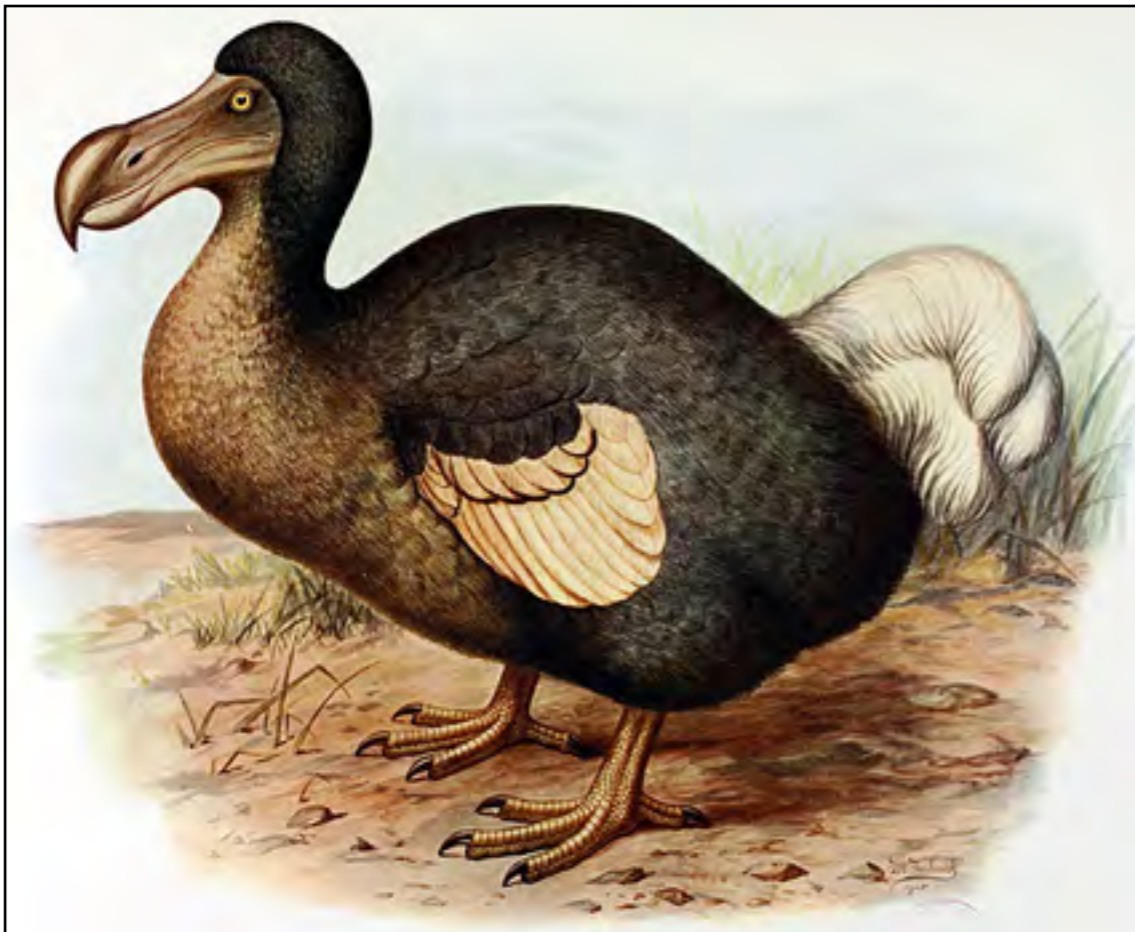


Extinction



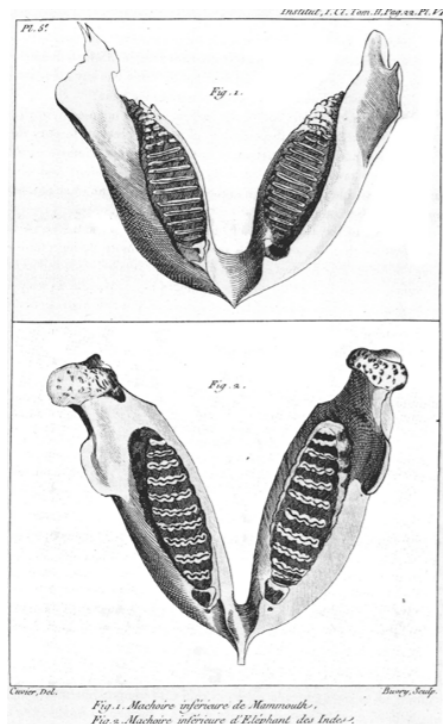
Extinction of species is a recent discovery

http://en.wikipedia.org/wiki/Georges_Cuvier

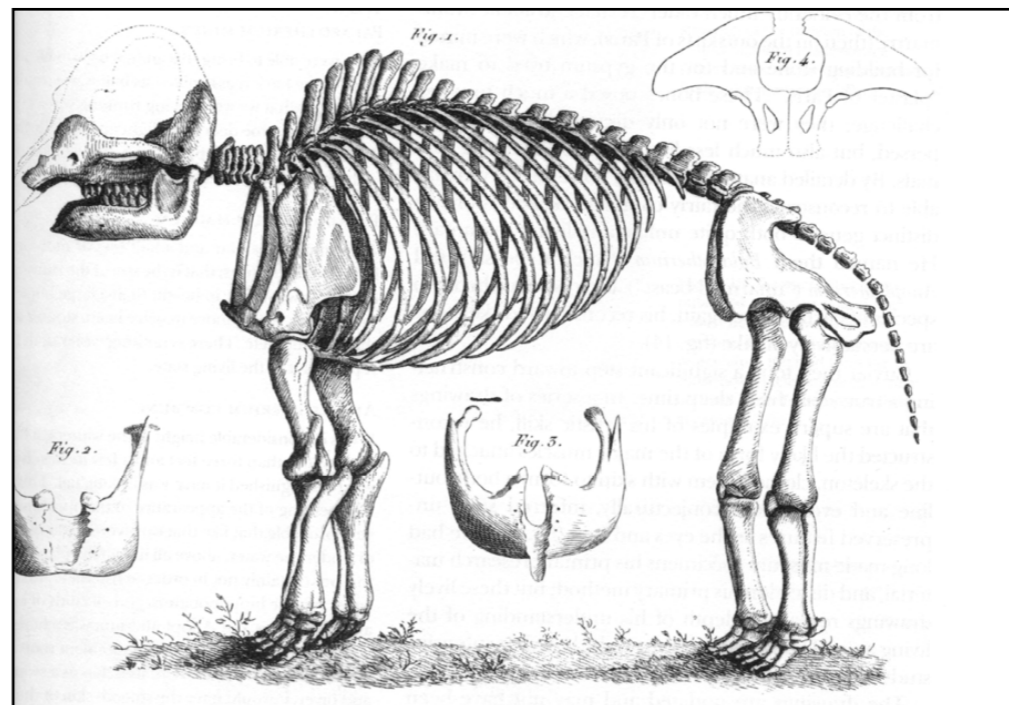


Georges Cuvier
(1769-1832)

- Georges Cuvier, anatomist and naturalist at the Museum of Natural History, Paris, used comparative anatomy to prove that fossil bones belonged to a species (American Mammoth) that no longer existed



lower jaw vs. Indian Elephant



“Ohio Animal”

Extinction is 'normal'

- >99% of all species that have ever existed are now extinct
- Extinction rates have varied quite a bit through time
- Different groups have different characteristic species durations:



Mammals: ~ 2 million years

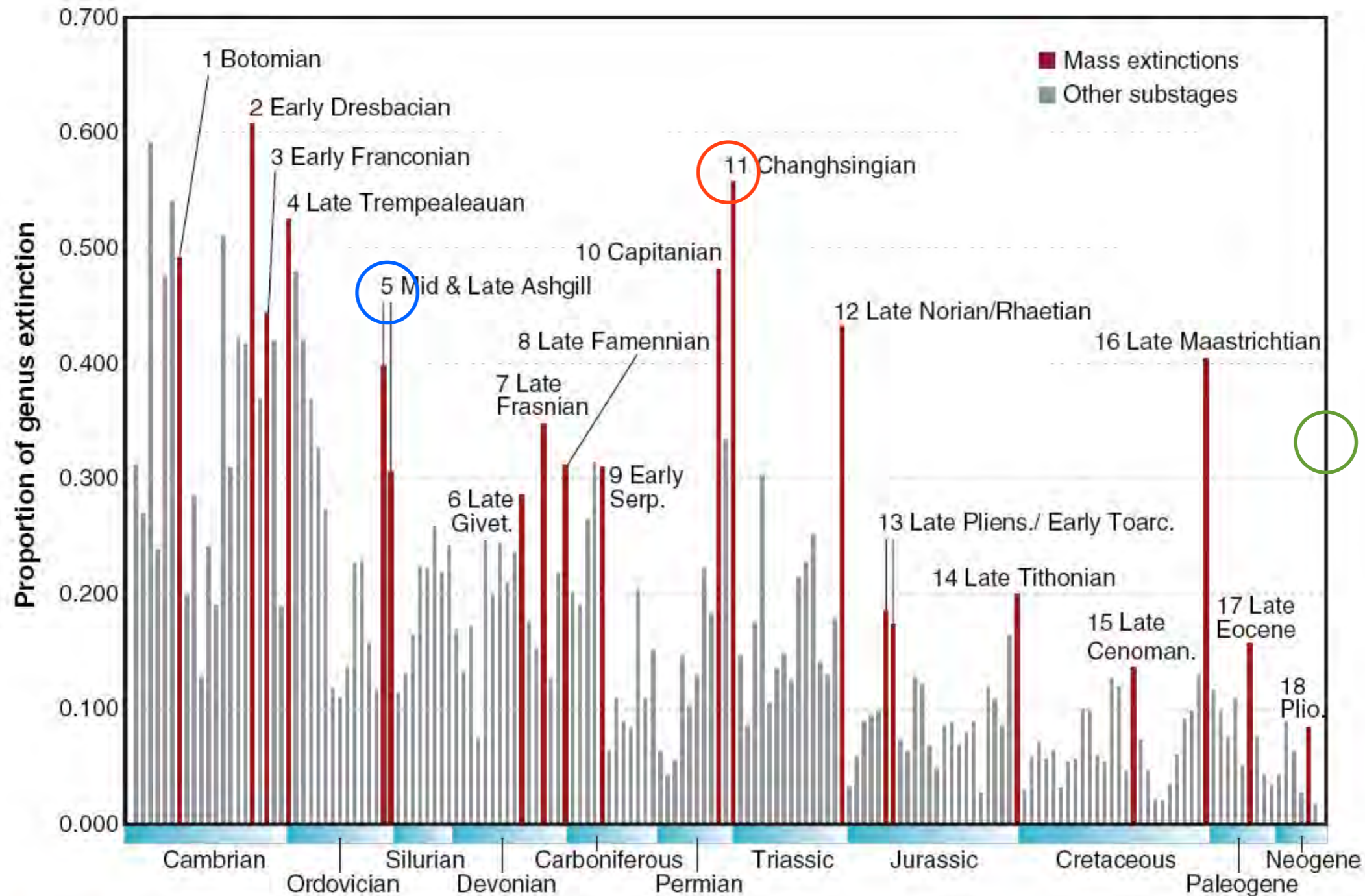


Foraminifera: ~ 20 million years



Marine Animal Extinction rates over the past 540 million years

- Late Ordovician
- Permian-Triassic
- Pleistocene-Recent



○ ?

Potential drivers of extinction

Background

- Competition
- Predation
- Habitat loss
- Disease
- Climate change
- Bad luck

Mass

- Rapid climate change
- Sea level change
- Wholesale habitat loss
- Ocean acidification
- Anoxia/hypoxia
- Bolide Impacts
- Disease?

Selectivity of extinction:

What traits might influence extinction risk under different scenarios?

Individual

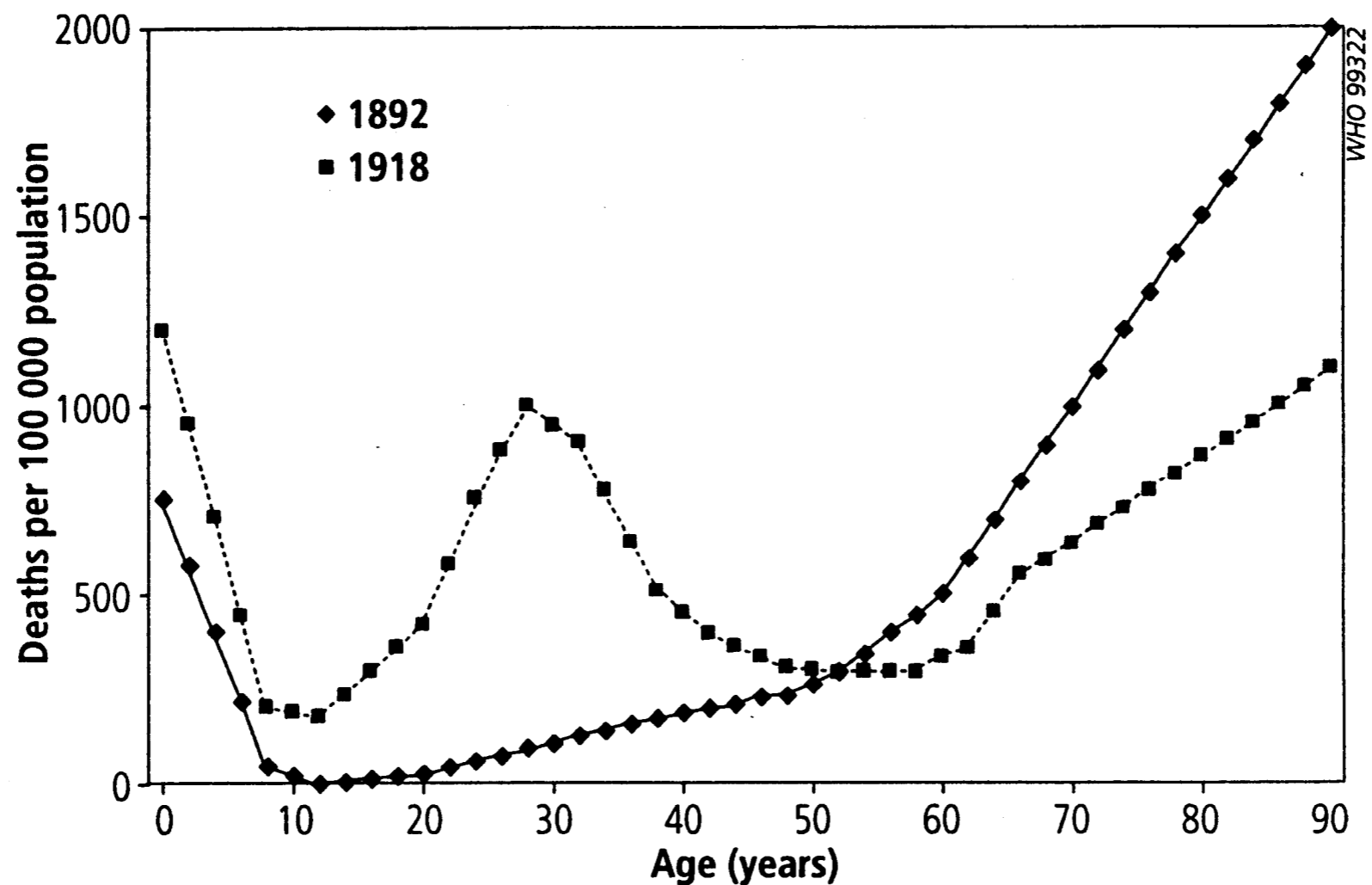
- Physiology
- Thermal tolerance
- Diet
- Home range size
- Reproduction
- Gestation period
- etc.

Population

- Geographic range
- Latitudinal range
- Environmental range
- Population density
- Population growth rate
- Dispersal
- etc.

Selective signature of mass extinctions: what is **unusual** about extinctions relative to extinctions at other times?

An analogy: age distribution of mortality during a 'normal' flu pandemic vs. during the 1918 pandemic

