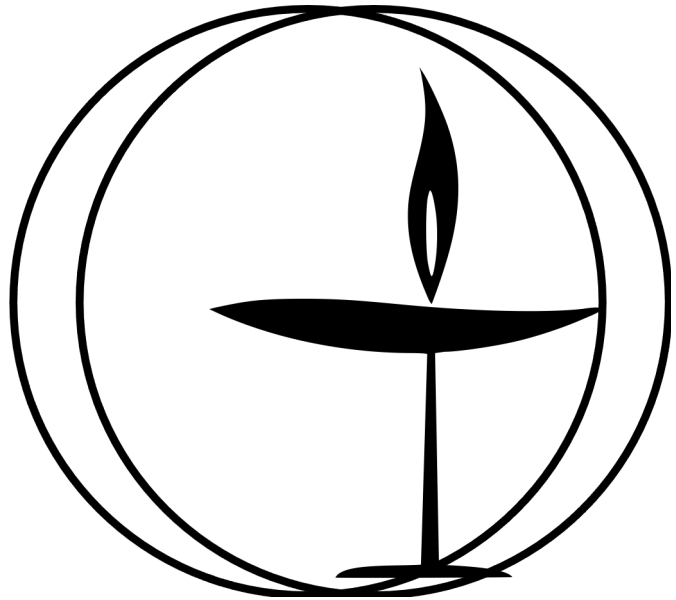
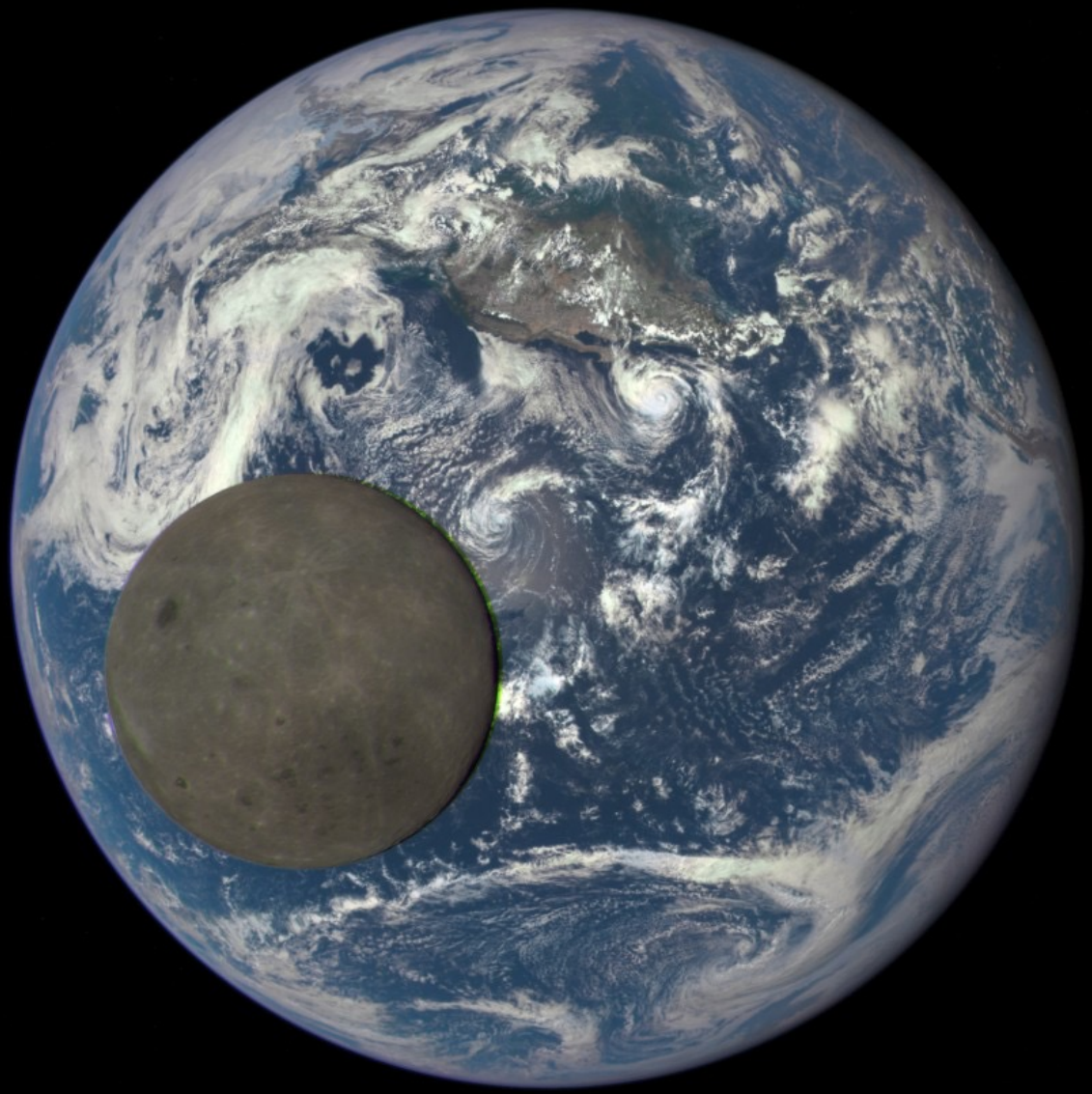
Gauguin, Where do we come from? What are we? Where are we going?

1897-98 Oil on Canvas (12 feet across!)

Where Do We Come From?

1. How Deep is the Past?
2. Tales of the Earth and Moon
3. Cosmic Origins & Destiny





Tales of the Earth & Moon


How Deep
is the Past?

Thinking About Glaciers

1850

1970

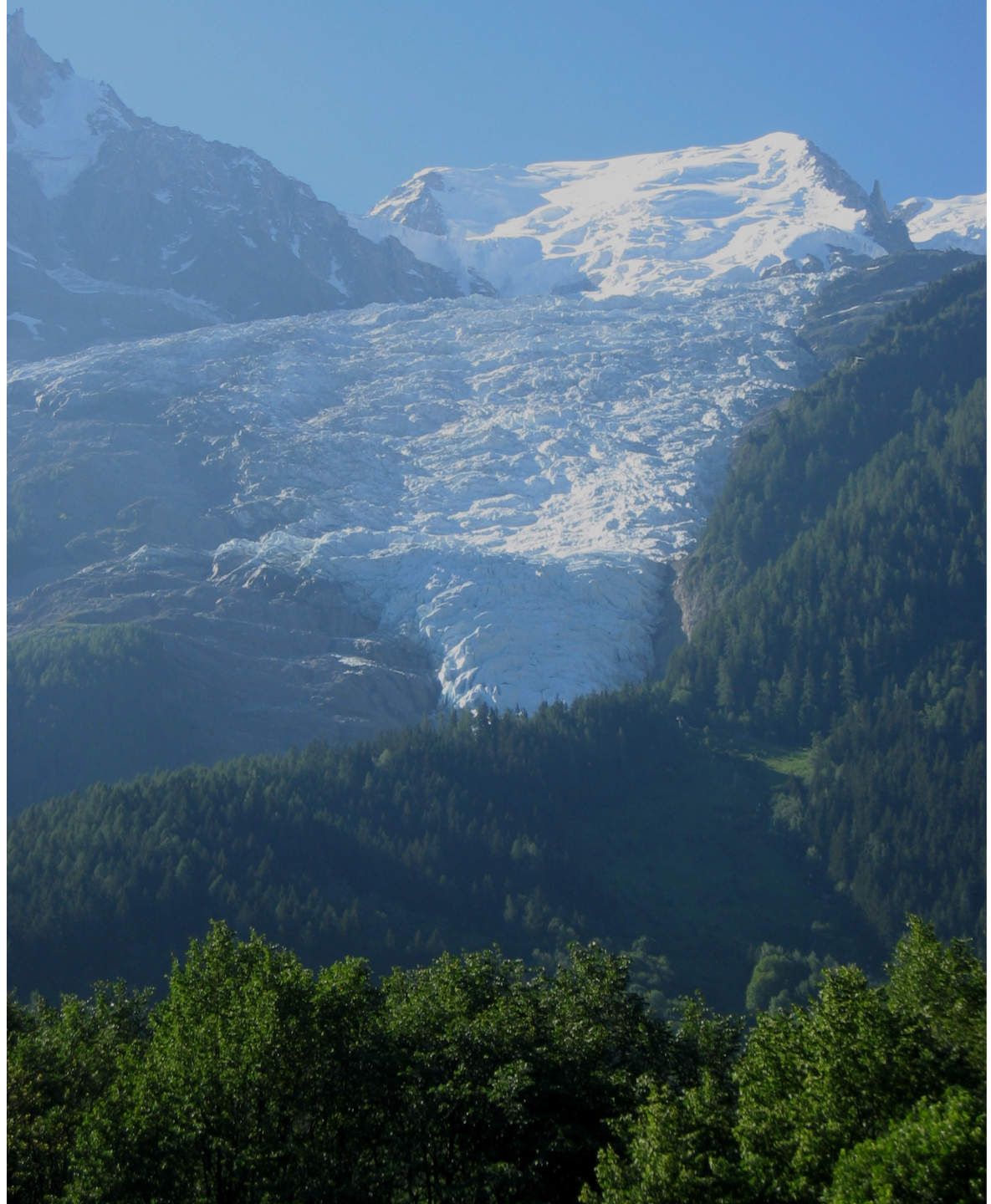
Europeans have been living with glaciers for millennia
They knew what land at glacial margins looked like
It wasn't much of a stretch to see those same landforms elsewhere!


June 26, 2011

Late July
2017

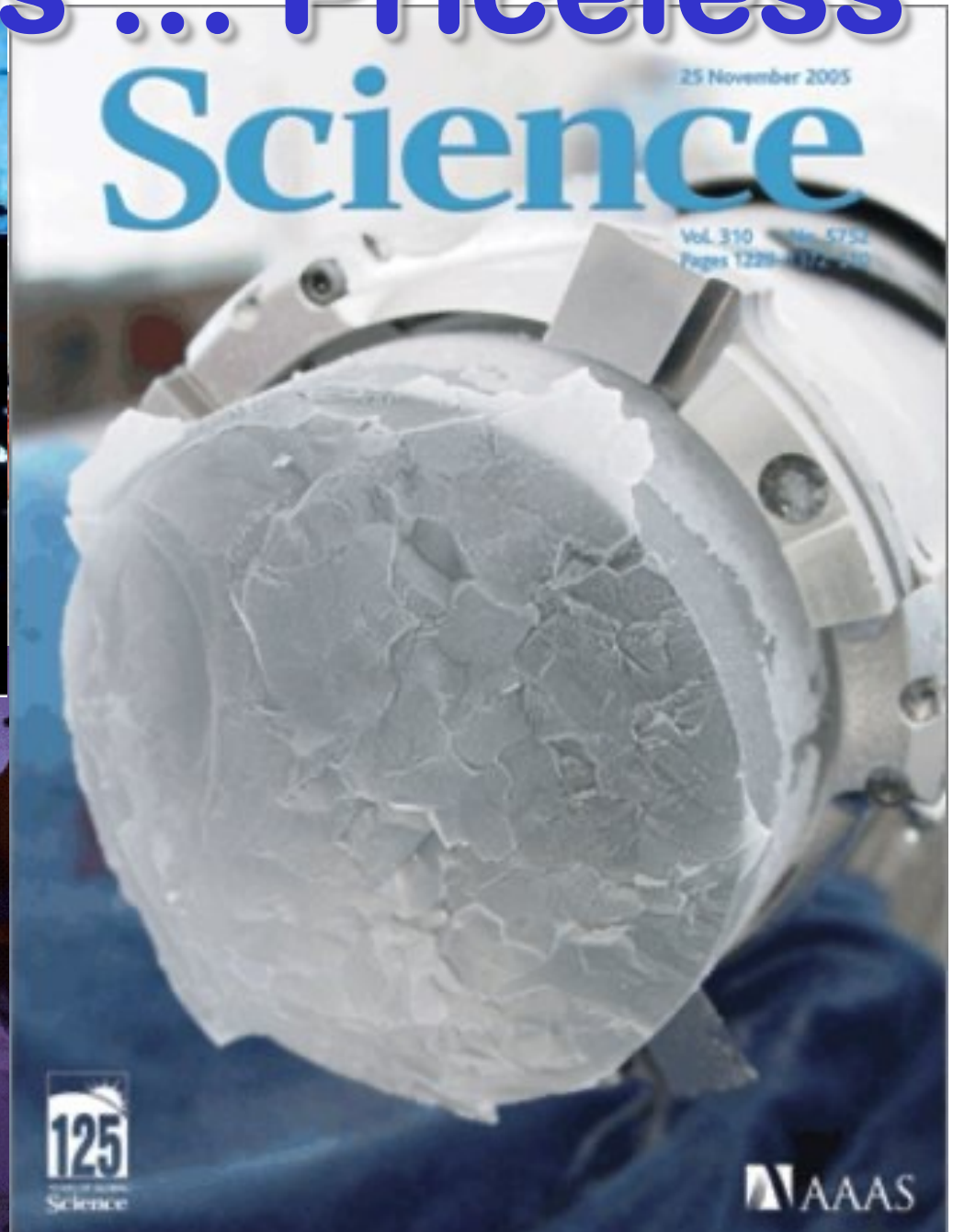

Bushnell
32F0C
09-25-2017 18:31:48


L'AIGUILLE DU MIDI

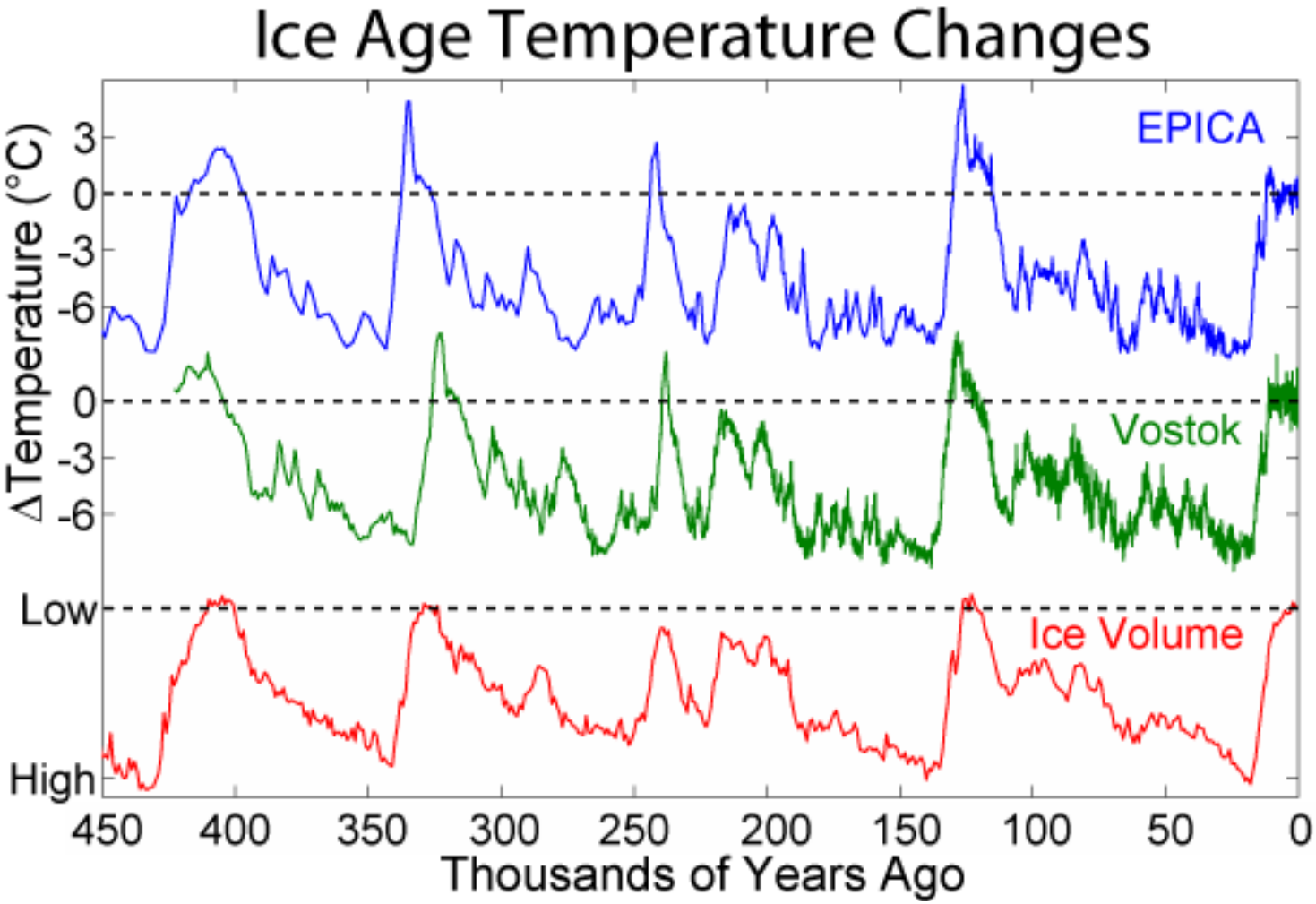


Tiny Bubbles … Priceless

Unloading fresh core, Siple Dome, Antarctica. This is a section from a 200-meter core drilled at Siple Dome, Antarctica to help assess recent climate history. Photo courtesy of Climate Change Research Center, University of New Hampshire.



