THE MIOCENE

Overview

When was the Miocene?

How was it different from today?

What is known about its climate and environments?

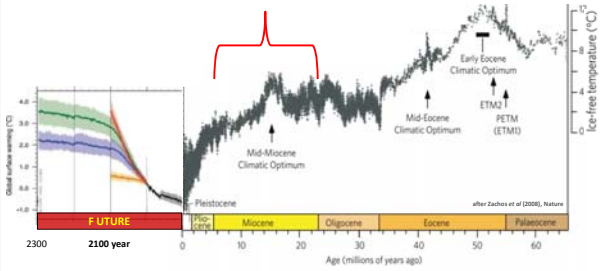
Sivapithecus indicus; early hominid, Pakistan, 13 - 9 Ma

The Miocene

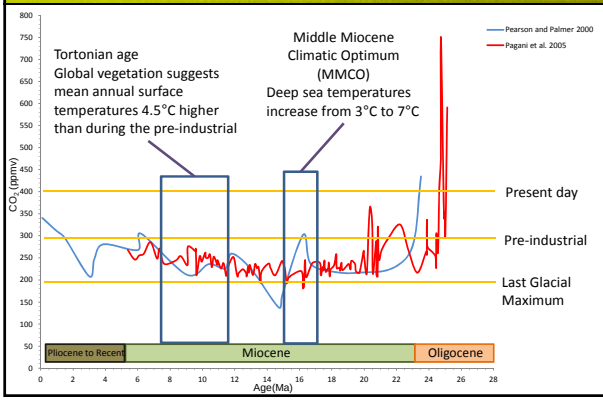
23.03 to 5.33 Ma

Global temperatures higher than today

Gradual decrease in temperatures from start to end with a climatic optimum in the middle



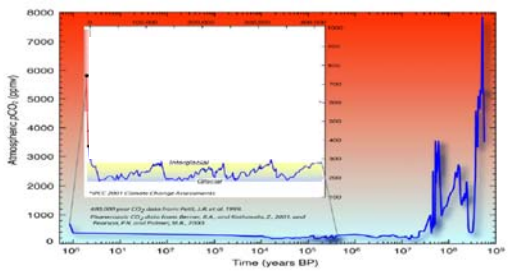
Miocene CO_2 levels



What is going on in the Miocene!?!

Warm climate low CO_2 paradox?

In the recent past CO_2 and climate have gone hand-in-hand



Some researchers have suggested that the Miocene climate was decoupled from CO_2

What is different about the Miocene?

Continental distribution
Ocean Gateways and circulation
Mountains
Ice
Vegetation

Could any of these (or a combination) create a warmer world with lower CO_2?

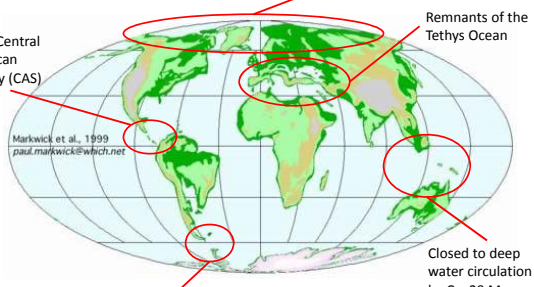
Palaeogeography and Ocean Gateways

Early Miocene
23.03 – 15.97 Ma

Arctic gateways narrower and shallower, no deep water movement

Remnants of the Tethys Ocean

Open Central American Seaway (CAS)



Closed to deep water circulation by Ca. 20 Ma

Deep Drake Passage by 20 Ma
Circum-Antarctic Current?