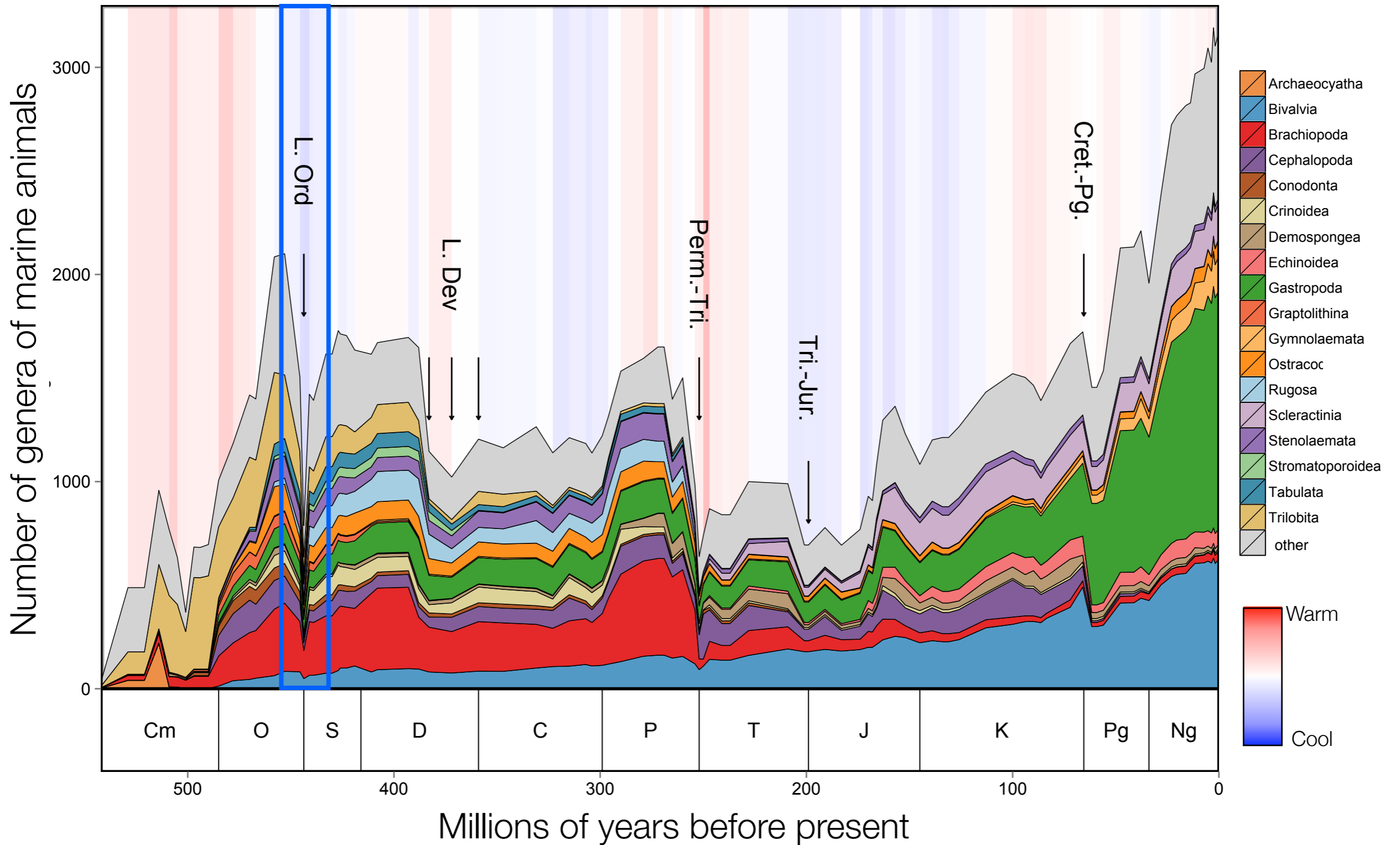


Dowdle, 1999, *Bulletin of the WHO*

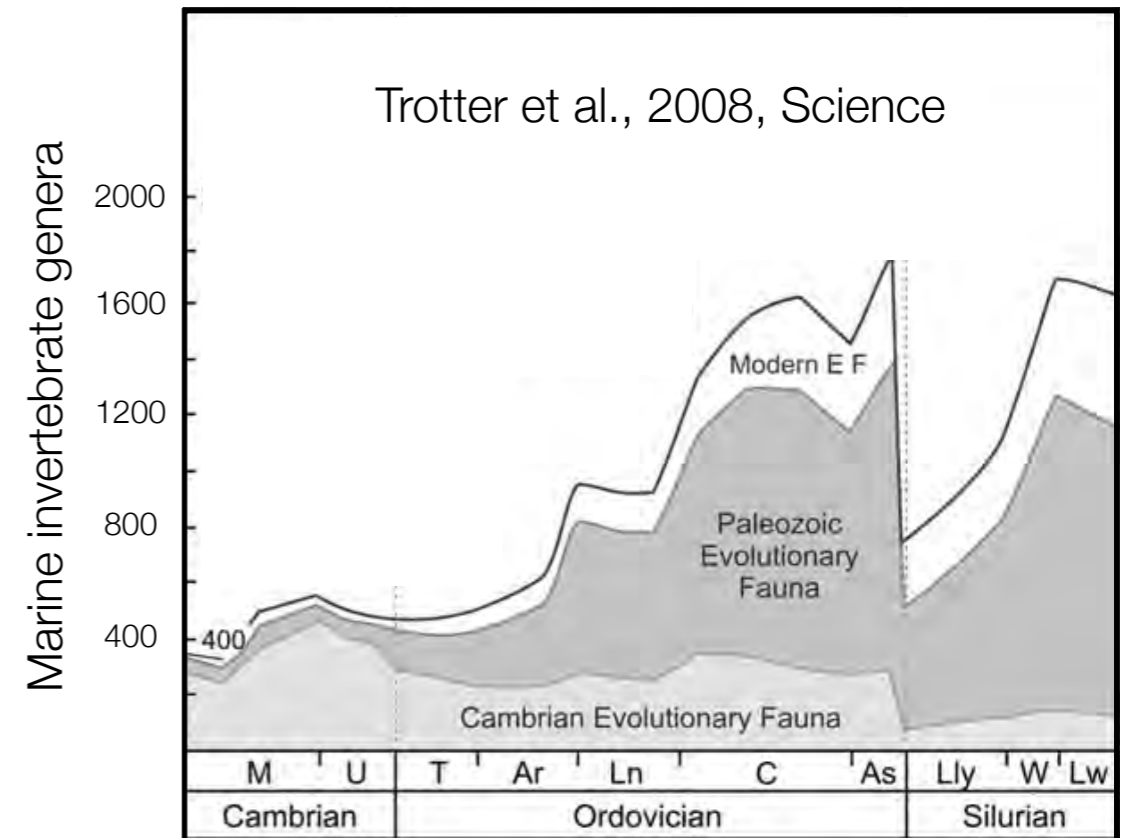
The Late Ordovician Mass Extinction



Climate change & mass extinctions



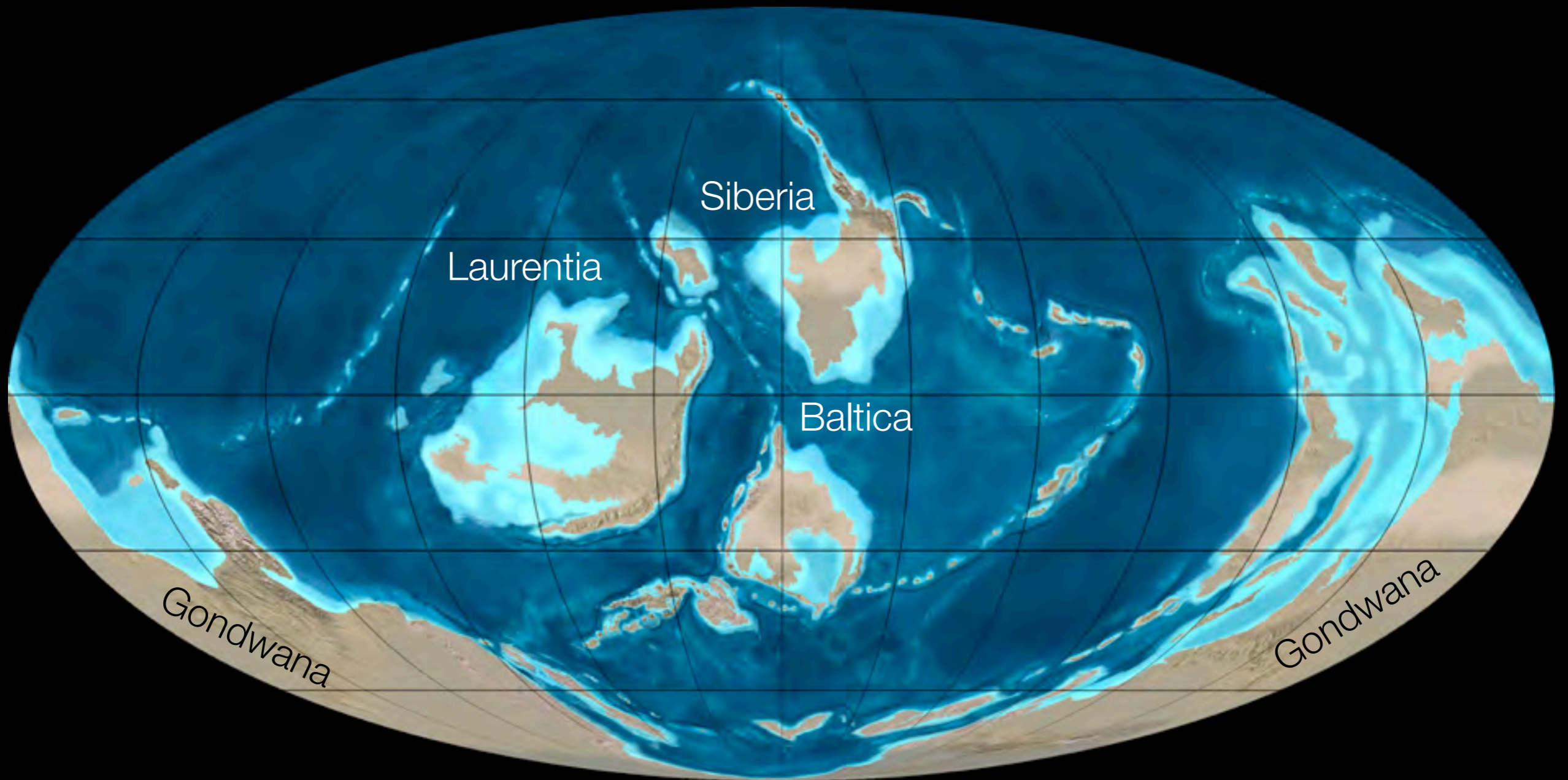
The Late Ordovician Mass Extinction



- ~60% of marine genera disappear during the **Katian** (457- 445.6 mya) and **Hirnantian** (445.6 - 443.7 mya) stages
- Two pulses: end-Katian pulse coinciding with cooling & expansion of Gondwanan ice sheets, end-Hirnantian pulse coinciding with warming & contraction of ice sheets
- No clear selective signature with respect to which taxonomic groups go extinct

The Late Ordovician globe

Very limited life on land, High CO₂ , Low O₂



modified after R. Blakey: <http://jan.ucc.nau.edu/~rcb7/450moll.jpg>

The Ordovician Period: little or no animal life on land, but abundant marine life



Who was hit by the extinction?

Trilobites



<http://weekstrilobites.com/Flexicalymene.htm>

Brachiopods



<http://drydredgers.org/brachplaty.htm>

Tabulate and Rugose Corals



<http://louisvillefossils.blogspot.com/2012/12/naming-fossils.html>

Mollusks



http://www.fossilsforsale.com/site_arc/index.cfm?action=item&prod_id=191&

Graptolites



<http://www.geo-logic.org/Palaeontology/Graptolites.htm>

Crinoids



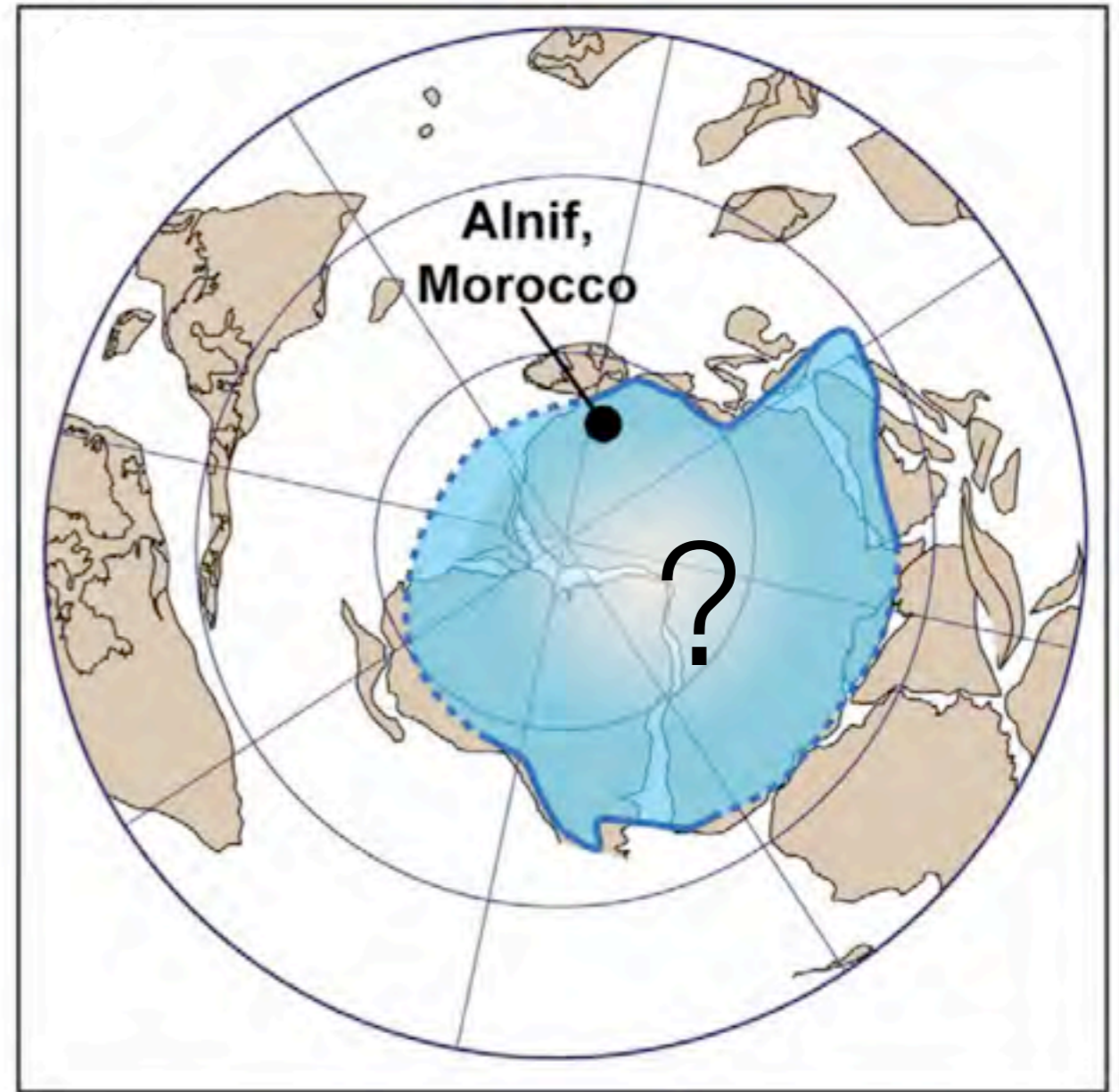
<http://louisvillefossils.blogspot.com/2010/12/agaricocrinus-americanus-crinoid.html>

Who was hit by the extinction?

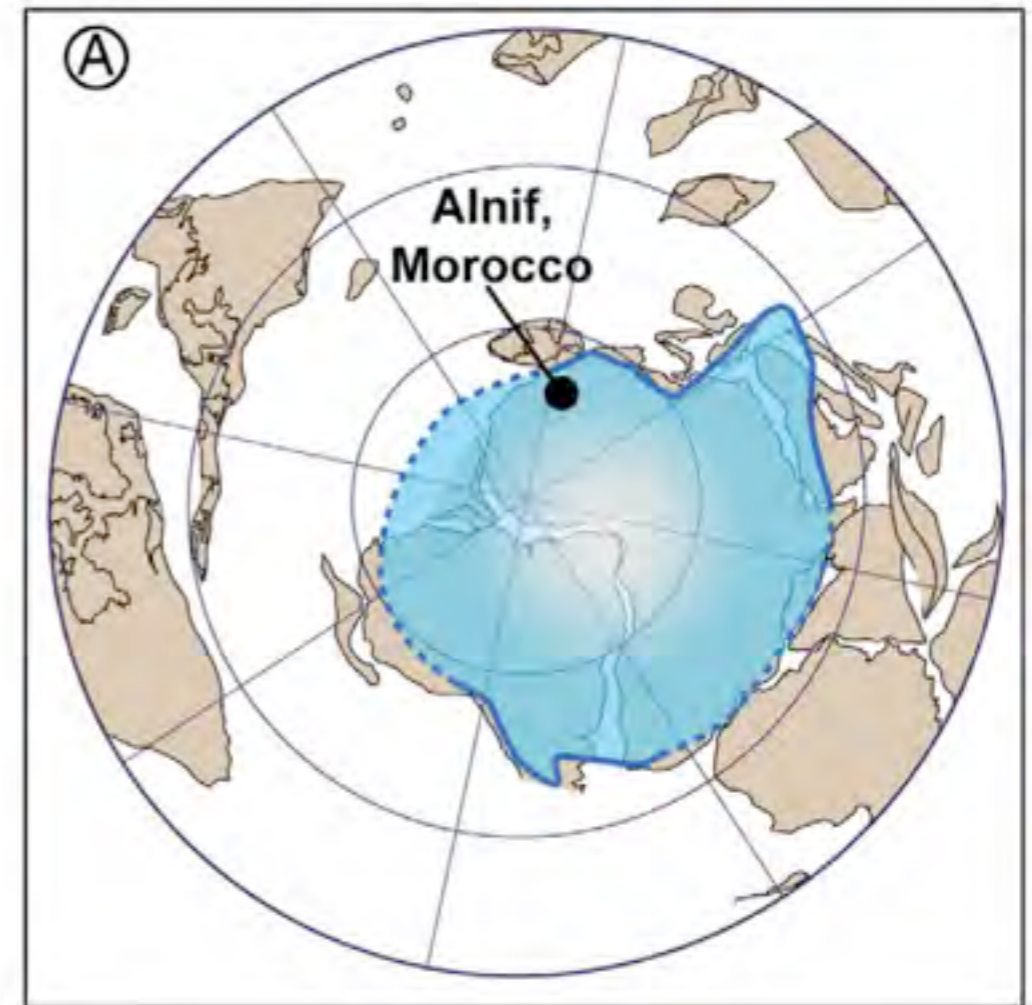
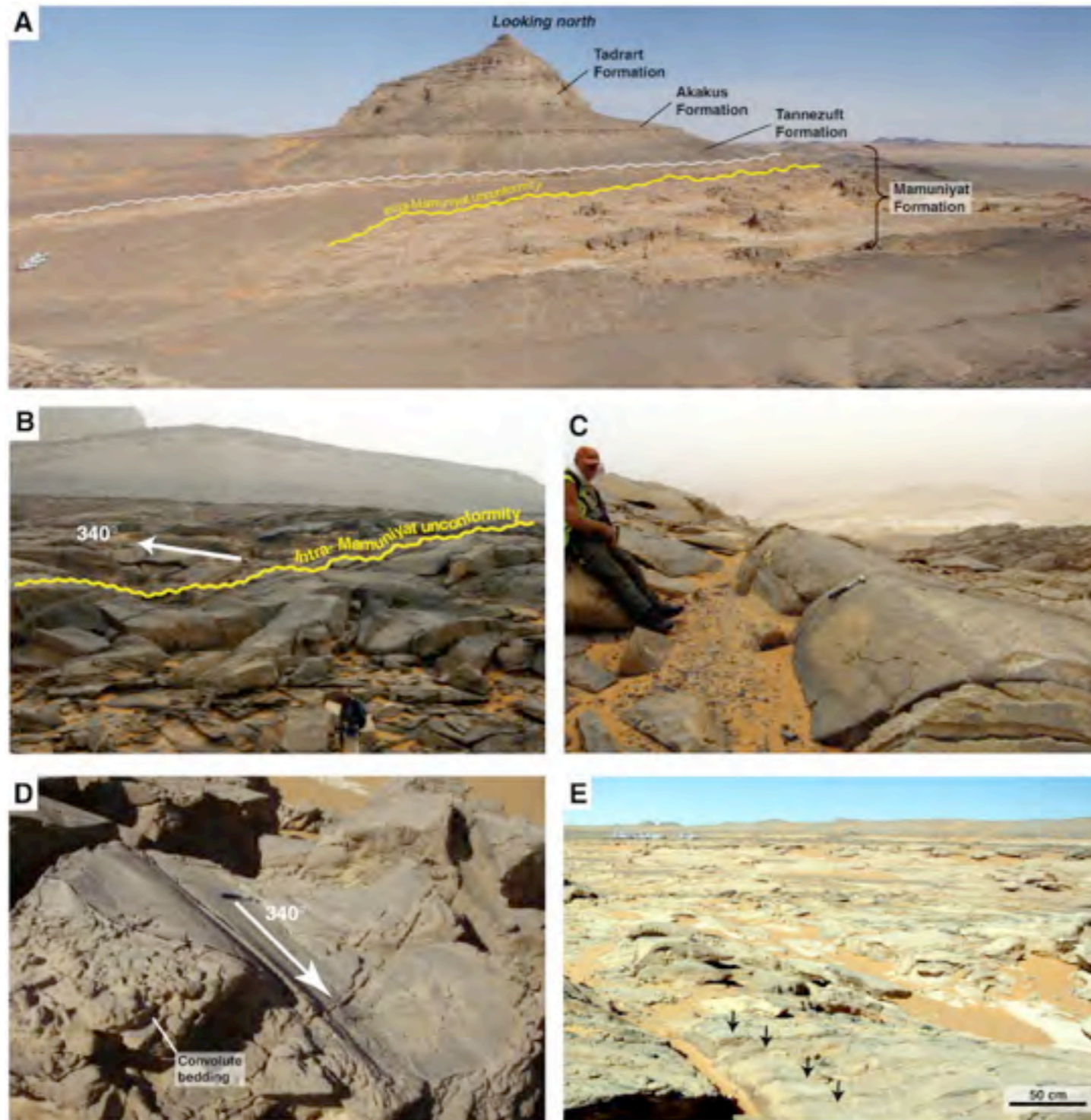