Reconstructions from Ice Cores

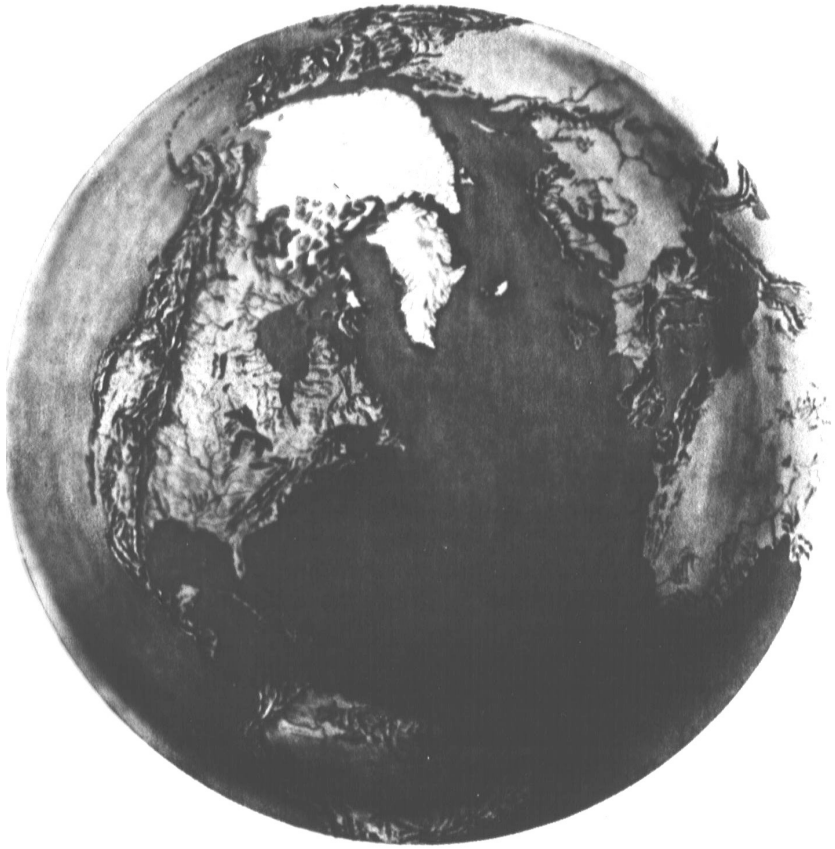


http://commons.wikimedia.org/wiki/File:Ice_Age_Temperature.png

Continental Ice Sheets

Present

20 ka



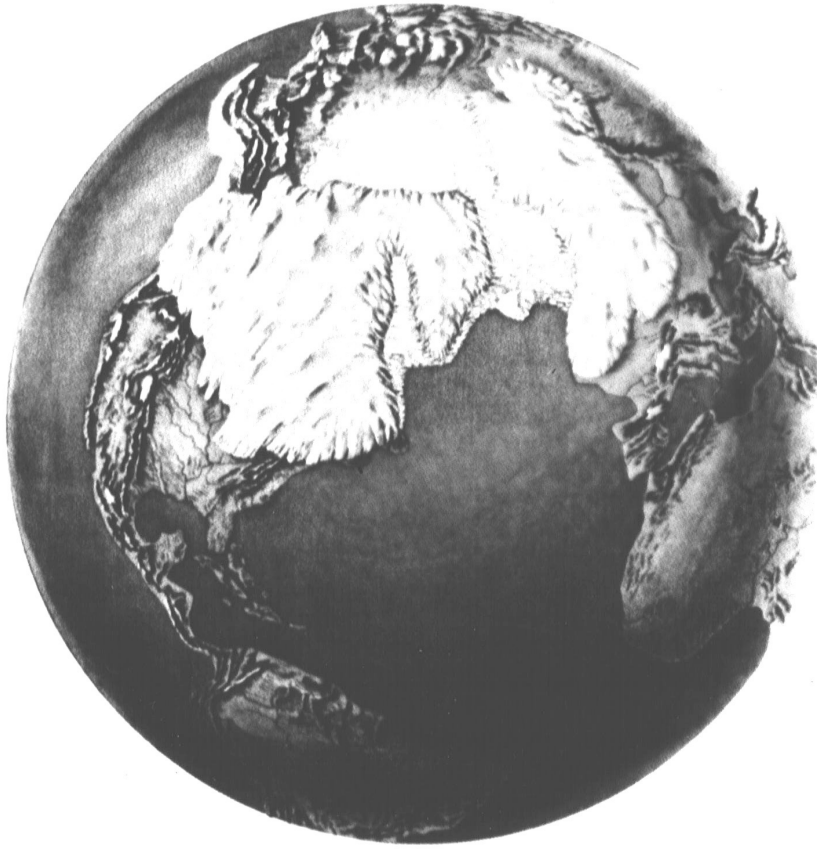
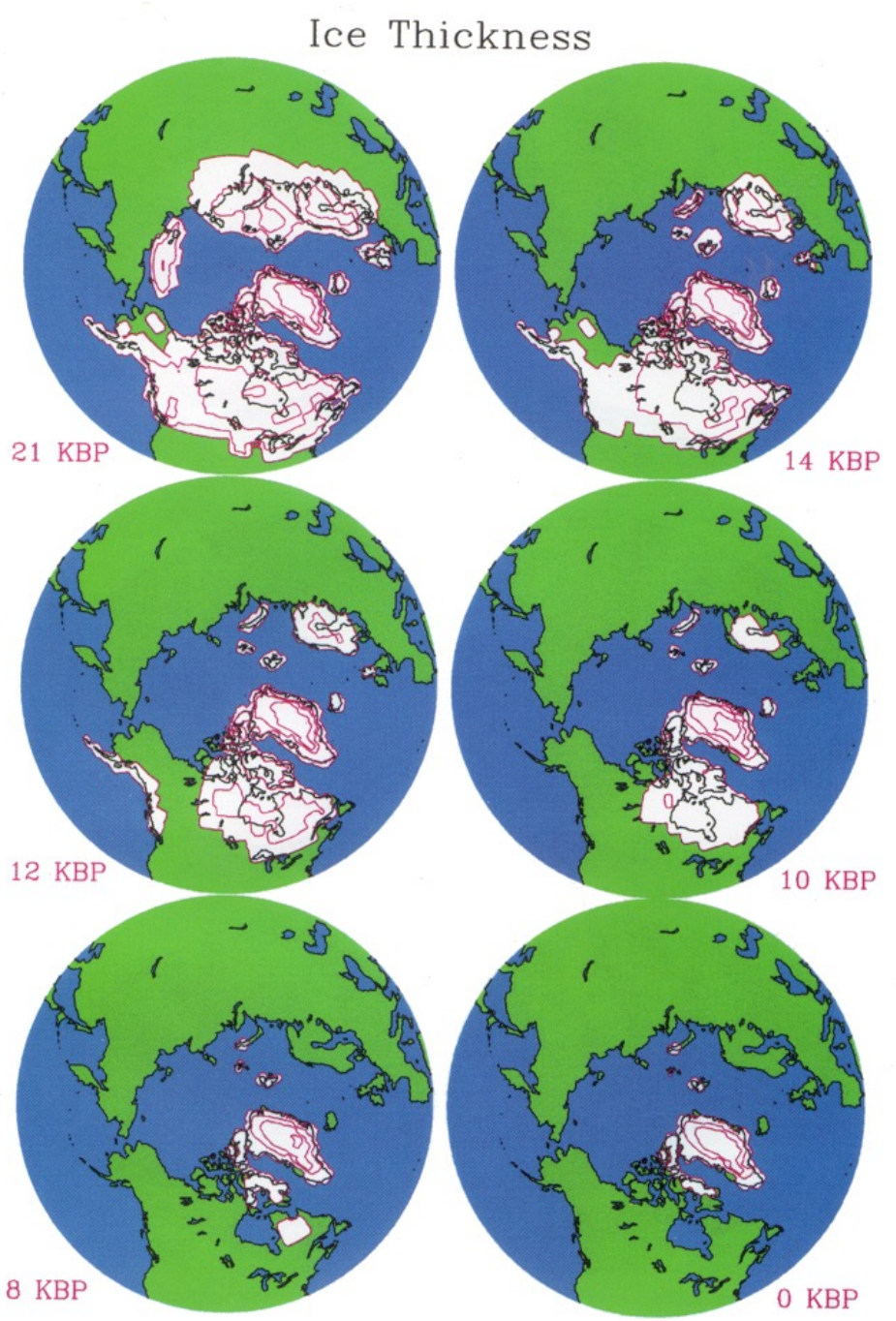
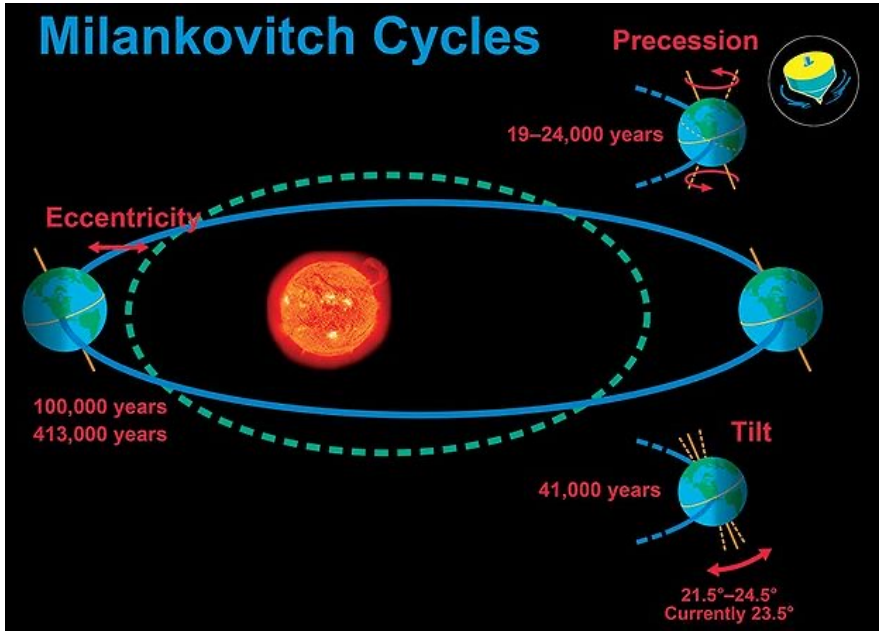


Figure 1. Earth today (left) and during the last ice age (right). Twenty-thousand years ago, great ice sheets covered parts of North America, Europe, and Asia; surface waters of the Arctic and parts of the North Atlantic Oceans were frozen; and sea level was 350 feet lower than it is today. Many parts of the continental shelf, including a corridor between Asia and North America, became dry land. (Drawing by Anastasia Sotiropoulos, based on information compiled by George Denton and other members of the CLIMAP project.)

Melting the ice took a long time!



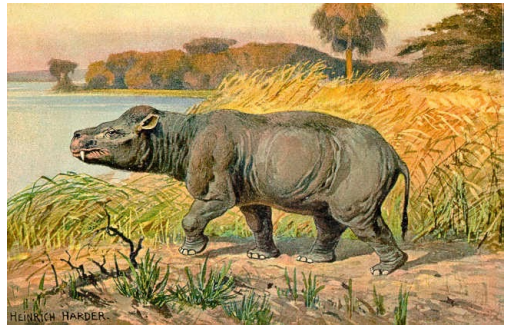


Orbital Timing of Ice Ages

- Regular changes in shape of Earth's orbit and Earth-sun geometry as the "timekeeper" of ice ages
- Quantified by Serbian mathematician Milutin Milankovitch in early 20th Century
- Modern paleoclimatic data by 1970's showed Milankovitch pretty much nailed the timing

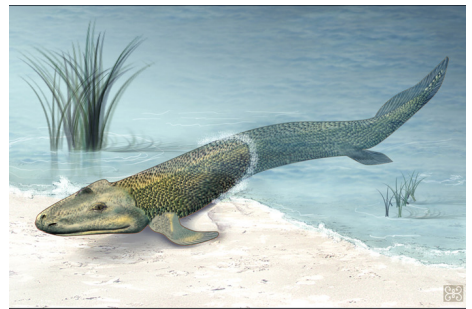
Geology & Paleontology

- **Cenozoic: "New Life"** -- the past 66 million years
  - Age of the Mammals
  - Progressive cooling & drying
  - Recurring ice ages at the end



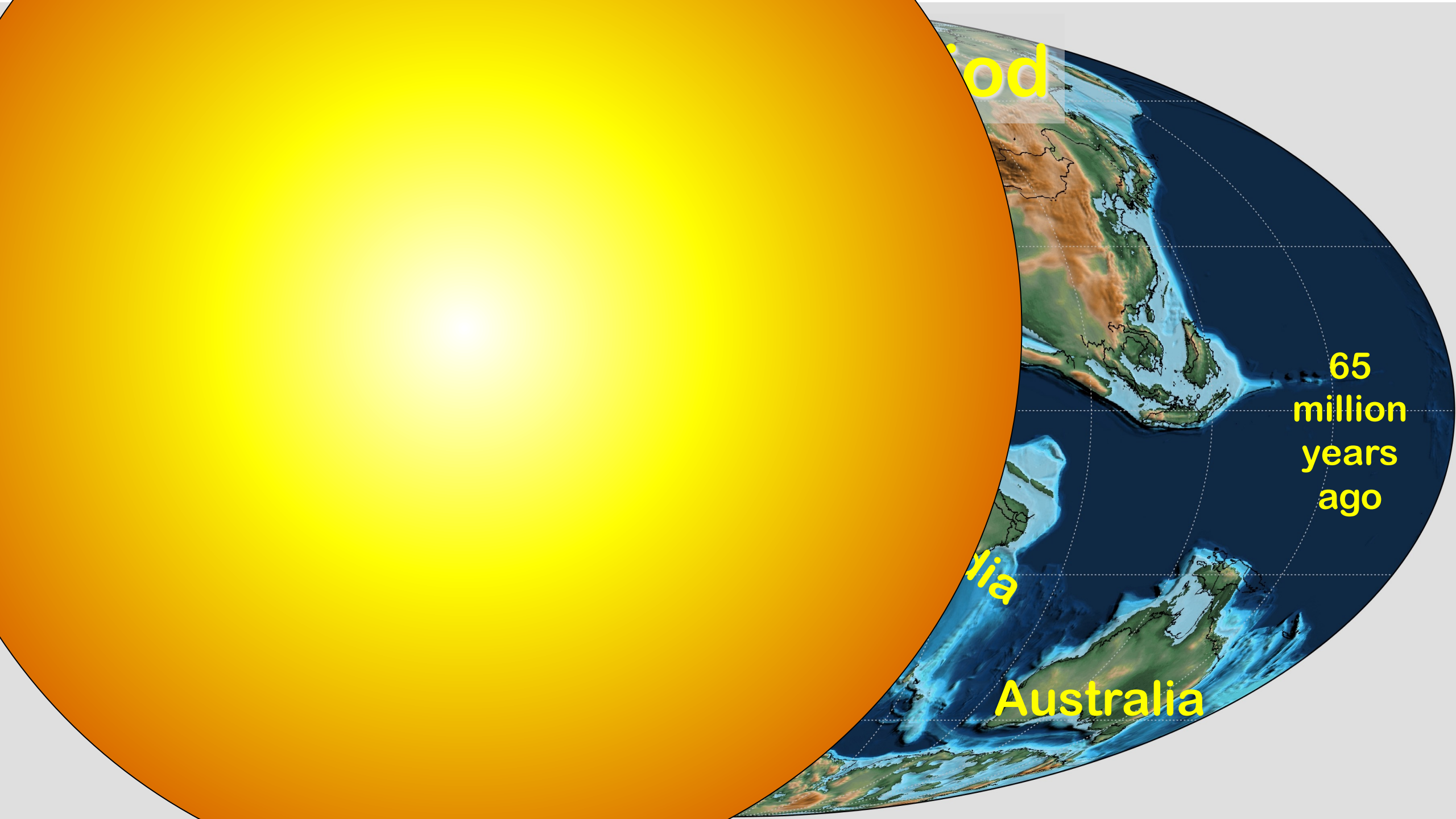
- **Mesozoic: "Middle Life"** – 252 million to 66 million
  - Age of the Dinosaurs
  - Ended with a bang!

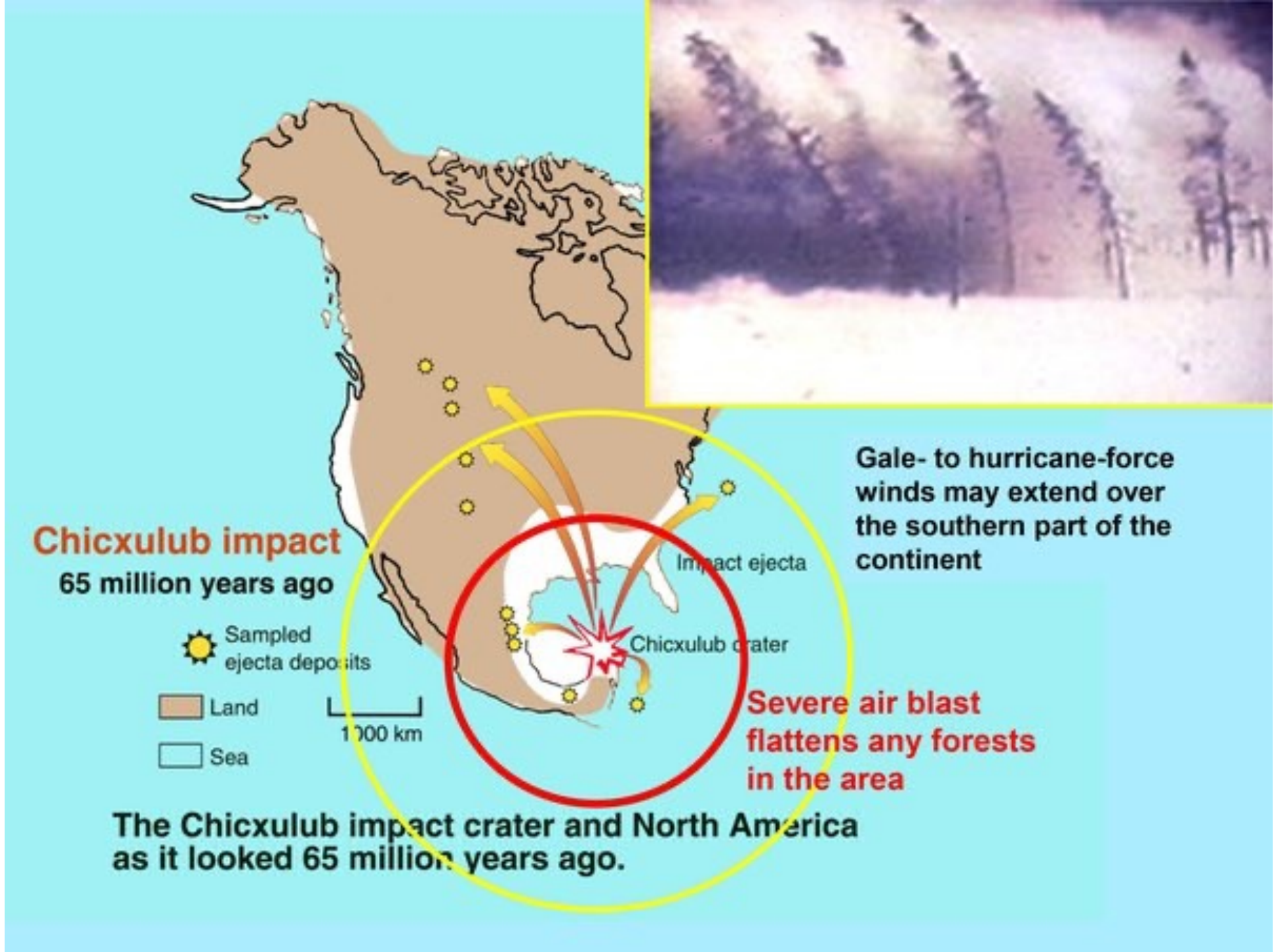
- **Paleozoic: "Old Life"** – 542 million to 252 million
  - Oceans to land
  - Ended with a gasp



