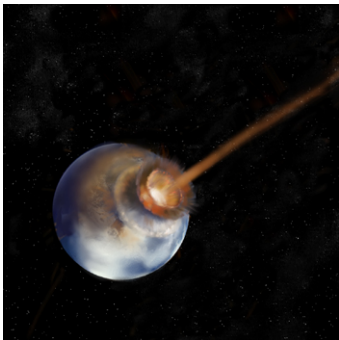
- Tectonic activity
  - ▶ Volcanic activity in North Atlantic
  - ▶ India meets Asia



- Problem: 3000 Gt would be over 100 times more volcanic degassing than usual

# Carbon Dioxide

- Carbon rich comet



- Problem: no evidence

# Carbon Dioxide

- Burning peat, other biomass
- Problem: 3000 Gt is 90% of biomass on Earth at this time



# Carbon Dioxide

Zeebe et. al. concluded that carbon dioxide is insufficient to explain PETM warming.

Climate sensitivity (Charney): doubling  $CO_2$  raises temperature by 1.5 – 4.5 degrees C. The effect of carbon dioxide on temperature is thought to be logarithmic.

Estimated 1000ppm at beginning of PETM.

3000 Gt is equivalent to increasing concentration by 700 ppm.

$$4.5 \frac{\log(1.7)}{\log(2)} \approx 3.5$$

# Methane



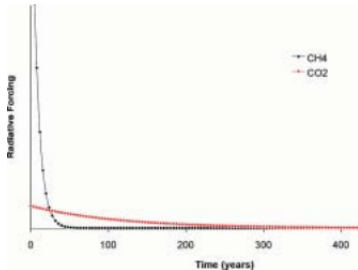
## Clathrate Gun Hypothesis

- Warming oceans releases methane from ice in seabed
- Positive feedback
- Methane released until all ice is melted



# Methane

Methane is a stronger greenhouse gas than  $CO_2$ .



Gas	Lifetime (years)	Global Warming Potential (time horizon in years)		
		20 years	100 years	500 years
CO <sub>2</sub>	5-200	1	1	1
CH <sub>4</sub>	12	62	23	7
N <sub>2</sub> O	114	275	296	156
HFCs	0.3-260	40-9,400	12-12,000	4-10,000

## Problems with methane theory

Methane turns into  $CO_2$  in atmosphere quickly.

Was there enough methane?

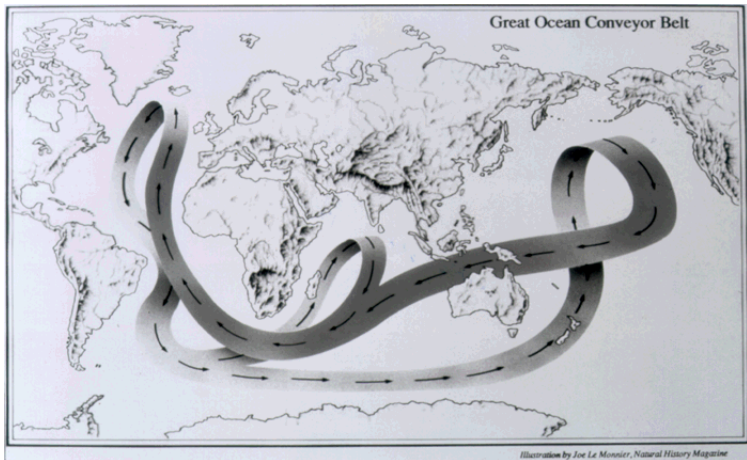
# Ocean Circulation

Nunes and Norris (2006) say that the ocean currents abruptly changed directions, lasting 20,000 years.

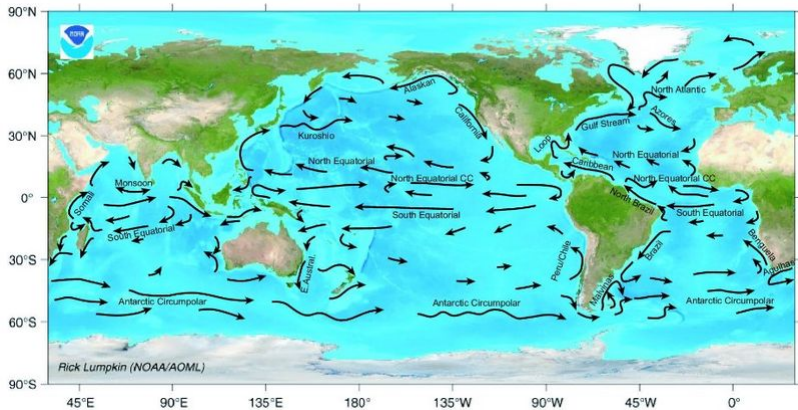
Overturning stopped occurring in the Southern Hemisphere, started occurring in the Northern Hemisphere.

Warmer water reached the deep ocean – could have started the clathrate gun.

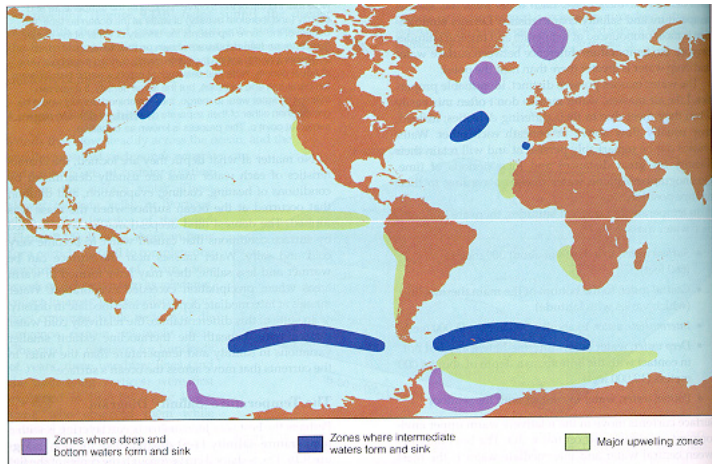
# Ocean Circulation



# Ocean Circulation



# Ocean Circulation



## Comparison to Present

- We are releasing carbon into the atmosphere at a greater rate than the PETM. 21 Gt/yr
- A similar amount of carbon will be released if we burn all of our fossil fuels.
- There is likely more methane in ocean and permafrost clathrates today.

# Questions about the PETM

- Where did all this carbon come from?
- Where did it go?
- How long did it take to enter the atmosphere?
- How fast was the warming and the cooling?
- What happened to the ocean currents?