<http://www.palaeocast.com/episode-2-isotelus-rex/#.UXHCgaUgF20>

Ultimate cause: glaciation and subsequent deglaciation of south polar Gondwana



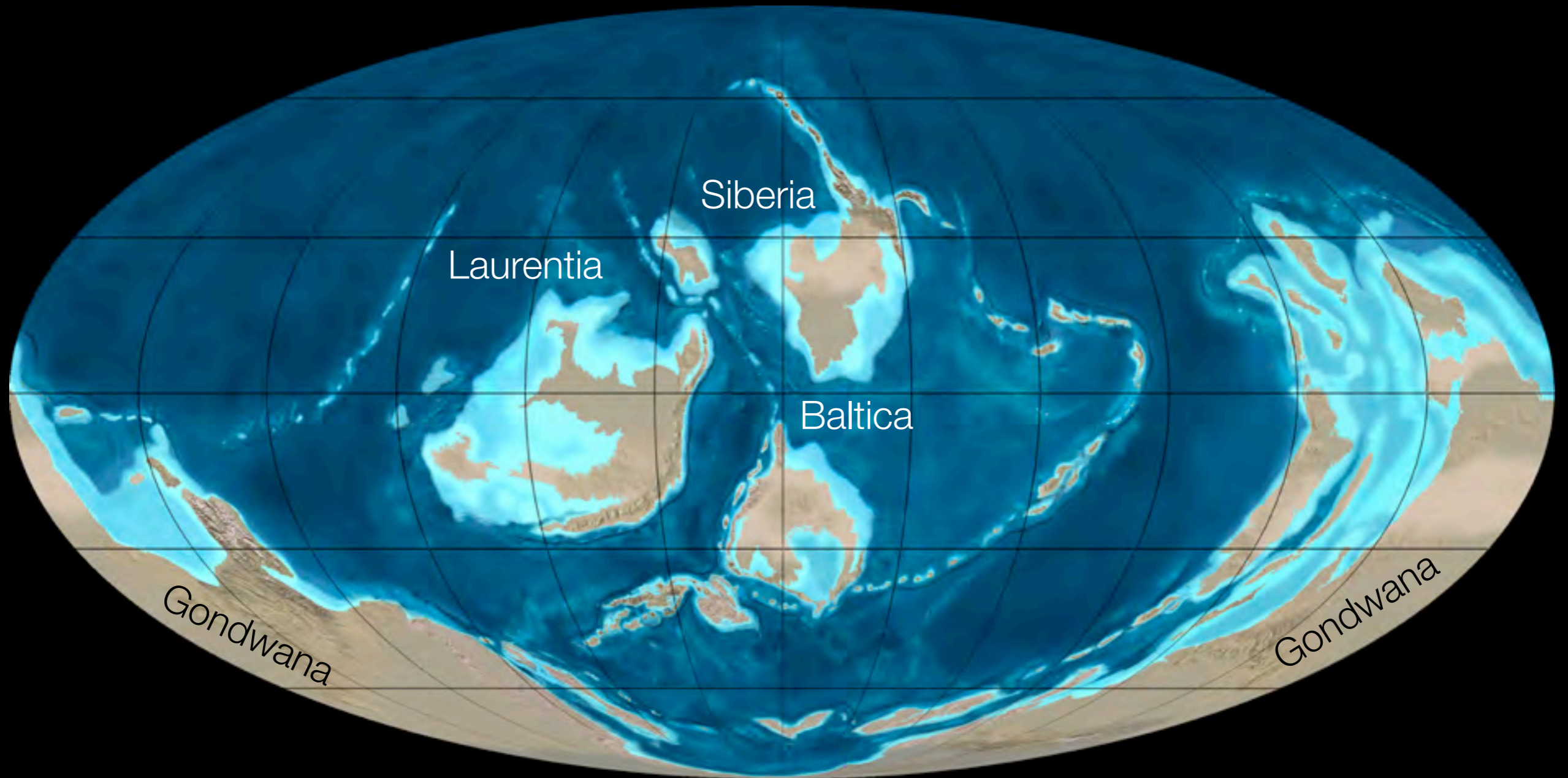
Late Ordovician glacial deposits in Morocco



Le Heron et al., 2010, *Sedimentary Geology*

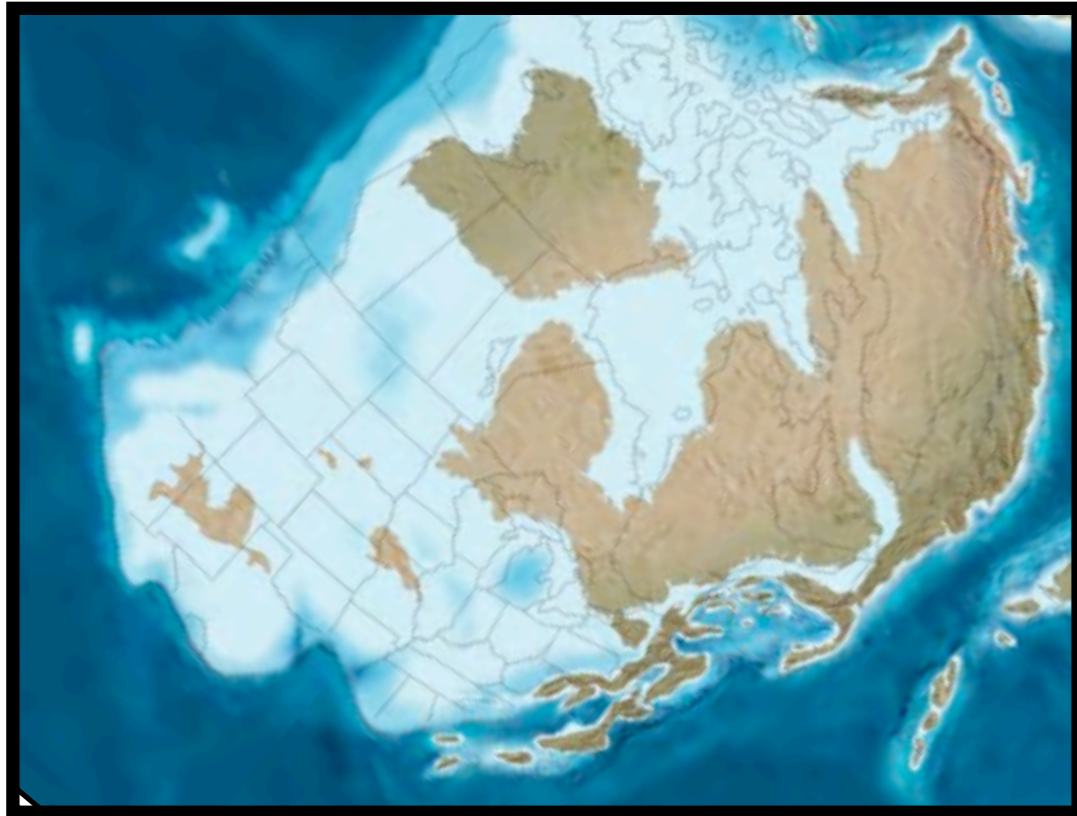
What caused cooling? Some ideas:

May have been caused by movement of Gondwana over the south pole...



modified after R. Blakey: <http://jan.ucc.nau.edu/~rcb7/450moll.jpg>

Or, increased chemical weathering of silicate rock due to Taconic mountain-building

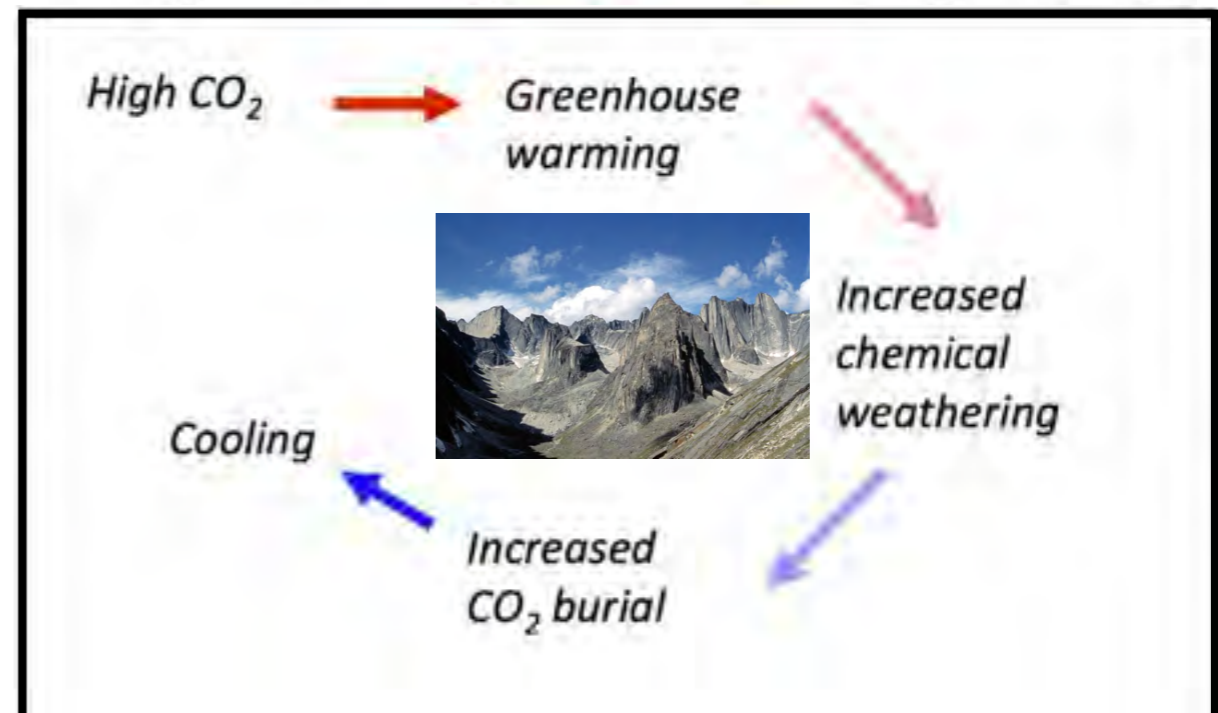


modified after R. Blakey: <http://jan.ucc.nau.edu/~rcb7/450moll.jpg>



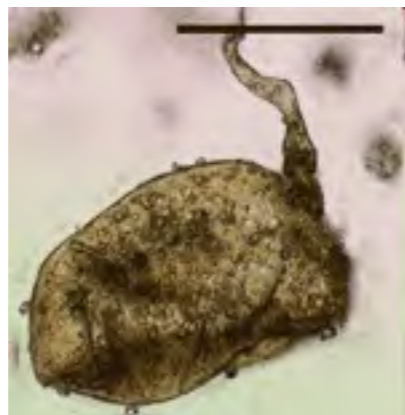
<http://images.summitpost.org/original/499686.jpg>

The silicate weathering feedback:



Or, increased chemical weathering of continental silicate rocks by early terrestrial ecosystems

Late Ordovician moss and fungal spores



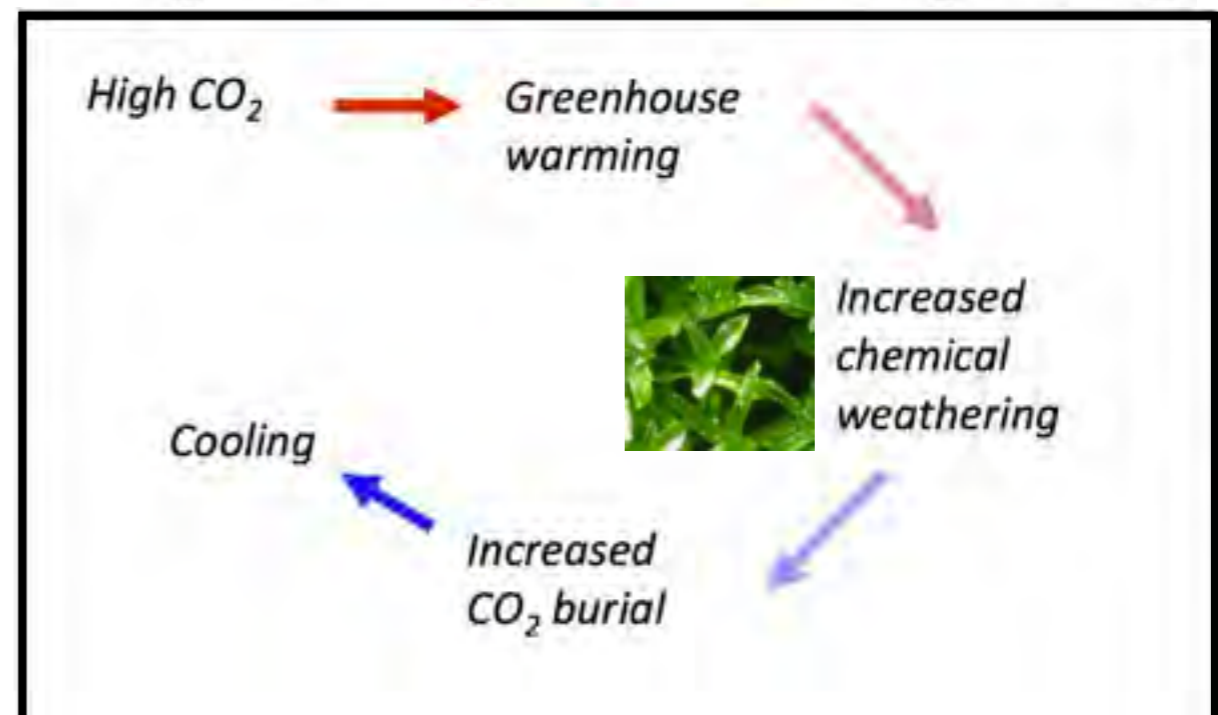
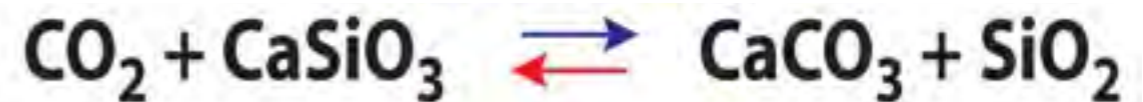
<http://www.shef.ac.uk/content/1/c6/03/41/74/wellman-research-pic-dec-07.jpg>

[Science. 2000 Sep 15;289\(5486\):1884-5.](http://www.sciencemag.org/content/289/5486/1884-5)

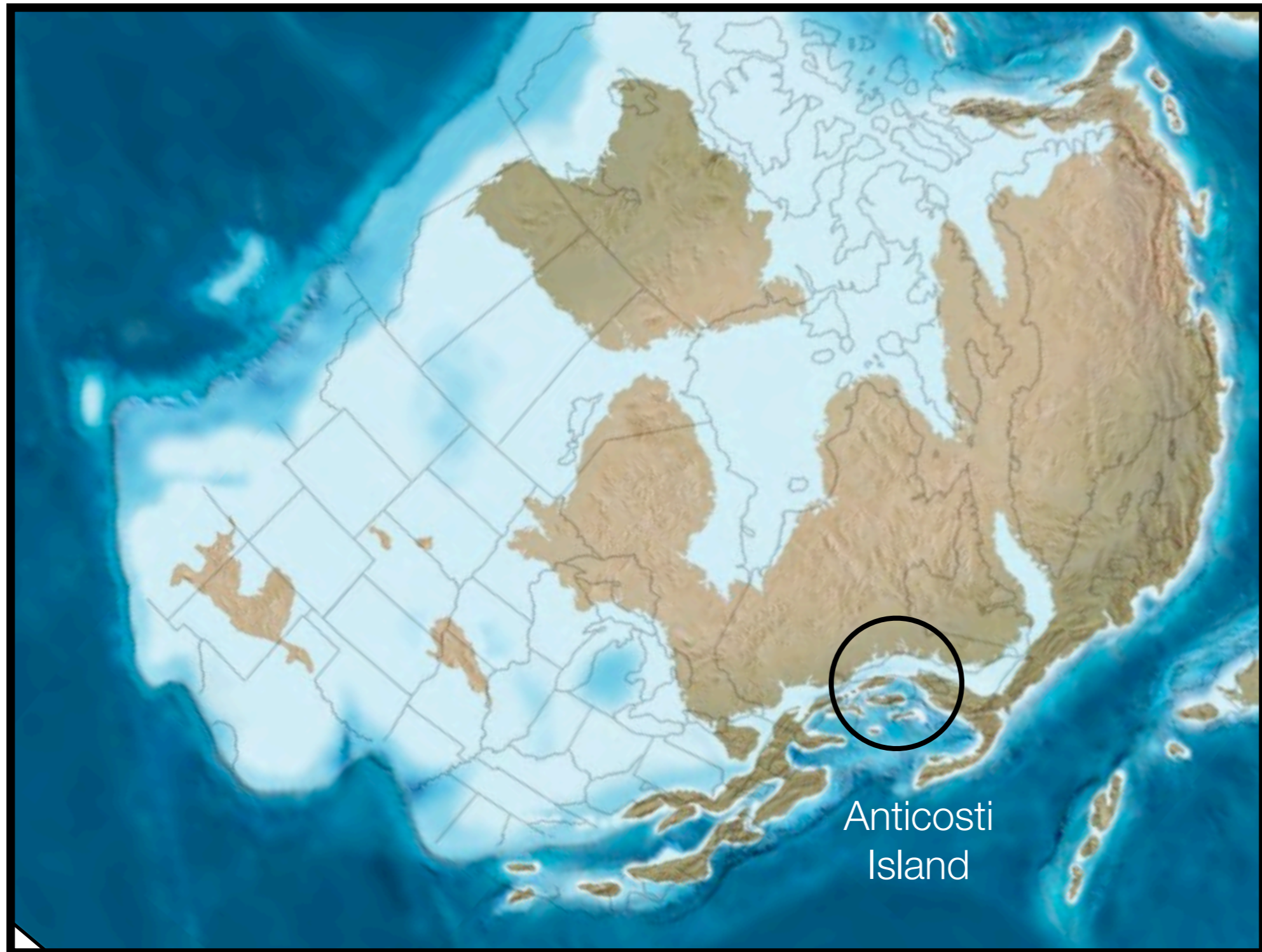


Physcomitrella patens is a species of moss, which is a basal lineage of land plants. Credit: JGI/US Department of Energy

The silicate weathering feedback:

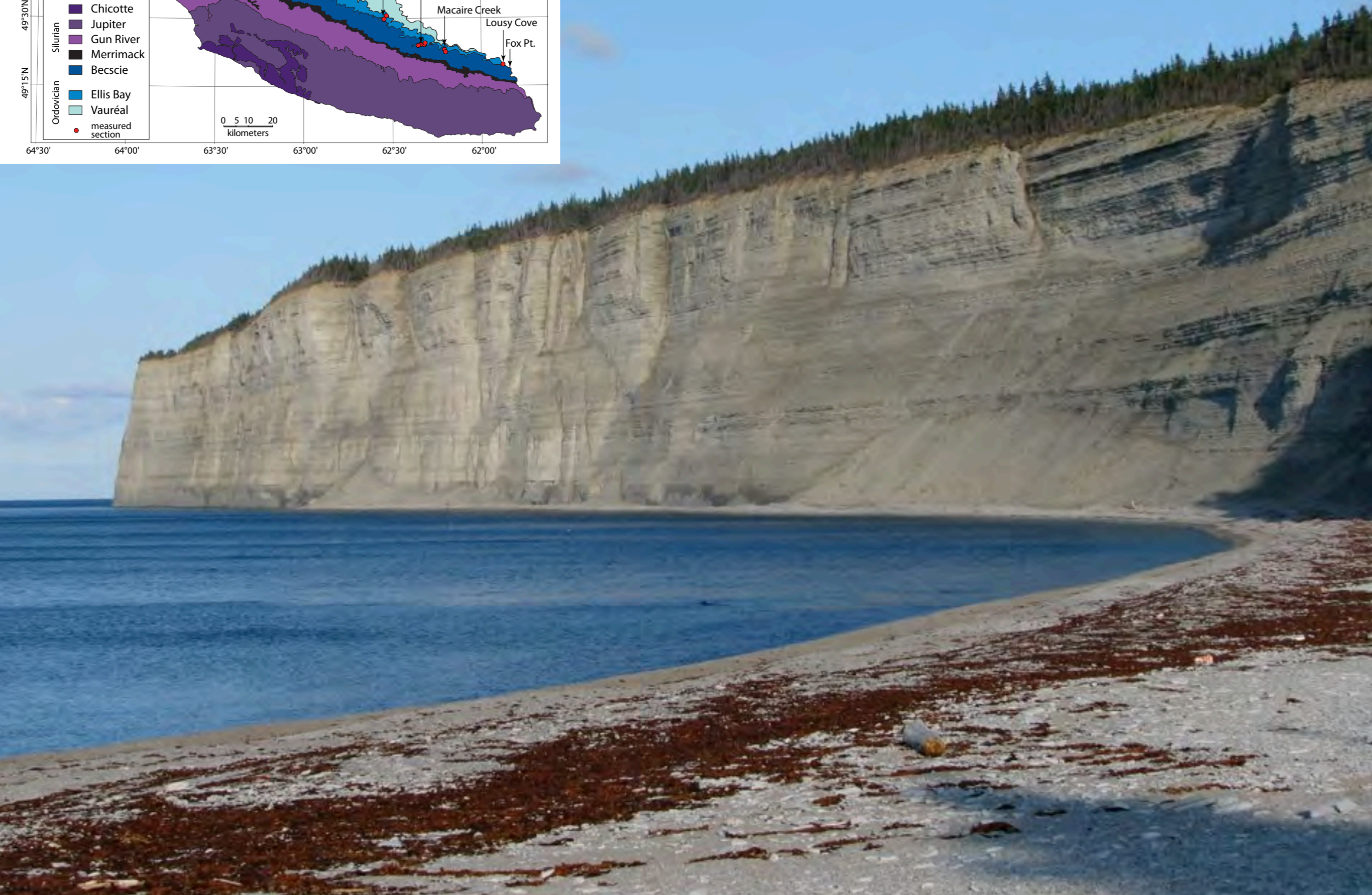
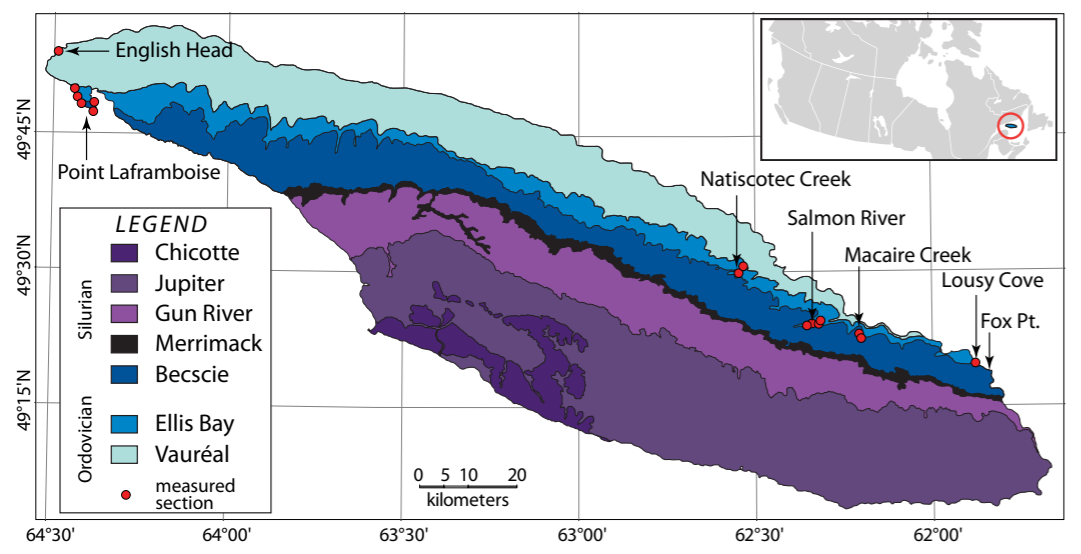


Late Ordovician North America (Laurentia)



modified after R. Blakey: <http://jan.ucc.nau.edu/~rcb7/450moll.jpg>

Baie des Homards



Vauréal Canyon





Gun River Fm.



Ellis Bay Fm.

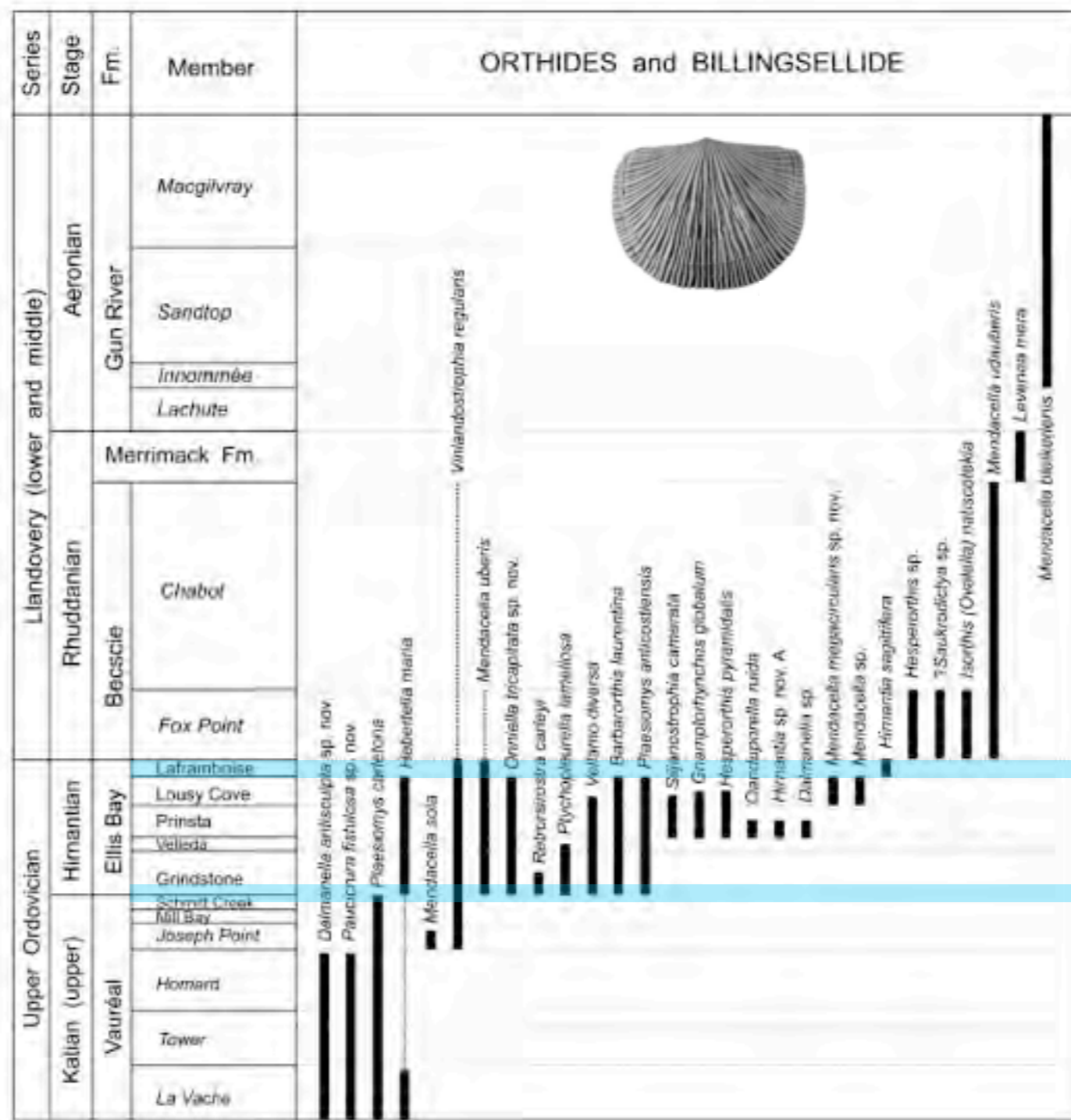


Becscie Fm.



Vauréal Fm.

Stratigraphic ranges of orthide brachiopods on Anticosti



Laframboise Mbr.,
Ellis Bay Fm.

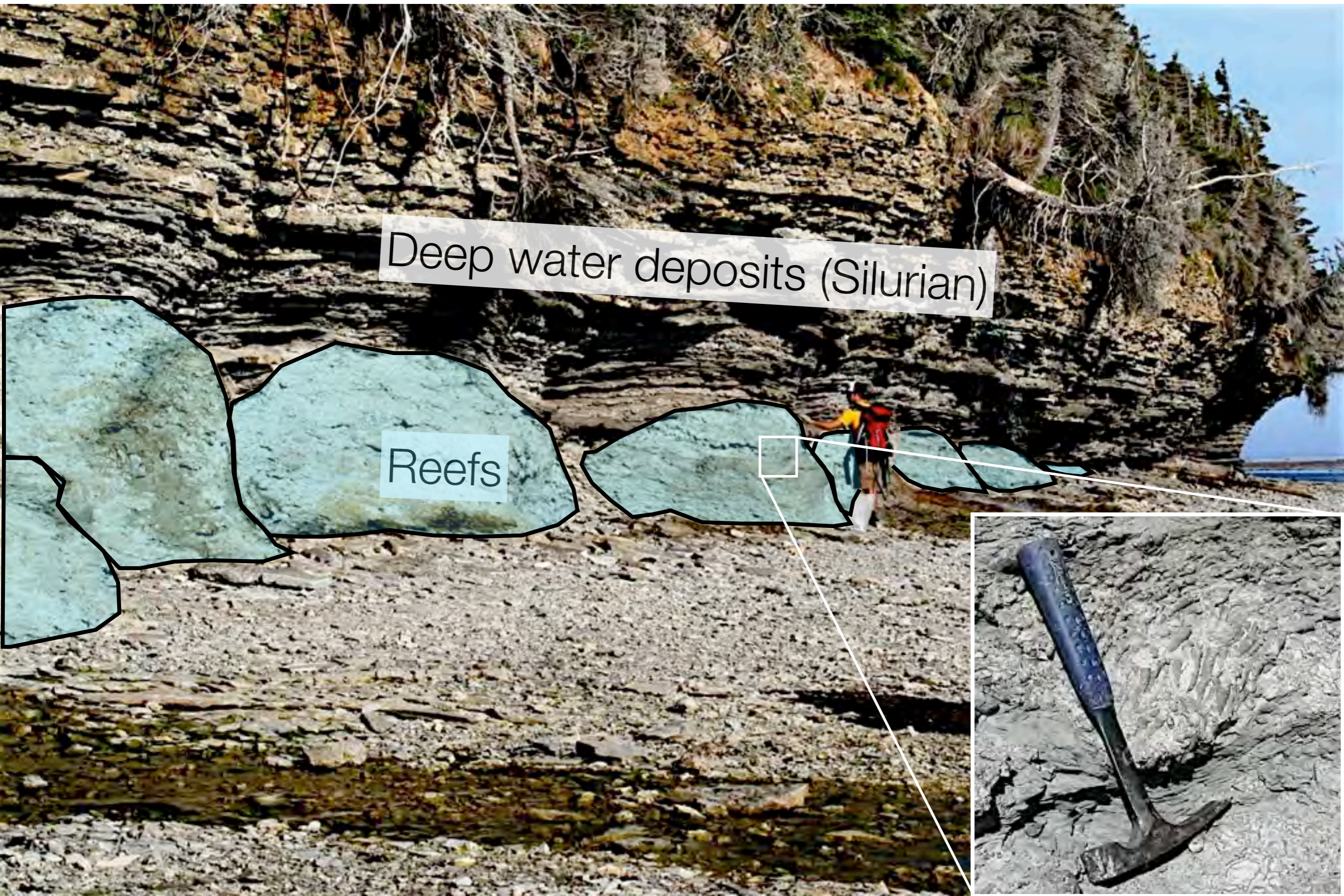
Western Anticosti: Pt. Laframboise

Shallow-water
deposits

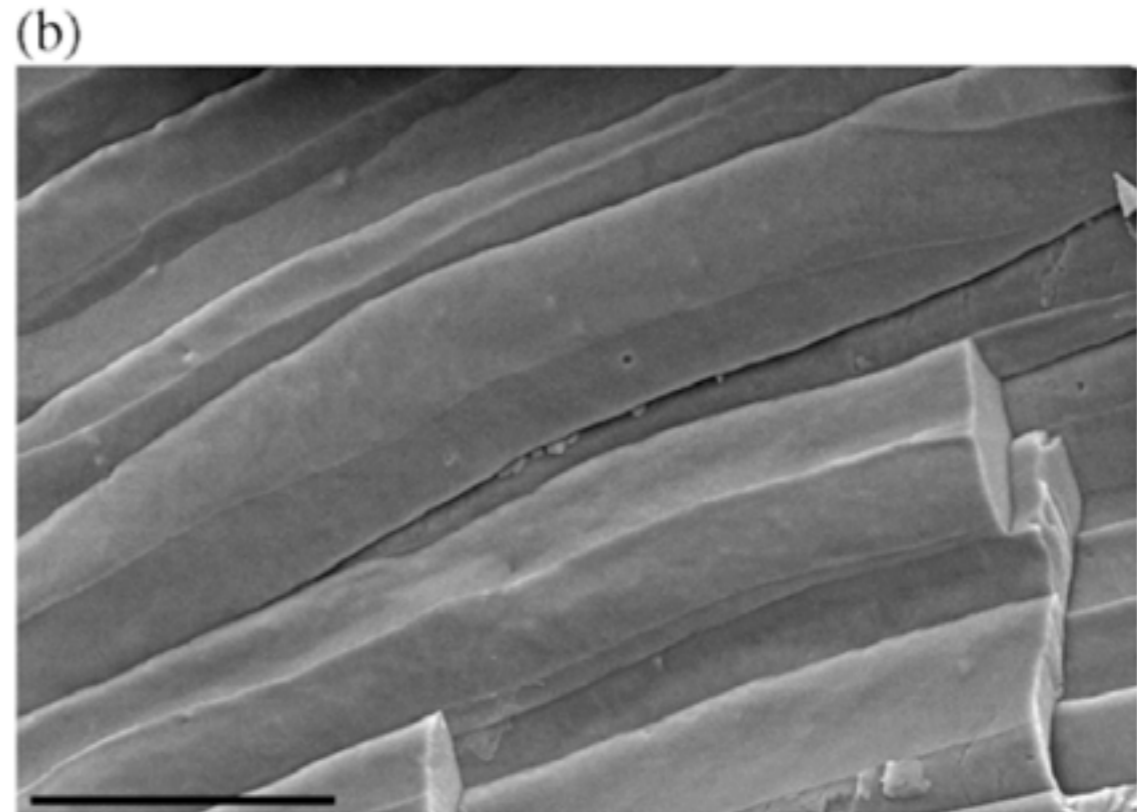
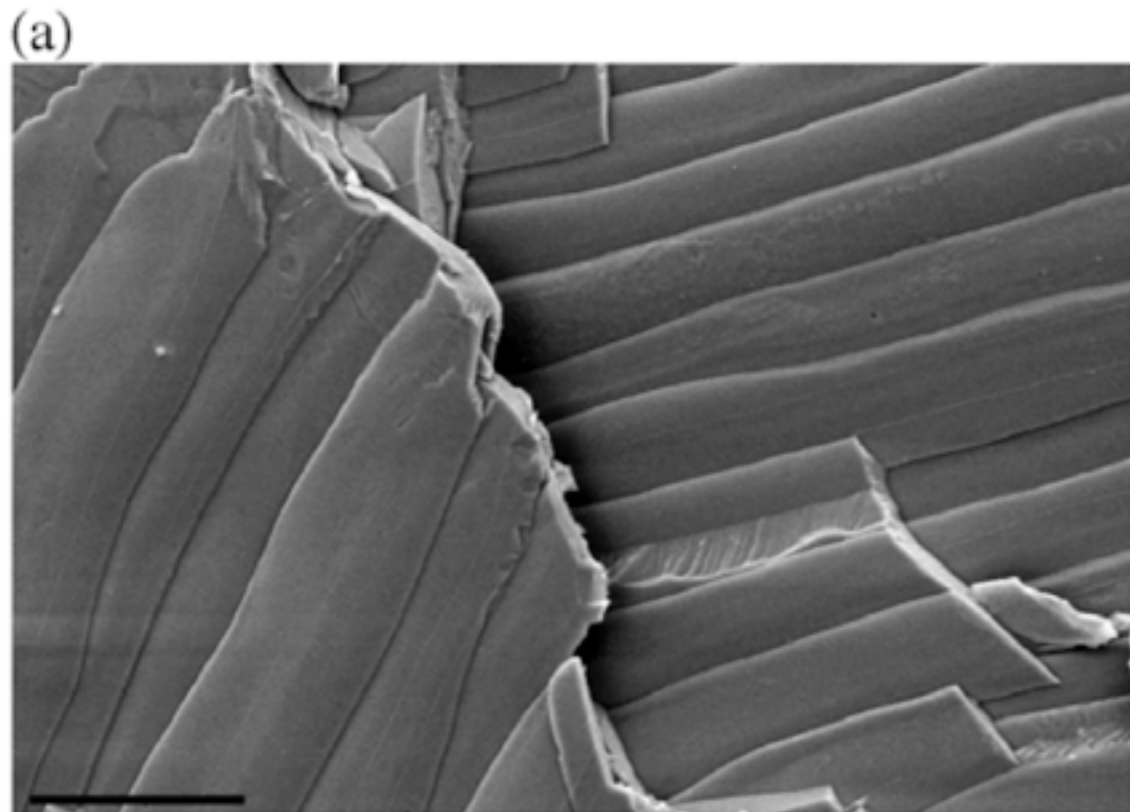
Deep-water
deposits



Western Anticosti: Pt. Laframboise



CaCO₃ shells
record the
chemistry of the
water in which
they grew...