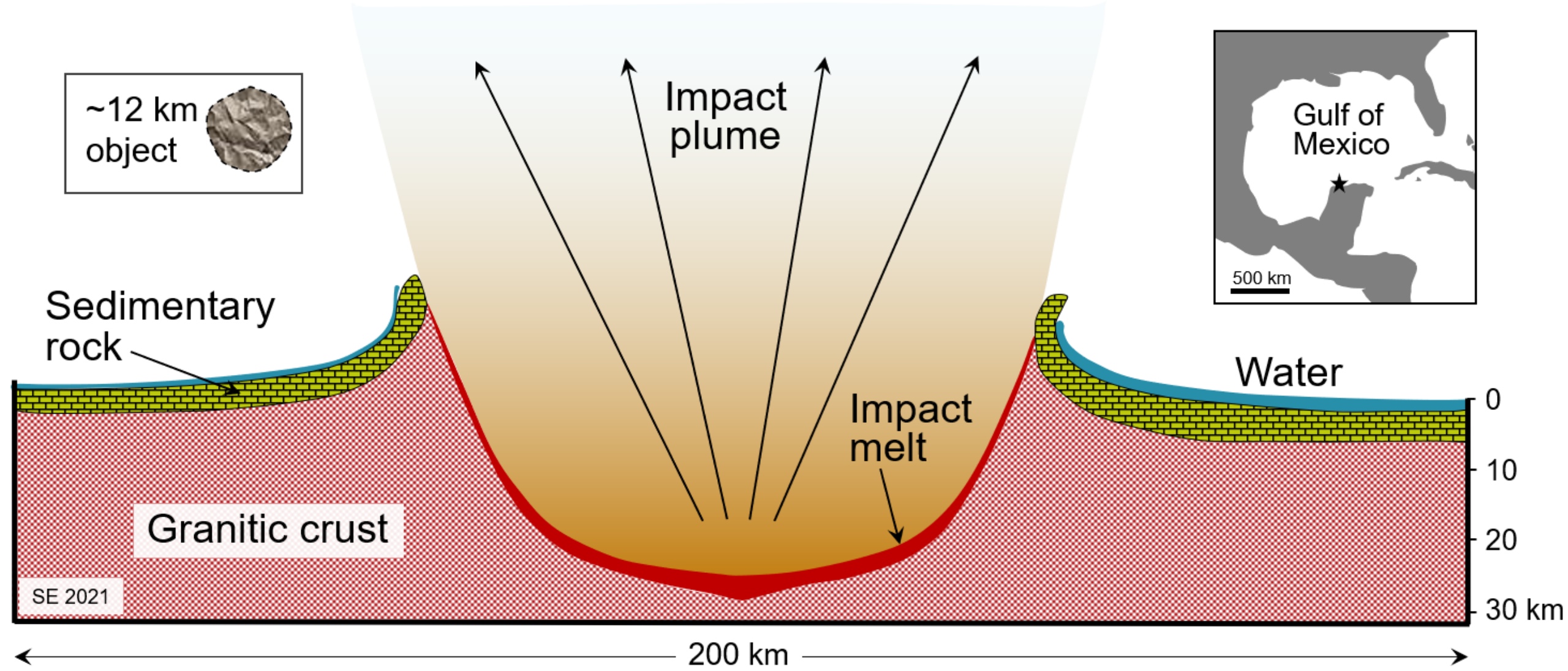
Geology & Paleontology

- **Cenozoic: "New Life"** -- the past 66 million years
  - Started with a BANG
  - Very hot at the beginning
  - Age of the Mammals
  - Progressive cooling & drying
  - Co-evolution of grasslands and mammals
  - Recurring ice ages at the end
- **Mesozoic: "Middle Life"** – 252 million to 66 million
- **Paleozoic: "Old Life"** – 542 million to 252 million


od
65
million
years
ago
lia
Australia



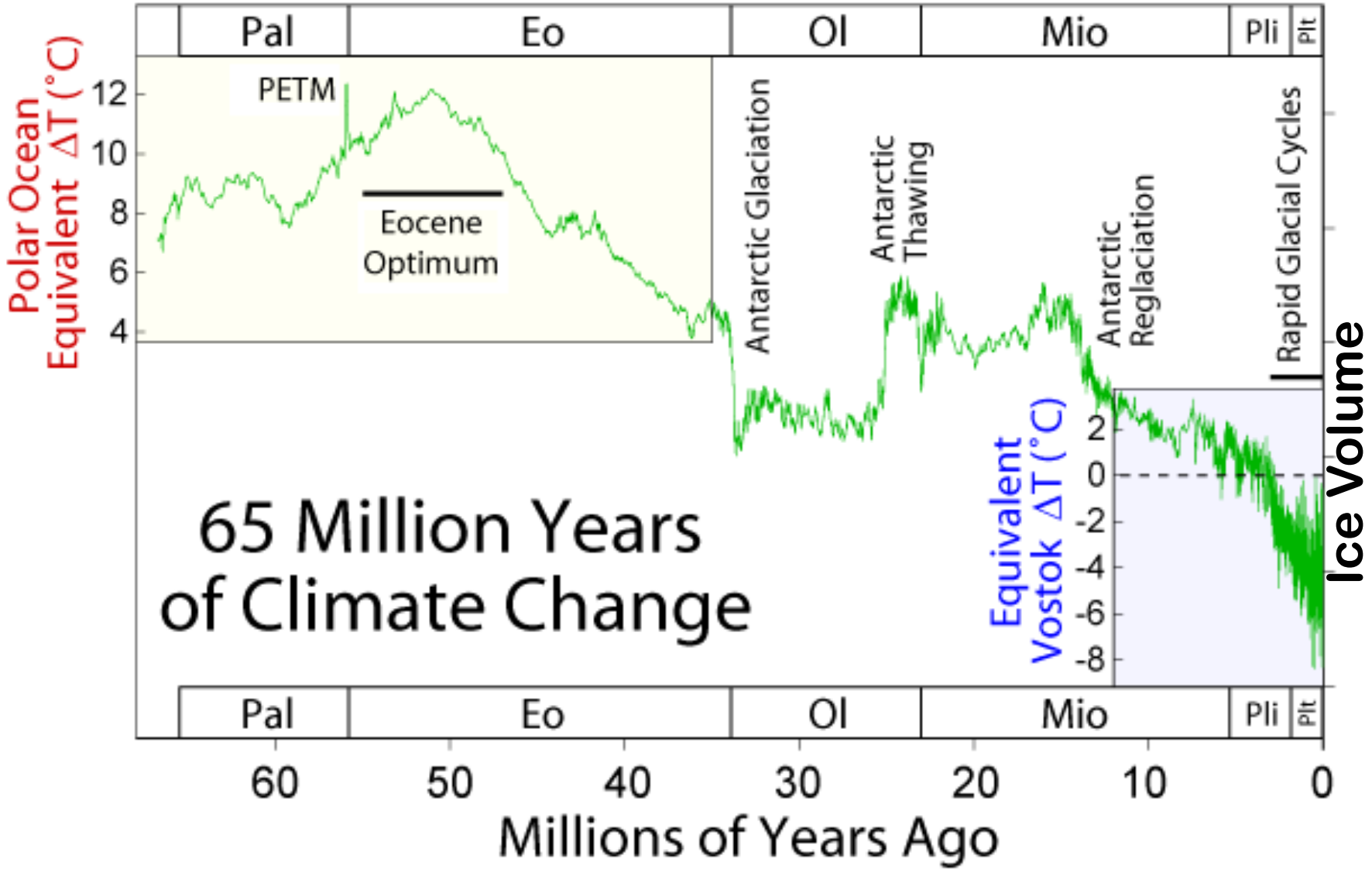
The Chicxulub impact crater and North America as it looked 65 million years ago.


~12 km object
Impact plume
Gulf of Mexico
500 km
Sedimentary rock
Water
Impact melt
Granitic crust
SE 2021
0
10
20
30 km
200 km

- End of Cretaceous Period (65 Ma) marked by extinction of ~ 75% of living species, including all dinosaurs
- K-T boundary clay layer found all over the world with cosmic levels of Iridium
  - (depleted at Earth's surface during early differentiation settling)
- Huge tsunami deposits (some are 25 m deep!) found throughout Caribbean Basin
- Giant subsurface impact crater (~200 km) in Mexico's Yucatan
- "Hole in the sky" … years of darkness? *Brrrr!*

The K–Pg boundary exposure in Trinidad Lake State Park, in the Raton Basin of Colorado, shows an abrupt change from dark- to light-colored rock.

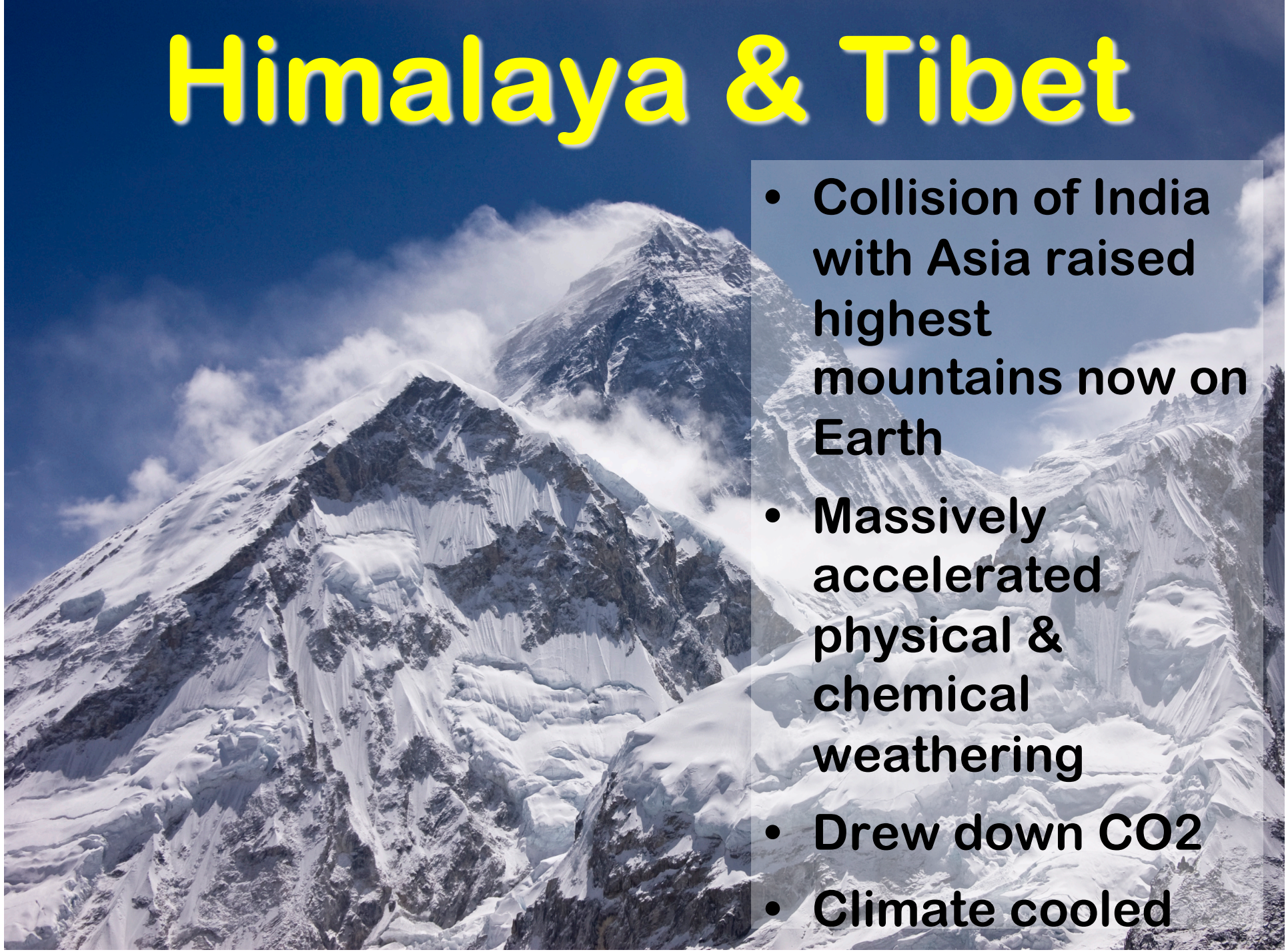
Since the Dinosaurs Died



https://en.wikipedia.org/wiki/Paleocene–Eocene_Thermal_Maximum#/media/File:65_Myr_Climate_Change.png


66 Ma
PALEOCENE

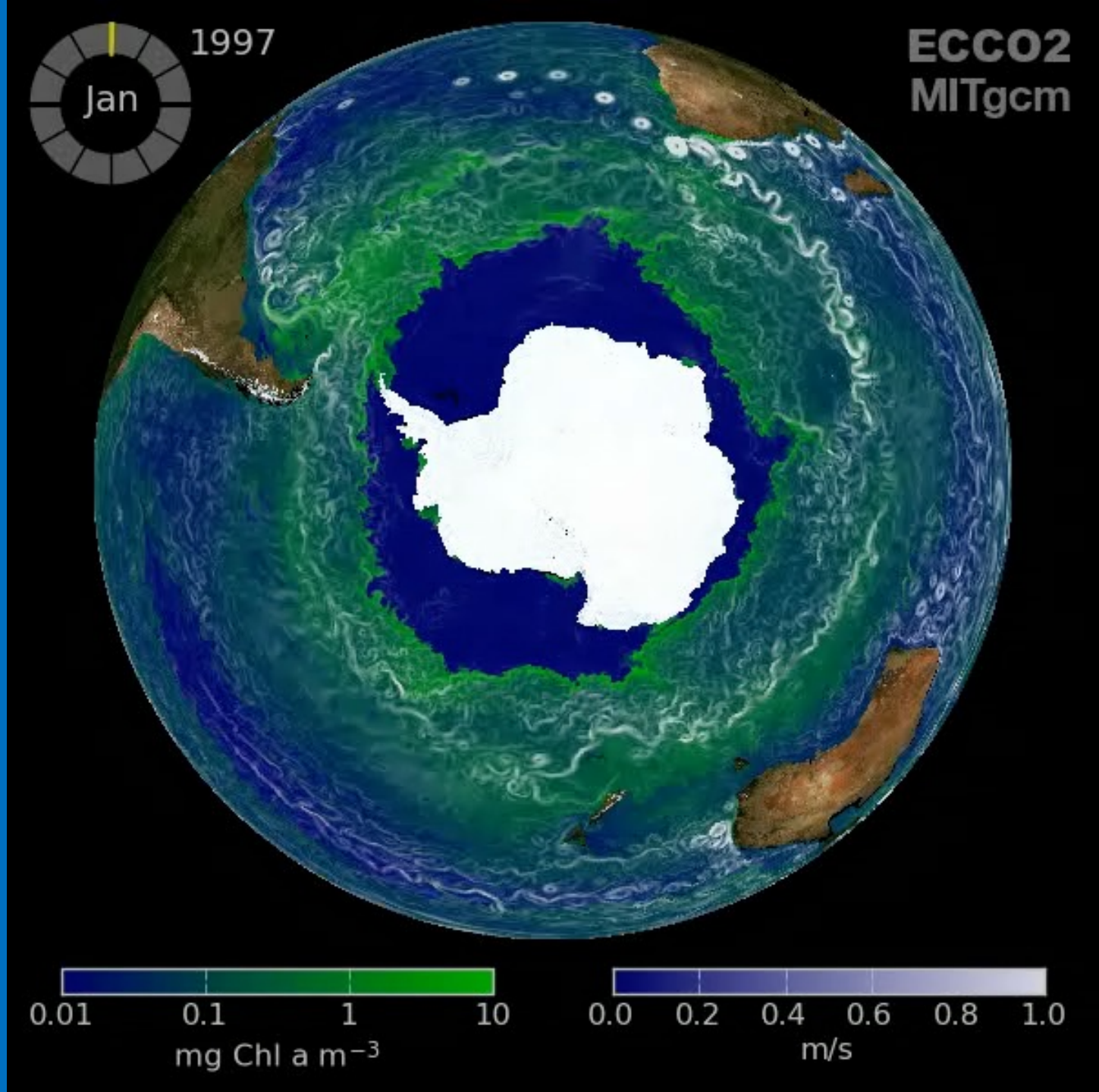
Himalaya & Tibet



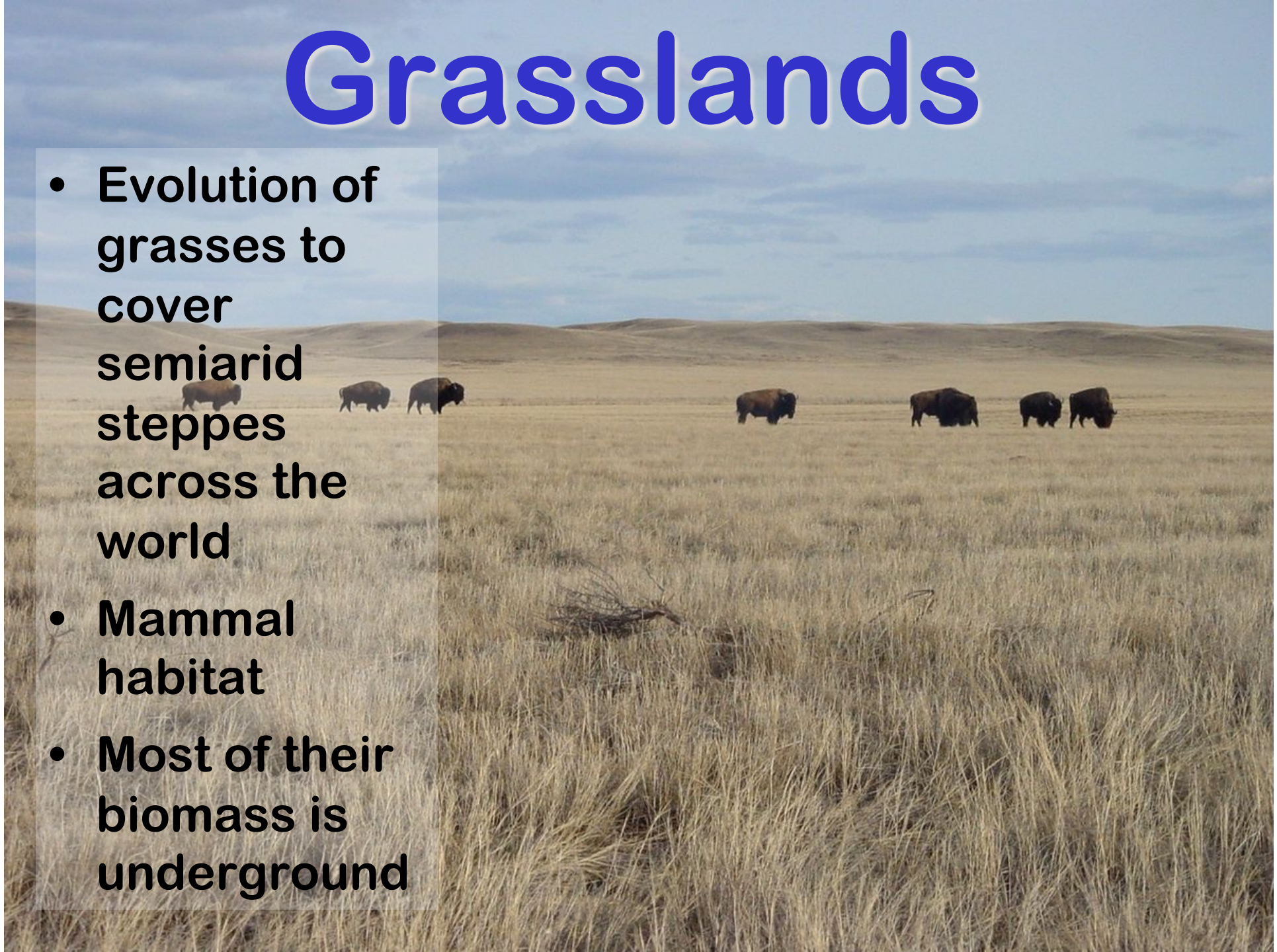
- Collision of India with Asia raised highest mountains now on Earth
- Massively accelerated physical & chemical weathering
- Drew down CO_2
- Climate cooled

Antarctica Isolated

- Antarctic Circumpolar Current, strongest of all the oceans
- The only latitude where there's no land
- Prevents tropical warmth from reaching the ice

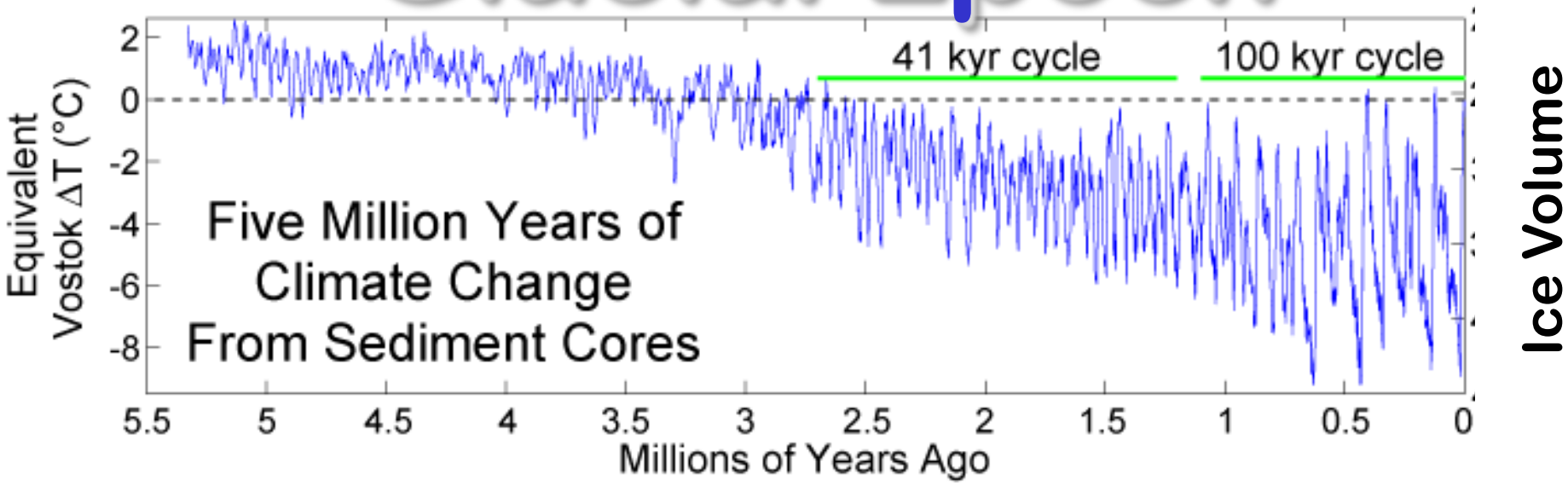


Grasslands



- Evolution of grasses to cover semiarid steppes across the world
- Mammal habitat
- Most of their biomass is underground