http://palaeogeography.net/

Palaeogeography and Ocean Gateways

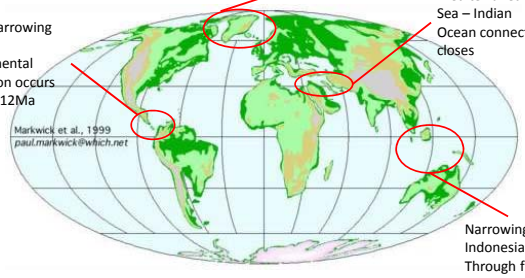
Middle Miocene
15.97 – 11.61Ma

Greenland – Scotland gateways open to deep water by 14 - 12 Ma

Mediterranean Sea – Indian Ocean connection closes

CAS narrowing

Continental collision occurs at Ca. 12Ma



Narrowing Indonesian Through flow

http://palaeogeography.net/

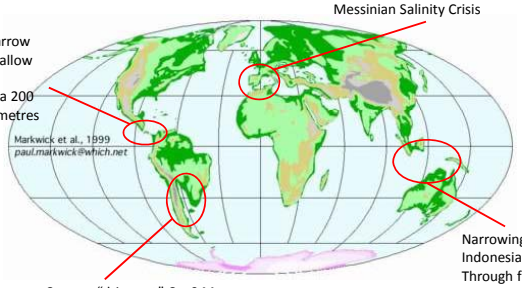
Palaeogeography and Ocean Gateways

Late Miocene
11.61 – 5.33 Ma

Straits of Gibralter close for 300,000 years at 5.6 Ma - Messinian Salinity Crisis

CAS narrow and shallow

At 6 Ma 200 – 500 metres deep



Narrowing Indonesian Through flow

Paranean Seaway "dries out" Ca. 9 Ma

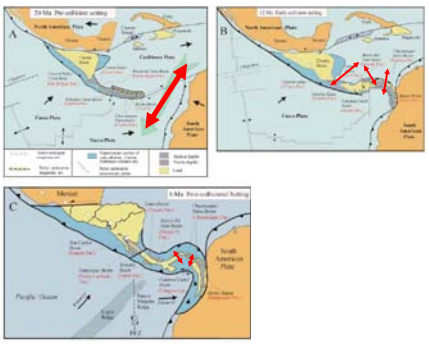
http://palaeogeography.net/

Central American Seaway – consequences of closure

Early Miocene (A)
Possible for Atlantic and Pacific waters to exchange

Middle Miocene (B)
Bathyal depths (200-4000m) until 12.8 Ma
After 12.8 Ma <200m

Late Miocene (C)
Narrow channels varying from 500 – 25m depth



Coates et al., 2004

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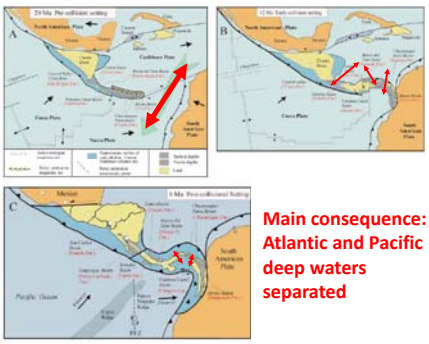


Main consequence: Atlantic and Pacific deep waters separated

Coates et al., 2004

Central American Seaway – consequences of closure

Animal migrations before the formation of a land bridge

Cricetid rodents at 6.1 – 5.73 Ma in Argentina

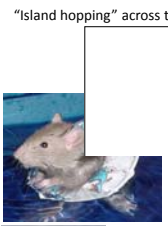
Ground sloths at Ca. 11 Ma in Florida, Oklahoma, California, Nebraska, Texas, New Mexico, Oregon and Mexico

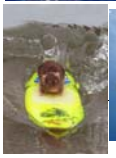
Gomphothere elephants at 11.6 – 7.3 Ma in Brazil and Peru

Cozzoul, 2006; Webb, 2006; Verzi and Montalvo, 2008

Central American Seaway – consequences of closure

"Island hopping" across the seaway and the Caribbean

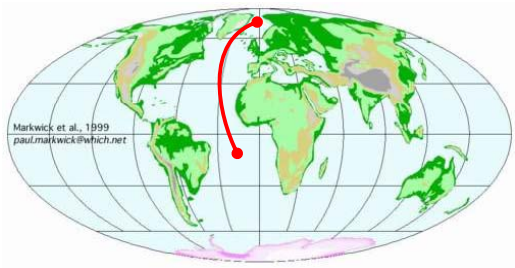




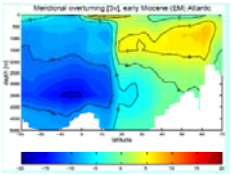
Cozzoul, 2006; Webb, 2006; Verzi and Montalvo, 2008

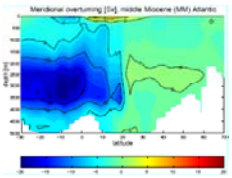
Central American Seaway – consequences of closure

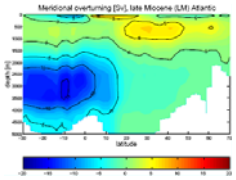
A transect through the Atlantic to explore Miocene ocean movement