Stable isotope ratios in fossil shells

- Isotopes of an element vary in number of neutrons, but have a fixed number of protons and electrons
- Isotopes have identical chemical interactions, but are often sorted by mass

carbon-12



^{12}C

6 protons
6 neutrons

light

carbon-13



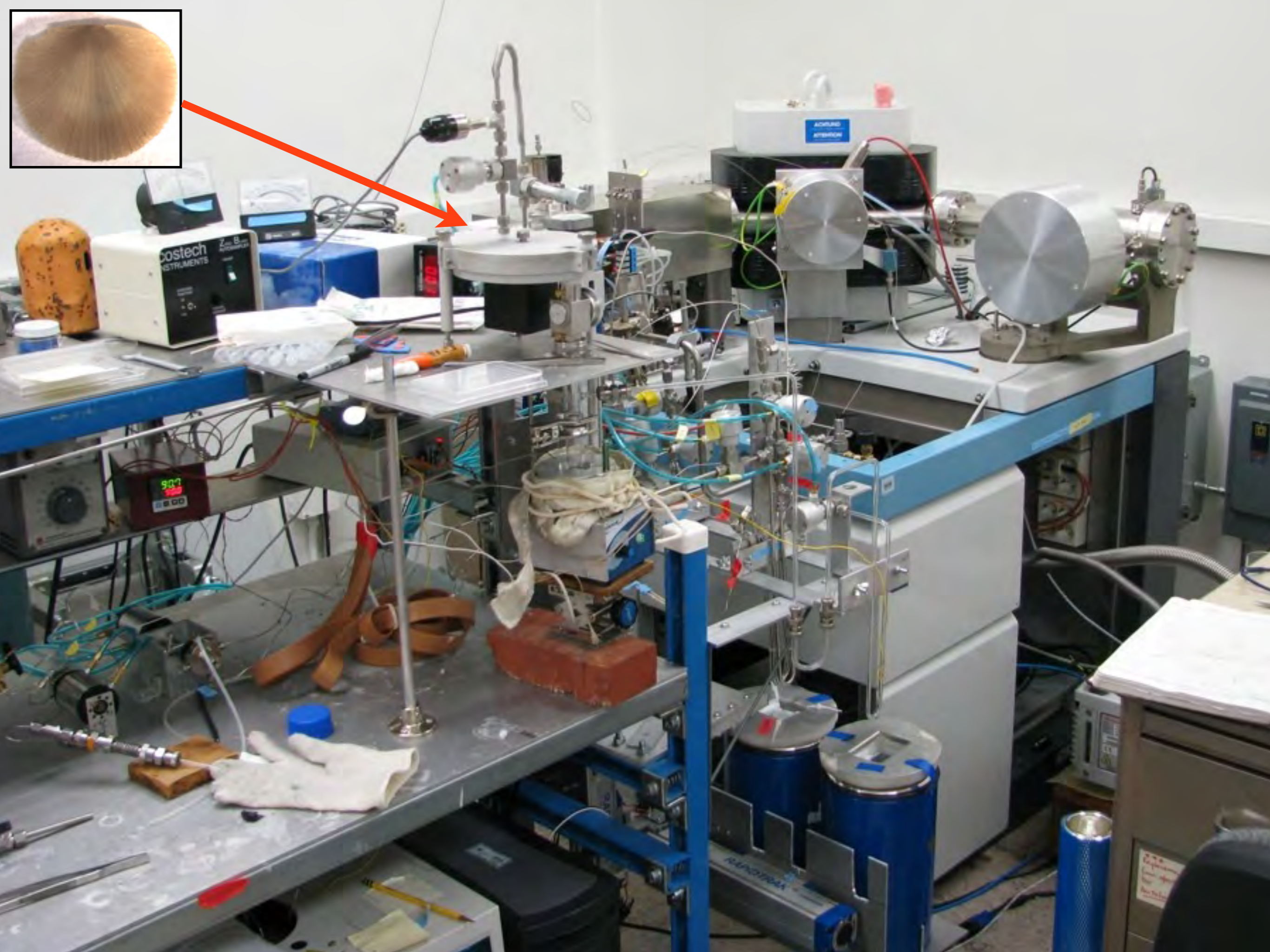
^{13}C

6 protons
7 neutrons

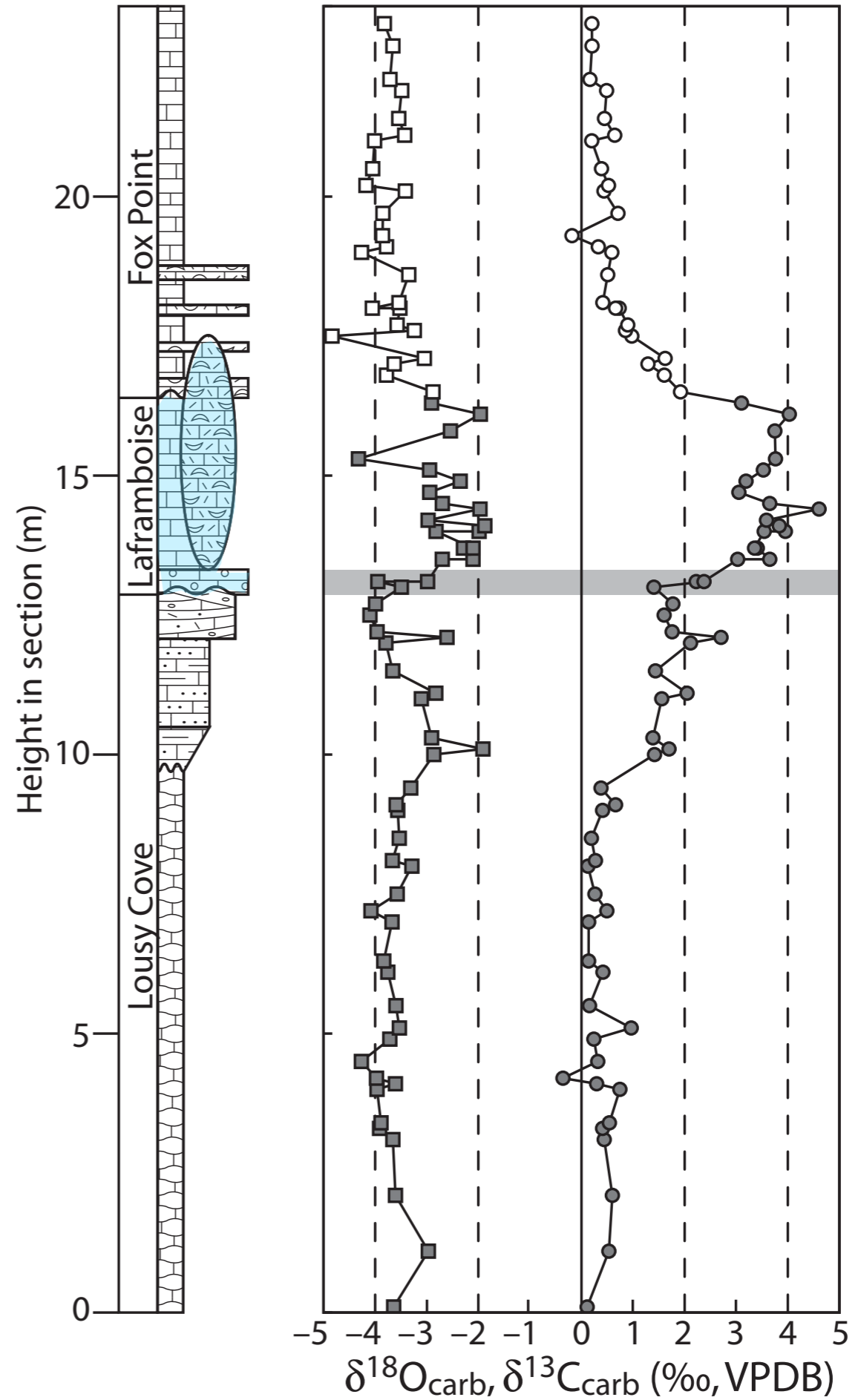
heavy

$\delta^{13}\text{C}$: ratio of ^{13}C to ^{12}C , provides information about changes in **carbon cycle**

$\delta^{18}\text{O}$: ratio of ^{18}O to ^{16}O , provides information about changes in **climate**

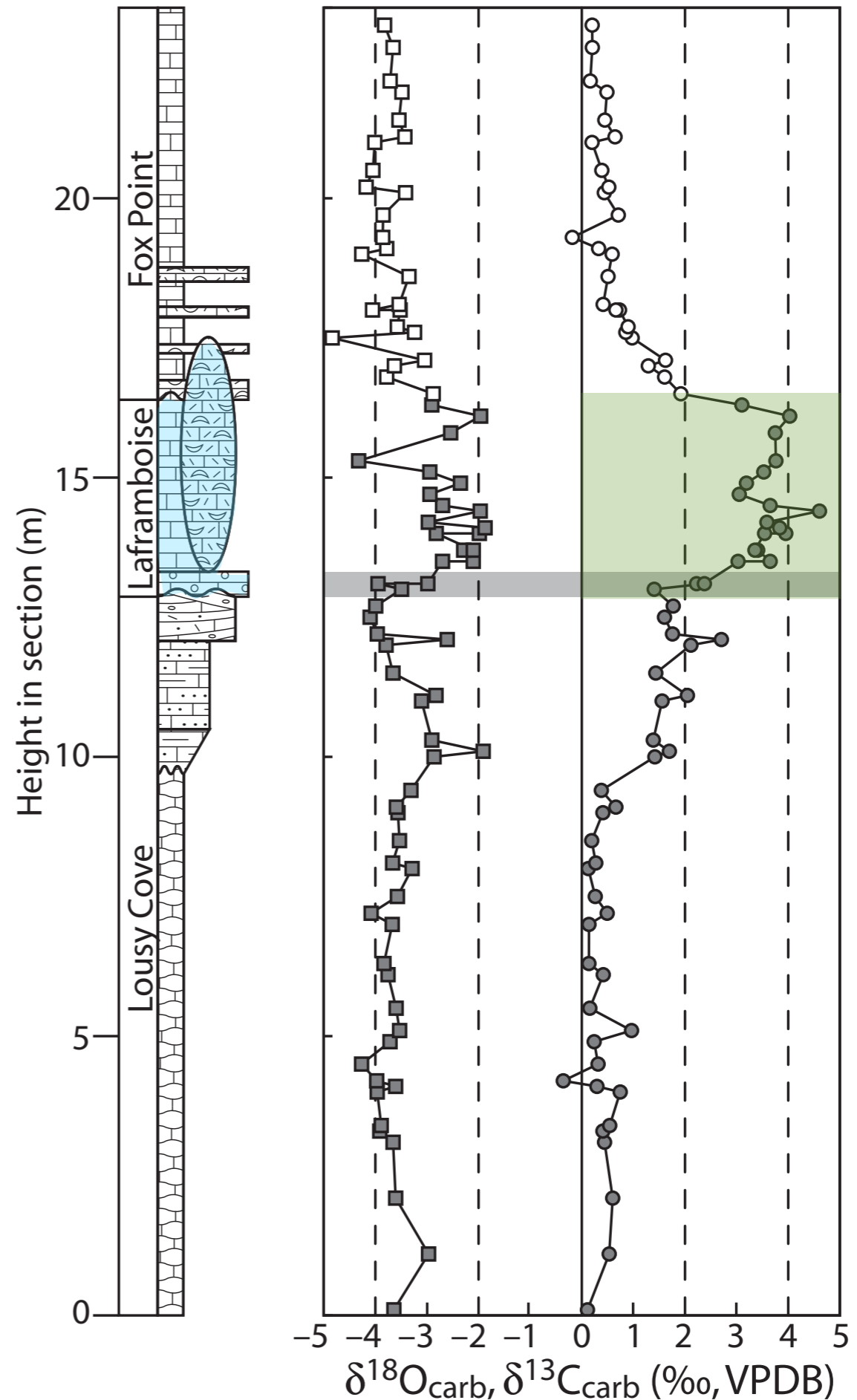


Pt. Laframboise: $\delta^{13}\text{C}$, $\delta^{18}\text{O}$



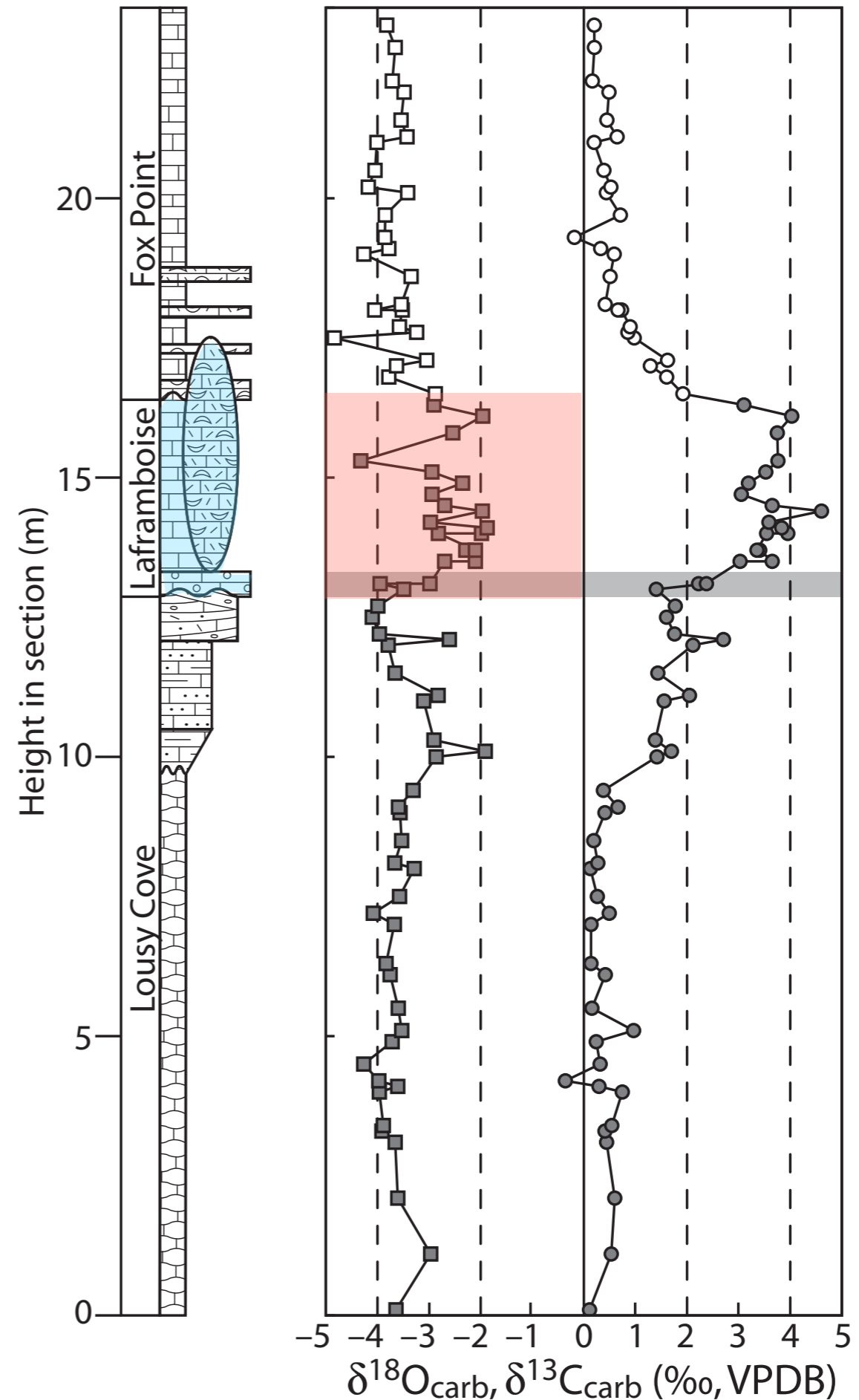
$\delta^{13}\text{C}$ is controlled by global organic carbon burial

- Enhanced upwelling, productivity and organic carbon burial?
- Decreased organic carbon oxidation rate?
- Weathering of exposed carbonate rocks?

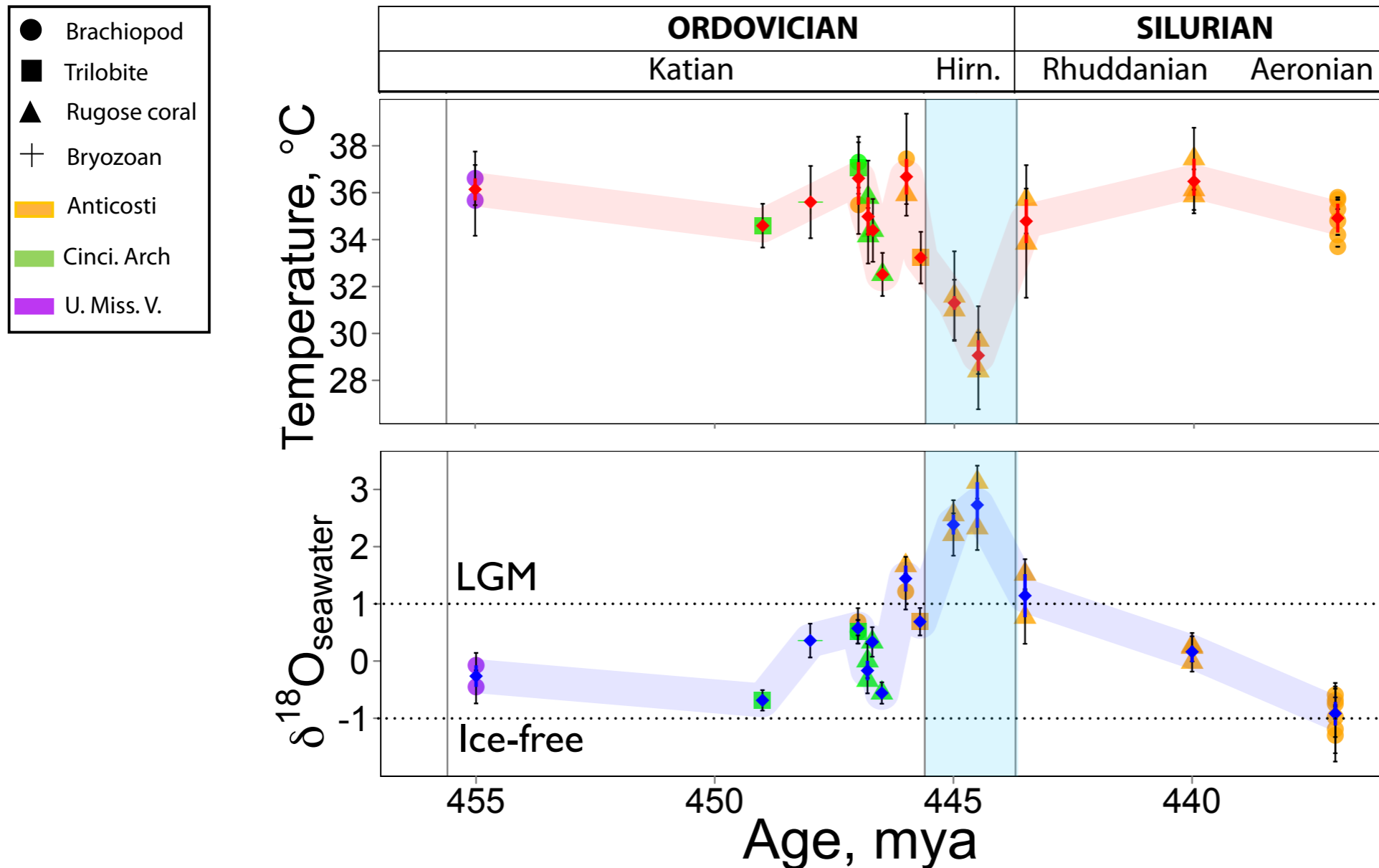


$\delta^{18}\text{O}$ is controlled by both **local** temperature and **global** ice volume

- Increased glaciation of the poles?
- Cooling of the tropics?
- Both?

