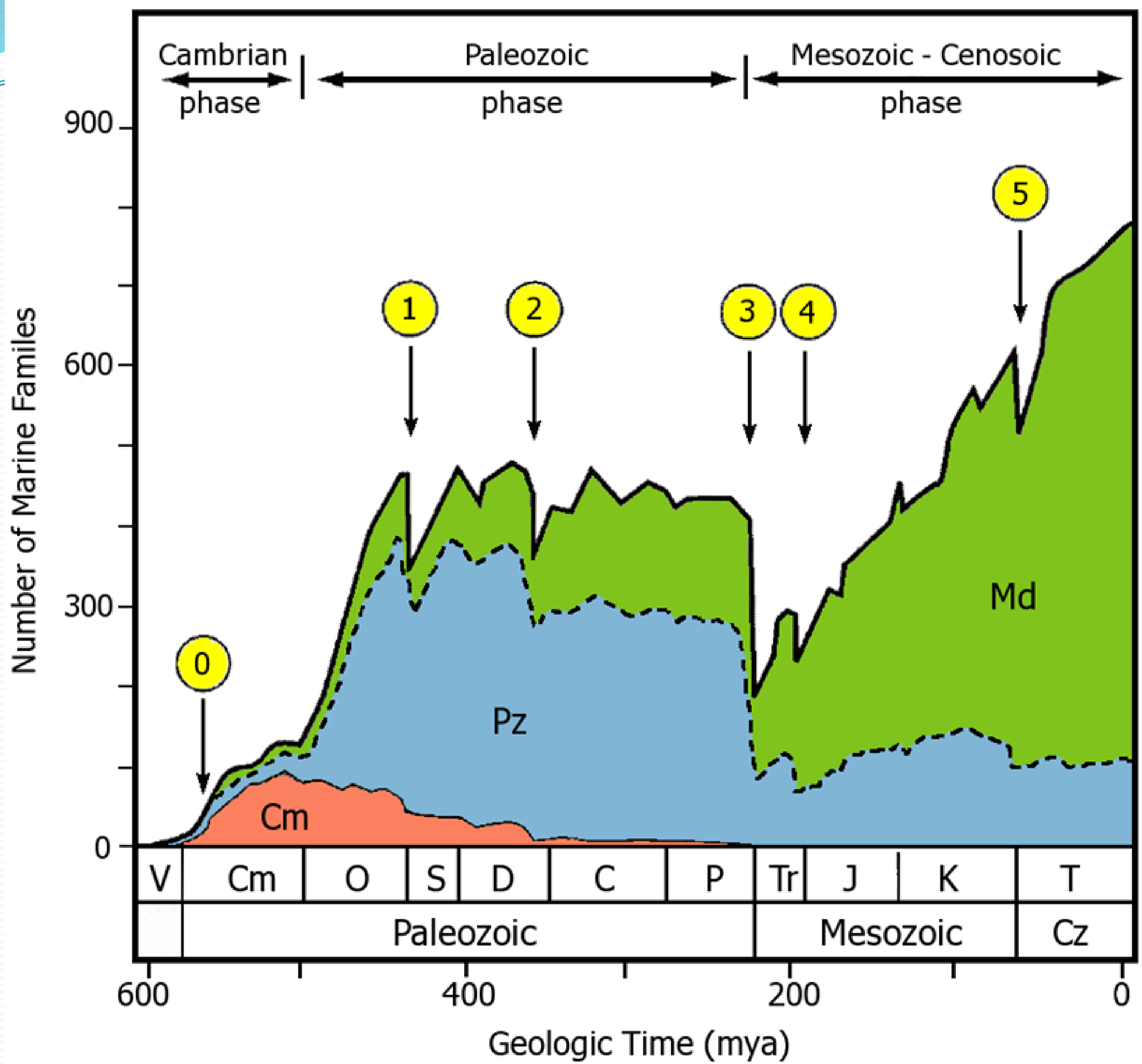
Lecture 11: Earth's Climate History II

Today's Learning Outcomes

1. Know the direction of climate change for each of the three events covered (Late Ordovician, End-Permian, and End-Cretaceous)

2. Know which climate change event was the most deadly to life

3. Be able to explain why the location of volcanism or impact site mattered so much in extinction events



Cambrian
phase
Paleozoic
phase
Mesozoic - Cenosoic
phase
900
600
300
0
Number of Marine Familes
0
1
2
3
4
5
Cm
Pz
Md
V
Cm
O
S
D
C
P
Tr
J
K
T
Paleozoic
Mesozoic
Cz
600
400
200
0
Geologic Time (mya)

The Big Five Mass Extinctions

Late-Ordovician (443-445 mya, 68% species extinct)

Late Devonian (360-375 mya, 38% species extinct)

End-Permian (252 mya, 81% species extinct)

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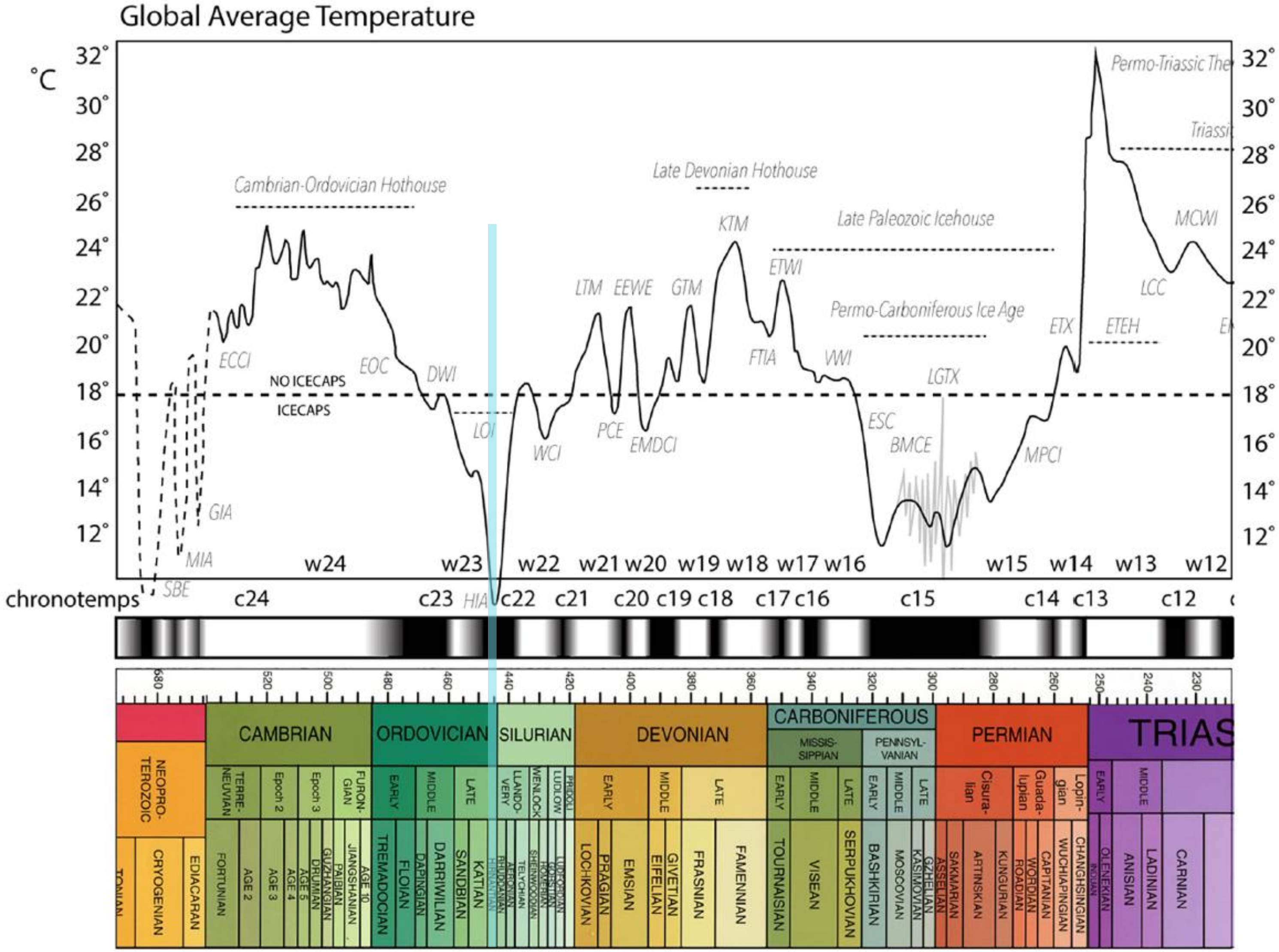
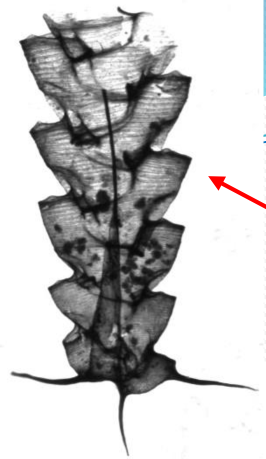
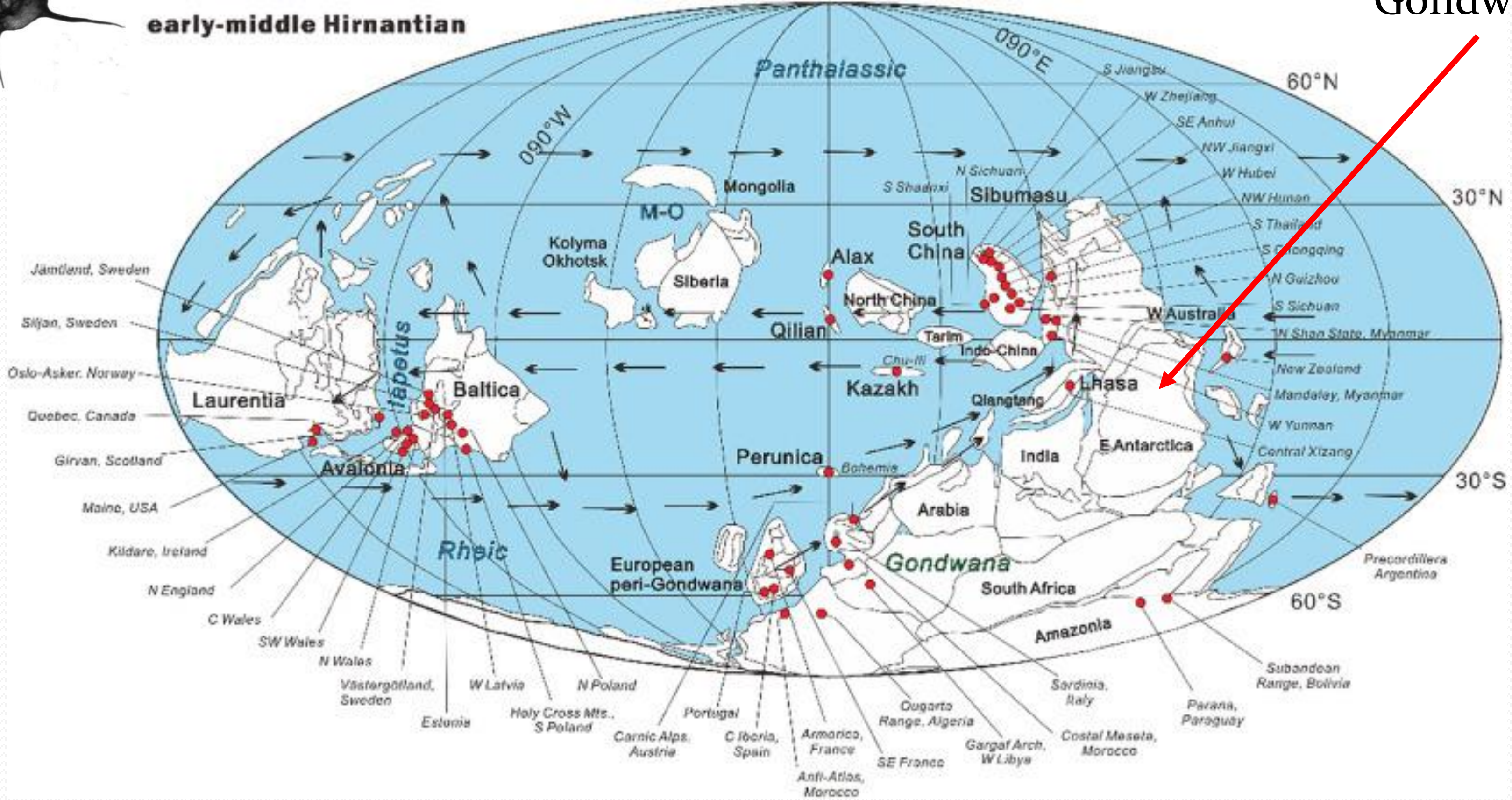
Late Ordovician Mass Extinction