Slow Descent into a Glacial Epoch



- Rapidly falling CO_2 as weathering increased
- Antarctic ice sheet reduced Earth's albedo
- Northern ice sheets began to grow and collapse in a cycle of ice ages ~ 3 Ma

http://commons.wikimedia.org/wiki/File:Five_Myr_Climate_Change.png

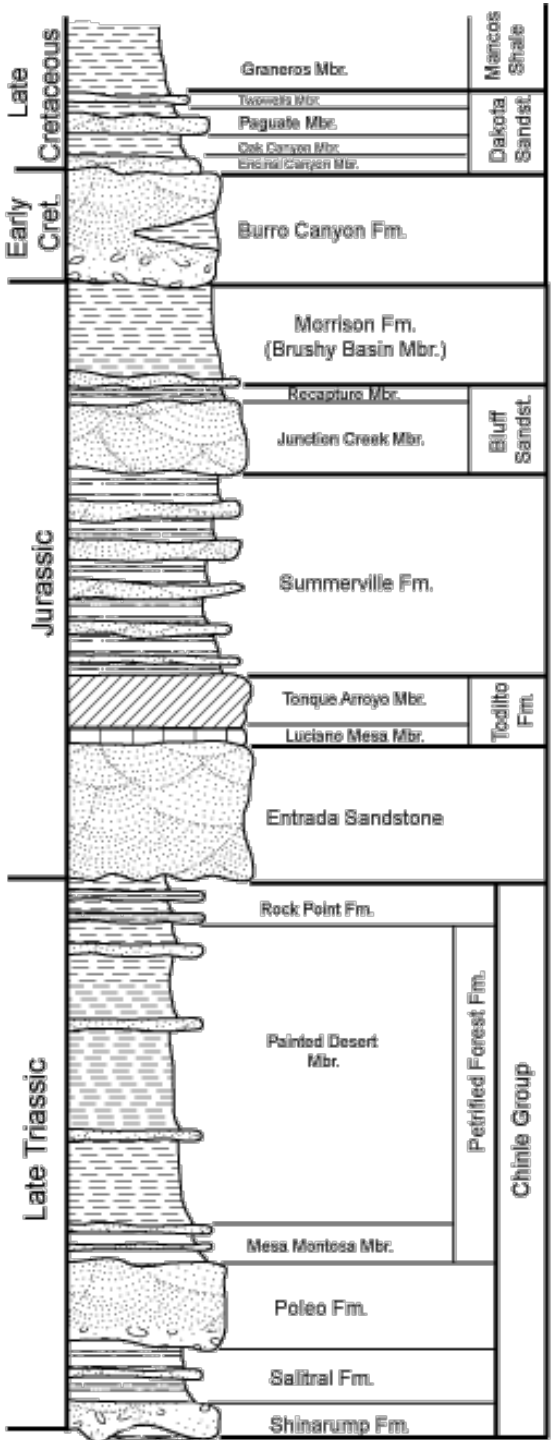
Geology & Paleontology

- Cenozoic: "New Life" -- the past 66 million years
- Mesozoic: "Middle Life" – 252 million to 66 million
  - Started with a Gasp
  - Age of the Dinosaurs
  - Much much longer than the Cenozoic
  - Nearly all the rocks at Ghost Ranch
  - Breakup of Pangea
  - Ended With a BANG!
- Paleozoic: "Old Life" – 542 million to 252 million

66 million yr

Mesozoic Era

225 million yr



Stratigraphy of Ghost Ranch

Spencer G. Lucas and Kate E. Zeigler

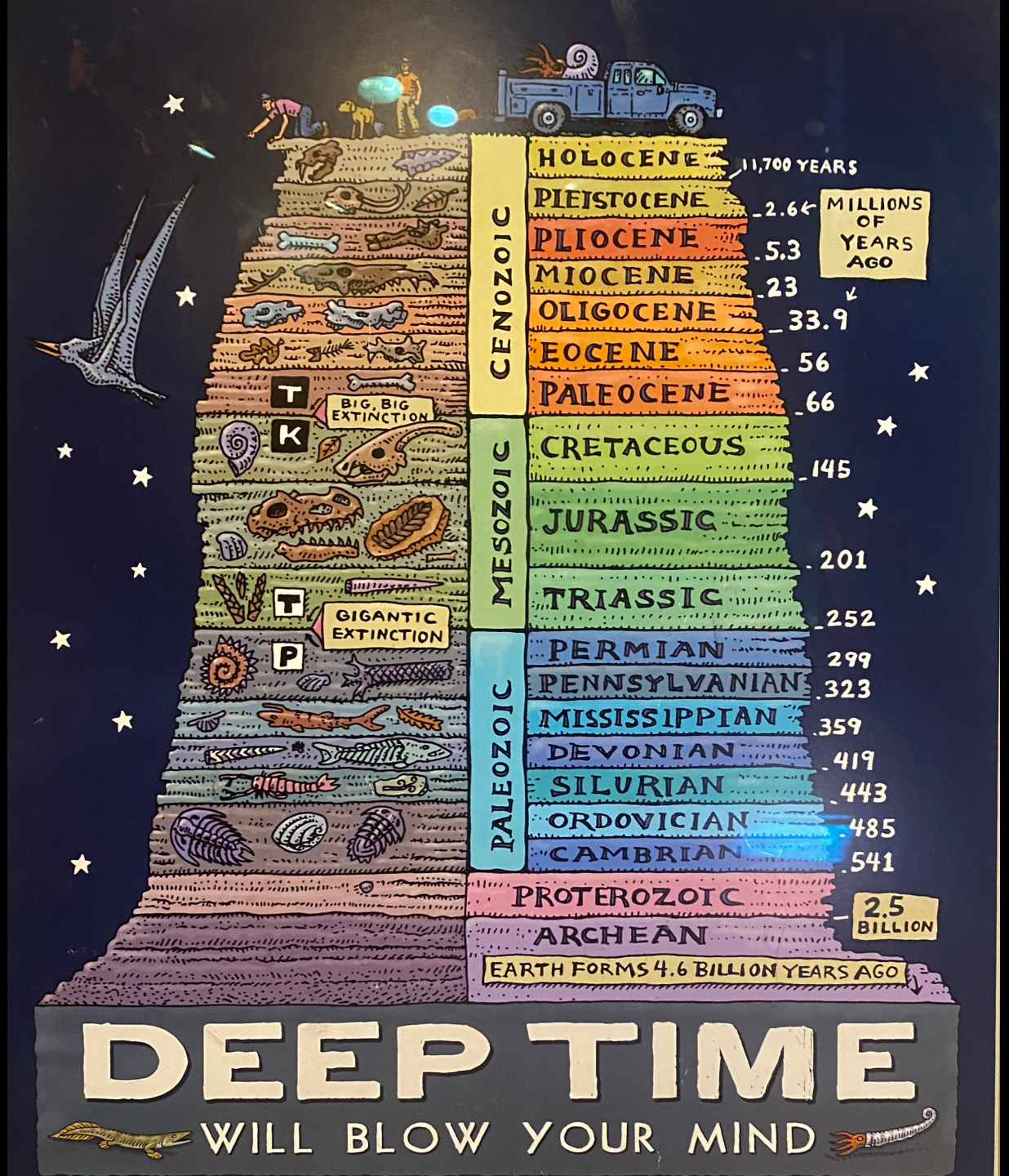
Key

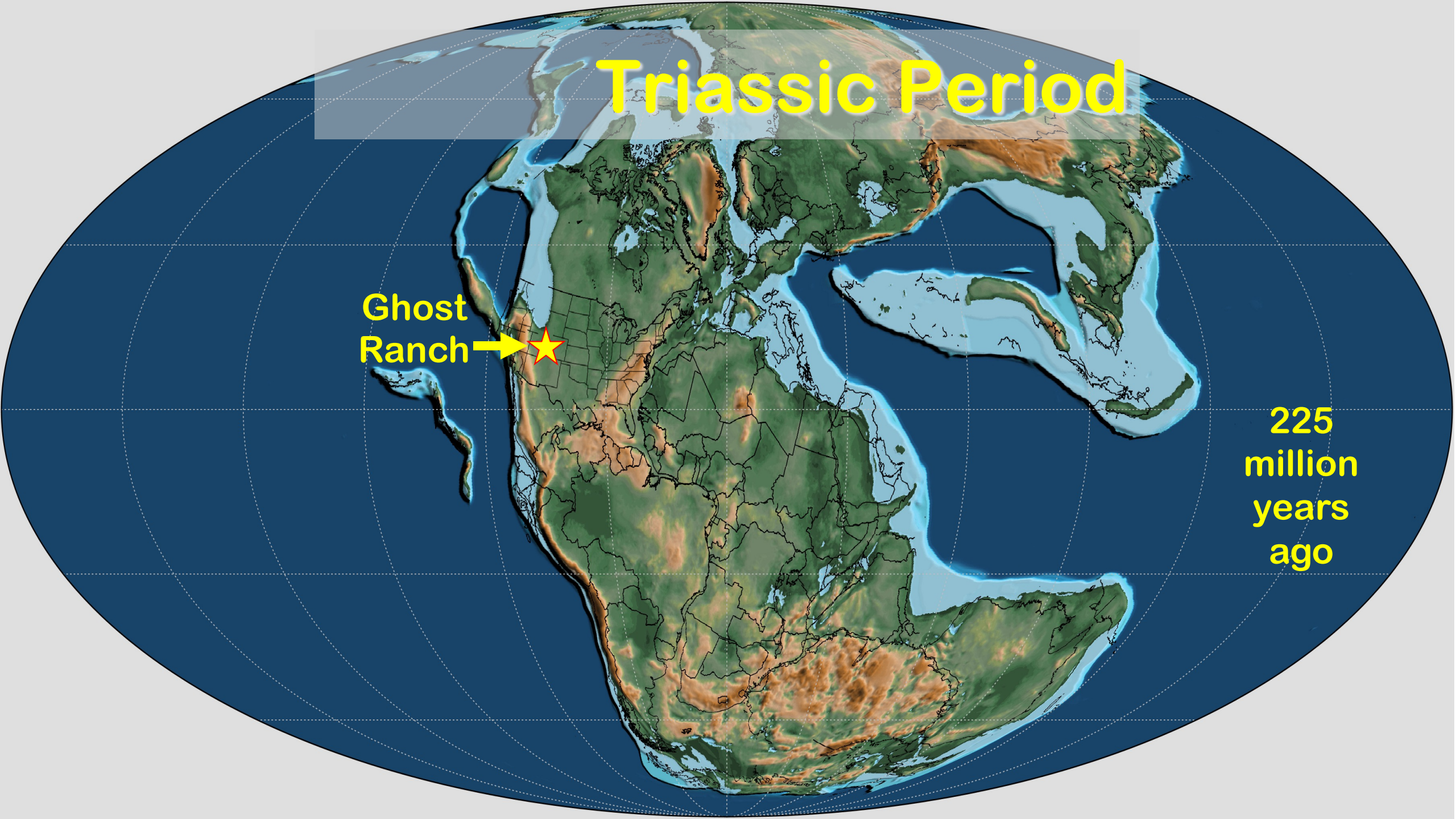
- Conglomerate
- Crossbedded sandstone
- Siltstone
- Mudstone
- Limestone
- Gypsum

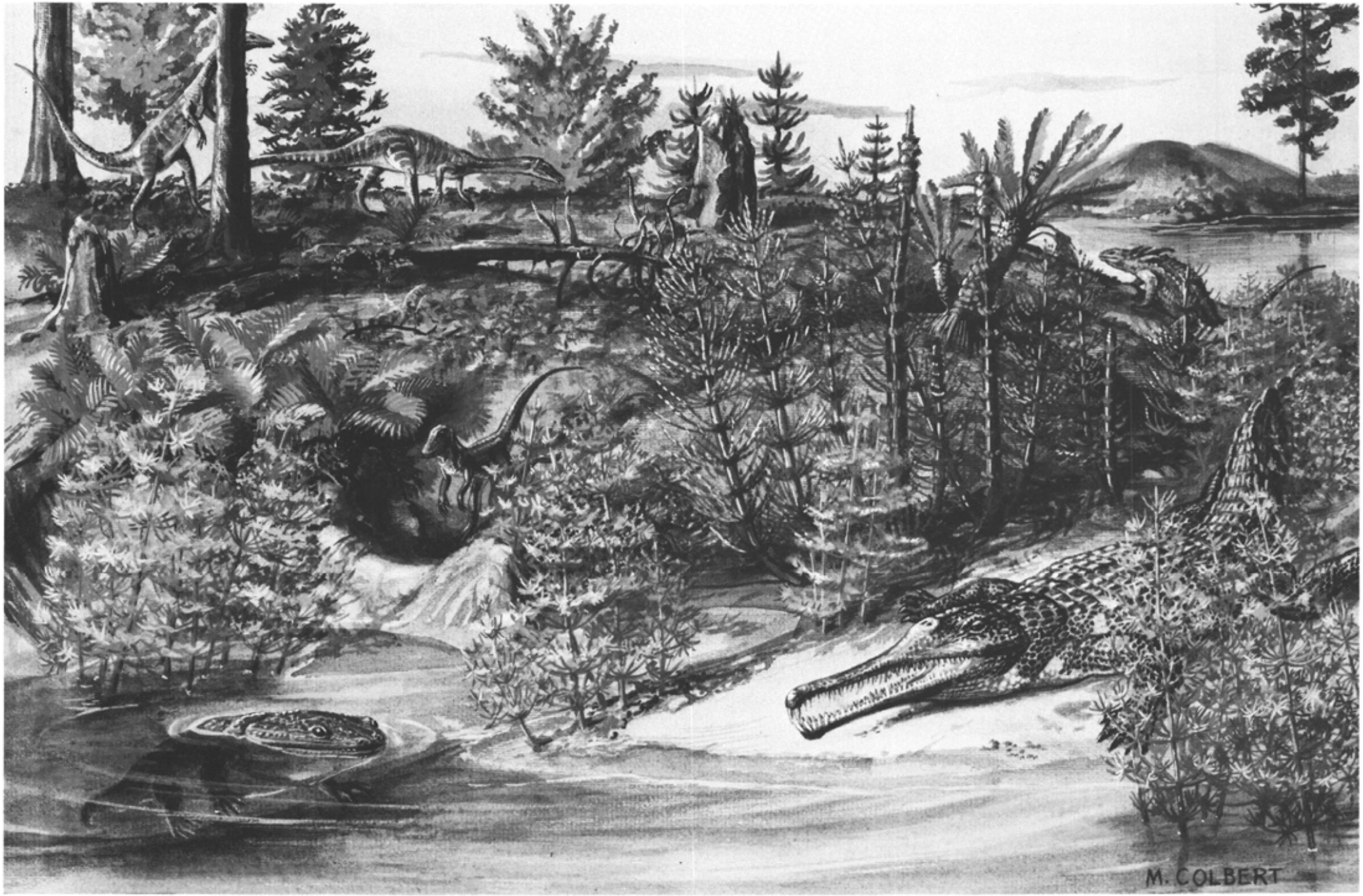
20 m

One day in the late Triassic period, thousands of small theropod dinosaurs called *Coelophysis* were living in a warm, monsoon-like climate, but struggling with drought during the dry season. Those who hadn't yet perished were languishing around a diminishing water source, when suddenly a violent storm arrived and the creatures were caught in a flash flood. Many hundreds were killed and their remains deposited in a muddy wash where they were quickly covered and would remain for over 200 million years.


DISCOVERY
EXCAVATING THE QUARRY
LIFE
Cast of a Coelophysis skeleton (AMNH 7224) collected in 1947.
(left to right): Effigia, Coelophysis, and Daemonosaurus
50 cm
CLEAN AIR LAWN CARE


HOLOCENE
11,700 YEARS
PLEISTOCENE
2.6
PLIOCENE
5.3
MIOCENE
23
OLIGOCENE
33.9
EOCENE
56
PALEOCENE
66
CENOZOIC
MILLIONS OF YEARS AGO
T
K
BIG, BIG EXTINCTION
CRETACEOUS
145
JURASSIC
201
TRIASSIC
252
MESOZOIC
T
P
GIGANTIC EXTINCTION
PERMIAN
299
PENNSYLVANIAN
323
MISSISSIPPIAN
359
DEVONIAN
419
SILURIAN
443
ORDOVICIAN
485
CAMBRIAN
541
PALEOZOIC
PROTEROZOIC
2.5 BILLION
ARCHEAN
EARTH FORMS 4.6 BILLION YEARS AGO
DEEP TIME
WILL BLOW YOUR MIND


Triassic Period
Ghost Ranch
225 million years ago


M. COLBERT

Tyrannosaurus Was a Beast

MULBERRY BOOKS

Dinosaur Poems by JACK PRELUTSKY

illustrated by ARNOLD LOBEL

COELOPHYSIS

see-lo-FYS-is
"Hollow Form"

FIE-toe-sore
"Plant Lizard"

Coelophysis was a hunter
with efficient teeth and claws,
it gobbled any animal
that fit between its jaws,
its head was rather narrow,
and its neck and tail were long,
its vision was uncommon,
and its legs were fast and strong.

Coelophysis chewed on lizards,
Coelophysis swallowed ants,
Coelophysis gnawed on mammals,
but it never dined on plants,
Coelophysis stayed attentive,
or a crisis was in store,
and the hunter made a morsel
for a mighty Phytosaur.

Edwin H. Colbert and crew at the Johnson House in the summer of 1947.

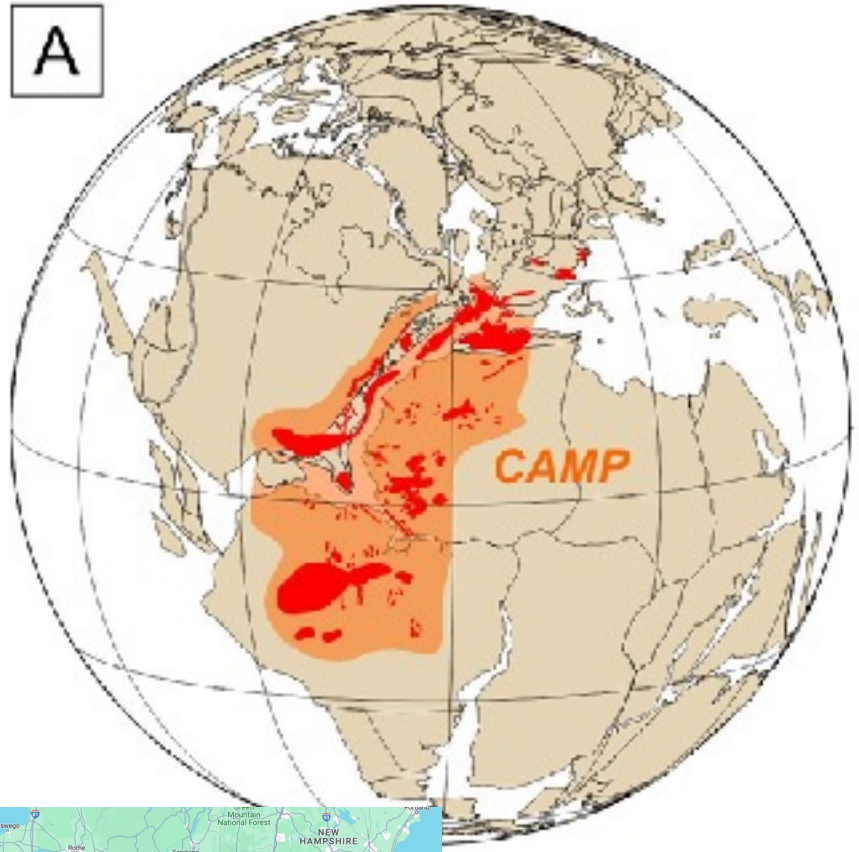
Dr. Charles Camp at the Canjilon Quarry at Ghost Ranch at 1933.

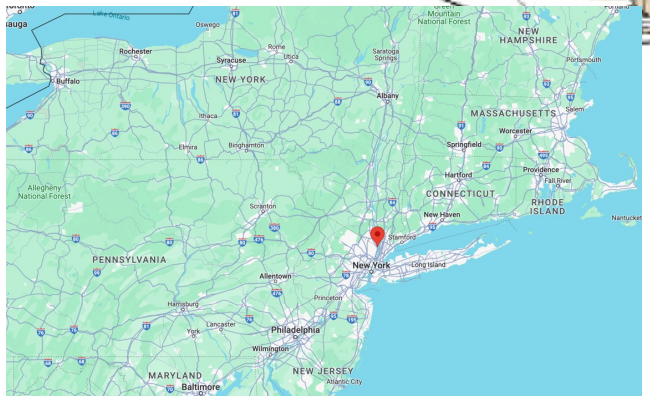
Georgia O’Keeffe and nuns from Abiquiú visiting Edwin Colbert and the fossil quarry in the summer of 1947.