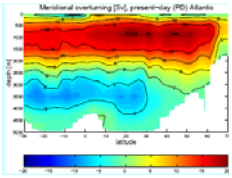


Central American Seaway – consequences of closure









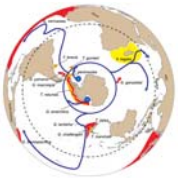
1 Sv (Sverdrup) = 0.001 Km^3/Second or nearly 1 billion litres of ocean a second

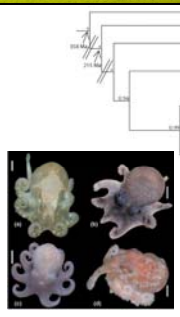
Evidence to support the models?

Deep sea octopus evolution!

Deep sea octopus groups originated around Antarctica

Northward movement of Antarctic deep water fuelled diversification within the group



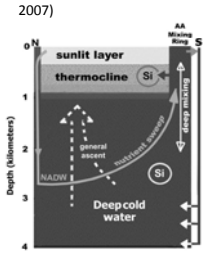


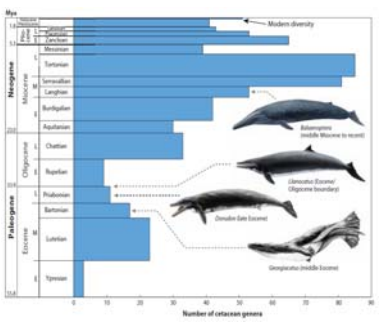
Strugnell et al., 2008

Evidence to support the models?

Peak whale diversity!

Related to the origins of the modern thermohaline oceanic circulation and increased amounts of silica (Berger, 2007)



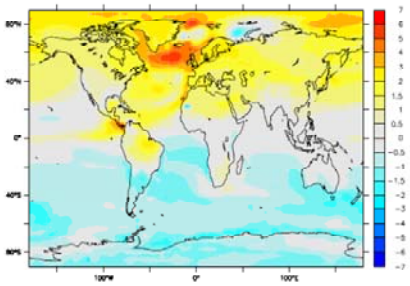


Uhen, 2010

Central American Seaway – consequences of closure

In model studies closing the CAS warms the high northern latitudes but does nothing for the southern hemisphere

But the CAS didn't fully close until the Pliocene



Ocean Gateways forcing Miocene climate?

During the Early Miocene the oceans had a remnant Paleogene circulation (equatorial)

By the Late Miocene a nearly modern thermohaline circulation had begun

Model studies show the origin of North Atlantic Deep Water formation during the Late Miocene
But Ocean turnover is not as strong as today – less heat transport to the North Atlantic?

Ocean current changes causing diversification and evolution in the oceans e.g. Whales and octopuses

Ocean circulation and continental configuration becoming more modern during the Miocene – no evidence to suggest they were the primary warming agent

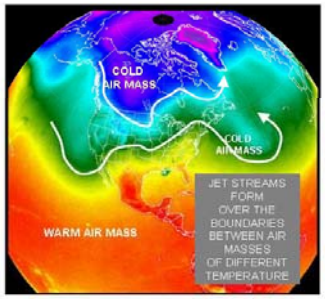
An important aspect but apparently not forcing Miocene climates.....