Graptolite

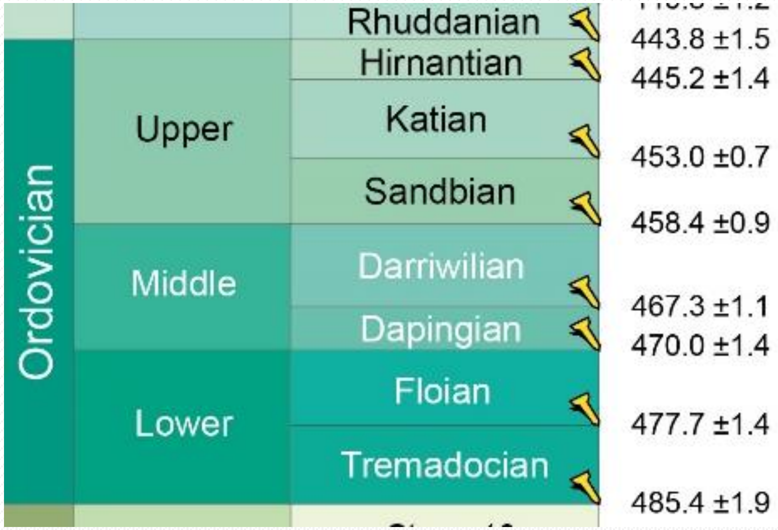
Continent of Gondwana

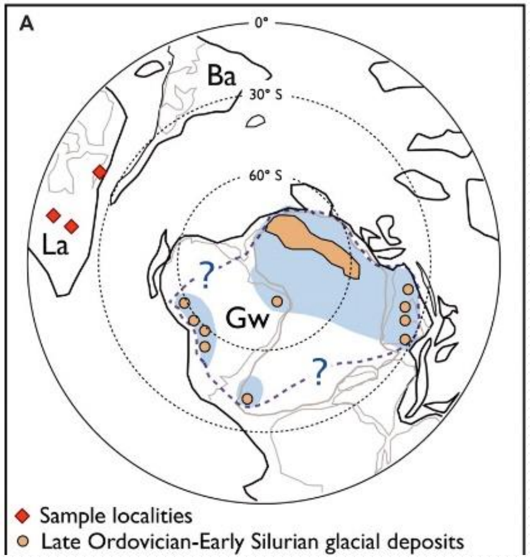


- All life in oceans
- Oceans stratified and low O_2
- CO_2 >5x higher than today

Late Ordovician

- Gondwana moves over the South Pole leading to rapid growth of ice caps
- Glaciation event marks the beginning of the Hirnantian
- Massive sea-level drop and reorganization of ocean currents
  - Loss of continental shelves
  - Loss of low-O_2 ocean habitat





Ventilating the Oceans

- Deep oceans were likely anoxic and stratified prior to the Hirnantian
- Cooling established a strong temperature gradient kicking off deep sea circulation
- Destroyed most common graptolites favored habitat

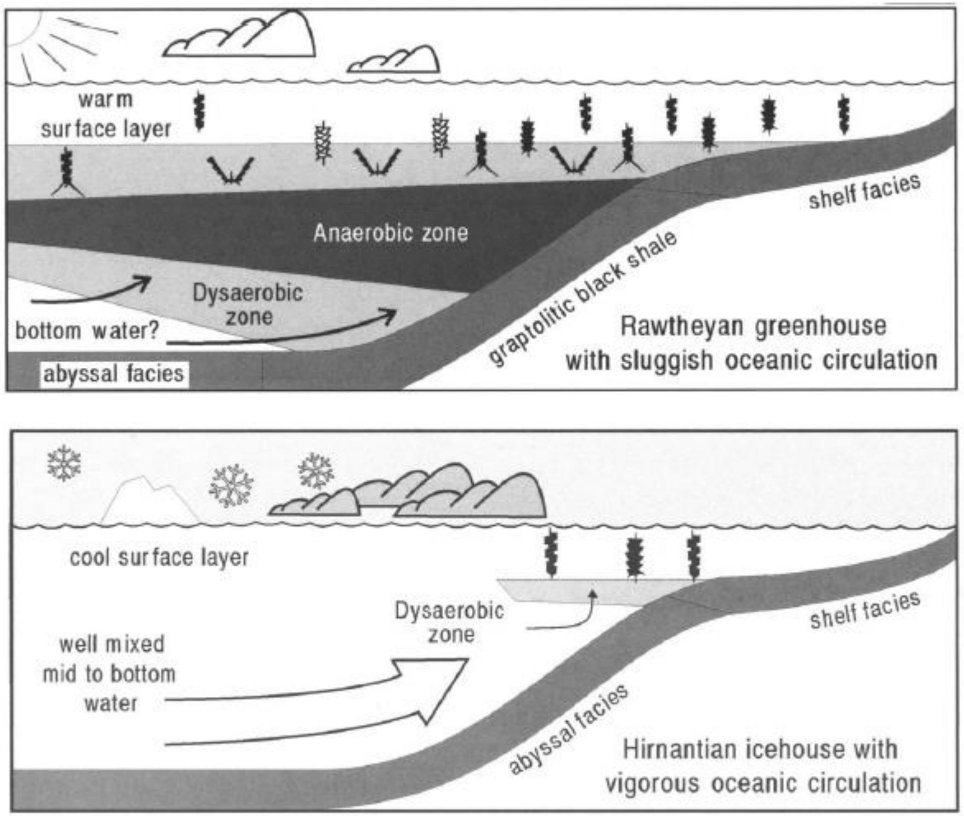
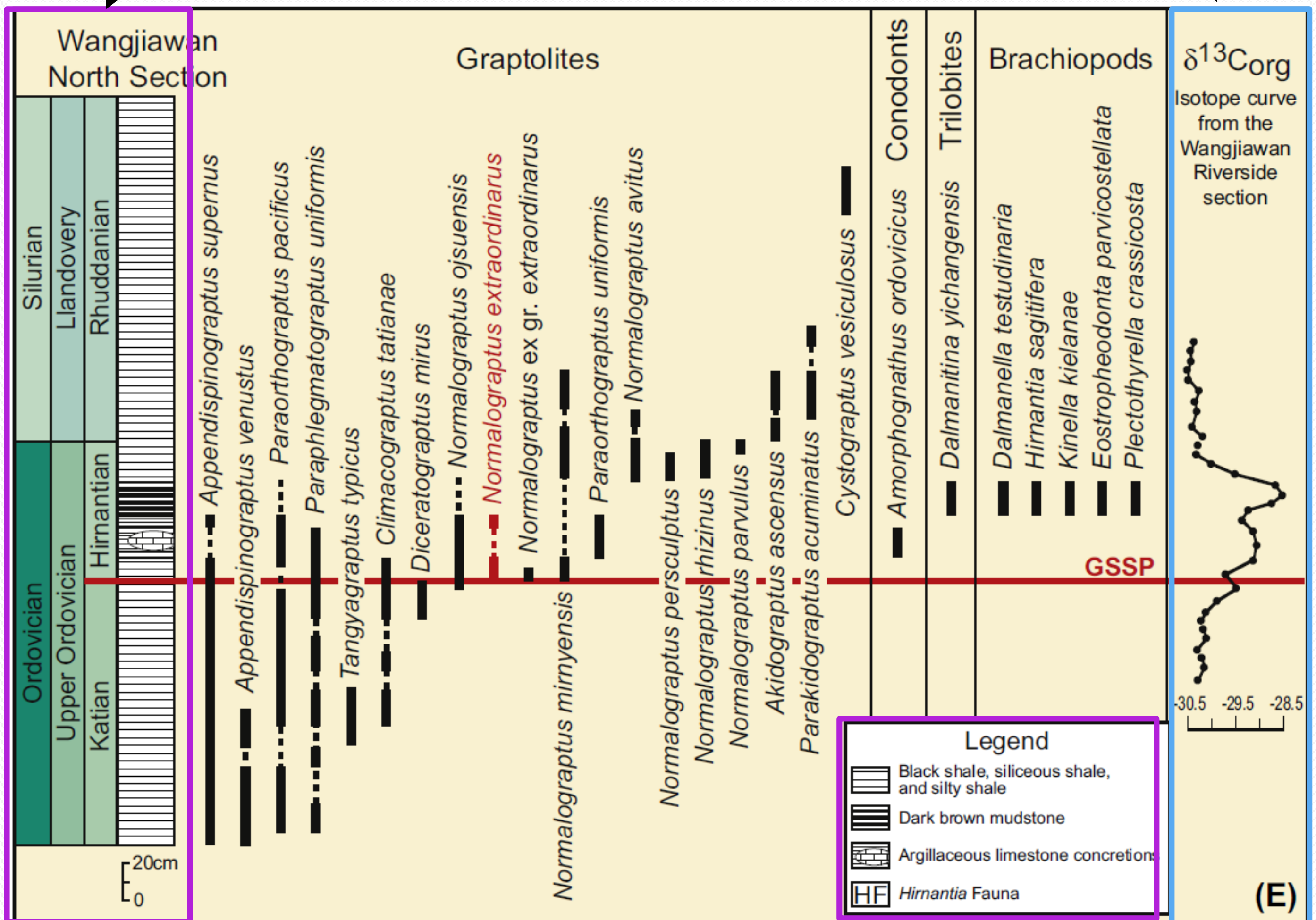