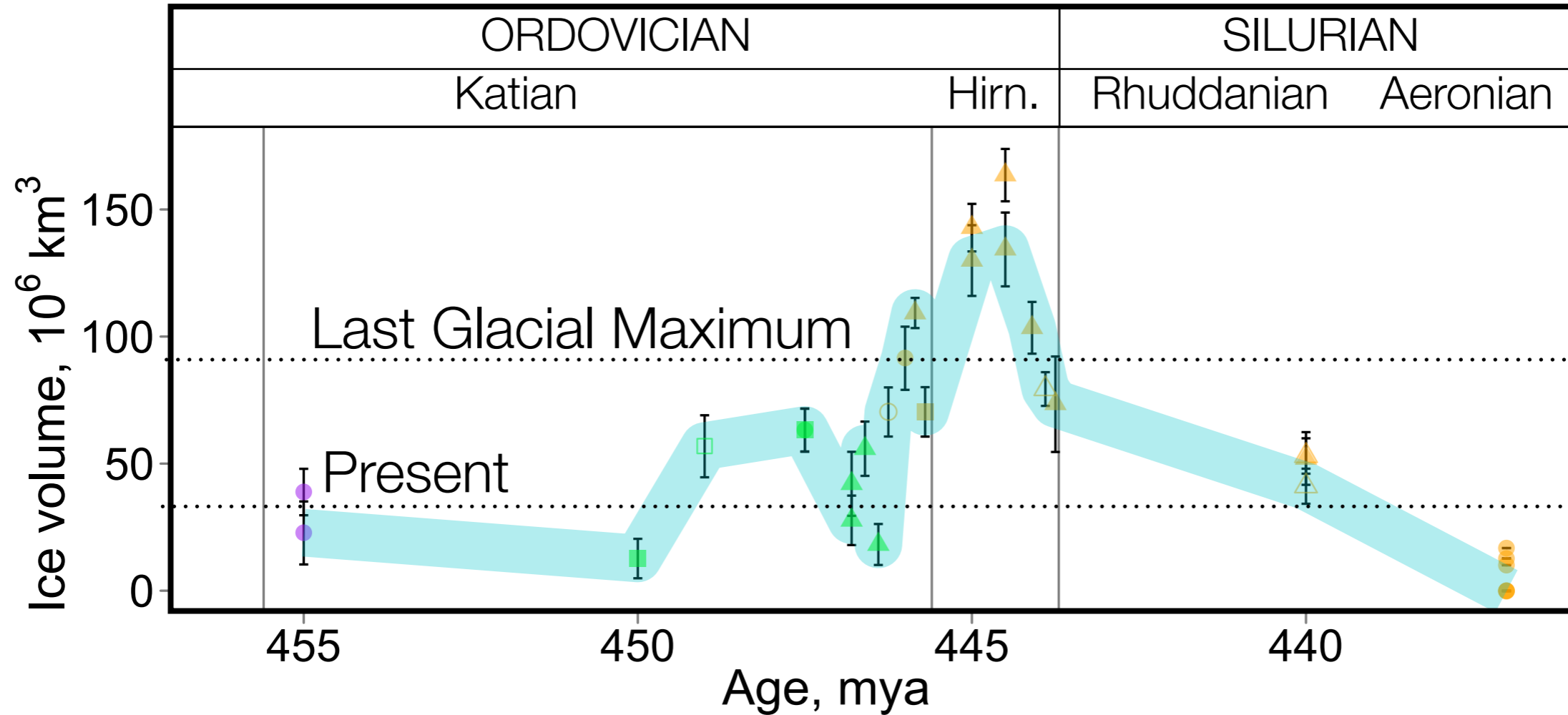


Temperature and seawater $\delta^{18}\text{O}$ trends from “clumped” isotope paleothermometry

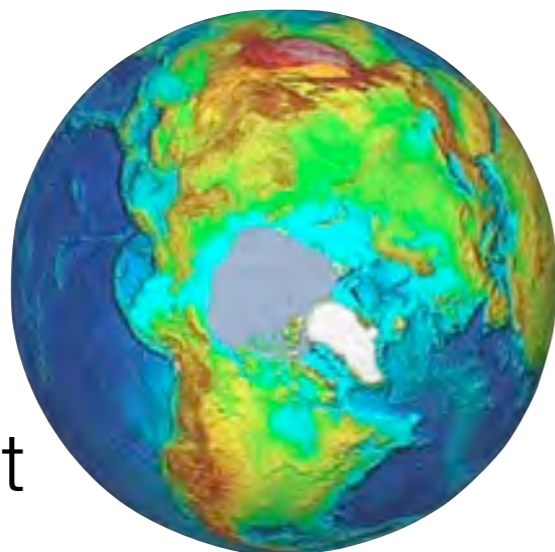


Results: Inferred Ice Volumes*

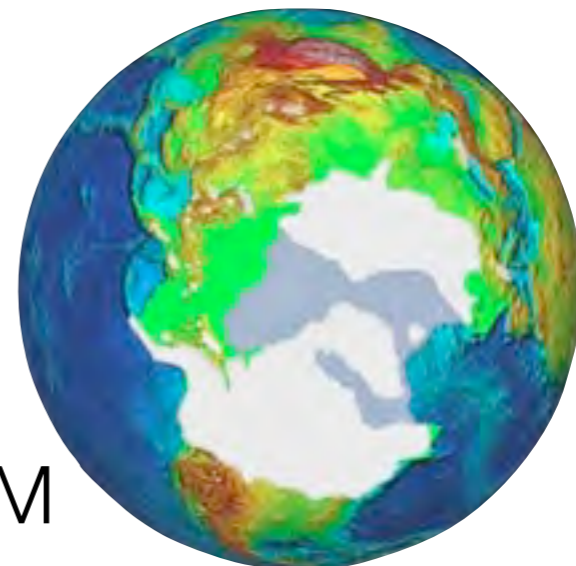
*Assuming mean $\delta^{18}\text{O}_{\text{ice}}$ equivalent to Last Glacial Maximum



Present



LGM

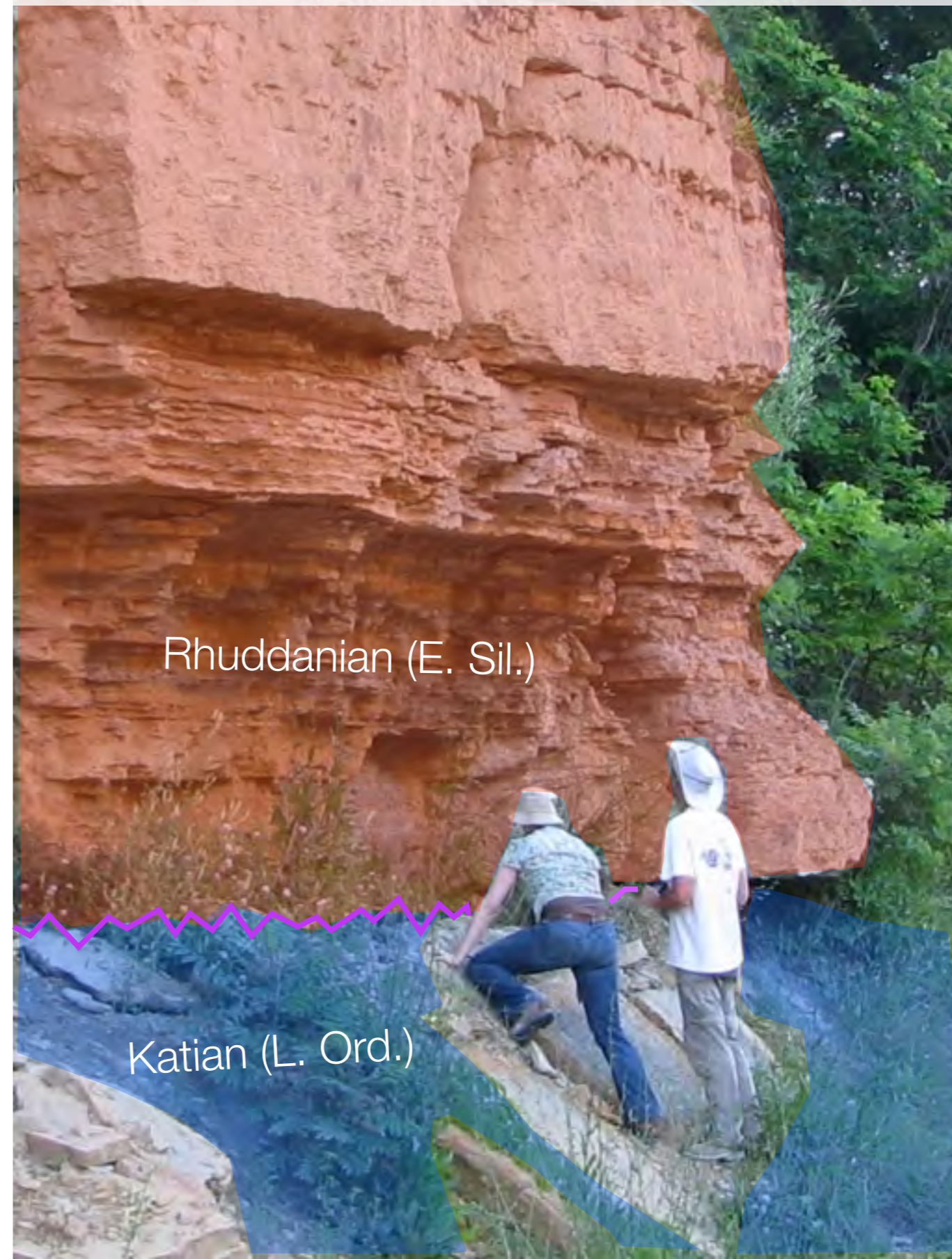


Ordovician-Silurian boundary sections

Atypical: Anticosti Island



Typical: Kentucky



Build-up of glaciers on land drains shallow marine habitats



San Francisco Bay 18,000 years ago

Image courtesy Lynn Ingram

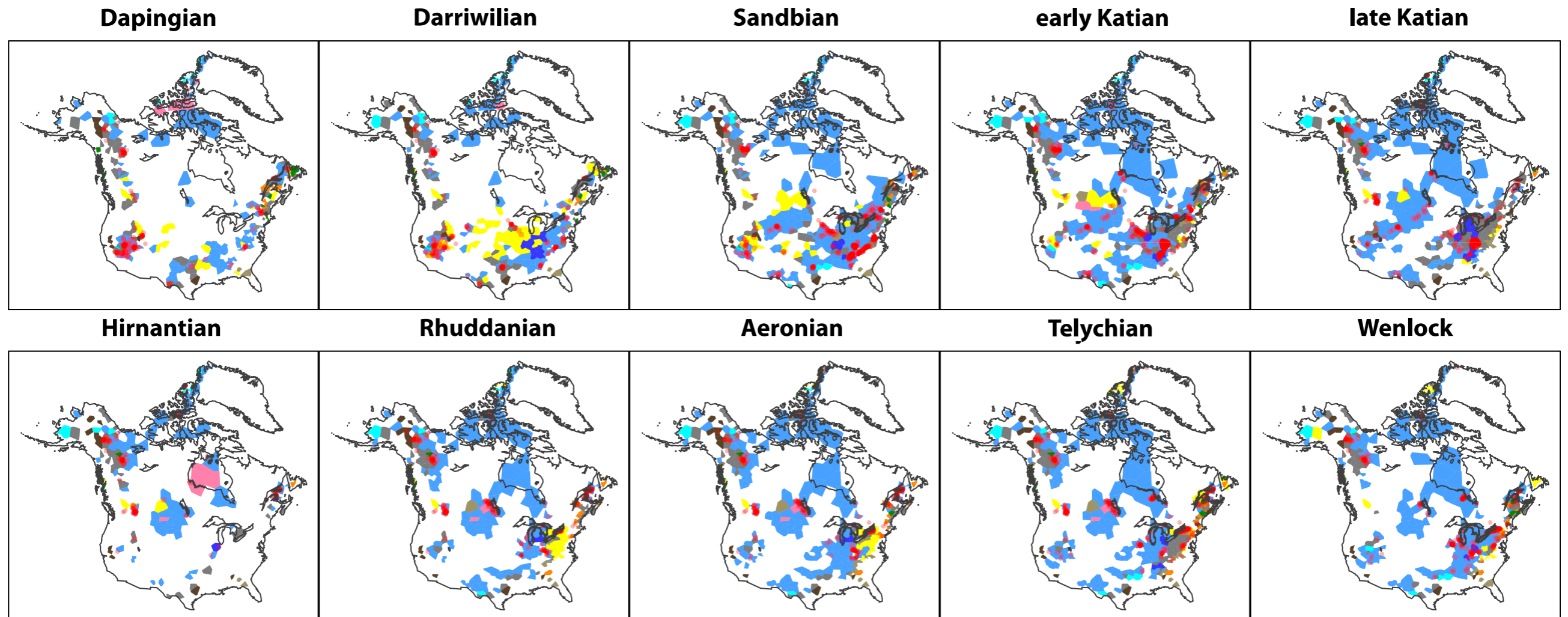
Sedimentary rocks record changes in continental flooding through time










Late Ordovician-Early Silurian sedimentary rocks and fossil collections in Laurentia

 Gap-bound sedimentary packages from Macrostrat (Peters, 2005)

 Fossil occurrences from PBDB (Alroy et al, 2008)



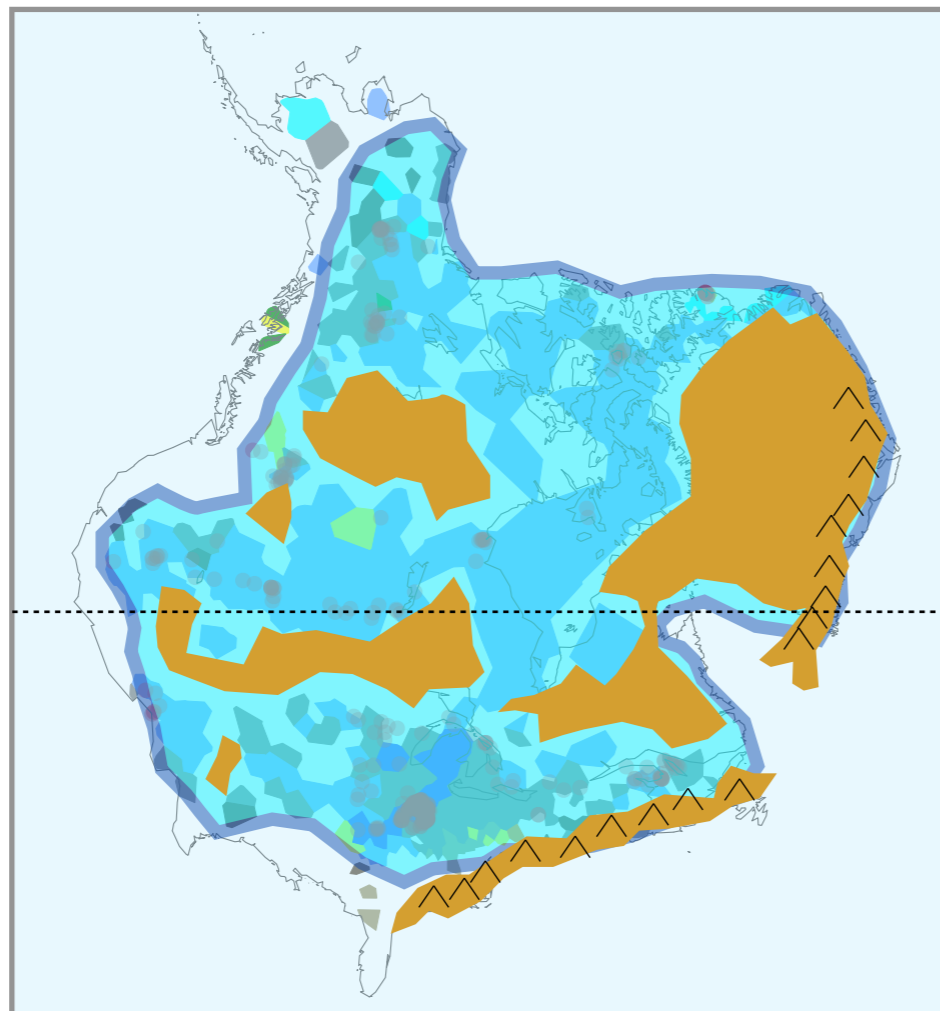
 Sandstone	 Mixed carbonate-clastic	 Chert
 Mixed clastic	 Carbonate	
 Fine clastic	 Evaporite	