Hippotherium primigenium; Late Miocene horse, Eurasia, 11 - 5 Ma

Mountains

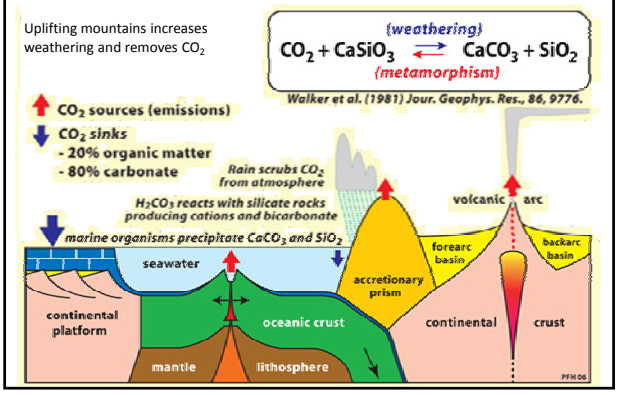
Mountains and Climate

Mountains deflect the jet streams, create rain shadows and separate air masses

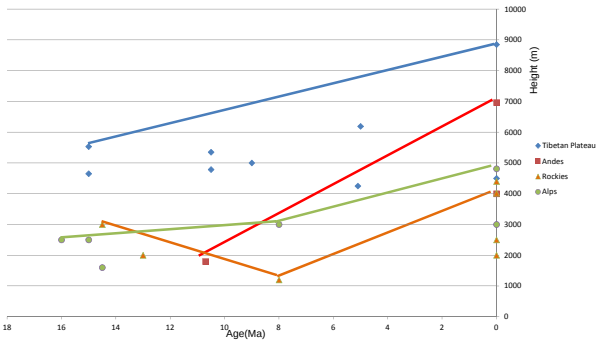


Carbon cycle refresher

Uplifting mountains increases weathering and removes CO_2

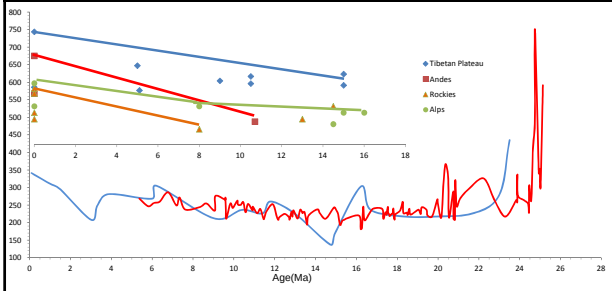


Mountain uplift



All mountain ranges recommence uplift from the Middle Miocene with an intensification after 10 Ma

Mountain uplift and CO_2

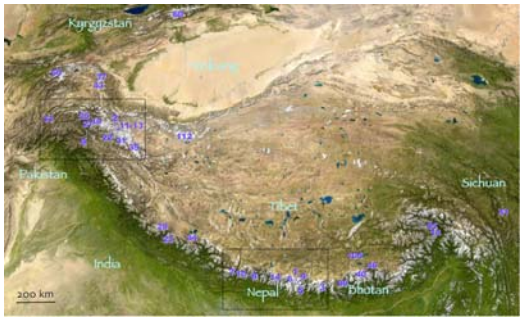


Boron isotopes (Blue line) does show drop in CO_2 with the onset of mountain uplift

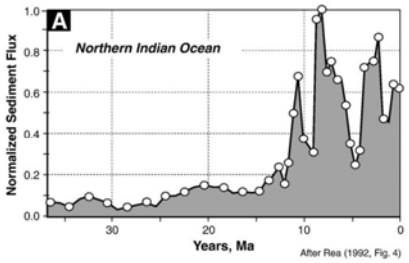
However following this neither shows a link with continued mountain uplift

Mountain uplift – Tibetan Plateau

Behind the Himalayan, Karakoram, Pamir and Hindu Kosh mountain ranges
These ranges contain over 100 mountains that are greater than 7200m high



Mountain uplift – Tibetan Plateau



Dramatic increase of sedimentation in the Indian Ocean after Ca. 15 Ma

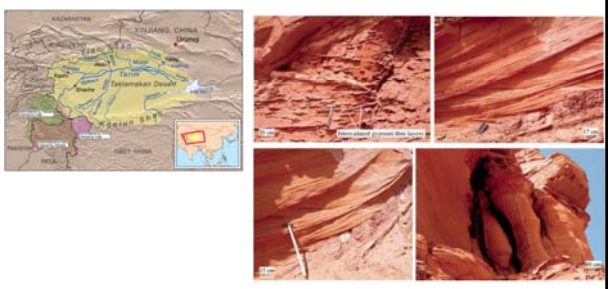
Increased uplift rate of the Tibetan Plateau

Potter and Szatmari, 2009

Mountain uplift – Tibetan Plateau

Formation of the Taklimakan Desert Ca. 7 Ma

Major rain shadow present by 7 Ma



Sun et al., 2009

Mountain uplift – Tibetan Plateau

Effects of Tibetan uplift:

Disruption of west-to-east air flow across the northern hemisphere

Cooling and drying of Eurasia north of the Himalayas

Initiation of monsoon-driven wind systems across India and increased precipitation across the Himalayas

Higher chemical erosion rates favoring a drawdown of atmospheric carbon dioxide and resulting in global cooling – seen in the Zachos curve but not CO_2 records….