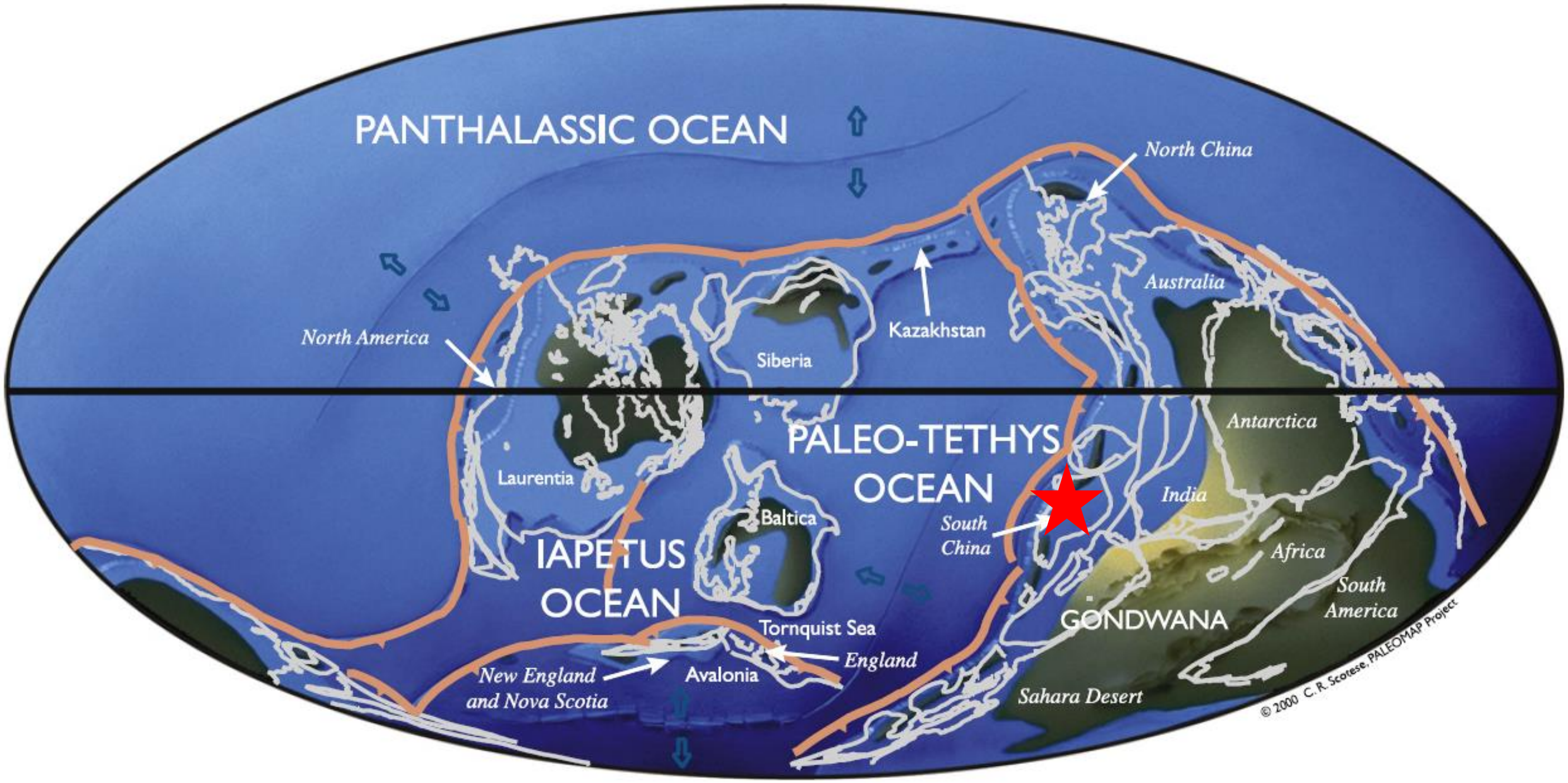
FIGURE 8—Model of paleoceanographic and graptolite habitat changes between Rawtheyan greenhouse (top) and Hirnantian icehouse (bottom) conditions (modified from Cooper, 1998).

Rocks go from shales (= deep sea) to limestones (= shallow sea). Paleoclimate proxy suggesting cooling as sea level drops

Large positive C_{org} shift consistent with either cooling and/or increased organic burial



458 Ma Ordovician

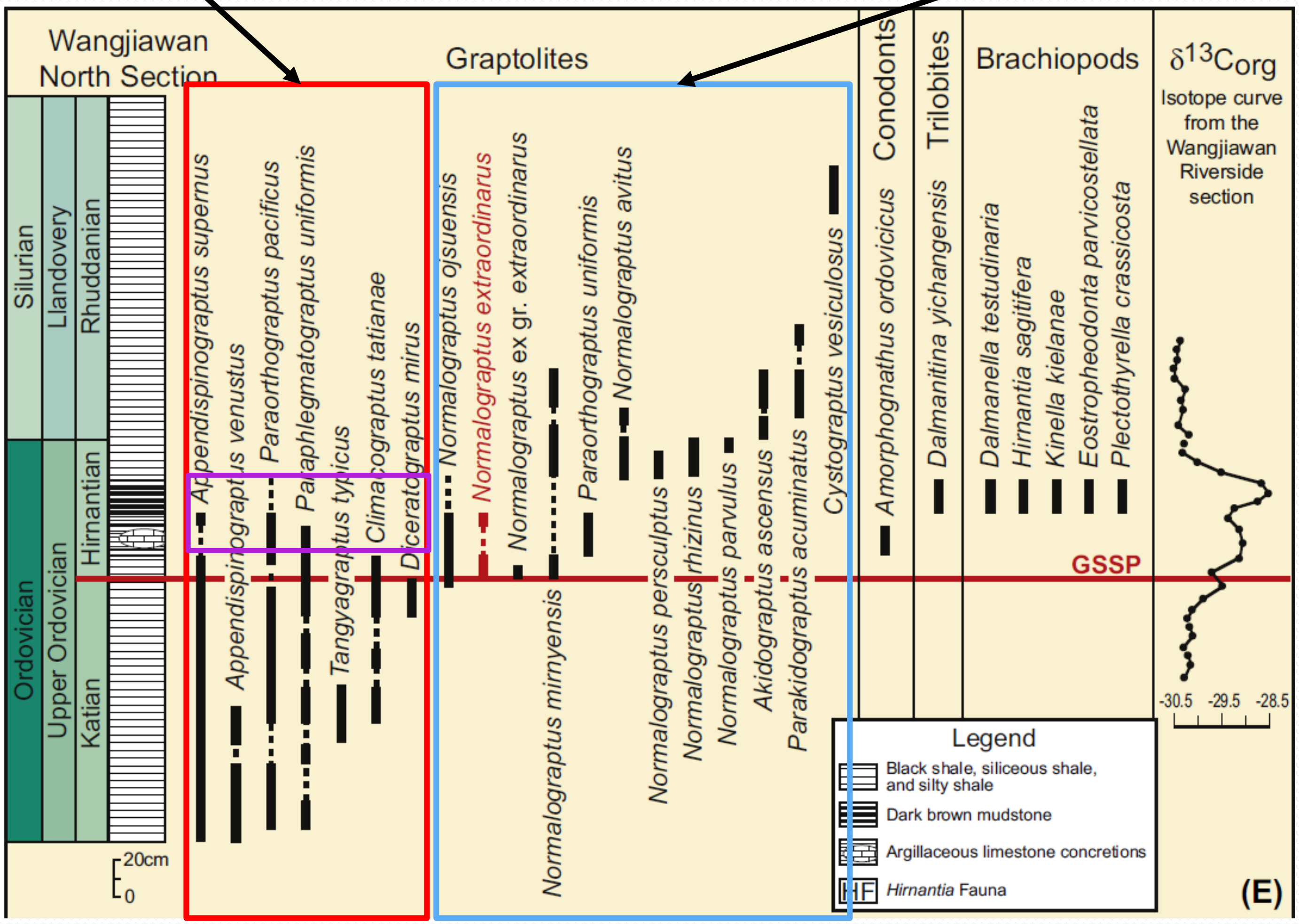


★ Location of Wangjiawan locality when it formed (subtropical)