Draining of shallow tropical seaways

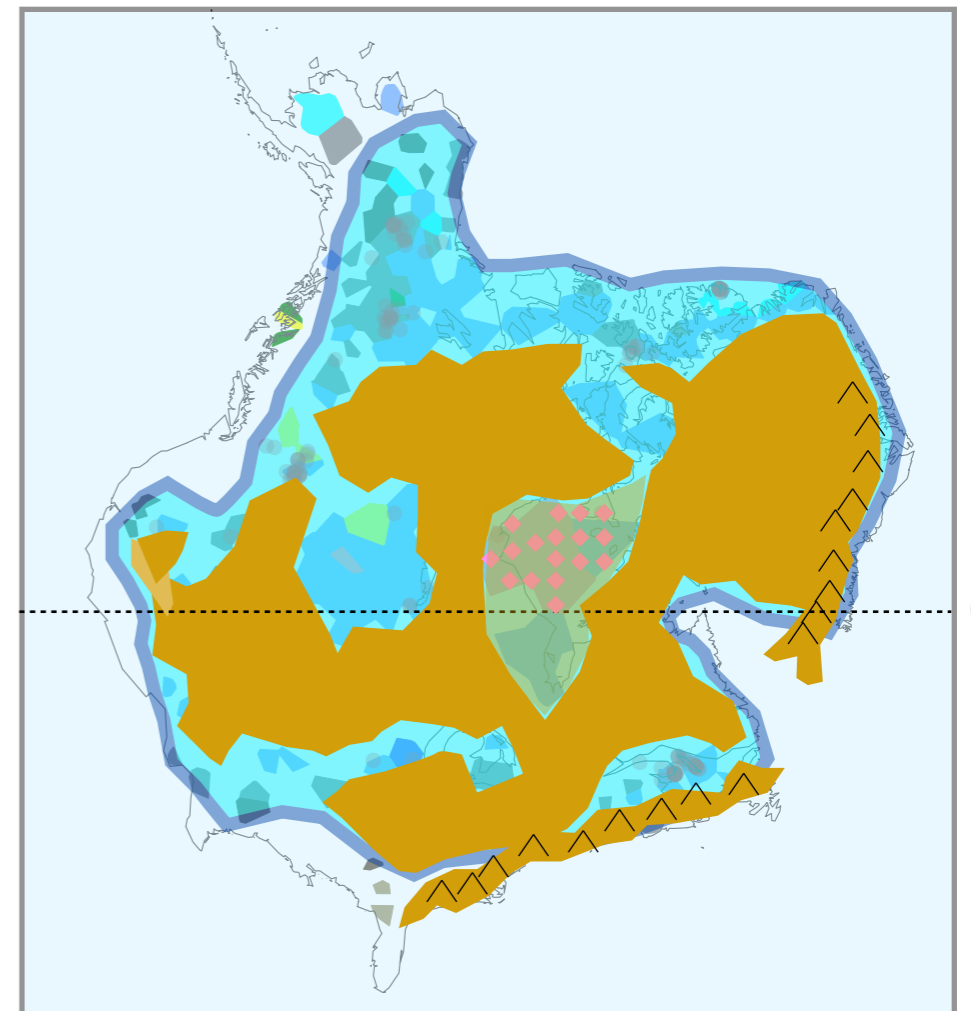
late Katian

Hirnantian

- Shallow ocean
- Exposed land
- Salt basin
- Open ocean



0°



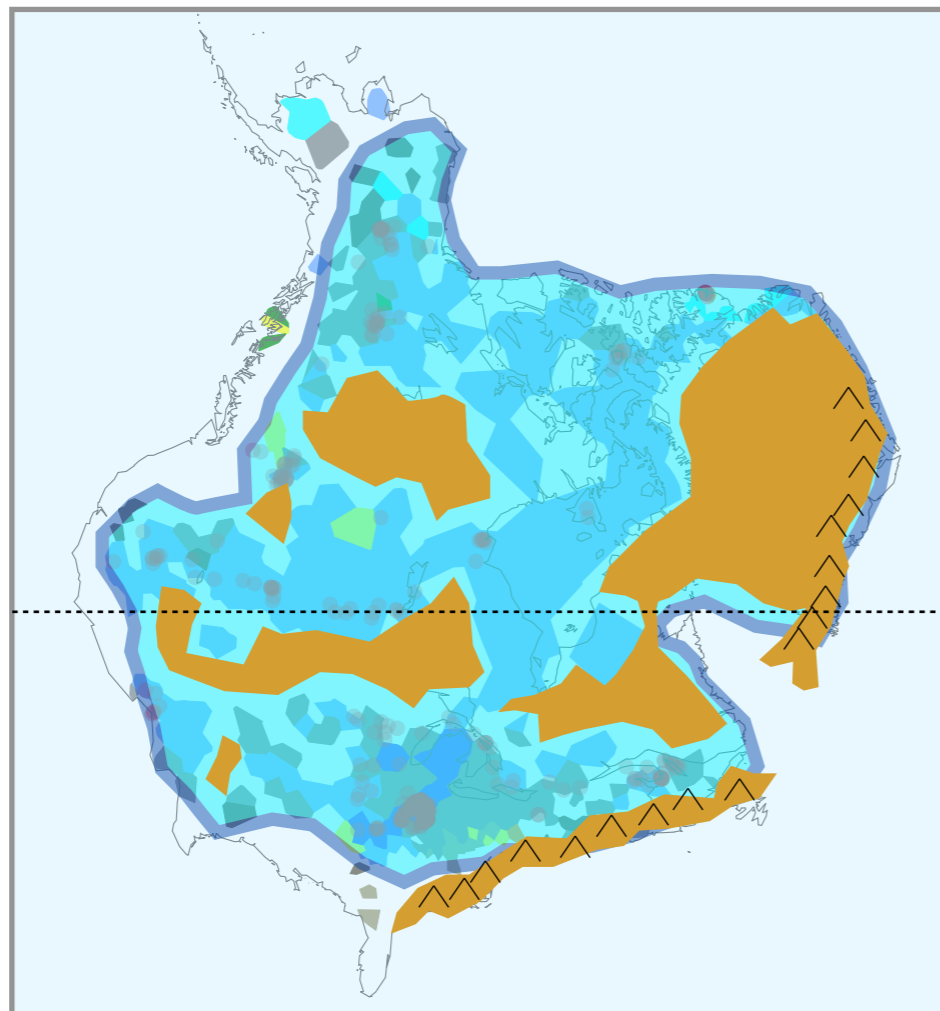
0°

Draining of shallow tropical seaways

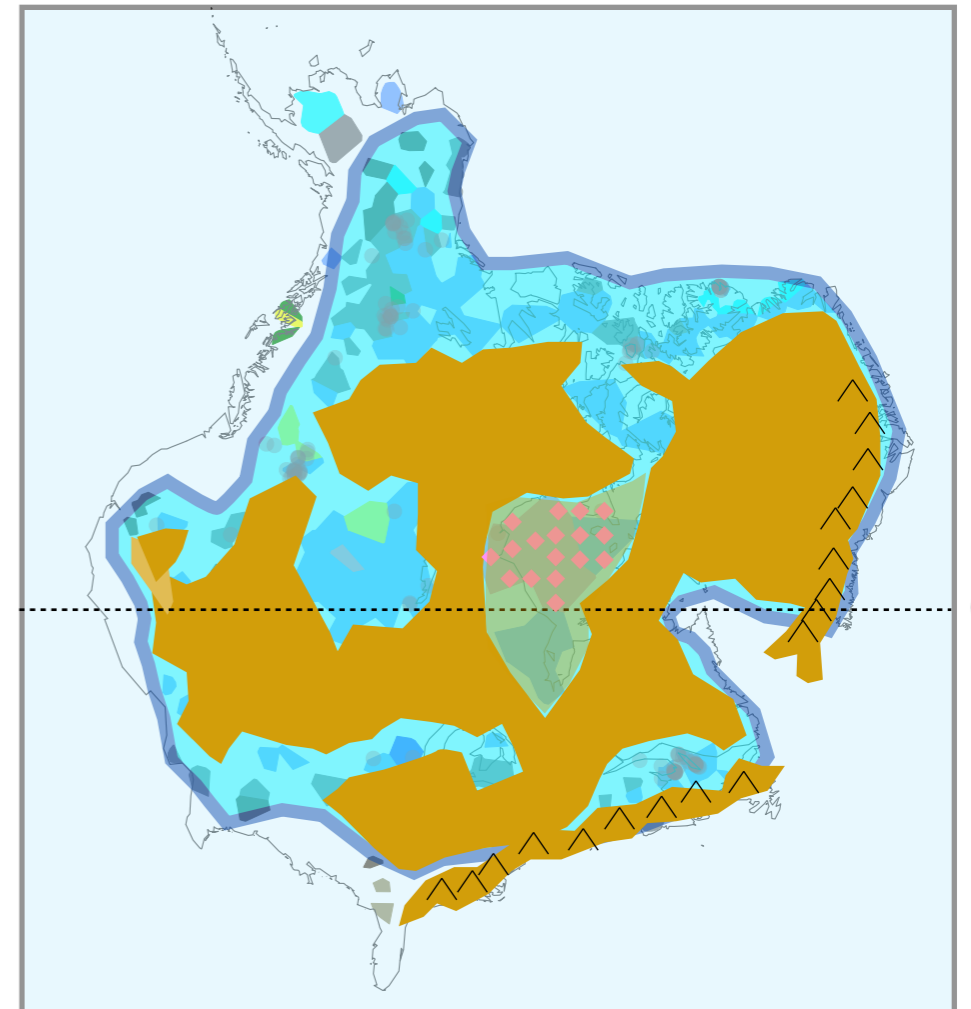
late Katian

Hirnantian

- Shallow ocean
- Exposed land
- Salt basin
- Open ocean



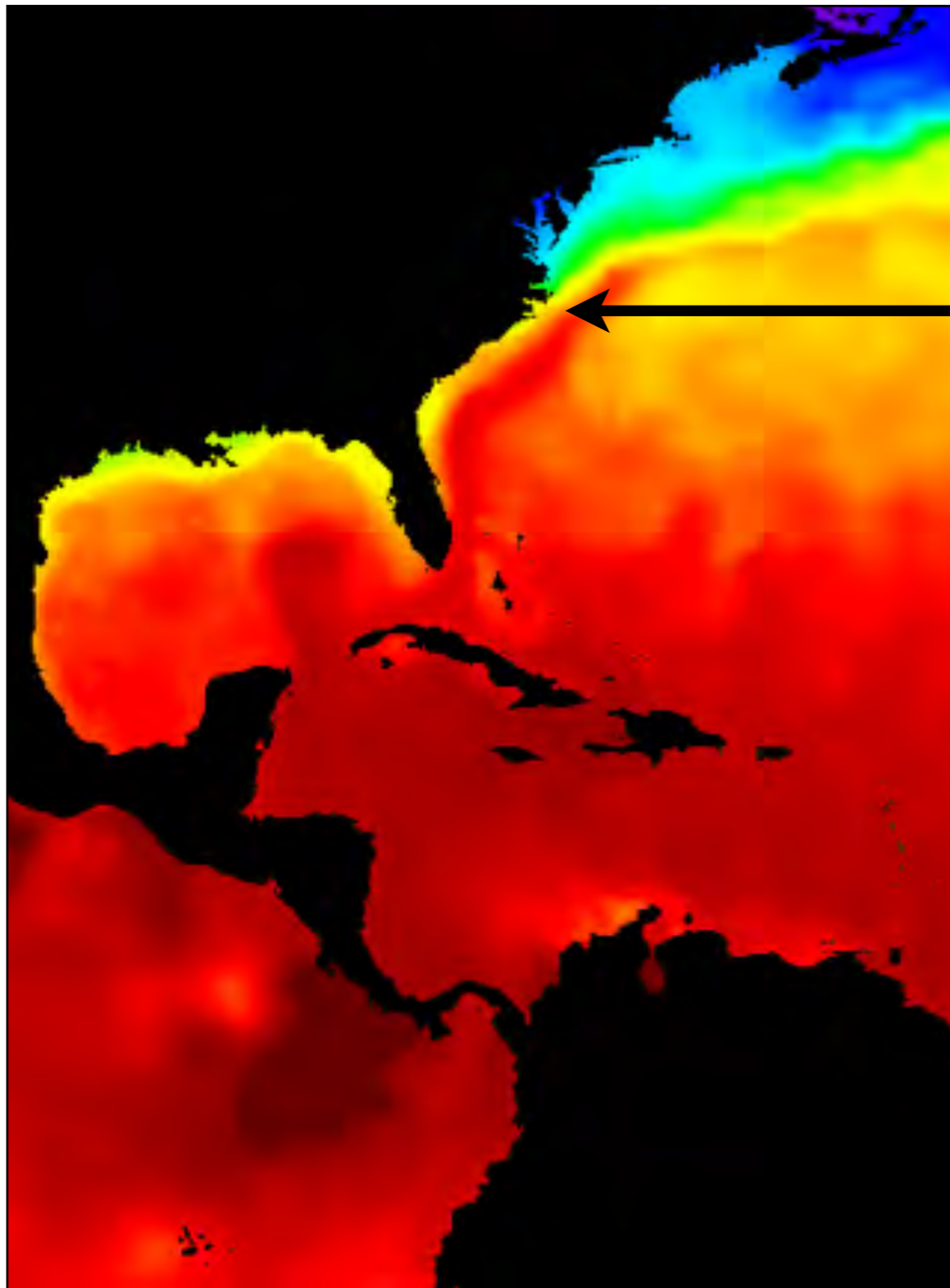
0°



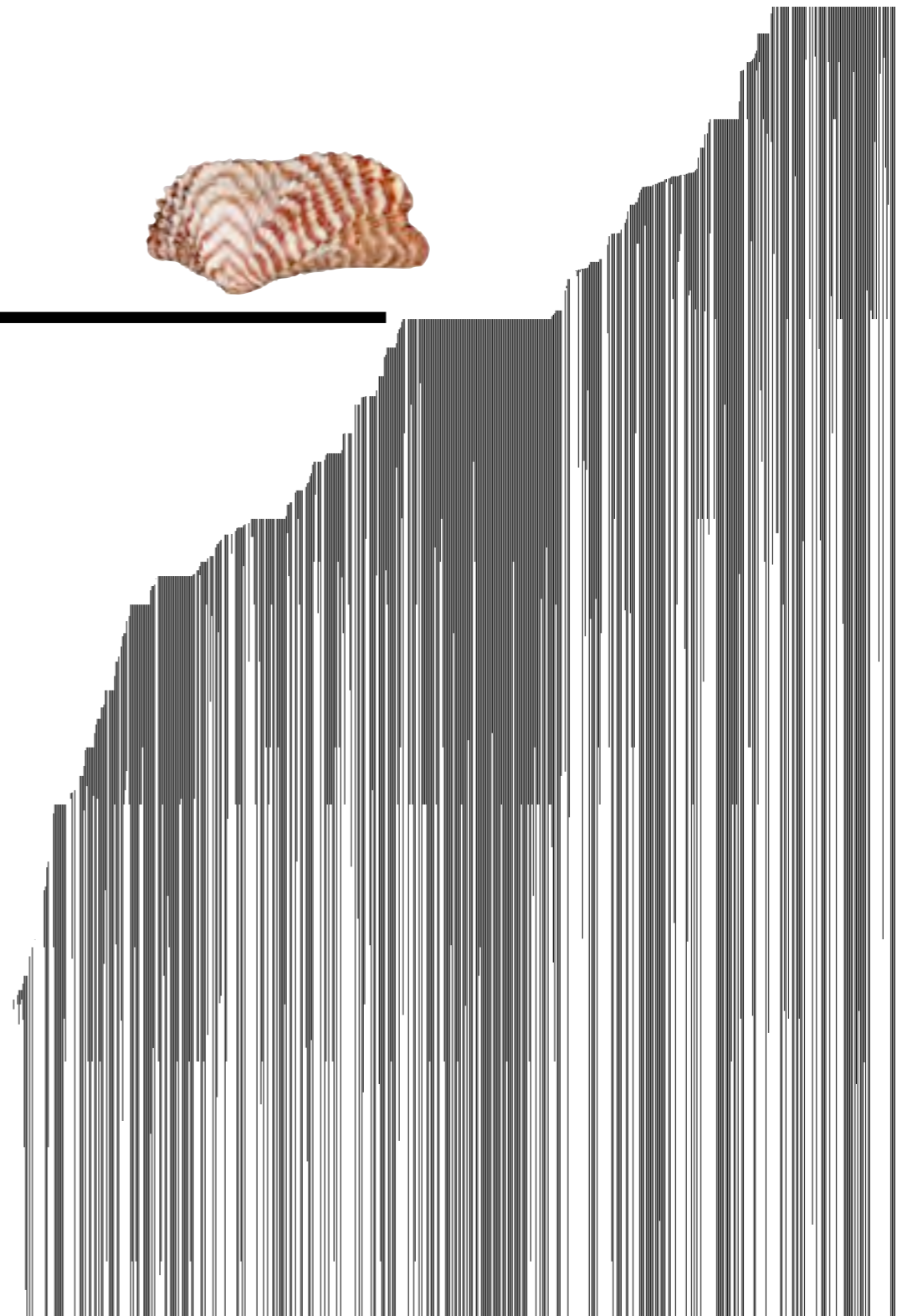
0°

Hypothesis: genera that had large areas of their Late Ordovician geographic ranges drained should have experienced exceptionally high extinction rates

Ranges reflect interaction of climate and geography



Mean sea surface temperature

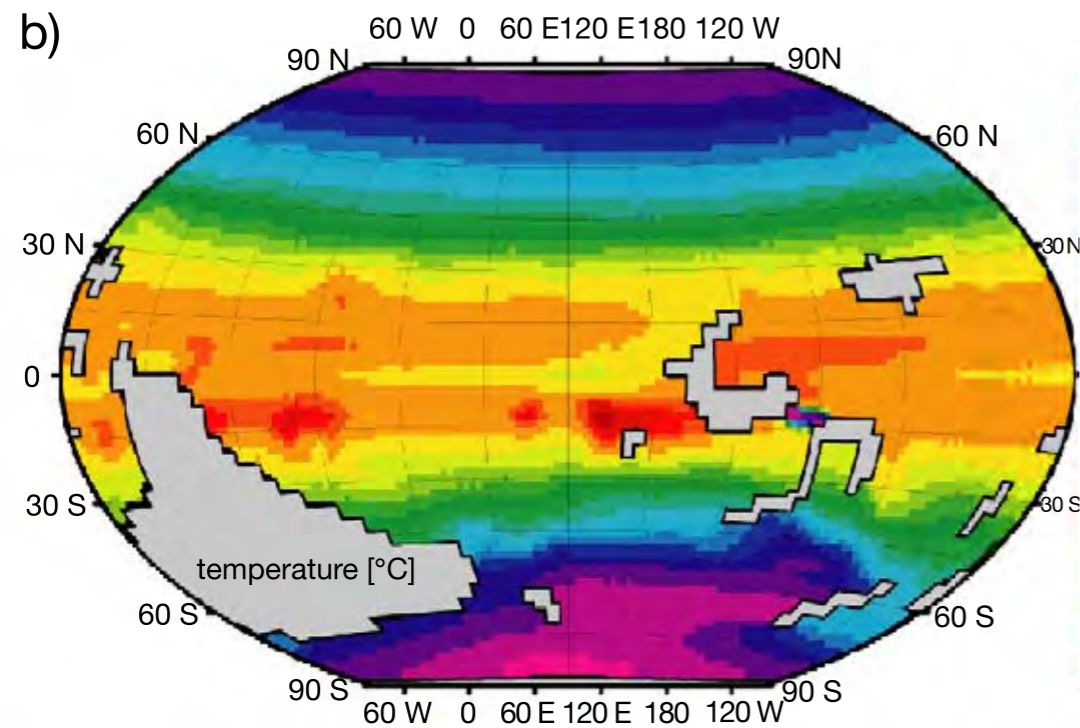


Bivalve species latitudinal ranges

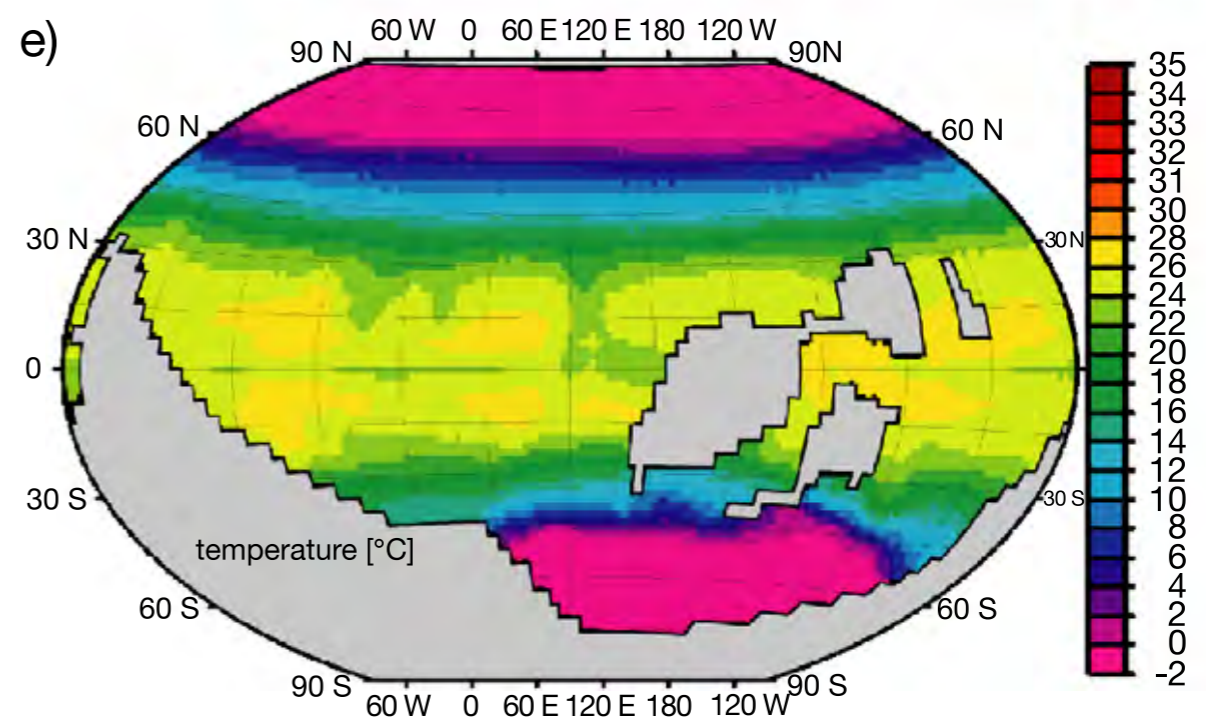
Changing temperatures would have imposed additional stresses on genera with limited thermal tolerance