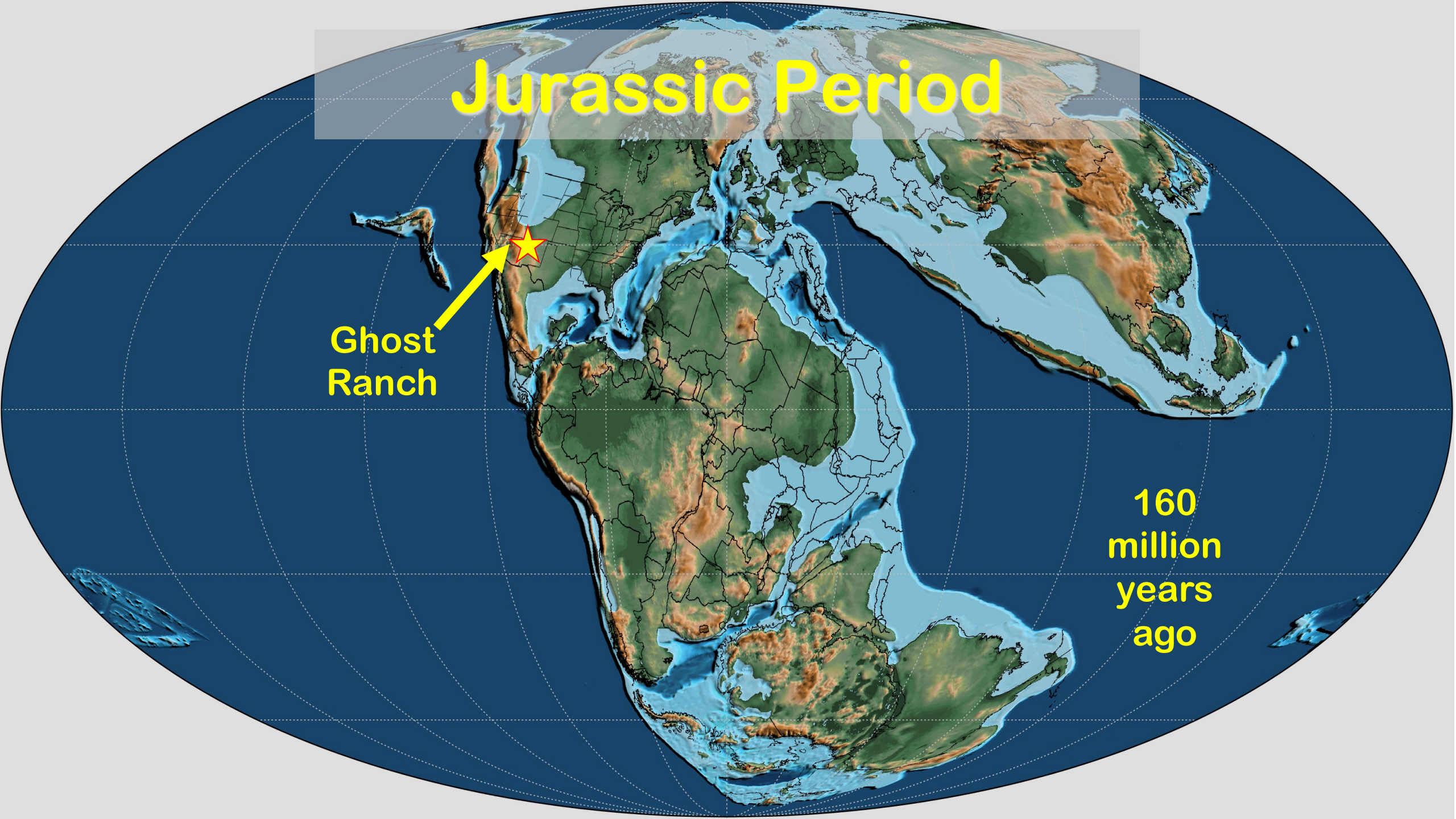
Plastering *Coelophysis* bones at the quarry in 1947.

Triassic-Jurassic Extinction

- Huge eruptions of lava as Pangea was torn apart
- Opening of the proto-Atlantic Ocean






Jurassic Period
Ghost Ranch
160 million years ago

Jurassic Entrada Sand Dune Field

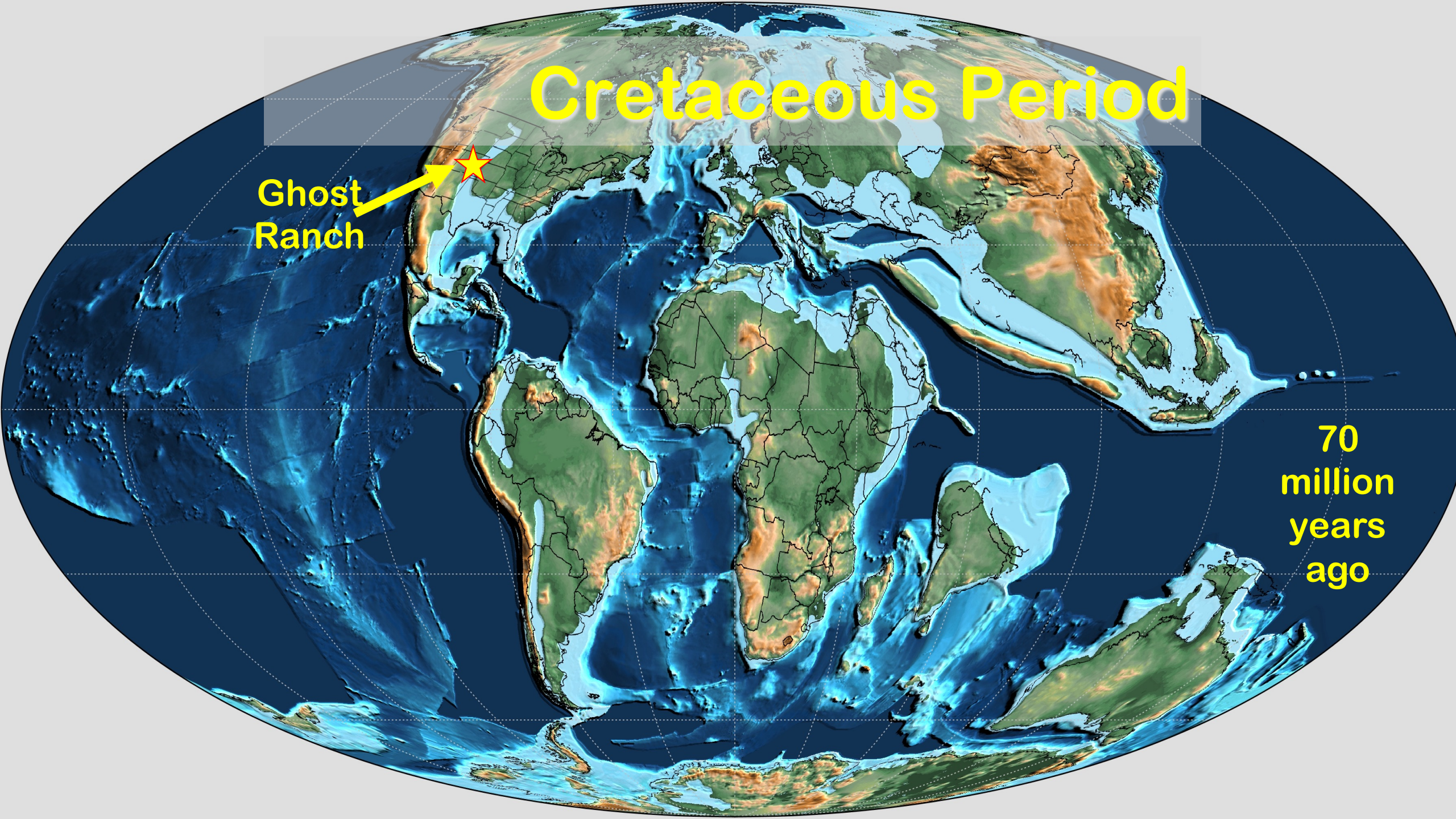
was desiccated when
gion, as evidenced by the
roup. The Entrada

The Jurassic Entrada Sandstone dune field extended hundreds of miles to the northwest.

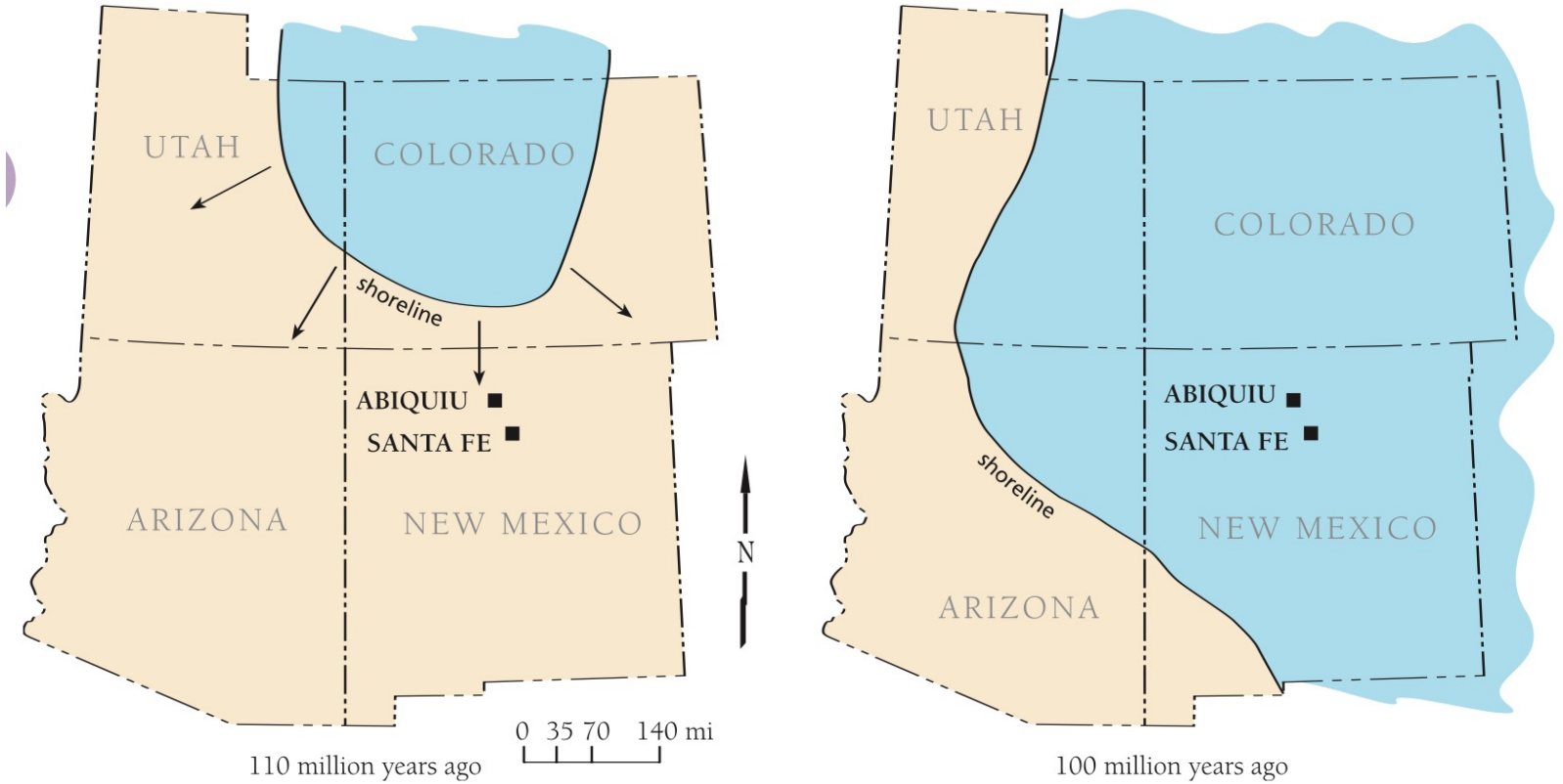
Triassic & Jurassic Rocks

Triassic and Jurassic sedimentary rocks form this cliff near the Box Canyon trail at Ghost Ranch. The brick-red Chinle Group at the base of the cliff is overlain by red, white, and yellow-banded Jurassic Entrada Formation. The banding is caused by variable chemical reactions with iron within the sandstone. The cliff is capped by gray Todilto Formation.

Echo Amphitheater is cut into the Jurassic Entrada Formation. This rock unit is underlain by brick-red Chinle (lower right) and overlain by Todilto Formation.


Cretaceous Period
Ghost Ranch
70 million years ago

Cretaceous Seaway



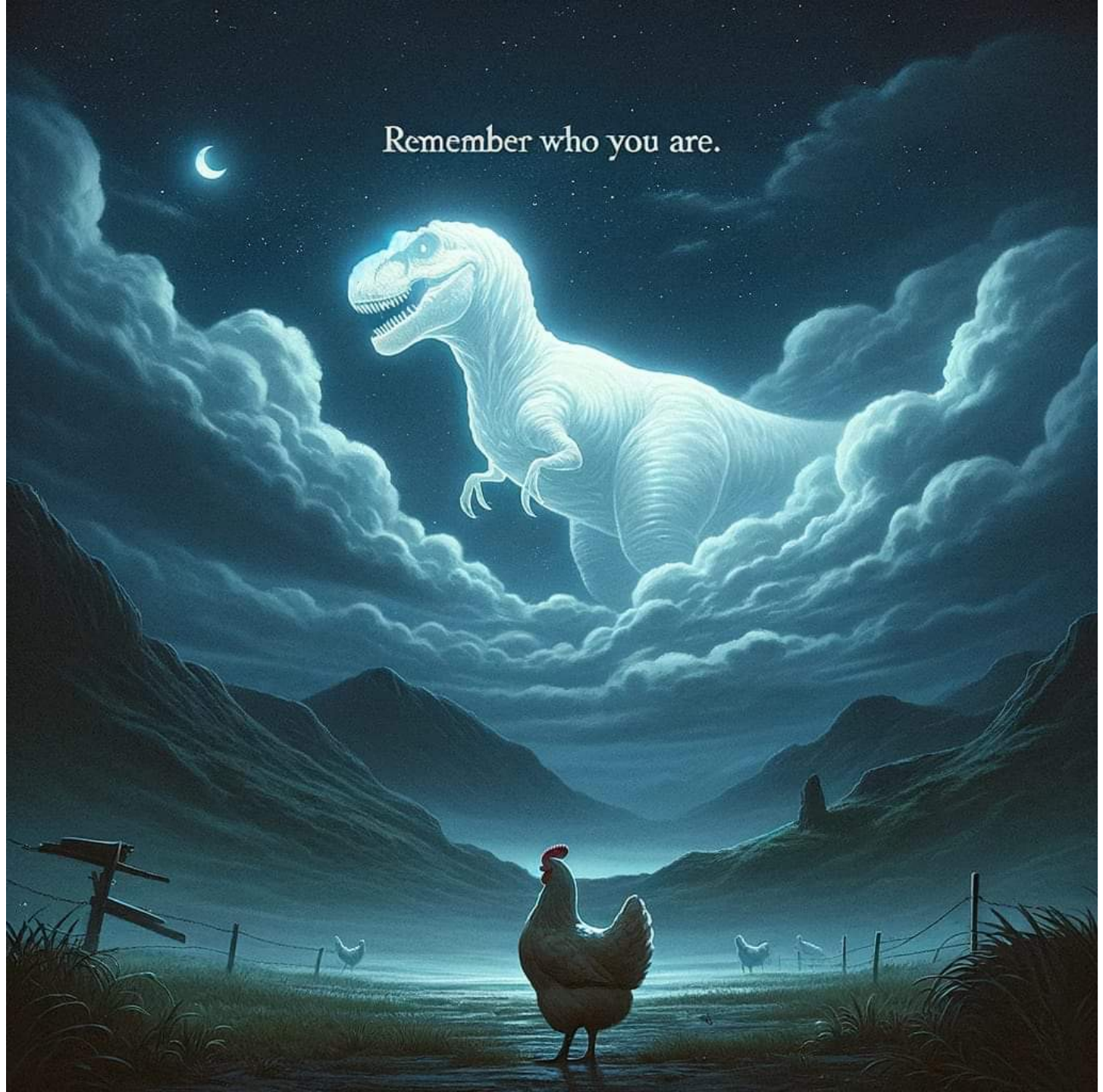
Cretaceous Dakota Sandstone

TYRANNOSAURUS

tie-RAN-uh-sawr-us

"Tyrant Lizard"

Tyrannosaurus was a beast that had no friends, to say the least. It ruled the ancient out-of-doors, and slaughtered other dinosaurs.


Remember who you are.

Churning Planet!

- Over geologic time, solid rock behaves like a liquid
- Hot plumes rise from the core through the mantle
- Spread and cool when they reach the crust
- Crust pulls apart , mashes together, & slabs sink as a result

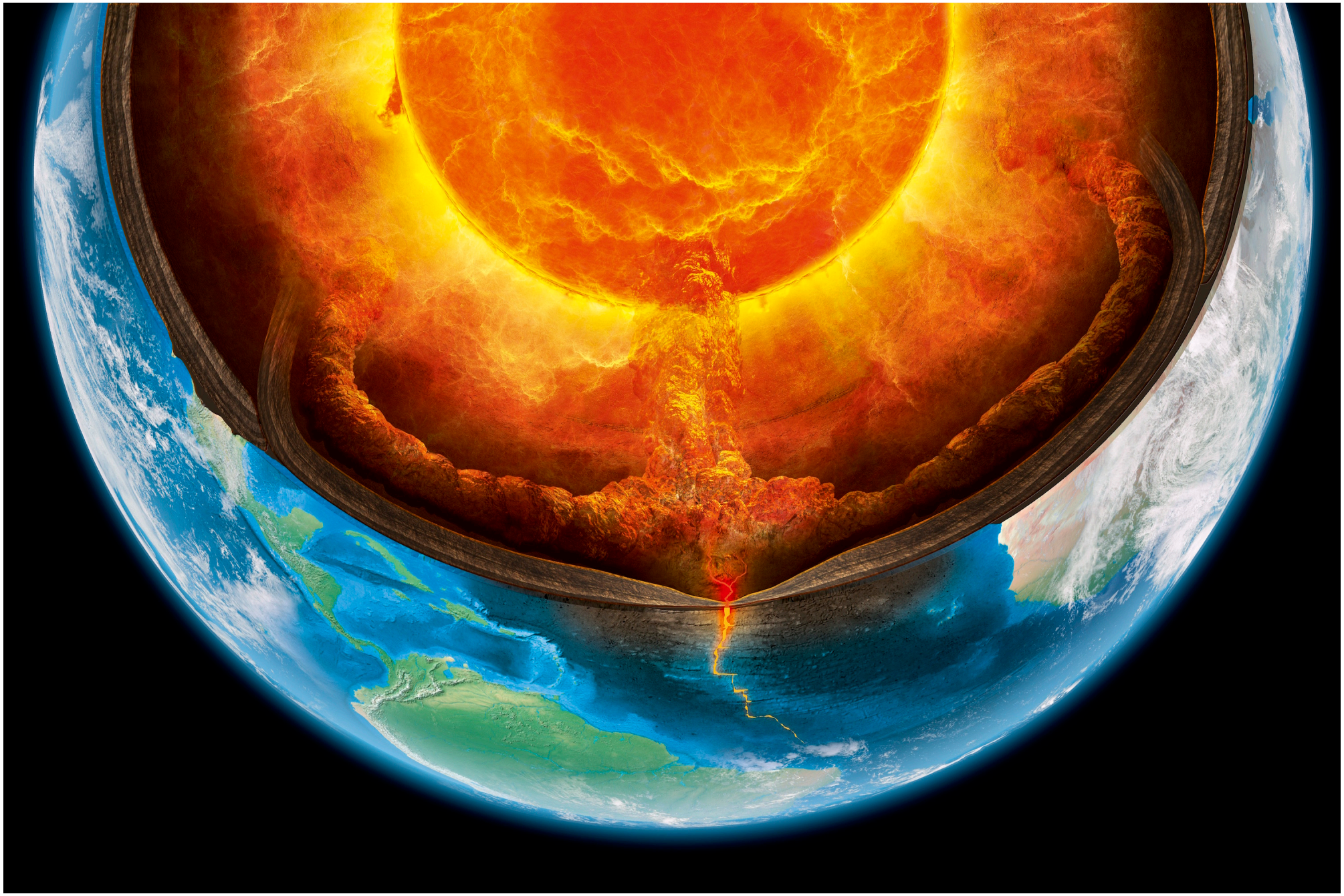


Plate Tectonics, Paleogeography, & Ice Ages
(540 million years ago - Present-day)

by

Christopher R. Scotese

June 1, 2019

Plate Tectonics

- Continental plates are lighter (buoyant) and rise in collisions, whereas oceanic plates subduct
- Continents can "bunch up" due to collisions, forming *supercontinents* ("Pangea," "Gondwana")
- Continental drift can radically alter the geometry of ocean basins, with corresponding dramatic changes in ocean circulation and poleward heat transport