Persistent Life

Tropical, low oxygen specialists

High-latitude, oxygen-rich generalists



Hirnantian Mass Extinction

- Two pulses of extinction (over a 1.4 million year span)

- Pulse 1 (glaciation) – 445.2 Ma
  - Extinction of species/groups that were adapted for warm-water low-O_2 habitats as glaciers rapidly grew
  - Evolution of short-lived *Hirnantia* fauna that was adapted for cooler more O_2 rich waters

At least one more smaller glacial-interglacial round here driven by Milankovitch cycles

- Pulse 2 (deglaciation) – 443.8 Ma
  - Extinction of *Hirnantia* fauna as sea level rose and anoxic conditions became widespread again
  - Even shallow waters became low-O_2 or even toxic

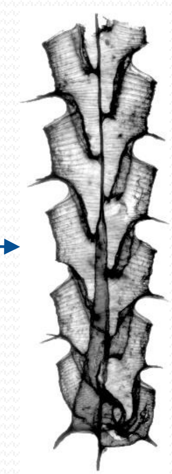
Organisms Hit Hardest

- Brachiopods

- Bryozoa

- Conodonts

- Graptolites



- Trilobites

Long-Term Consequences

- Despite being the 2nd or 3rd most destructive event in Earth's history by species count relatively little long-term impact
  - Ended an extended period of diversification (GOBE)
- Few groups were wiped out completely
  - Instead branches within groups were wiped out and replaced
- Tendency toward a smaller number of more widespread species after the 2nd pulse of extinction

The Big Five Mass Extinctions

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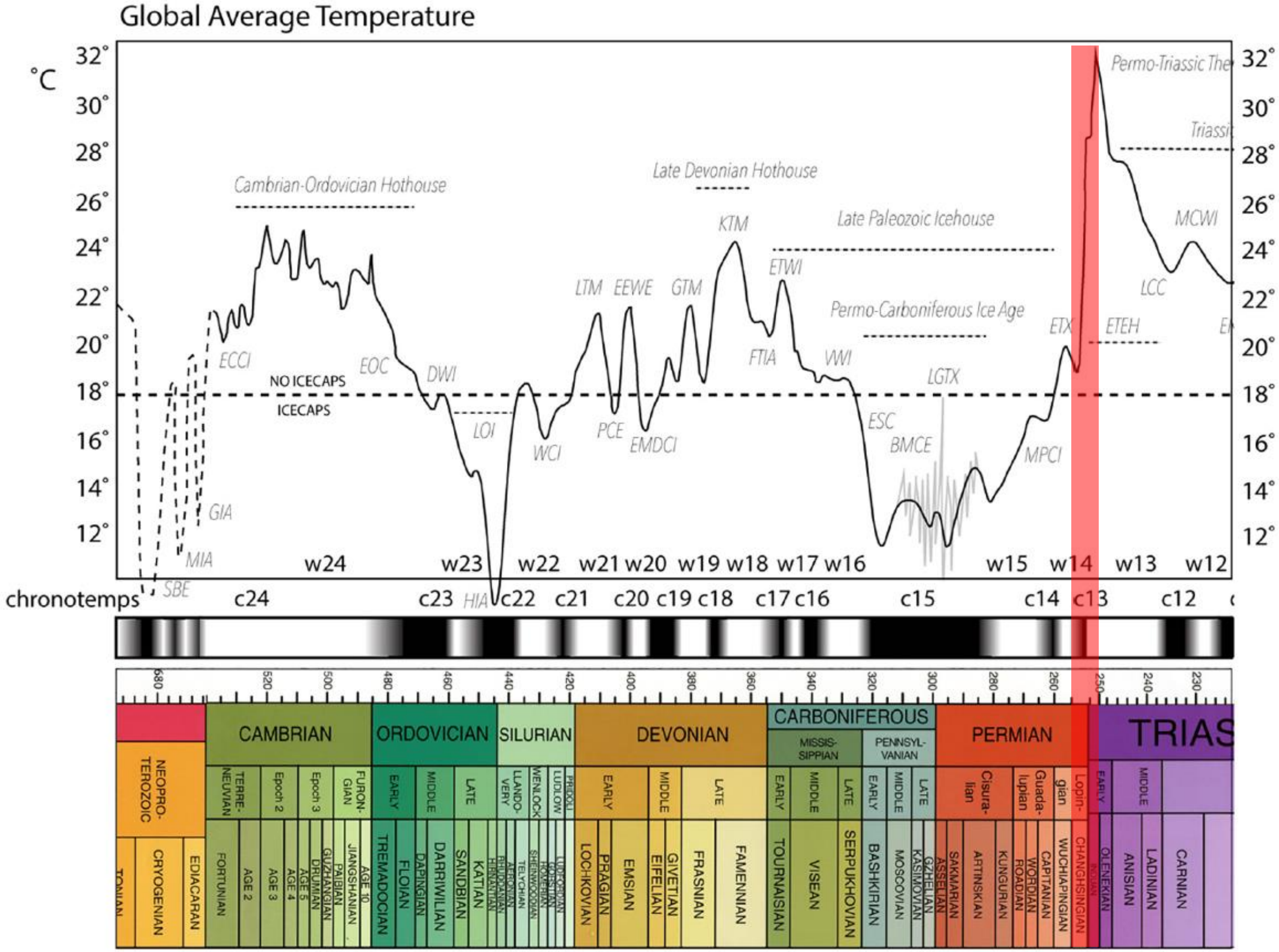
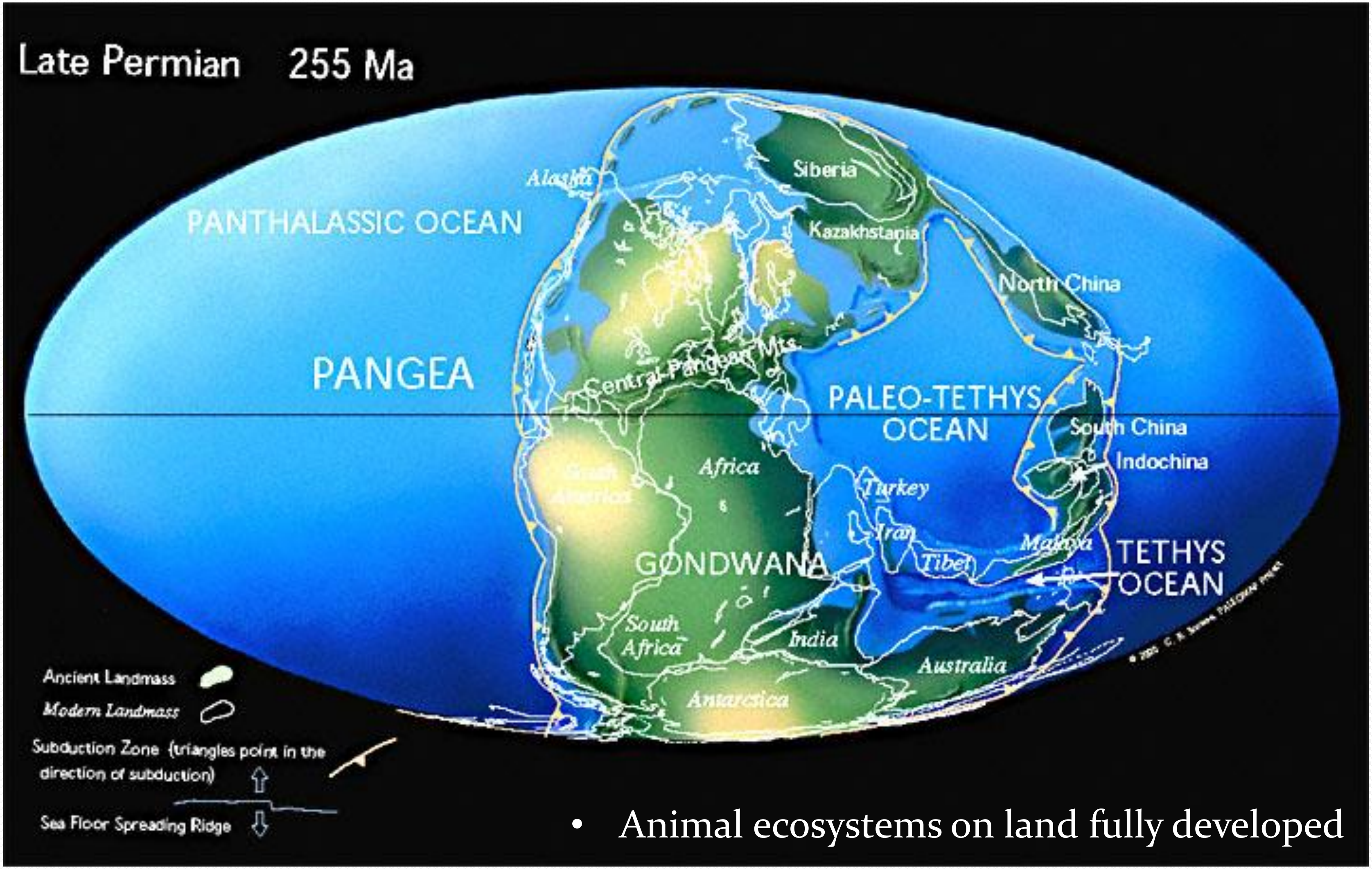
Late Ordovician Mass Extinction