REVIEW ARTICLE

Tectonic forcing of late Cenozoic climate

M. E. Raymo & W. F. Ruddiman

Raymo and Ruddiman, 1992; Molnar, 2010

Ice

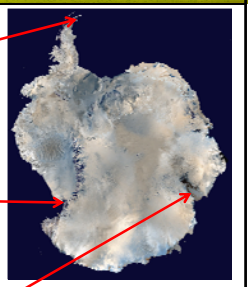
Southern Hemisphere

Full Antarctic ice sheet after Ca. 15 Ma

Glaciers in Argentina at Ca. 7 Ma

Seymour and James Ross Islands have Late Miocene glacial sediments with some evidence for interglacial periods

ANDRILL core shows vegetation present at 15.7 – 15.5 Ma



ODP Site 1165: Prydz Bay

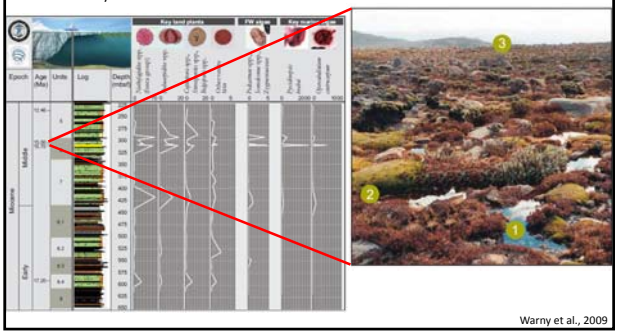
22 - 19 Ma there was a minimum ice shelf and thriving *leiosphaeridia*
19 – 17 Ma the ice shelf expanded and the climate is colder
17 - 15 Ma minimum of the ice shelf, maximum biota.
After 15 Ma only reworked palynomorphs; representing a large growth of ice

Pirrie et al., 1997; Hannah, 2006; Marenssi et al., 2010

Antarctica – Middle Miocene

ANDRILL drilling project

Remarkably warm Antarctica at 15.7 – 15.5 Ma



Warny et al., 2009

Northern Hemisphere

ACEX drill core at 88°N shows permanent sea ice in the Arctic Basin from 23 Ma, except for two perio

10 Ma Tilli

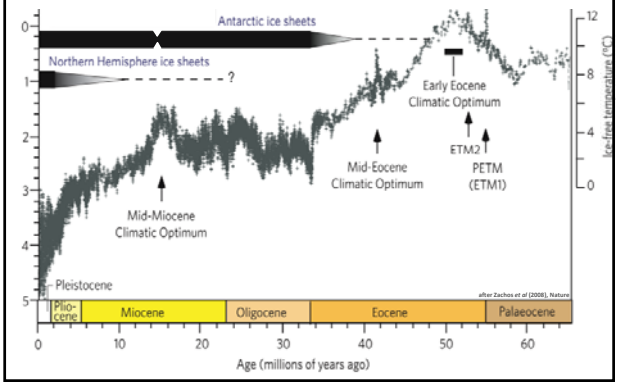
.3 Ma IRD in
nd Sea

Ice Rafted Debris (IRD)

Glaciers on Mountains in Alaska and Eastern Greenland during Late Miocene

Denton and Armstrong, 1969 ; Thiede and Myhre, 1996 ; St. John and Krisseck, 2002 ; Moran et al., 2006

Ice sheets and the Zachos curve



Vegetation

Vegetation and Climate

Vegetation is the "crystallized, visible climate" (Vladimir Köppen, 1936)

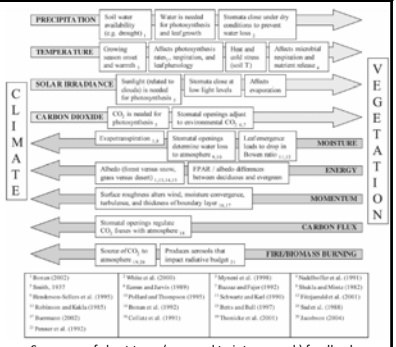
Vegetation and climate

Vegetation impacts on climate

Main impacts are:

Surface albedo
e.g. Forest vs. Snow

Evapotranspiration
e.g. Forest vs. Grass

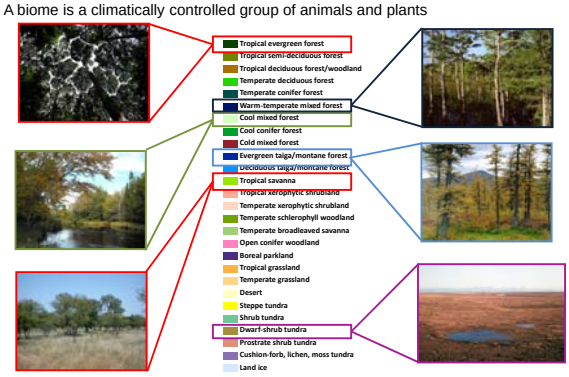


Summary of short term (seasonal to interannual) feedbacks

Notaro et al., 2006

Vegetation biomes

A biome is a climatically controlled group of animals and plants



Vegetation biomes

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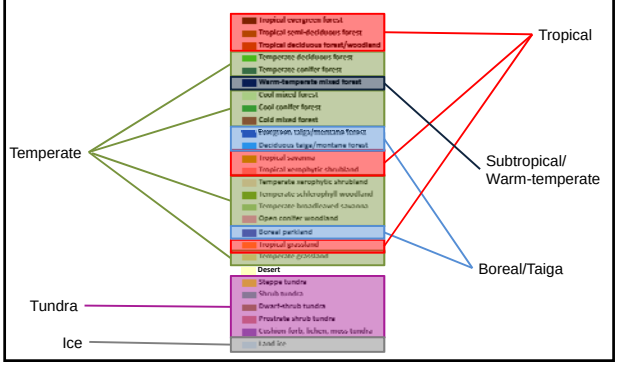
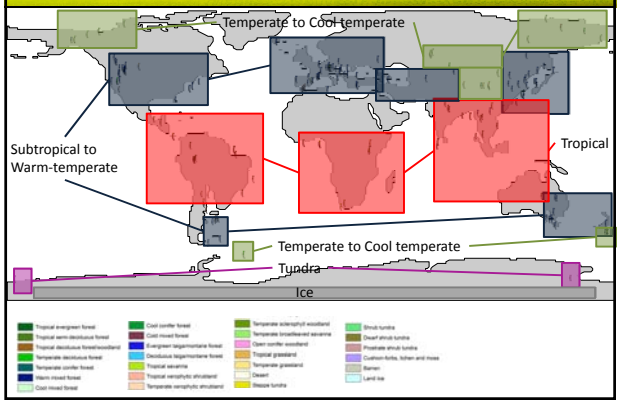
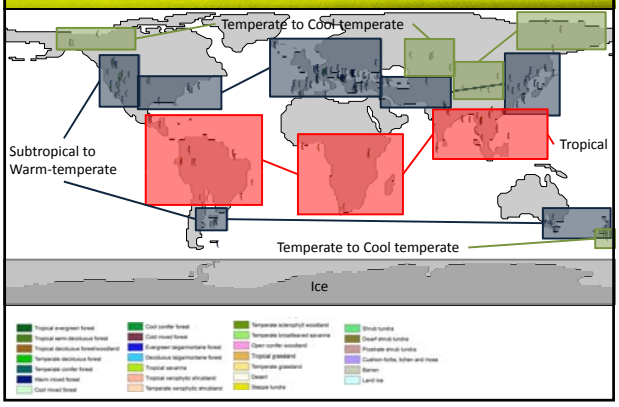