Modeled Late Ordovician sea surface temperatures

Before glaciation



During glaciation

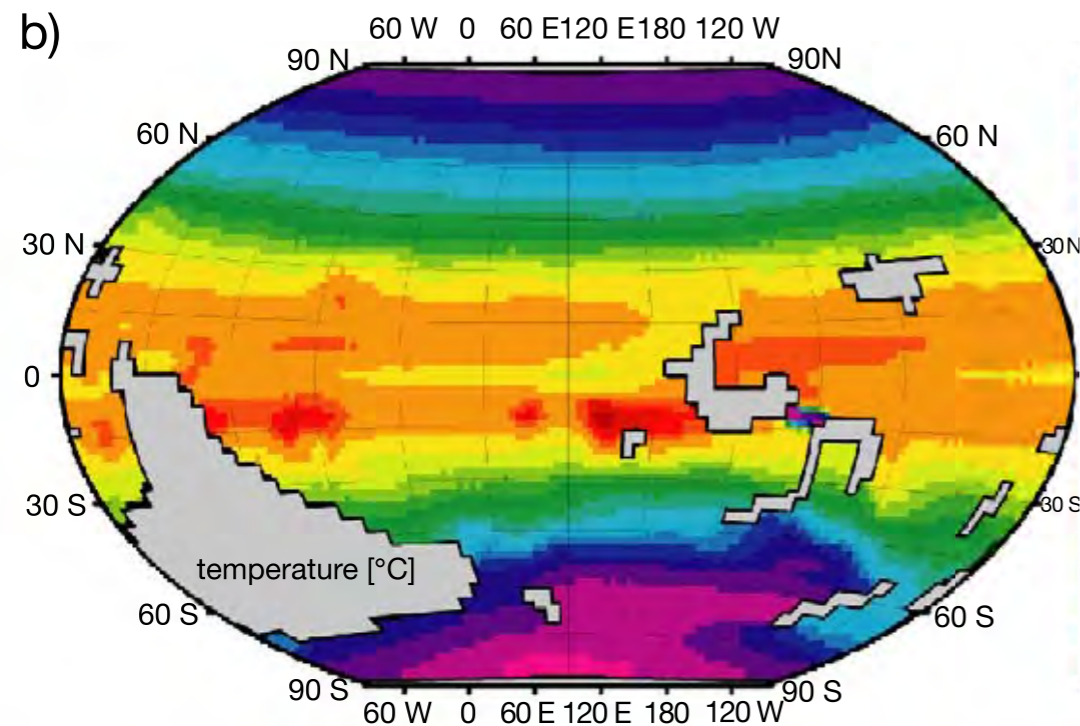


Modified from Herrmann et al., 2004, P³

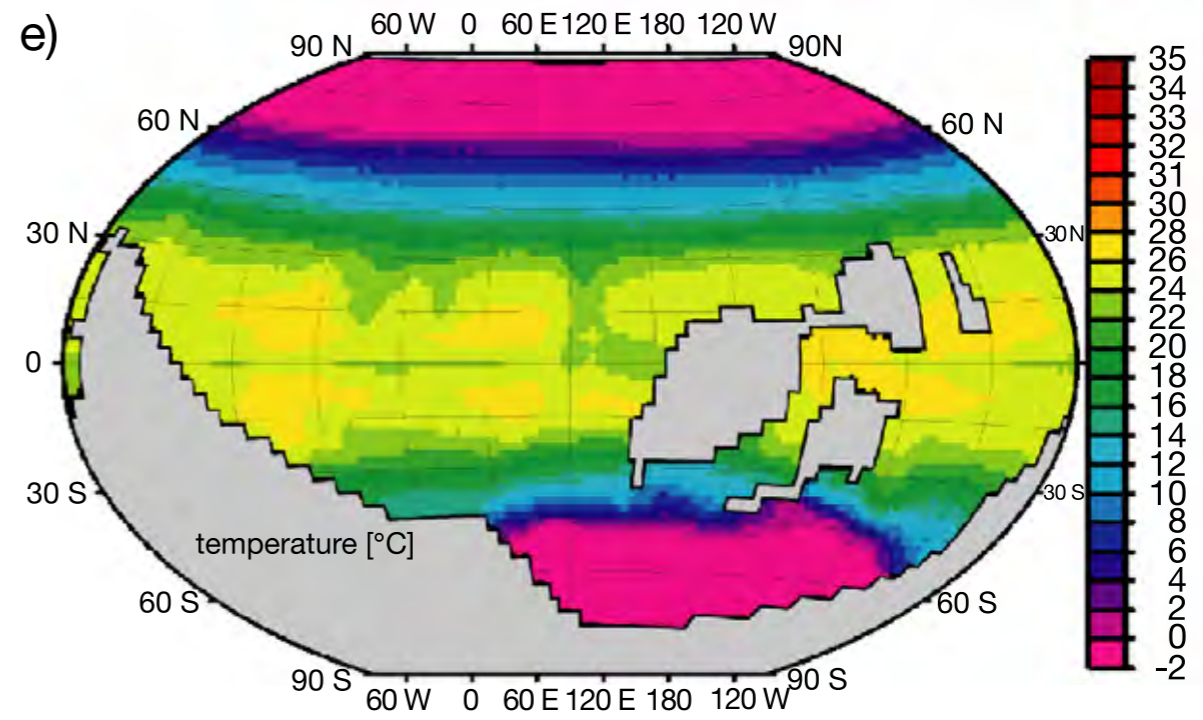
Changing temperatures would have imposed additional stresses on genera with limited thermal tolerance

Modeled Late Ordovician sea surface temperatures

Before glaciation



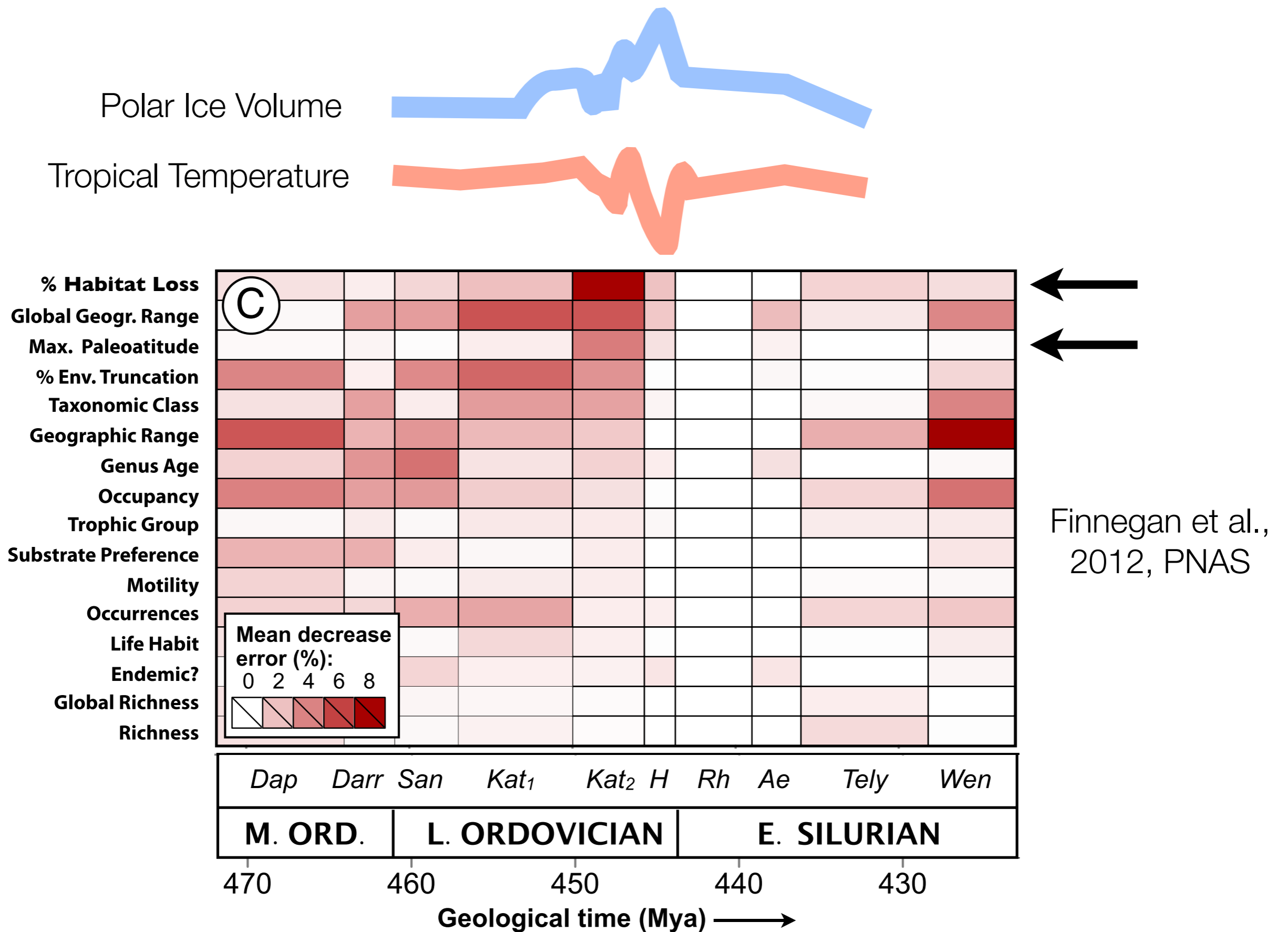
During glaciation



Modified from Herrmann et al., 2004, P³

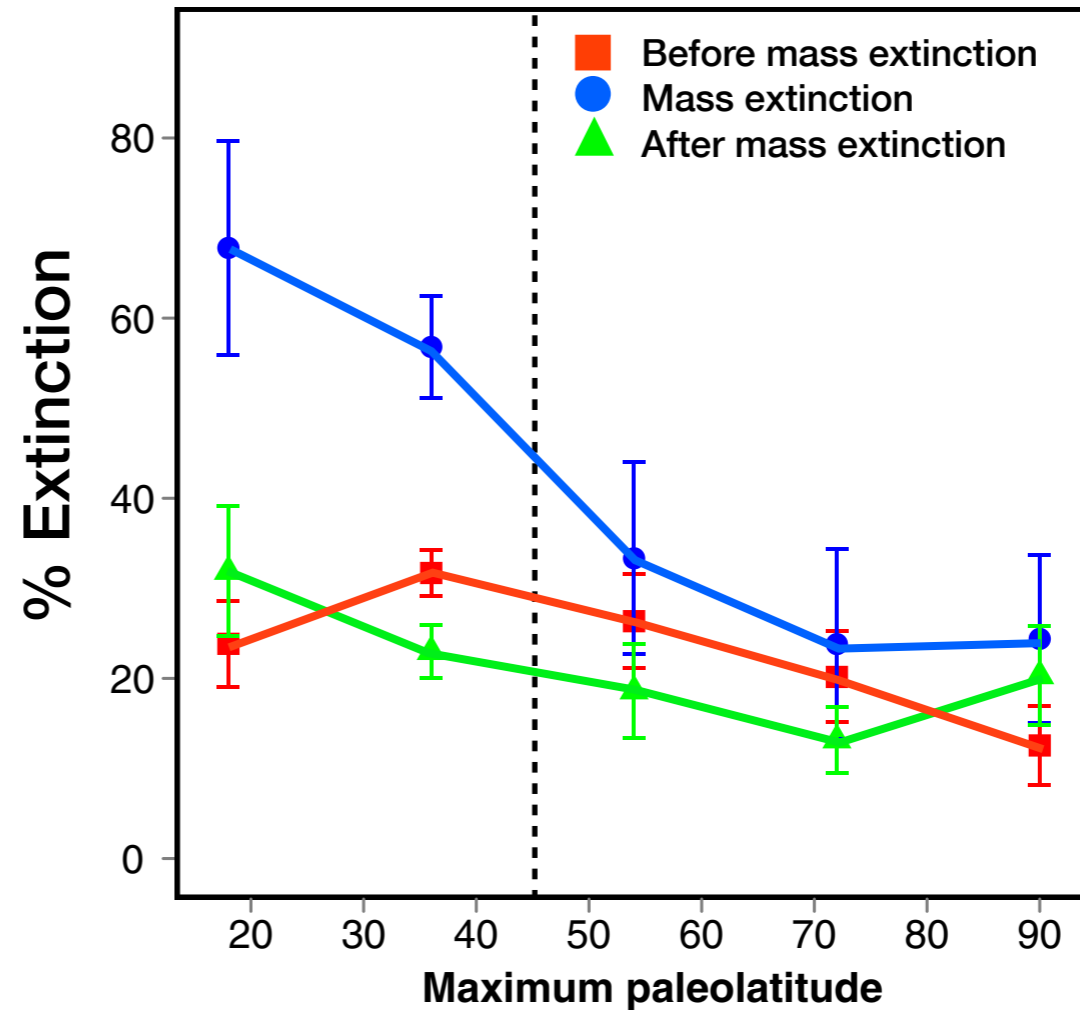
Hypothesis: genera with narrow latitudinal ranges should have experienced exceptionally high extinction rates

Determinants of marine invertebrate extinction risk

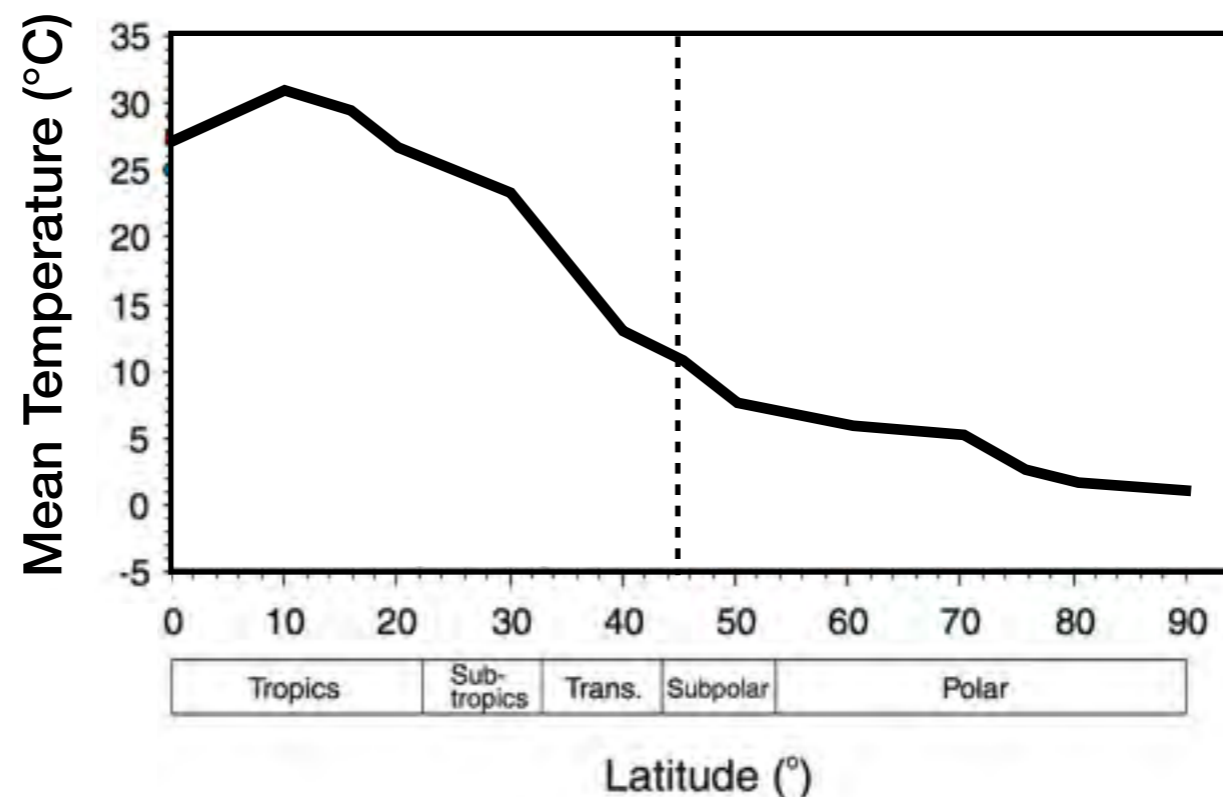


Selective Signature:

Exclusively low-latitude genera much harder hit than those with broad latitudinal distributions



Finnegan et al.,
2012, PNAS



Vandenbrouke
et al., 2010

Conclusions:

- The Late Ordovician glaciation was at least as large, in terms of ice volumes, as the Pleistocene glaciation
- Tropical seawater temperatures fell by $\sim 5^{\circ}$ C during the Late Ordovician glacial maximum
- Growth of glaciers caused sea levels to fall and drove a massive reduction in the area of shallow seaways
- Reduction of shallow seaways combined with cooling temperatures led to large-scale habitat loss and resulting extinction

Why did Late Ordovician glaciation cause a major mass extinction, but not subsequent glaciations?

Late Ordovician

Sea level, continental configuration & biogeography

Mio-Pliocene