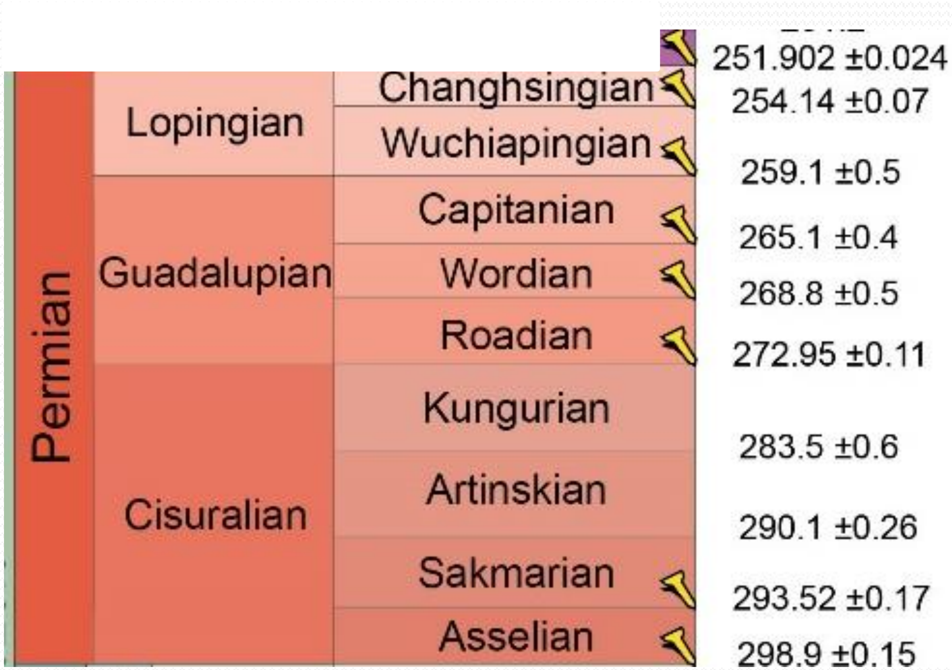
Late Permian Paleogeography



- Animal ecosystems on land fully developed

End Permian

- Largest of the Big Five mass extinctions and the first one to hit after terrestrial communities like today had become established



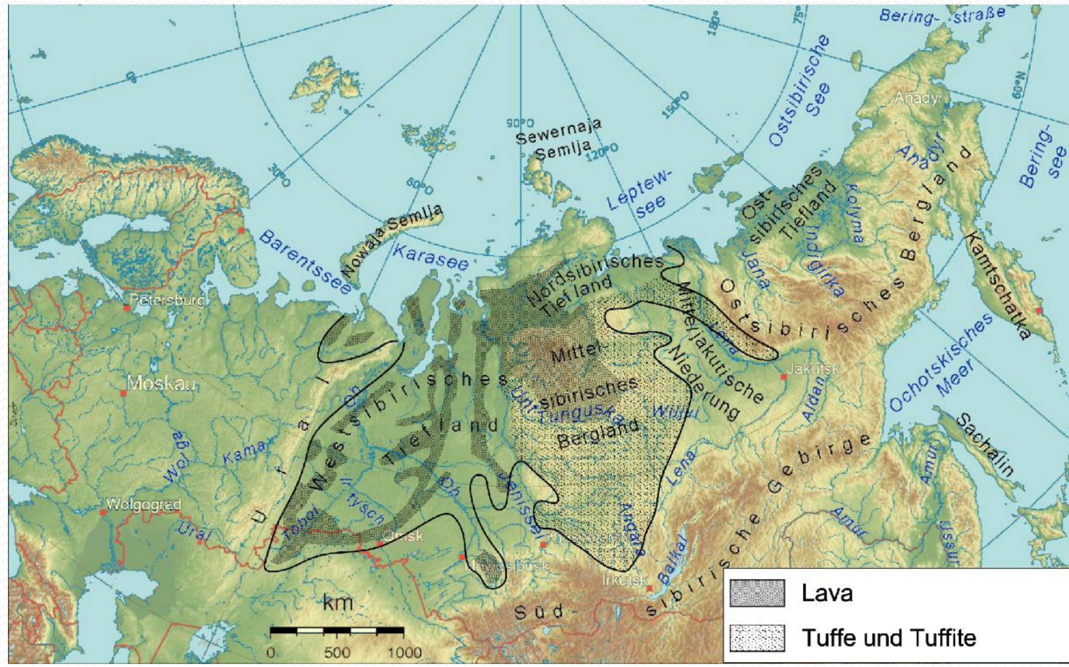
- Plant diversity sharply declines
- Only mass extinction to effect insects

Environmental Changes

- Extinction coincides with sea-level rise, rapid warming, widespread anoxia in shallow and deep water
- 6-10°C increase in <60 k.y.
  - CO_2 levels were 10-20x higher than today
- Continents warm and dry in Late Permian/early Triassic
  - Coal deposits disappear for ~5 myr
- Oceans hot and acidic in Late Permian/early Triassic
  - Coral reefs disappear almost entirely for ~5 myr
  - Oceans ~8x more acidic than prior to warming
- Eruption of the Siberian Traps (LIP = massive volcanism)

Siberian Traps

- Cover an area 2/3 the size of the continental United States



- Erupted in pulses ~250 mya

- Would have pumped enormous amounts of CO_2 into the atmosphere (burned through coal seams)

Baking Limestones and Sulfates

- By bad luck the Siberian Traps were cutting through an area with lots of limestone (grey regions) and even coal (black region)

- Massively increased the release of CO_2 relative to what would be expected without them