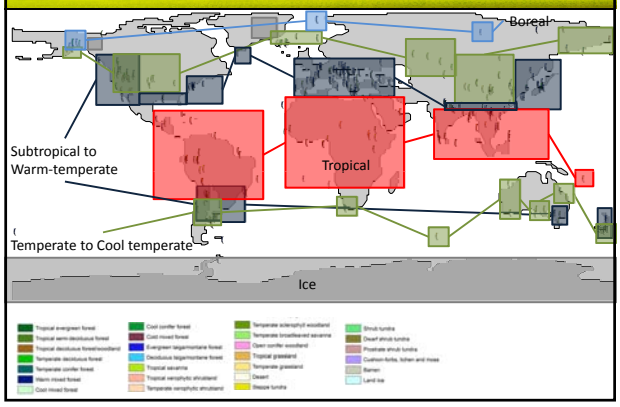
Miocene Vegetation 15.97 – 13.65 Ma



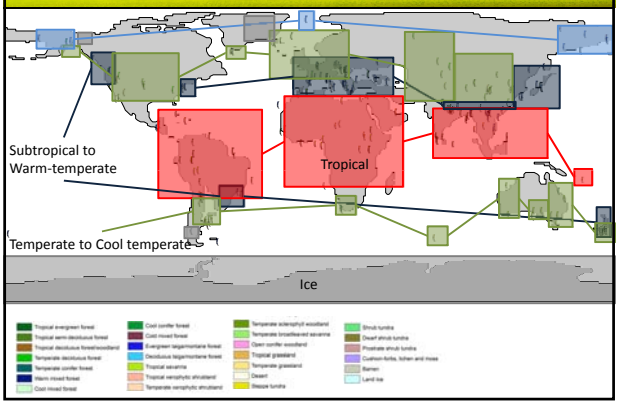
Miocene Vegetation 13.65 – 11.61 Ma



Miocene Vegetation 11.61 – 7.25 Ma



Miocene Vegetation 7.25 – 5.33 Ma



Miocene Climate from vegetation

Middle to Late Miocene was a warmer and wetter world than today

- More subtropical to warm temperate forests
- Boreal and temperate forests at higher latitudes than today
- Greatly reduced desert regions

Middle Miocene to latest Miocene shows a cooling trend, especially at the high latitudes

- Temperate and warm-temperate zones are pushed towards the equator
- Boreal forests expand in the Late Miocene
- Drier vegetation types expand in the Late Miocene
- Appearance of major deserts in the latest Miocene

What is driving this cooling seen both in the Zachos curve and the vegetation?

Pound et al., 2011

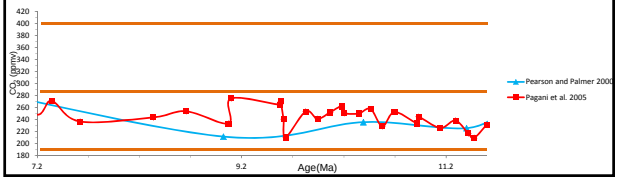
Modelling Miocene Climate

Modelling the Miocene climate

Global circulation models (GCMs) offer the opportunity to test if the unusually low CO_2 of the Miocene can still produce the vegetation of a warmer wetter world

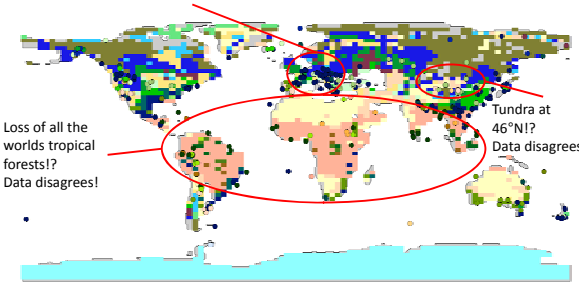
GCMs can also be used to generate vegetation, this will allow for a direct comparison with the fossil evidence

Focussing on the Tortonian (11.61 – 7.25 Ma) lets look at Miocene vegetation under 180 ppmv, 280 ppmv and 400 ppmv and compare the results to the fossil data



Miocene vegetation at 180ppmv

Boreal forests in Europe!? The data says Warm-temperate

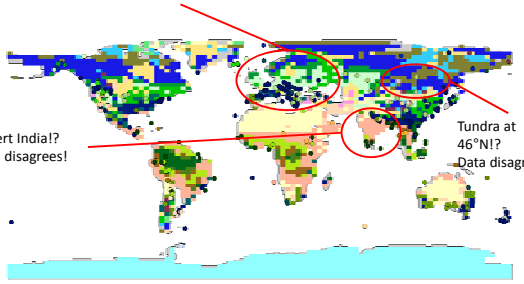


With CO_2 at 180ppmv the climate model reconstructs a vegetation similar to that of the Last Glacial Maximum

Bradshaw et al., 2009; Pound et al., 2011

Miocene vegetation at 280ppmv

Cool temperate forests in Europe, the data says Warm-temperate



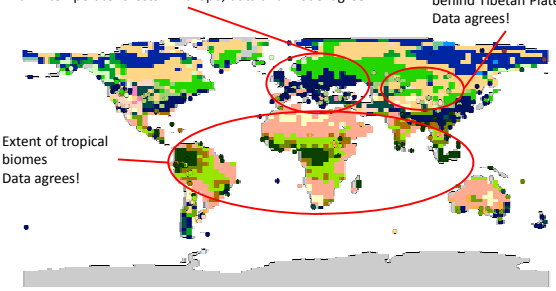
With CO_2 at 280ppmv the climate model reconstructs a better fit vegetation but the world is still to cold and dry

Bradshaw et al., 2009; Pound et al., 2011

Miocene vegetation at 400ppmv

Warm-temperate forests in Europe, data and model agree

Temperate savanna behind Tibetan Plateau Data agrees!