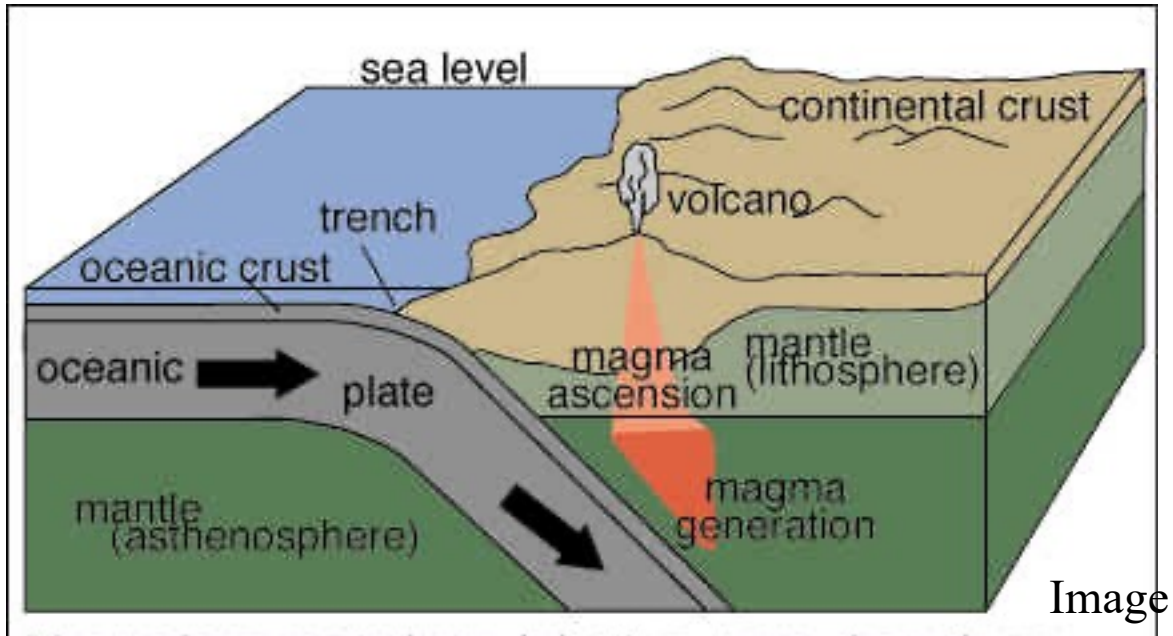
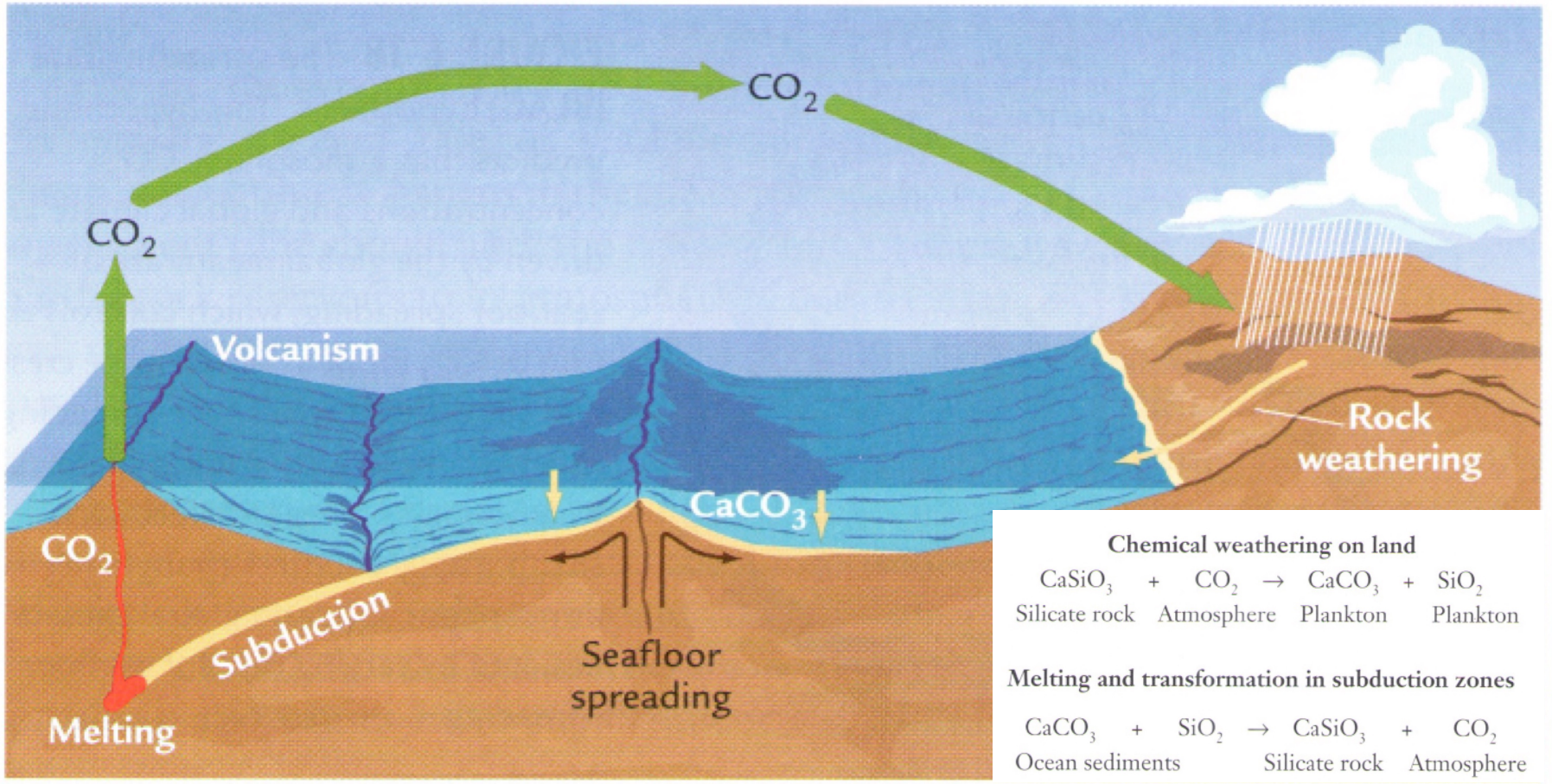


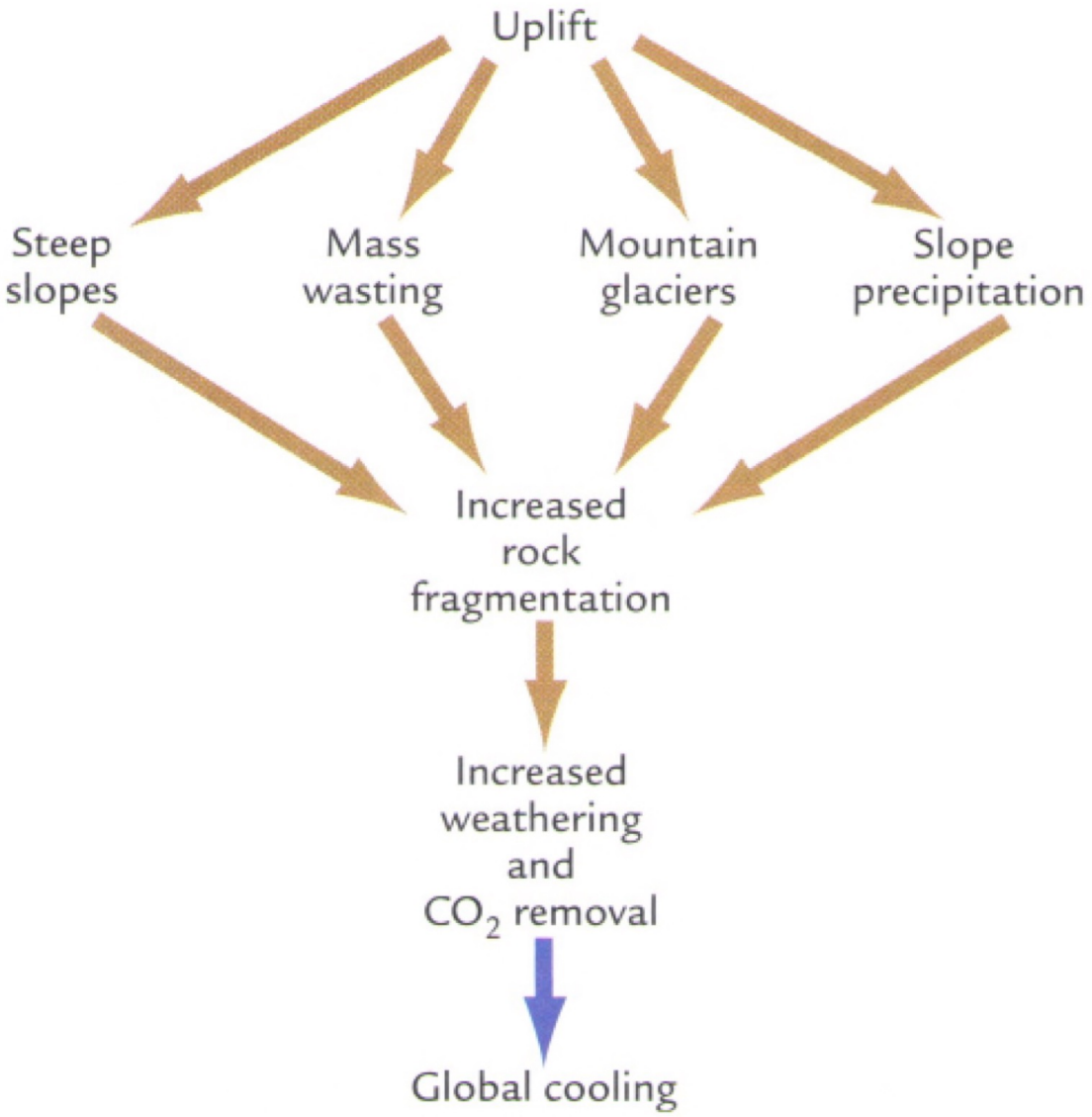
Image Courtesy USGS

Plate Tectonics and CO_2



- Seafloor spreading -> volcanism releases CO_2
- Mountain building enhances chemical weathering consumes CO_2

Uplift Cools Climate

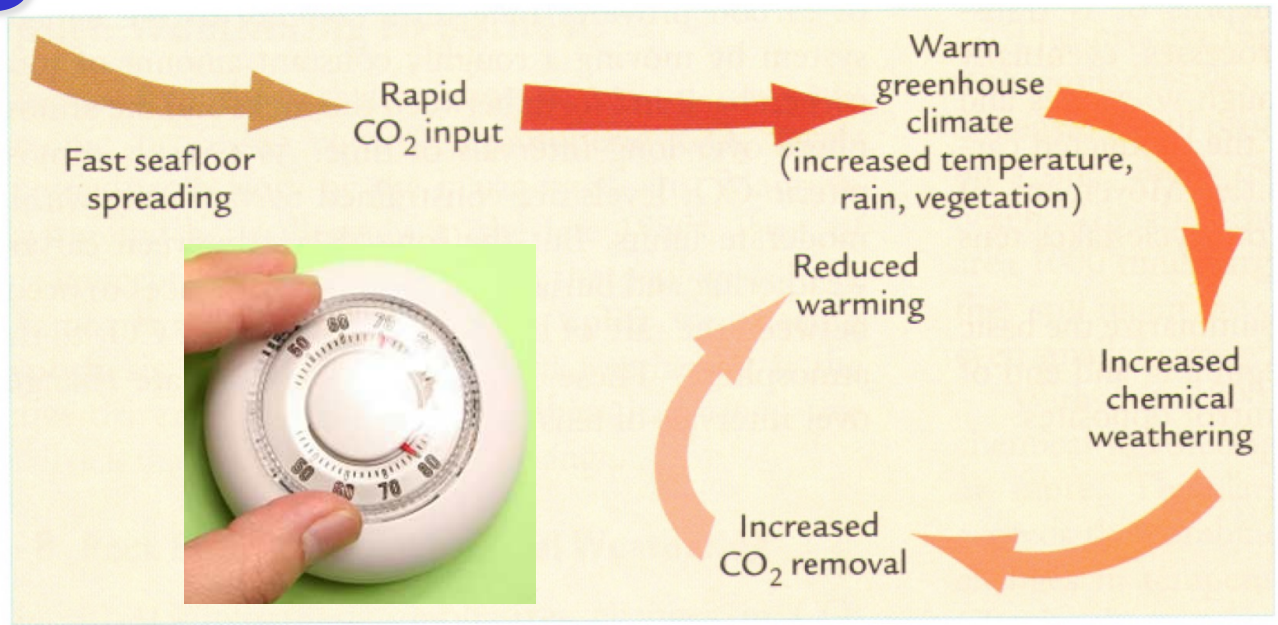


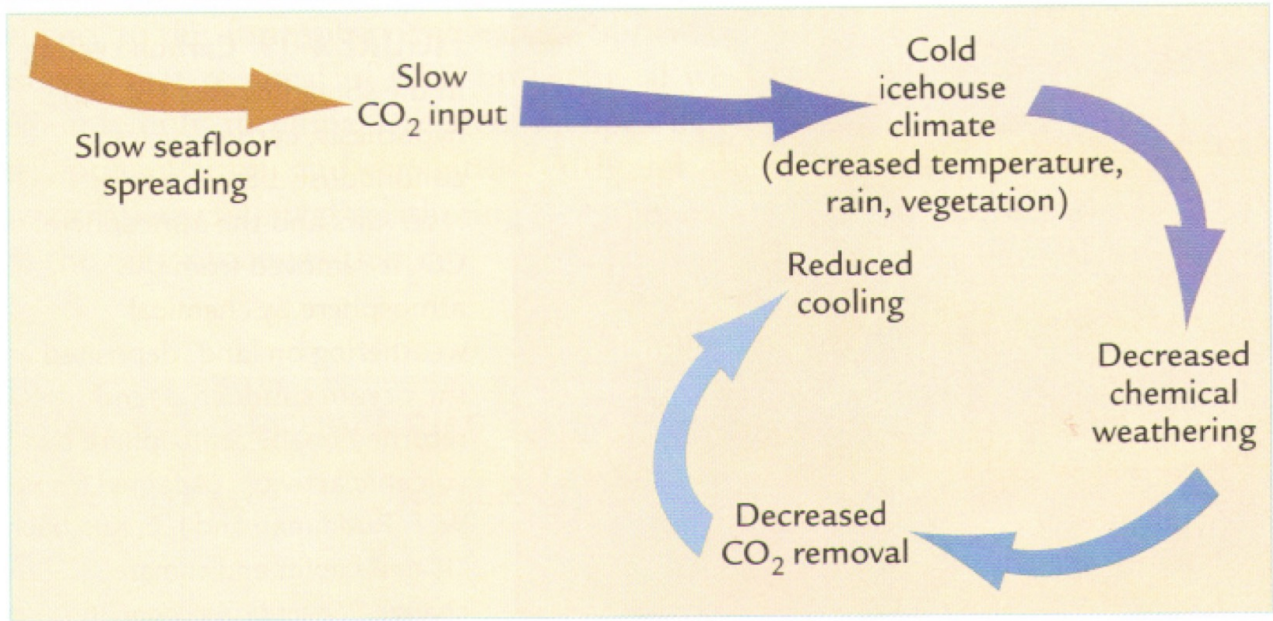
- Rock weathering is a chemical reaction that consumes CO_2
- Uplift of mountains exposes fresh rock to air, consuming Co2 and cooling climate over time

Geologic Thermostat

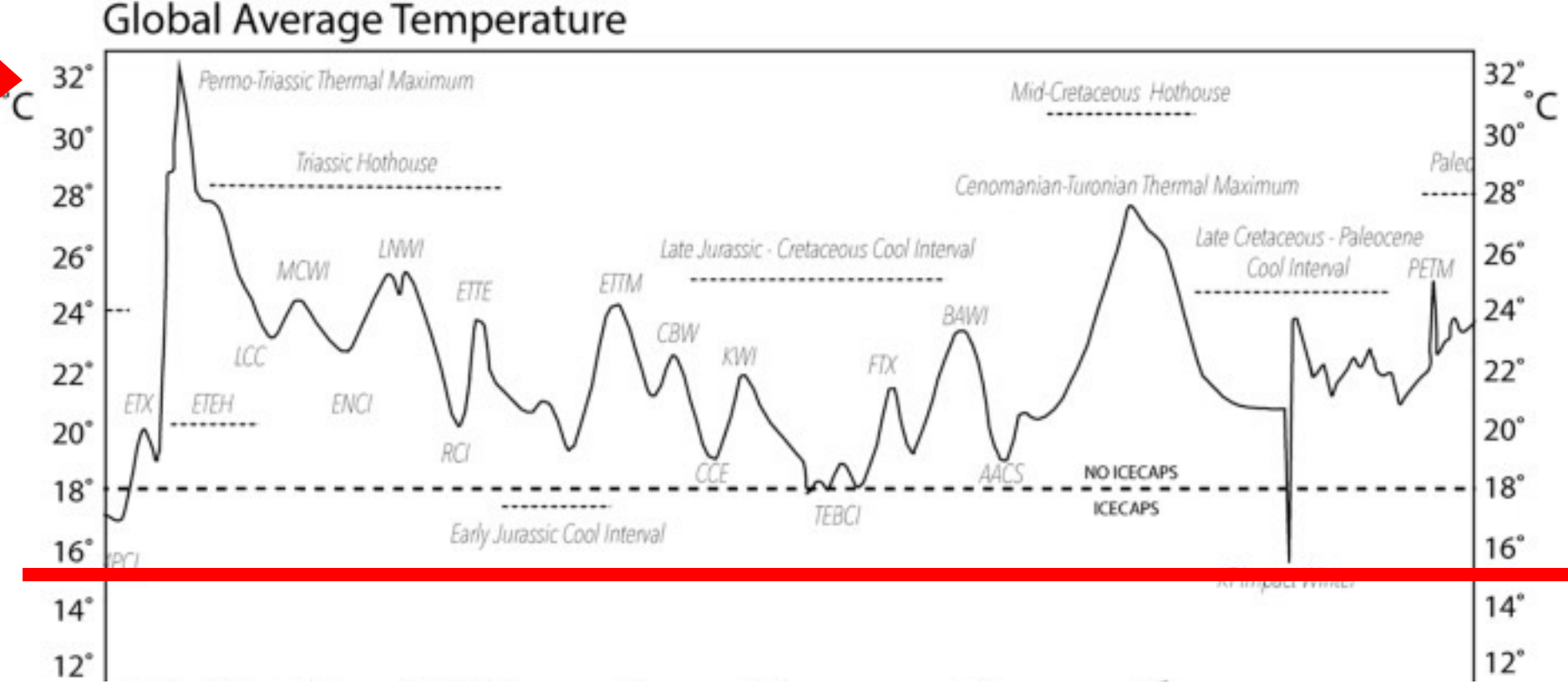
Negative Feedback

- Warming leads to cooling
- Cooling leads to warming





Inconceivably hot!