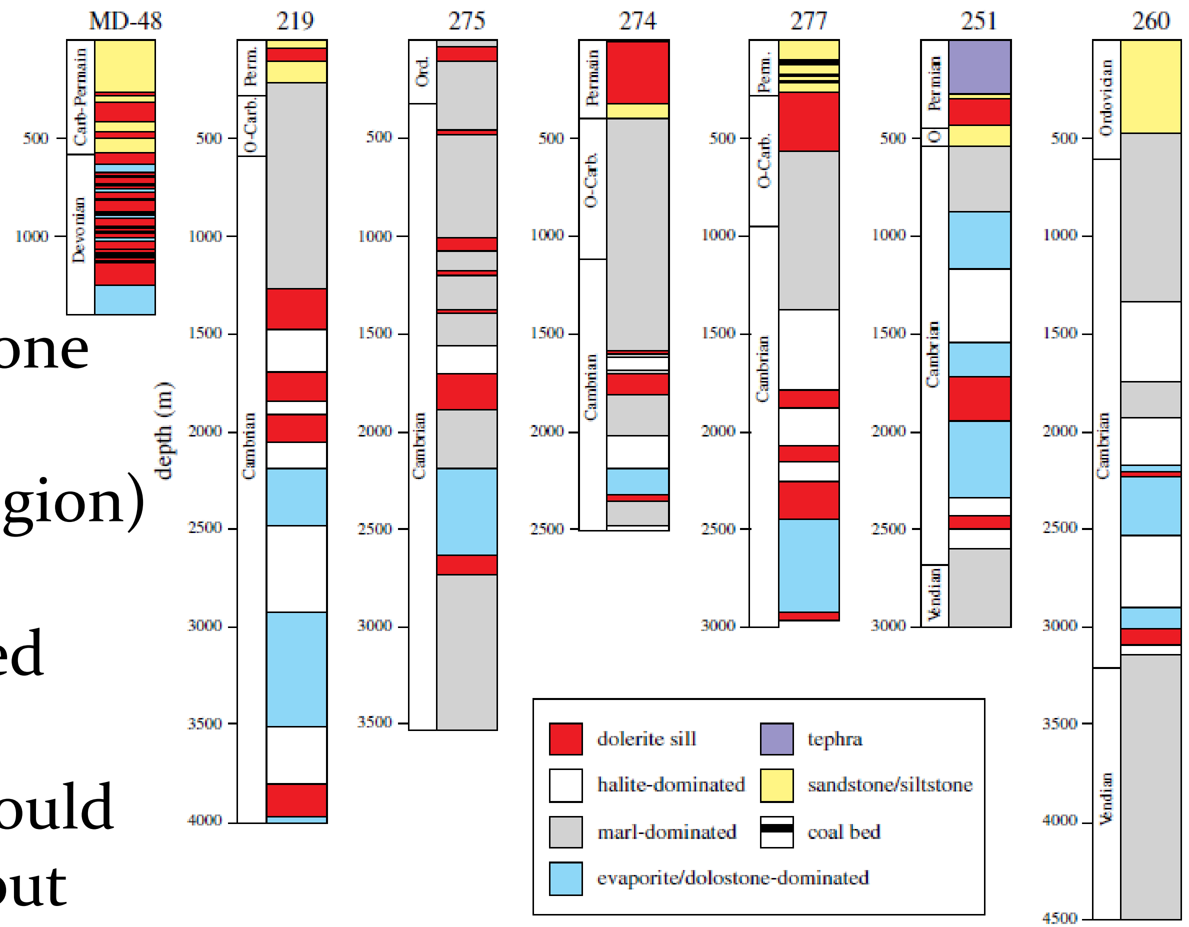


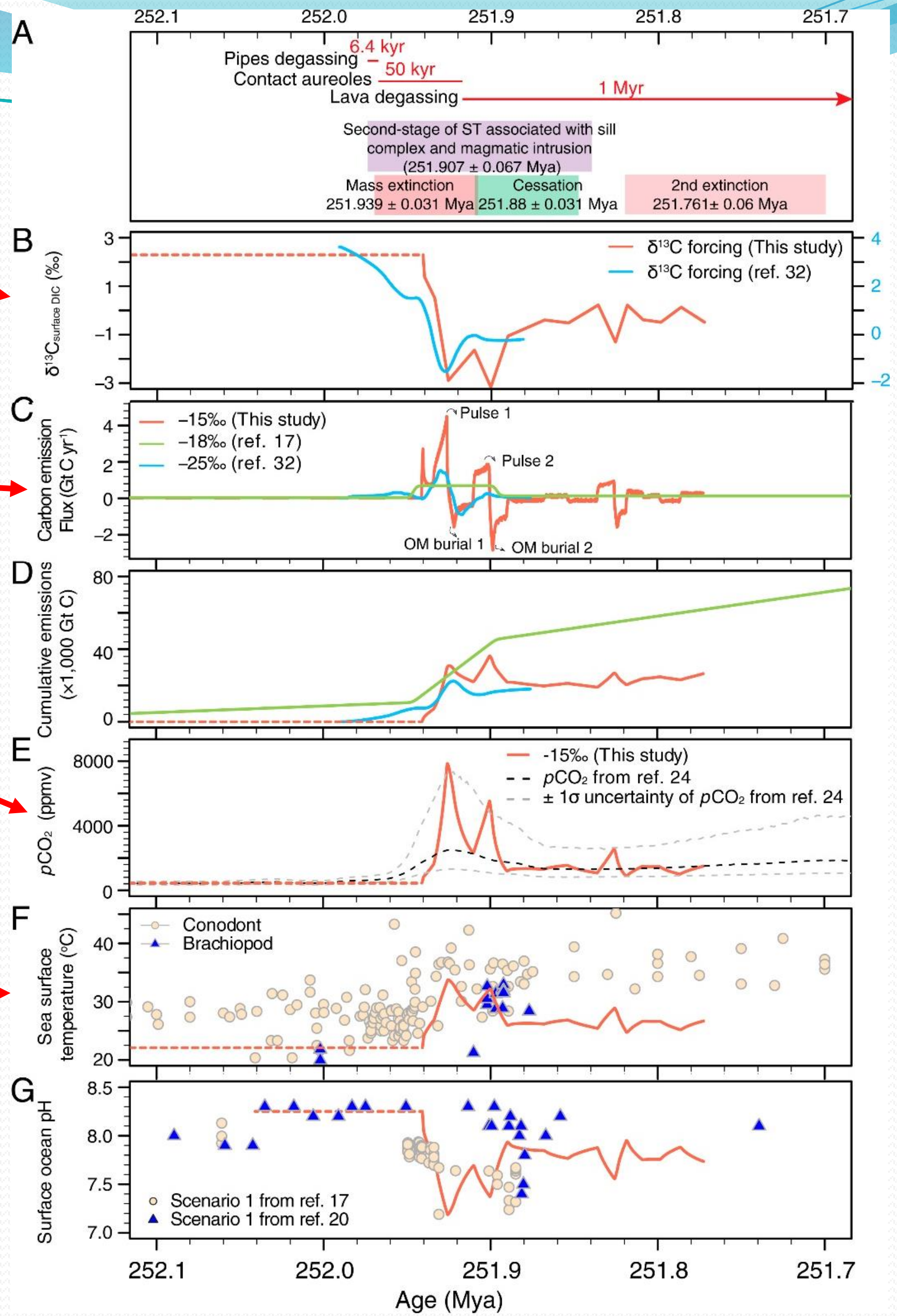
Figure 4. Logs from seven boreholes, five are from the E-W transect shown in figure 1. Three of these boreholes (219, 275, 277) are used for thermal modelling as detailed lithological logs are available. (Online version in colour.)

Negative carbon isotope excursion correlating to warming

Massive fluxes of carbon to the atmosphere
Current rate is ~7 GtC/yr

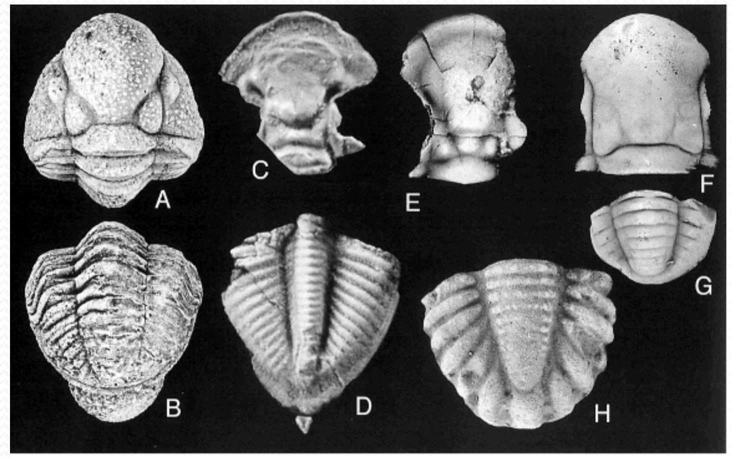
Ppm of CO_2 massive spike, but over 20,000 years. Current CO_2 levels are at ~429 ppm

Surface temperatures increased by ~8°C and pH dropped by ~1 (=10x more acidic). Current rates of ocean warming would reach these levels in ~3500 years



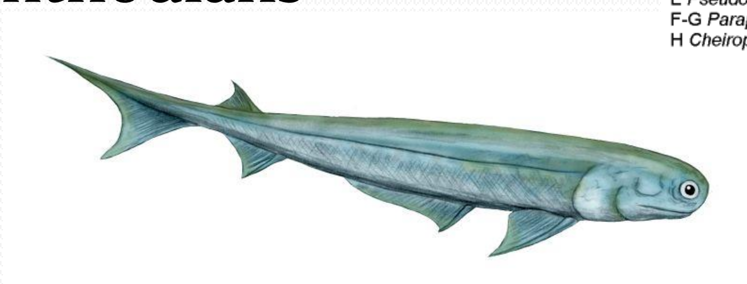
The Killing Blow

- [Trilobites]()
  - last 5 genera



A-B *Kathwaia capitorosa* Grant 1966 (Bollandinae)
C-D *Acropyge brevica* Yin 1978 (Ditomopyginae)
E *Pseudophillipsia raggyorcakaensis* Qian 1981 (Ditomopyginae)
F-G *Paraphillipsia* aff. *karpinskyi* Tumanskaya 1935 (Cummingellinae)
H *Cheiropyge himalayensis* Diener 1897 (Brachymetopidae)

- Acanthodians



- Eurypterids

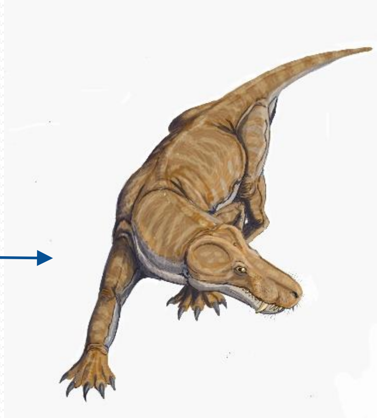
Organisms Most Affected

- Ammonites

- Crinoids

- Reefs

- Therapsids



Long-Term Consequences

- Ecosystem collapse and near complete reorganization of dominant organisms

Lystrosarus

- Early Triassic faunal diversity low
  - *Lystrosaurs* makes up bulk of fossils in some regions post-extinction