Extent of tropical biomes Data agrees!

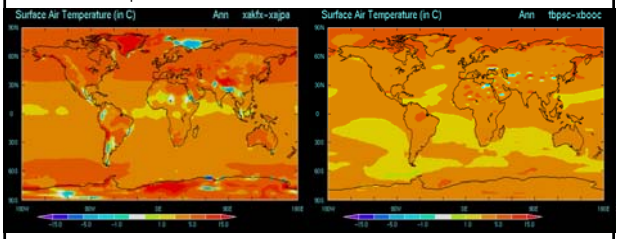
With CO_2 at 400ppmv the climate model reconstructs a comparable vegetation to the data but the world is still to cold and dry (in places!)

Pound et al., 2011

The climate of the best fit model

Miocene temperature difference

Post-20th Century temperature difference



Similarities in temperature trends between the Tortonian and future doubling of CO_2

Model studies and vegetation - Summary

Fossil evidence from the Middle to Late Miocene shows a vegetation from a warmer wetter world

Modelling studies fail to generate a vegetation comparable to the fossil evidence without higher than pre-industrial CO_2 levels (>280 ppmv)

Maybe we need another way to calculate the Miocene CO_2?

Phoberomys pattersoni; 700kg rodent, Venezuela, 8 Ma

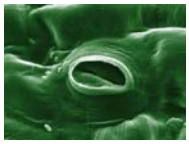
Thankfully there is a new proxy.....

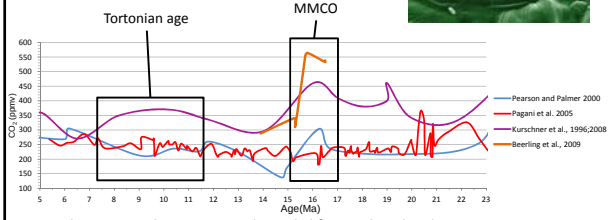
New Miocene CO_2 records

Stomata numbers on leaves provide a new proxy for CO_2

Controlled by plant genetics

New CO_2 estimates suggest much higher atmospheric concentrations

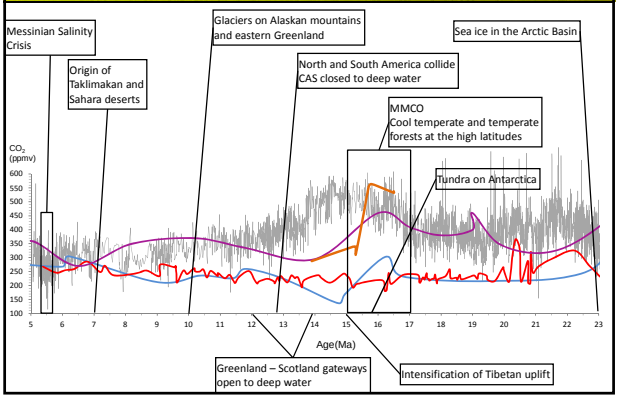




So maybe Miocene climate was not decoupled from carbon dioxide

But why do the CO_2 proxies from the land and sea disagree?

Summary timeline



Conclusions

The Miocene was a period of gradual climatic cooling punctuated by the Mid-Miocene Climatic Optimum

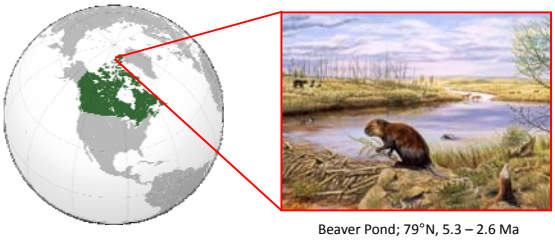
The Miocene climate was not decoupled from carbon dioxide, however the differences between the marine and terrestrial proxies is interesting

During the Miocene modern oceanic circulation originated and major mountain chains uplifted at an increased rate

Antarctica became fully glaciated and good evidence suggests the Northern Hemisphere was glaciated as well

Overall the Miocene was a warmer and wetter world (when compared to today!)

Thank you for your attention



Beaver Pond; 79°N, 5.3 – 2.6 Ma

Next time the Pliocene.....