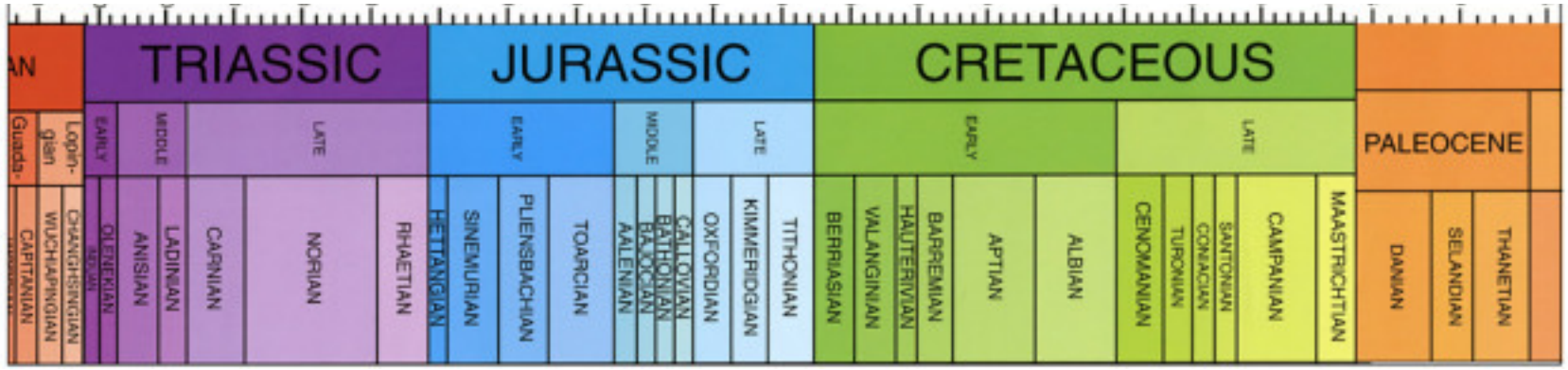


Modern climate

250my 200my 150my 100my

Mesozoic

Global Paleo Temperature




Antarctica!

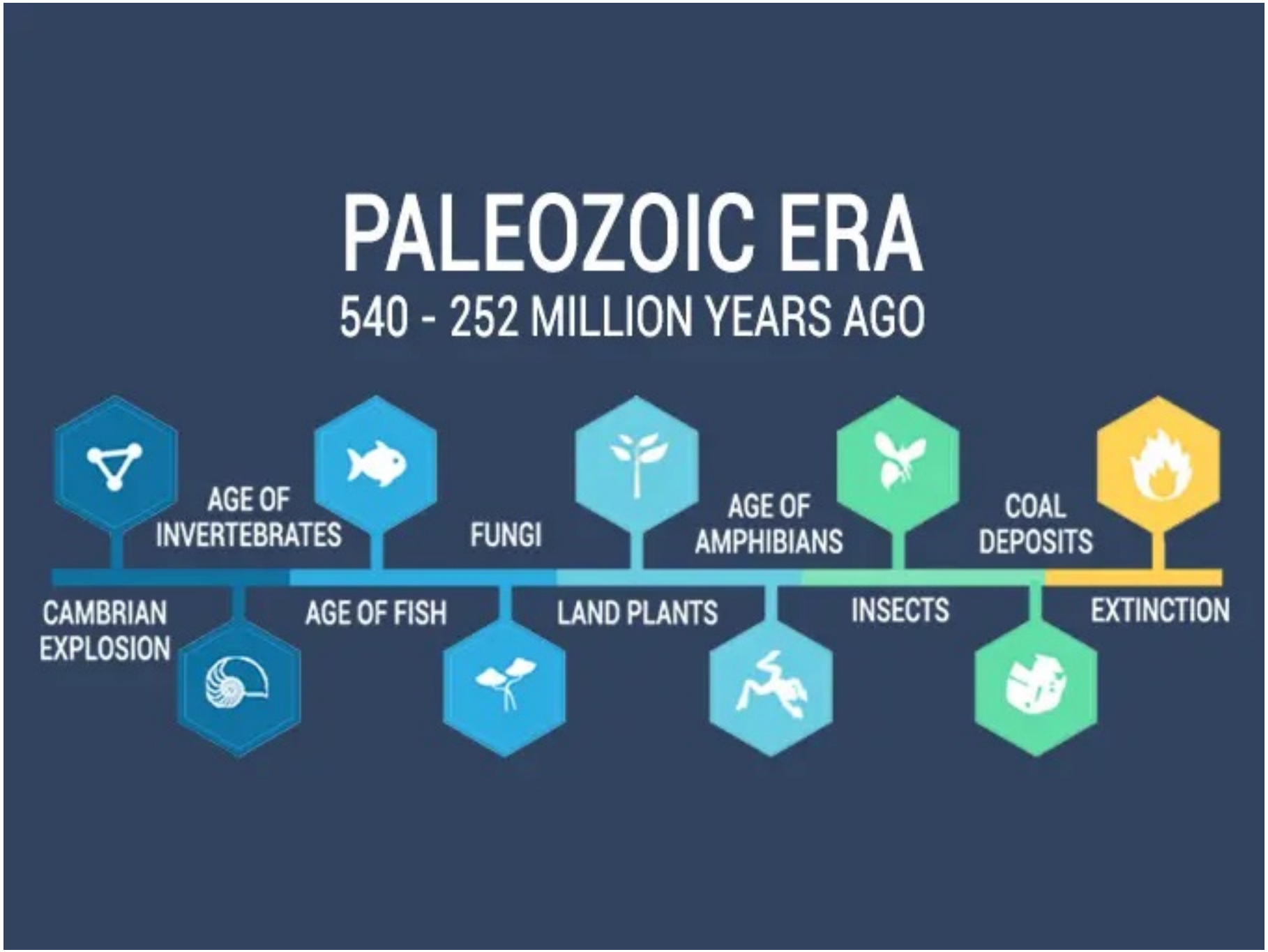
Geology & Paleontology

- Cenozoic: "New Life" -- the past 66 million years
- Mesozoic: "Middle Life" – 252 million to 66 million
- Paleozoic: "Old Life" – 542 million to 252 million
  - Earliest visible fossils
  - Explosion of complex macro-life
  - Skeletons & Backbones
  - Oceans to land
  - Beginning of plants and soils on land
  - Ended with a gasp

PALEOZOIC

Permo–Triassic boundary
(250 Ma)

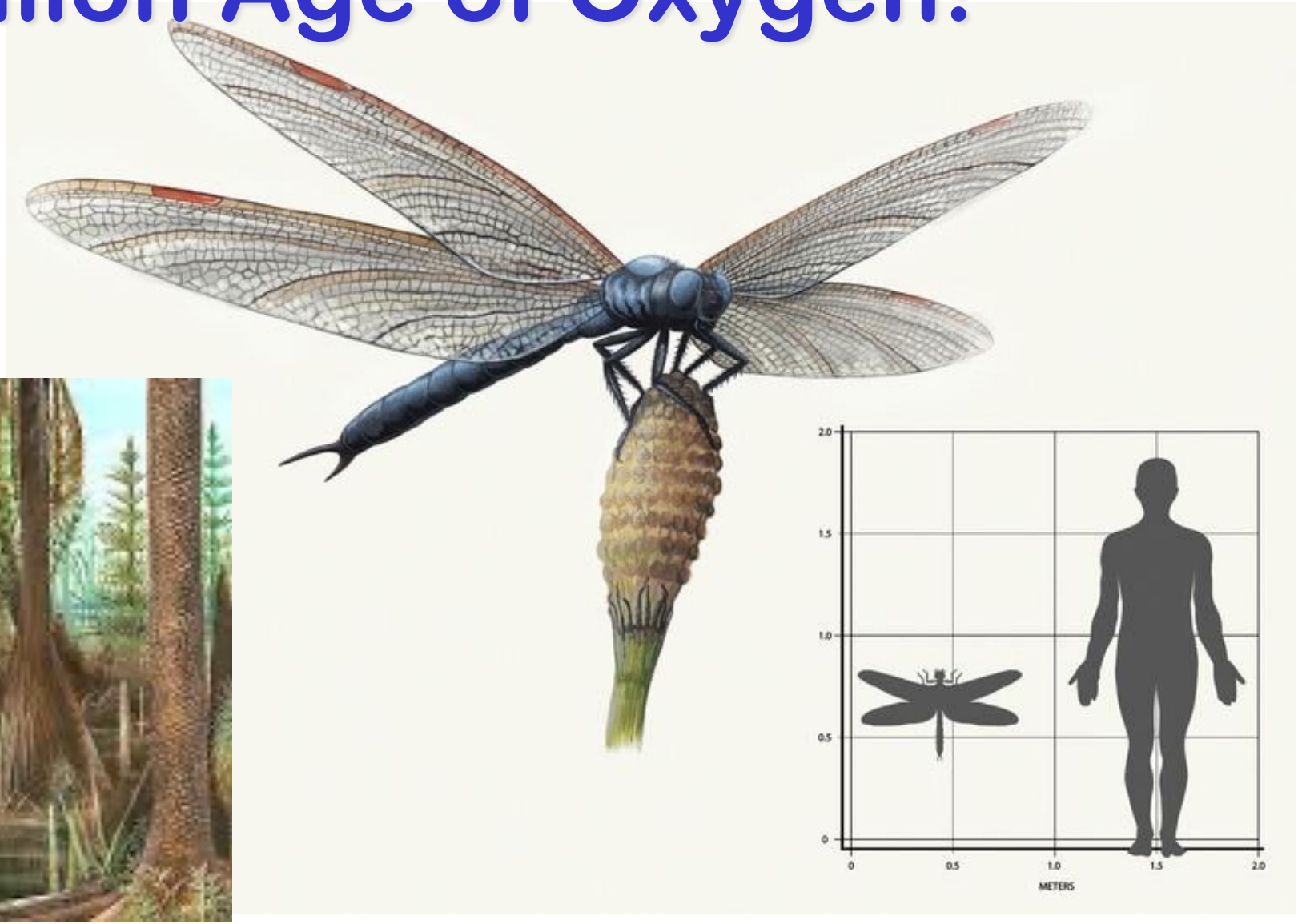
Elevation (m)
10,500
2,800
1,400
0
−2,200
−4,280
−11,000
MOUNTAINS
LOWLANDS
FLOODED CONTINENTS
DEEP OCEAN


PALEOZOIC ERA
540 - 252 MILLION YEARS AGO
CAMBRIAN EXPLOSION
AGE OF INVERTEBRATES
AGE OF FISH
FUNGI
LAND PLANTS
AGE OF AMPHIBIANS
INSECTS
COAL DEPOSITS
EXTINCTION

Earliest Land Plants
about 460 million years ago

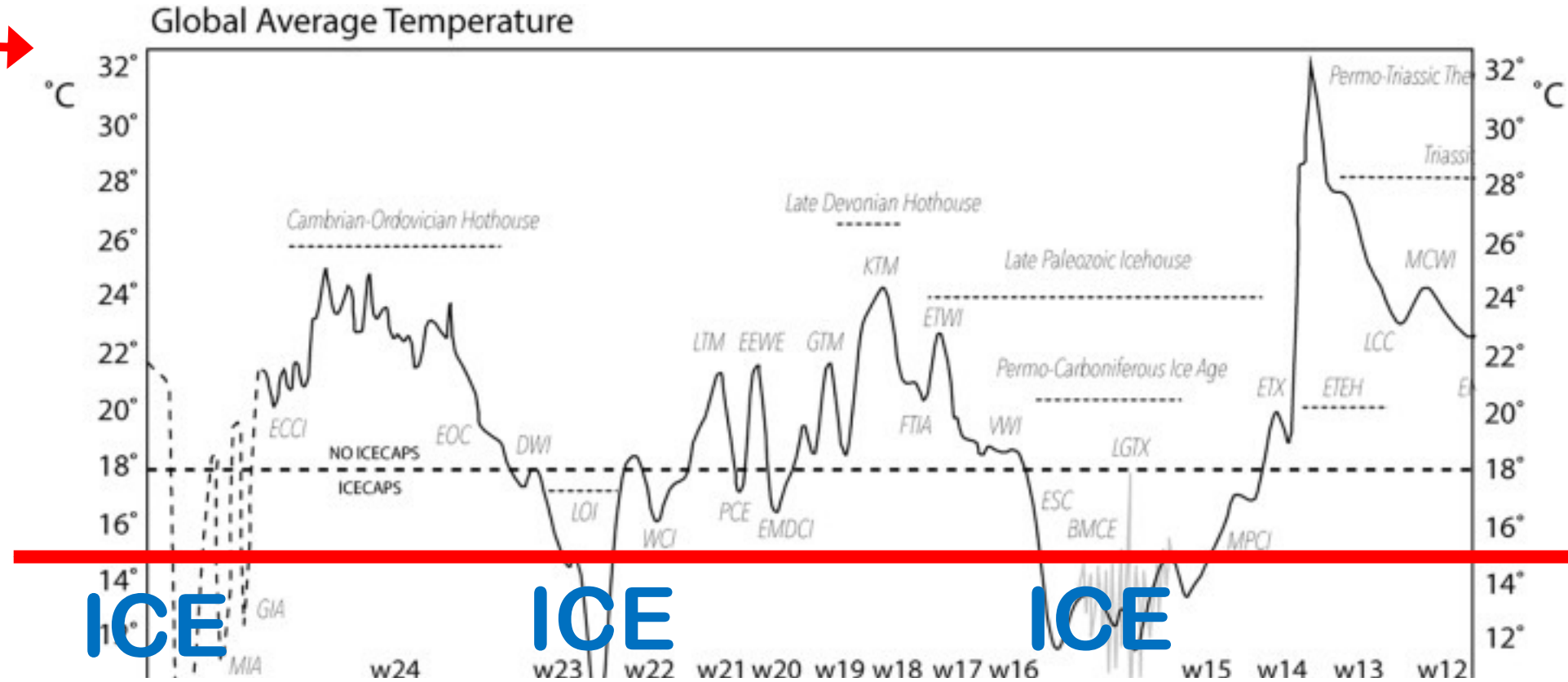
Devonian Plants
about 400 million years ago

Carboniferous Period
~ 300 million Age of Oxygen!