- Reset evolutionary clock and allowed wide variety of odd Triassic groups

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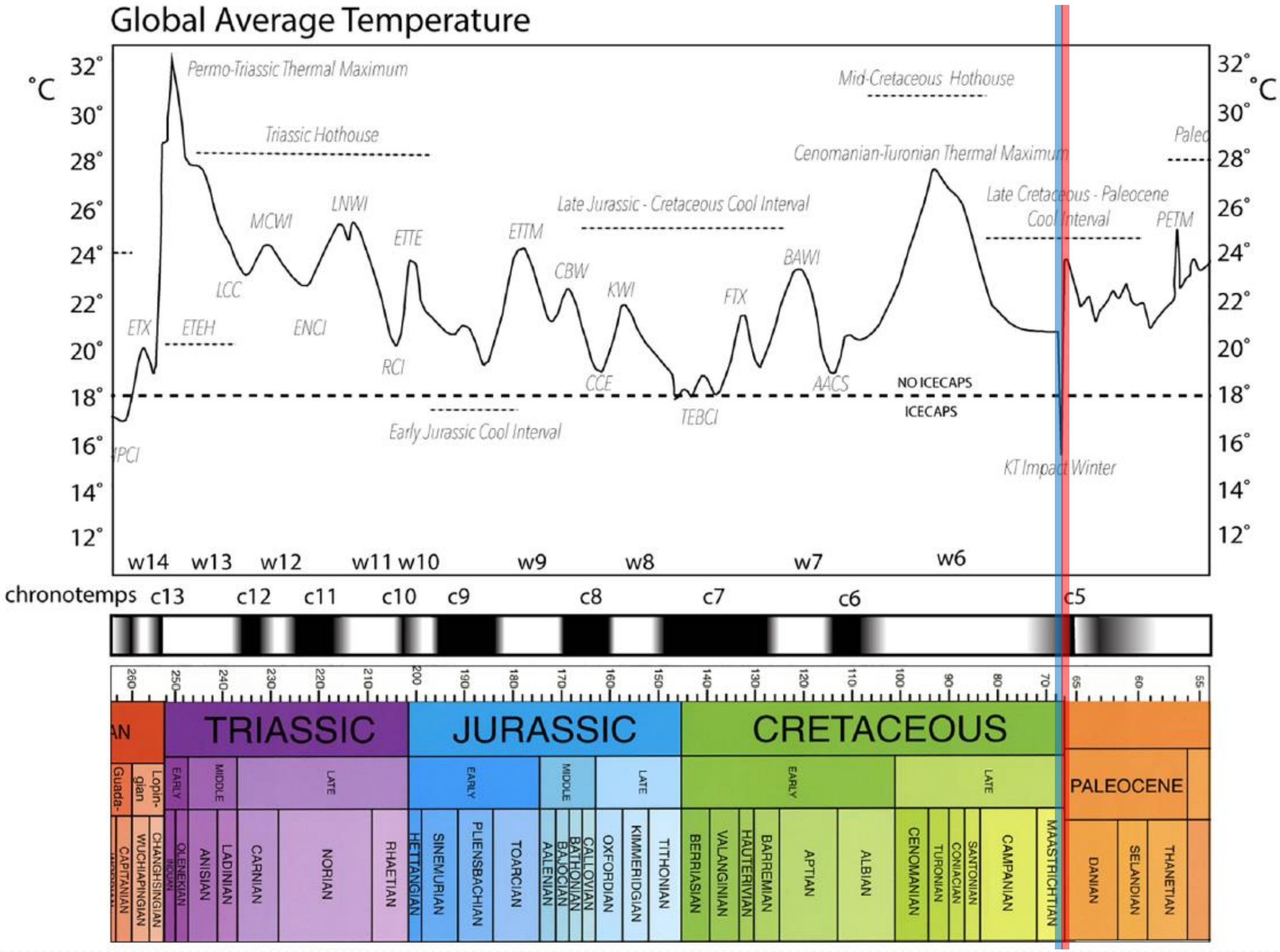
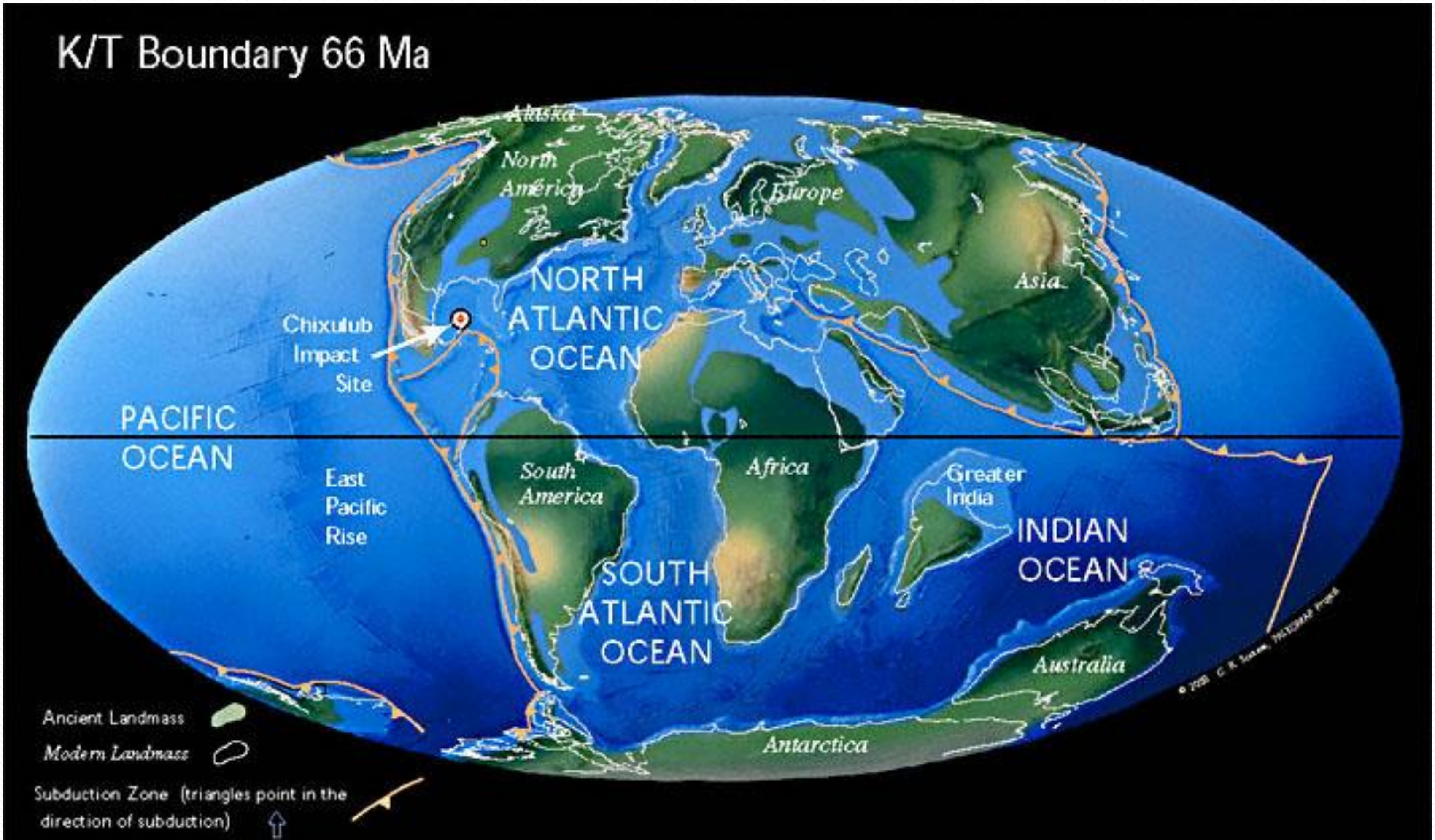
End Cretaceous Mass Extinction



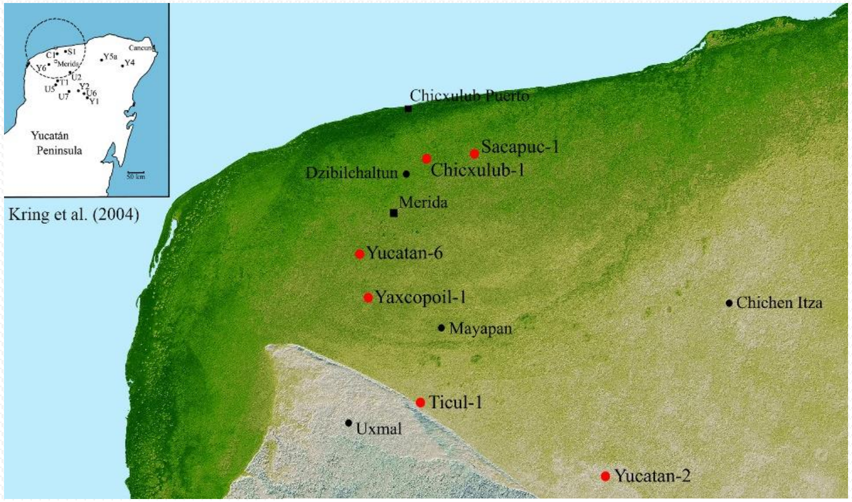
End Cretaceous Paleogeography



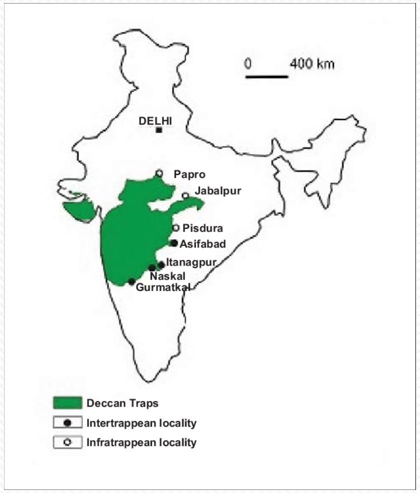
- Warm but recognizable world

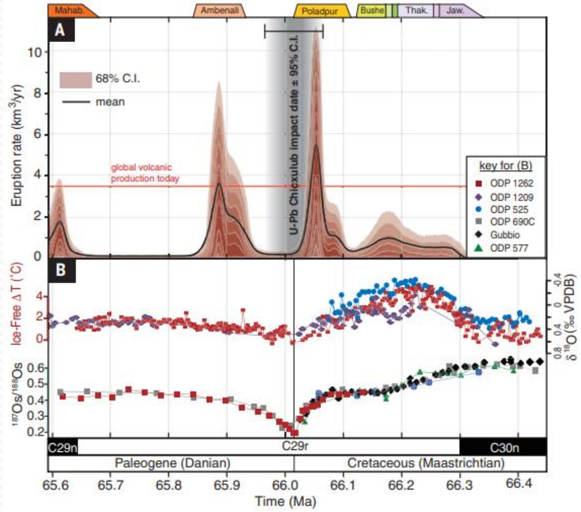
End-Cretaceous Extinction

- Asteroid/Comet impact
  - Modern-day Yucatan
  - ~66 mya



- Deccan Traps of India erupting as well
  - ~Mongolia sized
  - Timing off by 200,000 years