Inconceivably hot! →

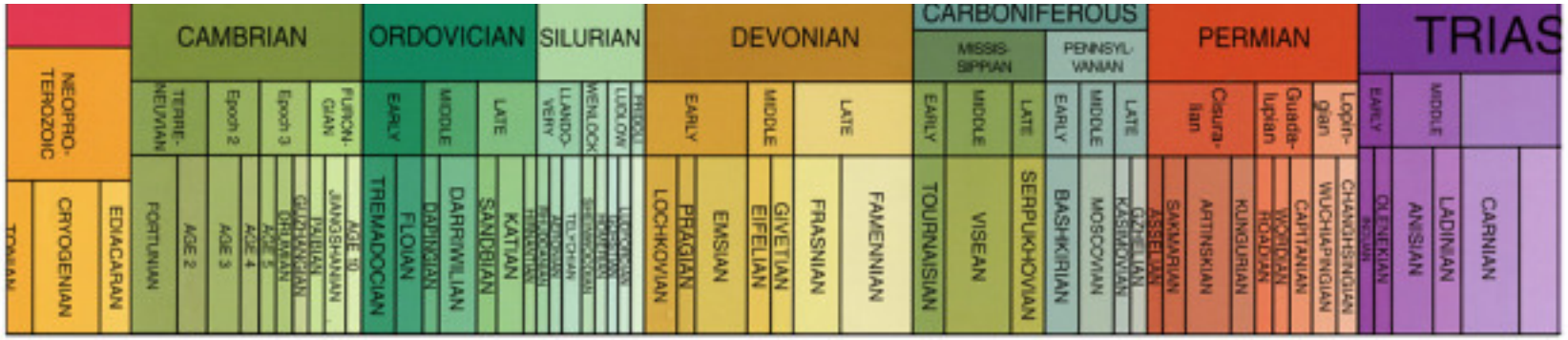
Modern climate →



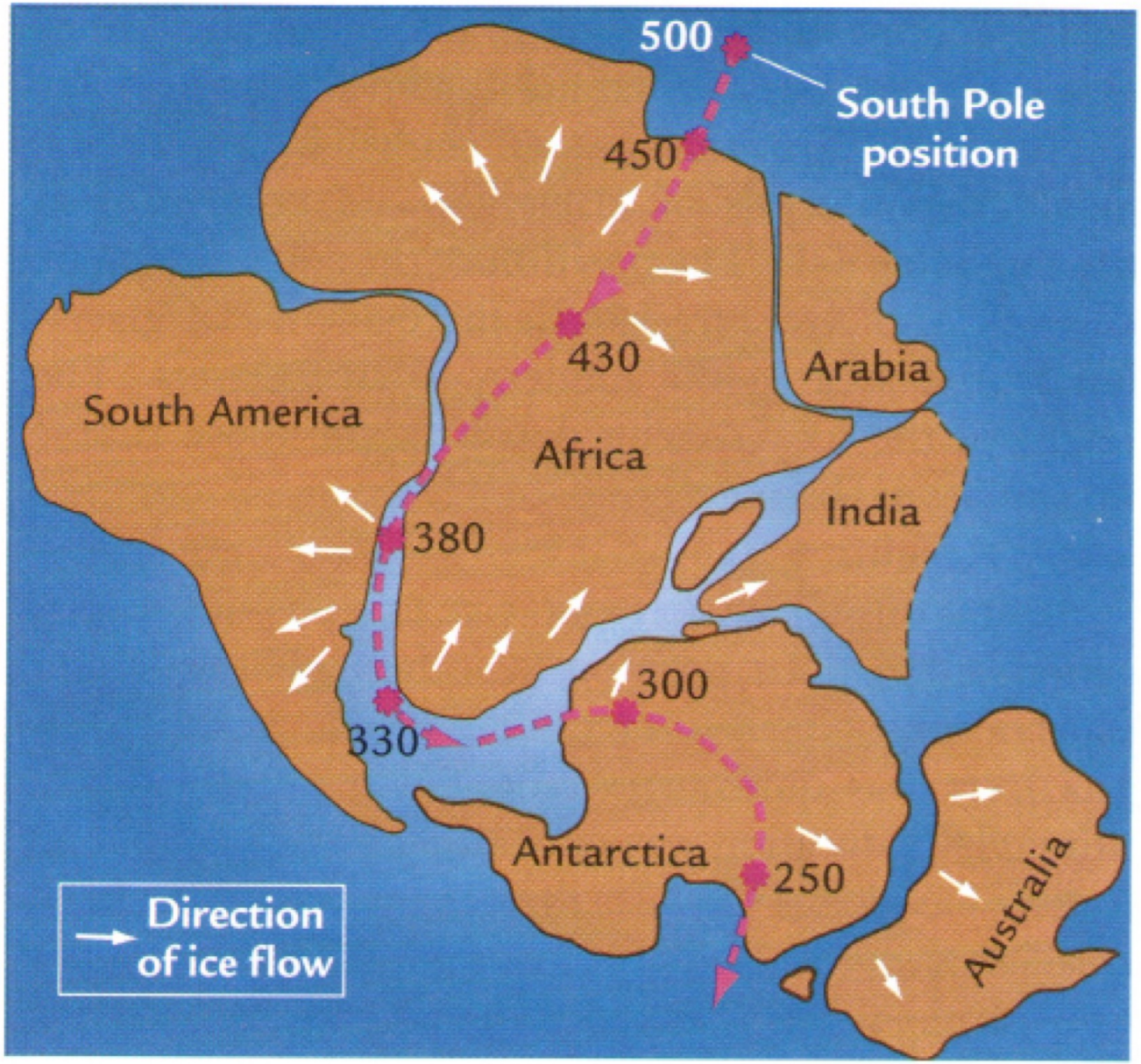
500my 400my 300my

Paleozoic

Global Paleo Temperature

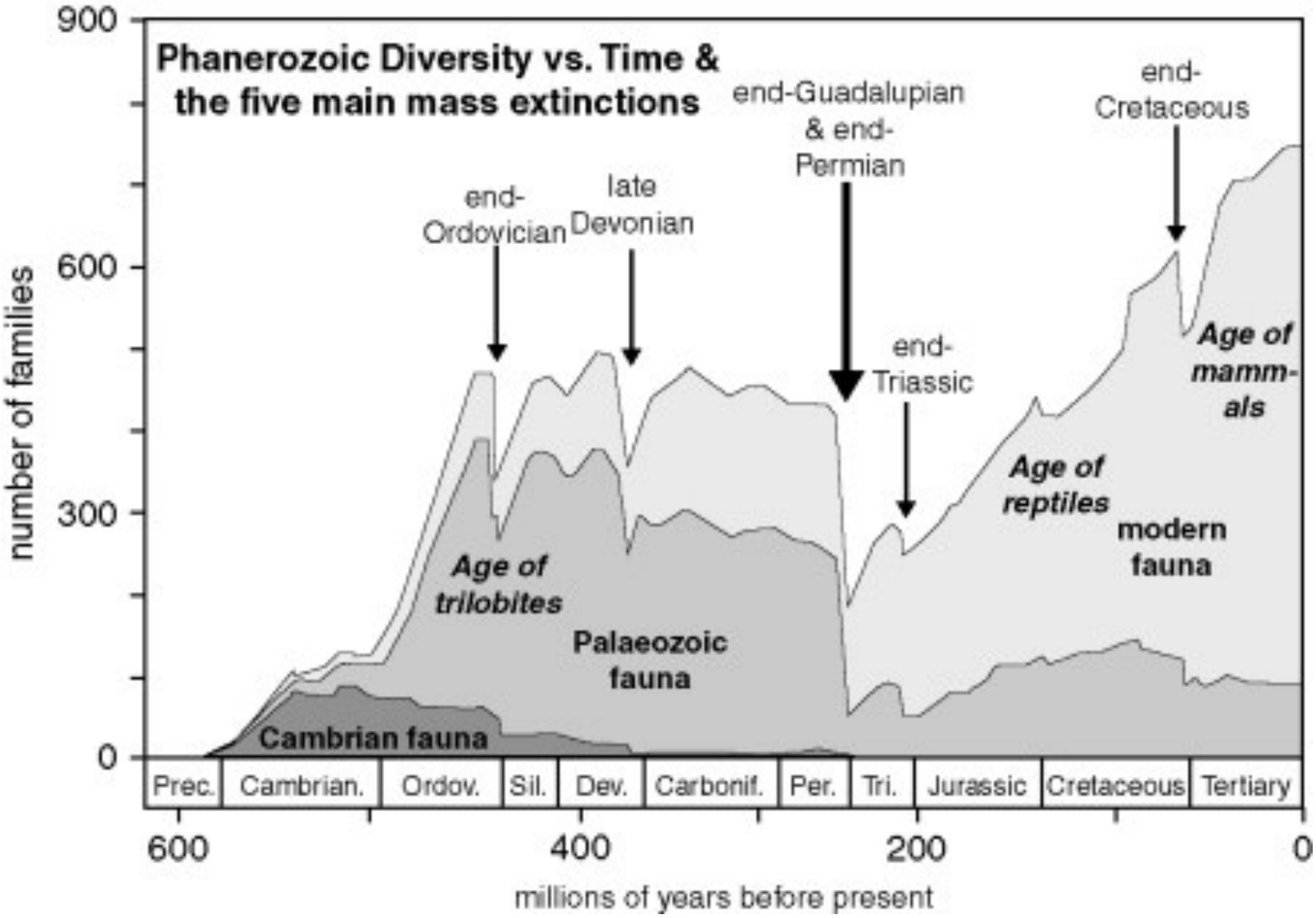


Gondwana Glaciation



- Continents bunched up at South Pole about 500 million years ago
- Huge ice sheets left deposits and erosion across Southern Hemisphere

Great Dying (252 my)

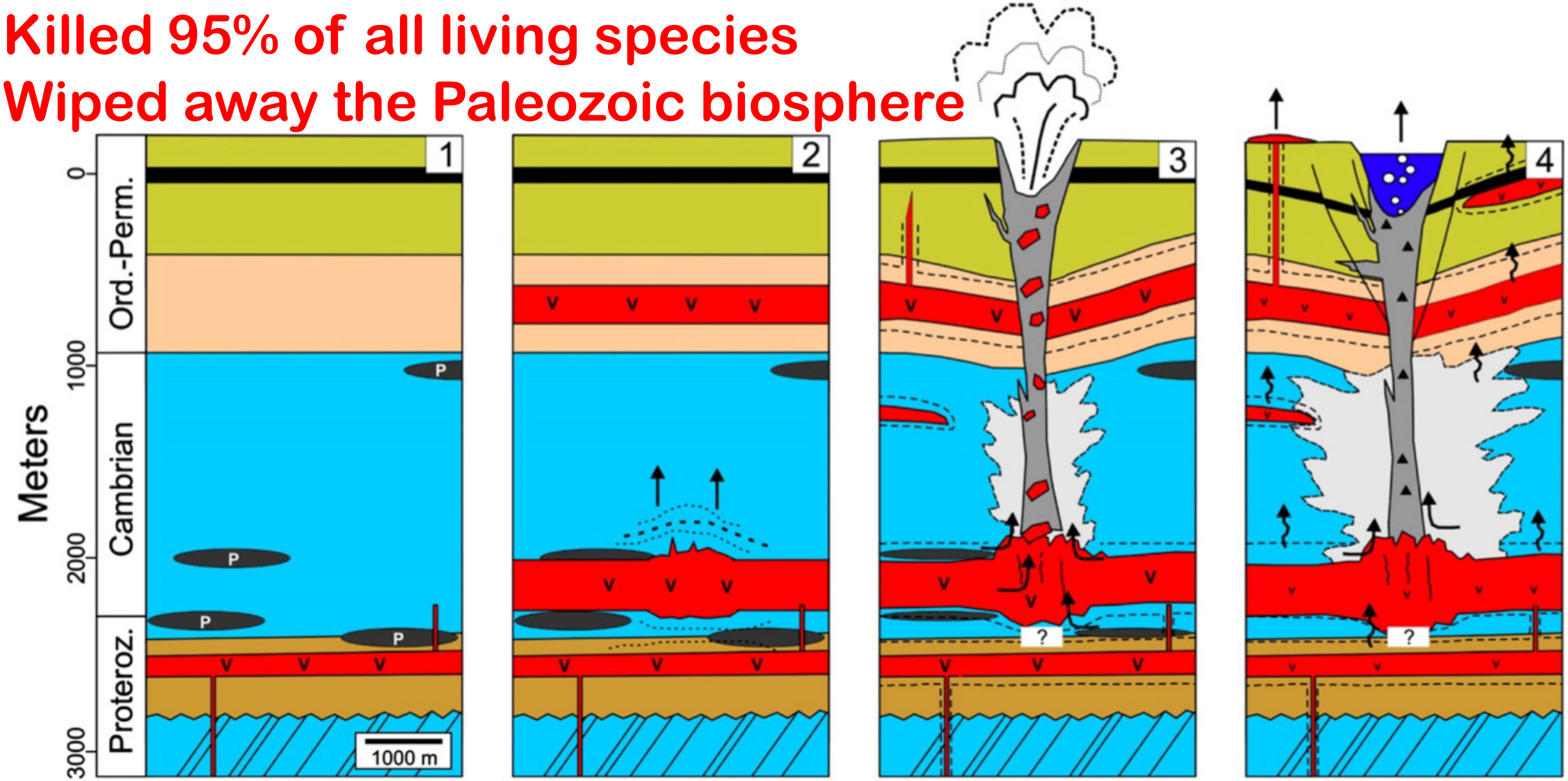


Great Dying (252 my)

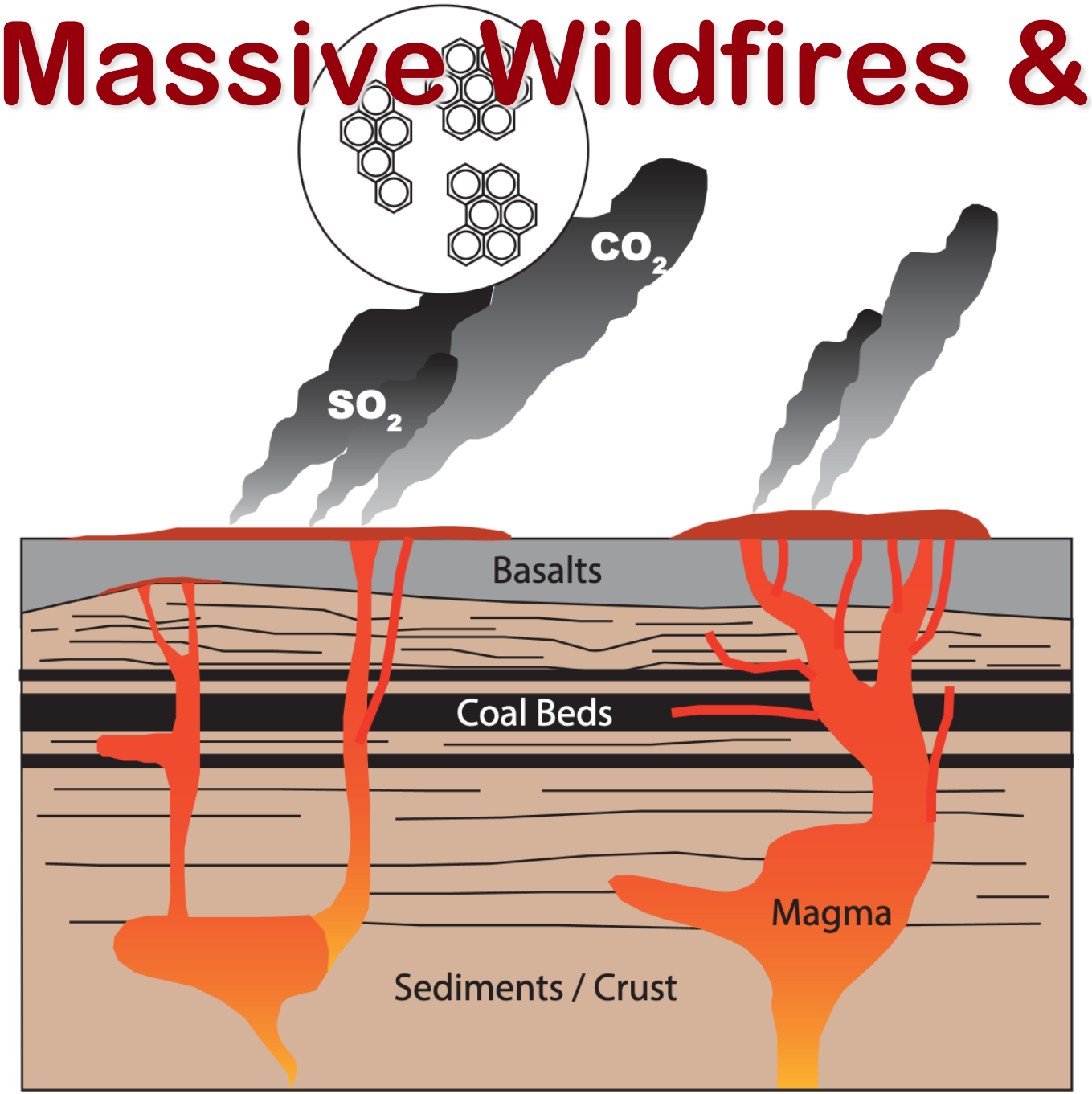
Magma Vaporized Limestone & Coal

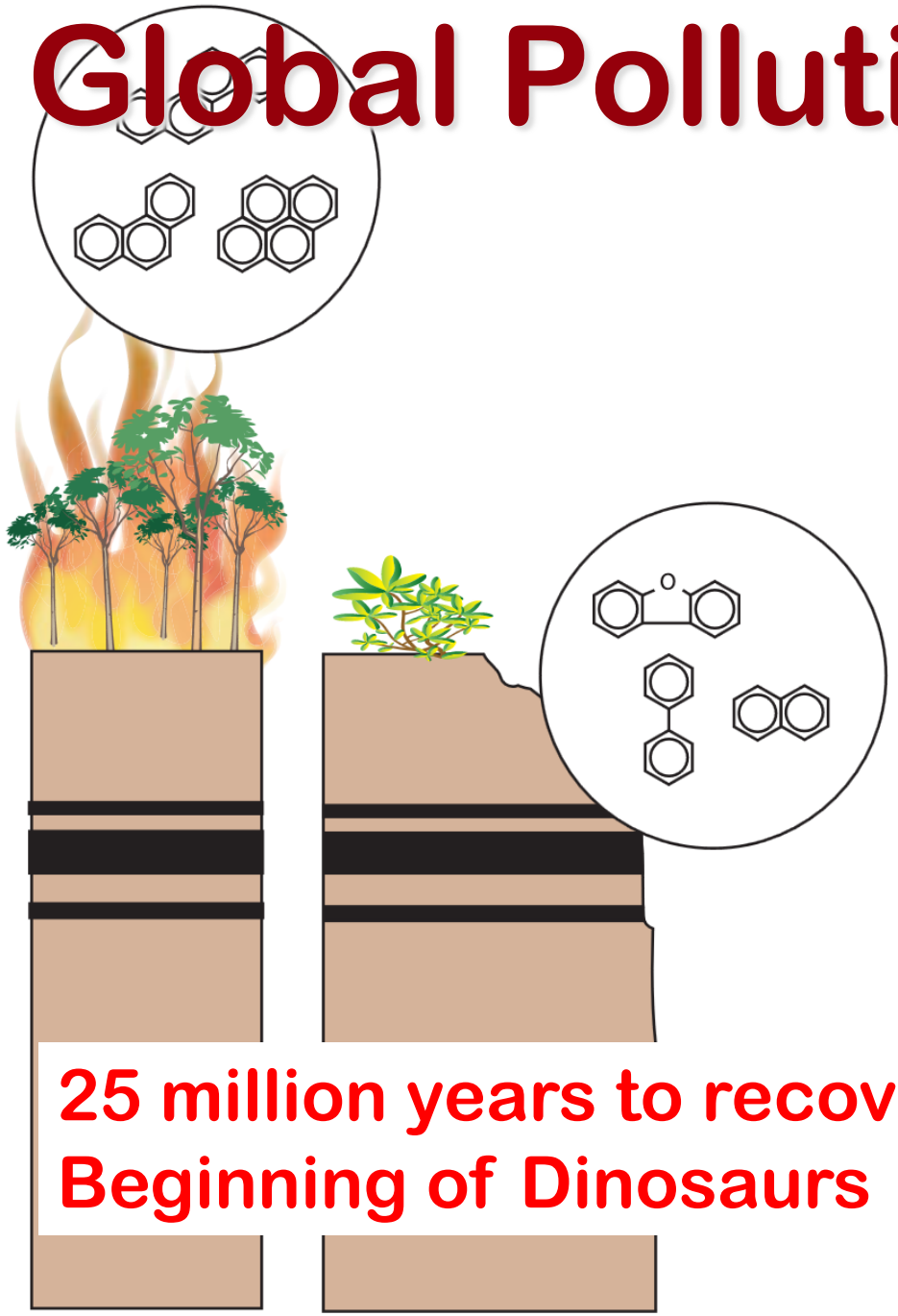
Killed 95% of all living species

Wiped away the Paleozoic biosphere

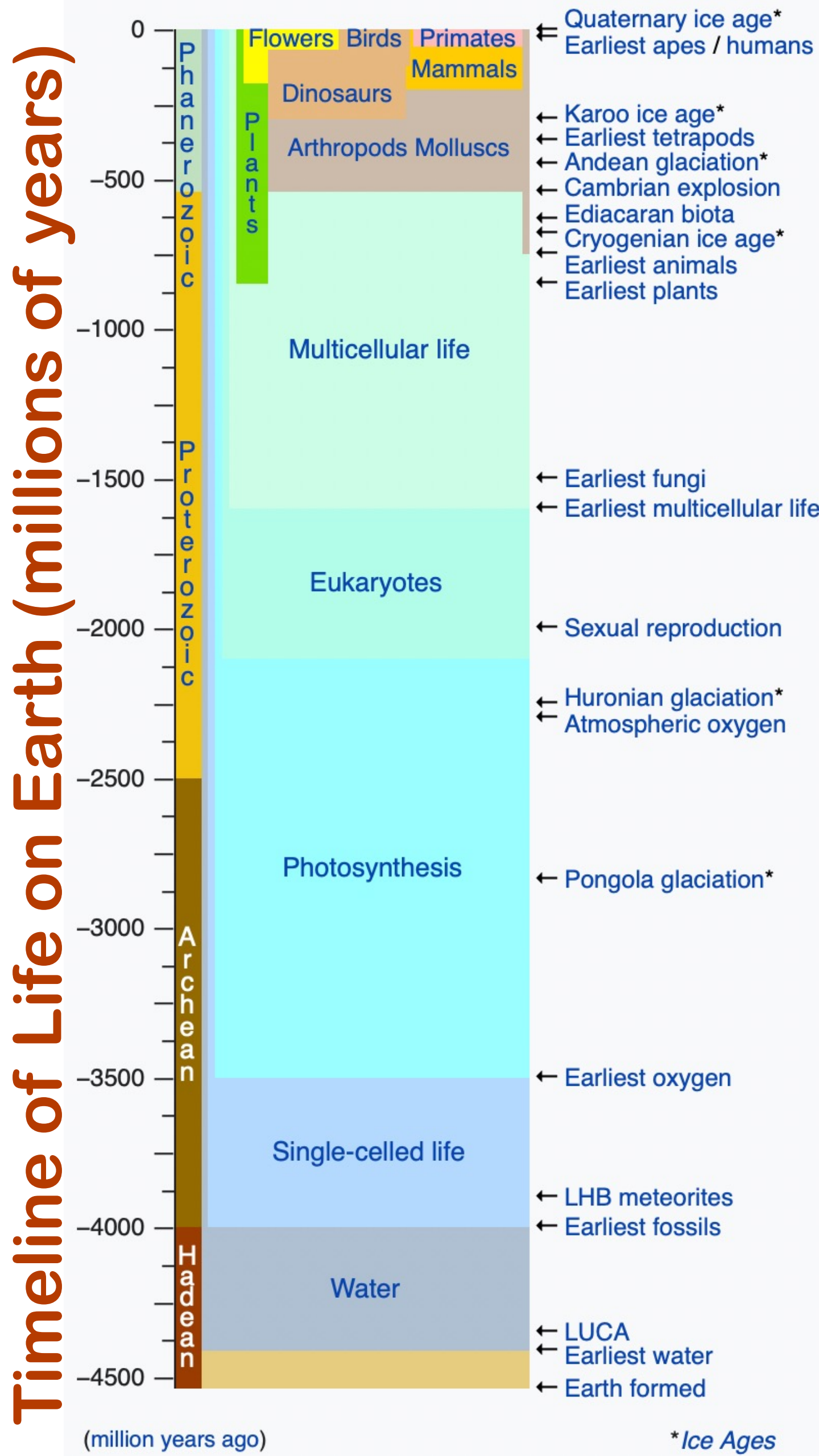


Massive Wildfires & Global Pollution





25 million years to recover
Beginning of Dinosaurs


Timeline of Life on Earth (millions of years)
0
−500
−1000
−1500
−2000
−2500
−3000
−3500
−4000
−4500
Phanerozoic
Proterozoic
Archean
Hadean
Flowers
Birds
Primates
Mammals
Dinosaurs
Plants
Arthropods
Molluscs
Multicellular life
Eukaryotes
Photosynthesis
Single-celled life
Water
← Quaternary ice age*
← Earliest apes / humans
← Karoo ice age*
← Earliest tetrapods
← Andean glaciation*
← Cambrian explosion
← Ediacaran biota
← Cryogenian ice age*
← Earliest animals
← Earliest plants
← Earliest fungi
← Earliest multicellular life
← Sexual reproduction
← Huronian glaciation*
← Atmospheric oxygen
← Pongola glaciation*
← Earliest oxygen
← LHB meteorites
← Earliest fossils
← LUCA
← Earliest water
← Earth formed
(million years ago)
*Ice Ages