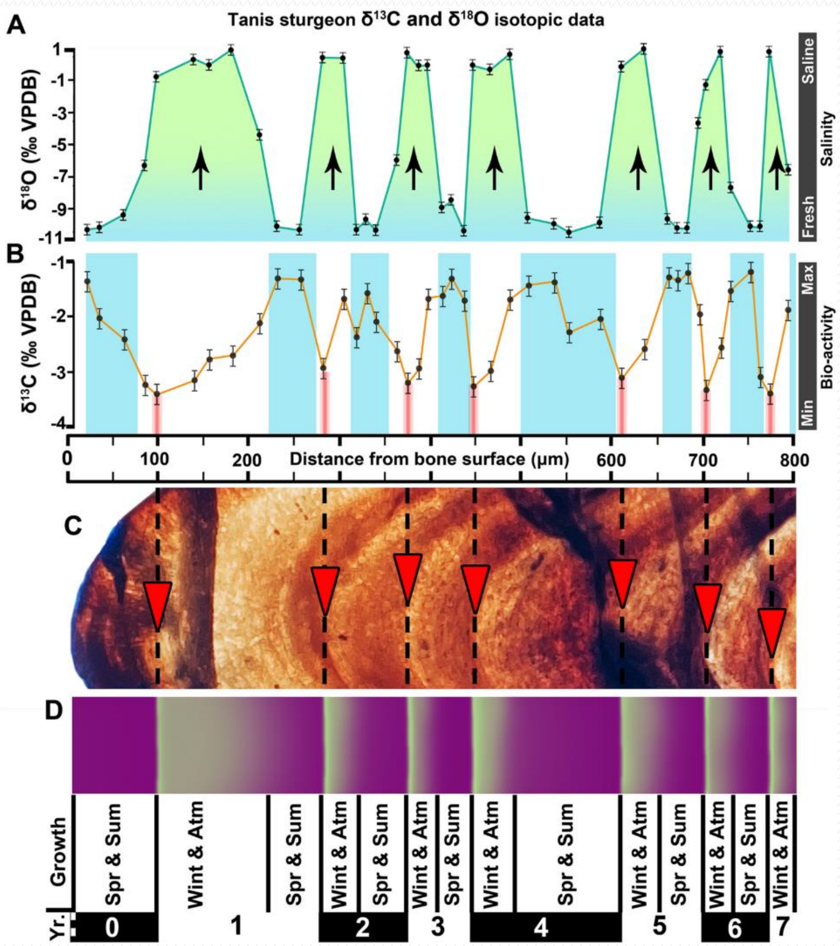
Tanis Site

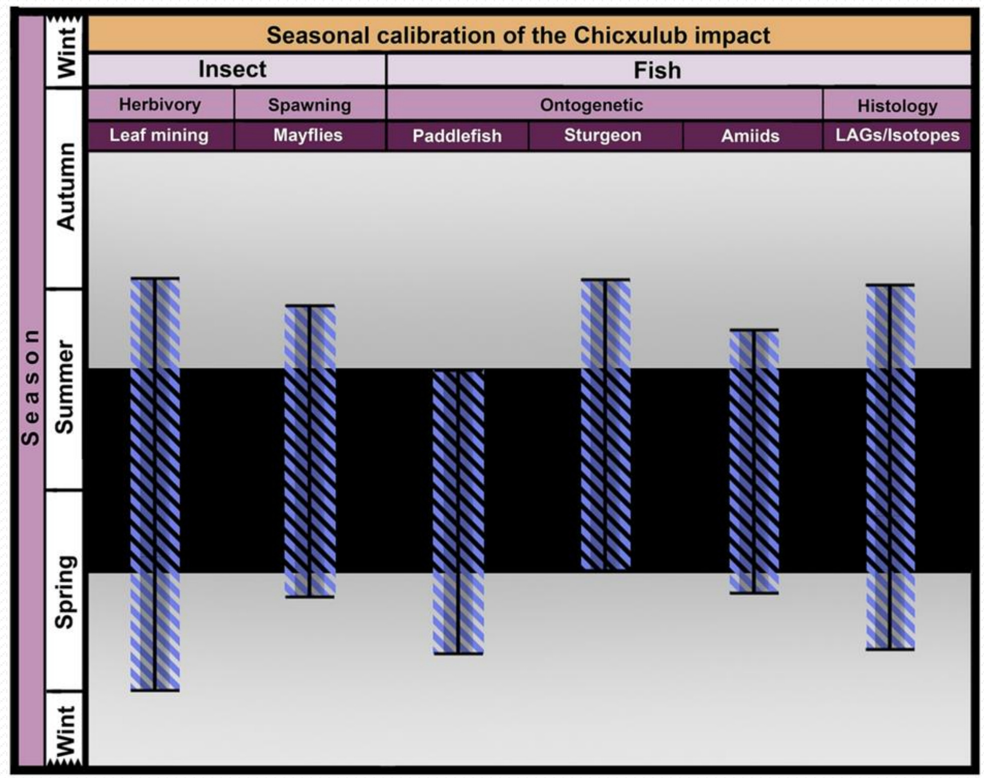
Longer detailed breakdown of the day's events

- Recently announced site in North Dakota that purports to record the day of the impact event!
  - Sheered off dinosaur leg
  - Fish with glass spherules in gills
  - Jumbled mess of fossils, both marine and terrestrial

Tanis Site

- Using growth rings and isotopes from fish killed by the impact wave have worked out a late Spring/early Summer timing





DePalma Controversy

- Robert DePalma personally holds the property the Tanis site is located on
  - Not a huge issue alone but not great
- Hyped up the site prior to the publication of any peer-reviewed paper and allowed stories in the popular media to run prior to publication
  - Again, not a huge issue by itself, self-promotion is important in career advancement but…
  - The deliberate Indiana Jones act is a bit much

DePalma Controversy

- Recent evidence has emerged that DePalma (and collaborators) may have engaged in pretty egregious academic and ethical practices

1. The publication of the Tanis site identifying the impact as occurring in Spring might have used completely or partially faked data
   - Duplication of specimens, hand-plotted data, numbers on charts do not match raw data, collaborator who supposedly ran analyses died in 2017 without any record of the work being done

DePalma Controversy

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2. That same publication strongly appears to have been rushed into print ahead of another student's findings in order to "scoop" the results
   - DePalma was even originally listed as a co-author on the other paper, but his name was taken off after the surprise publication coming to the same conclusion from the same data

Kill Mechanism

- Impact would have vaporized anything nearby and had other locally devastating effects

- Impact triggered tsunami wave that passed **over** Cuba and a secondary tsunami after reflecting off land

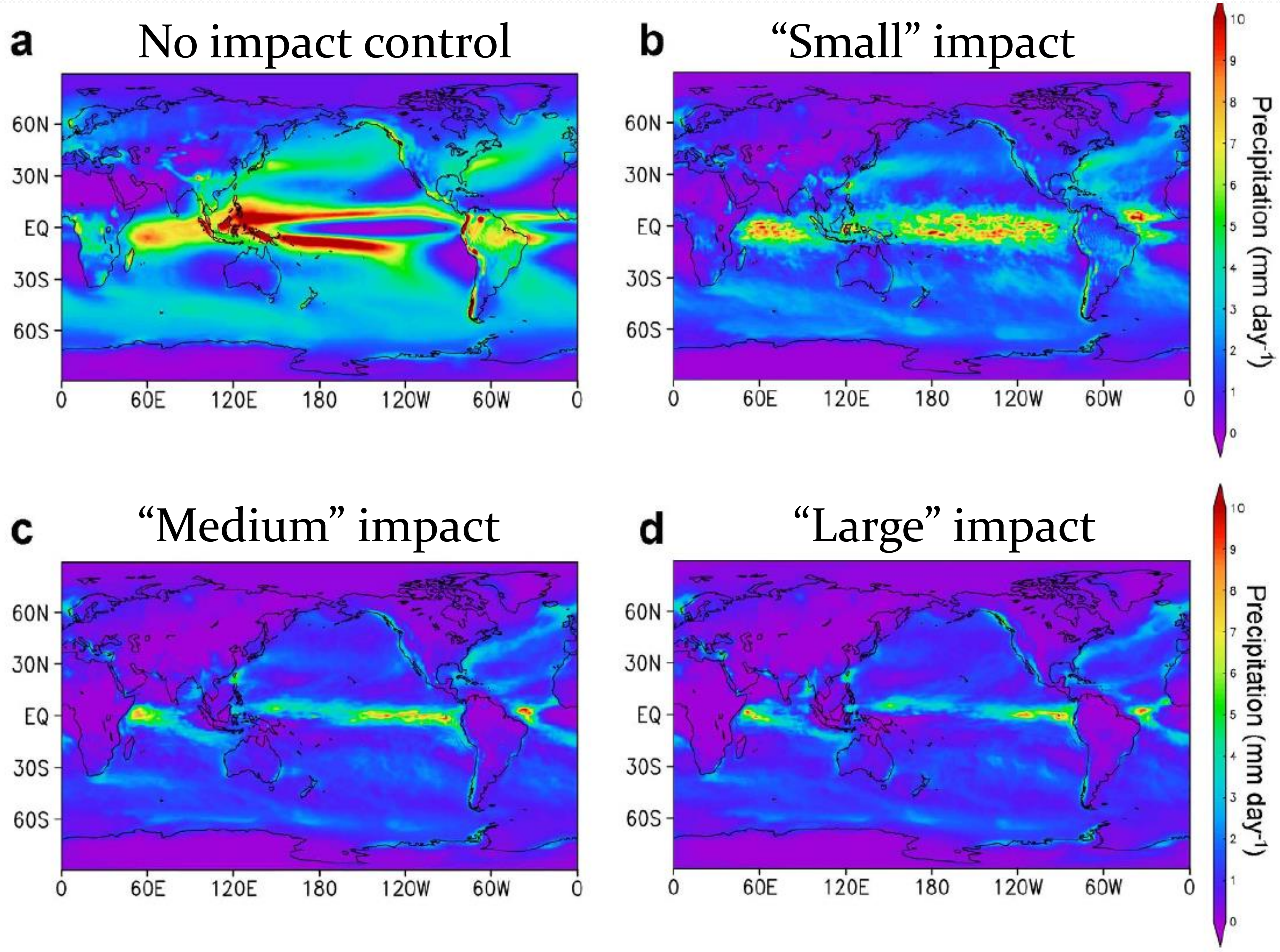
- Ejected material triggered forest fires over large parts of the continents (charcoal layers, release of CO_2)

Charcoal ring around fossil tree trunk

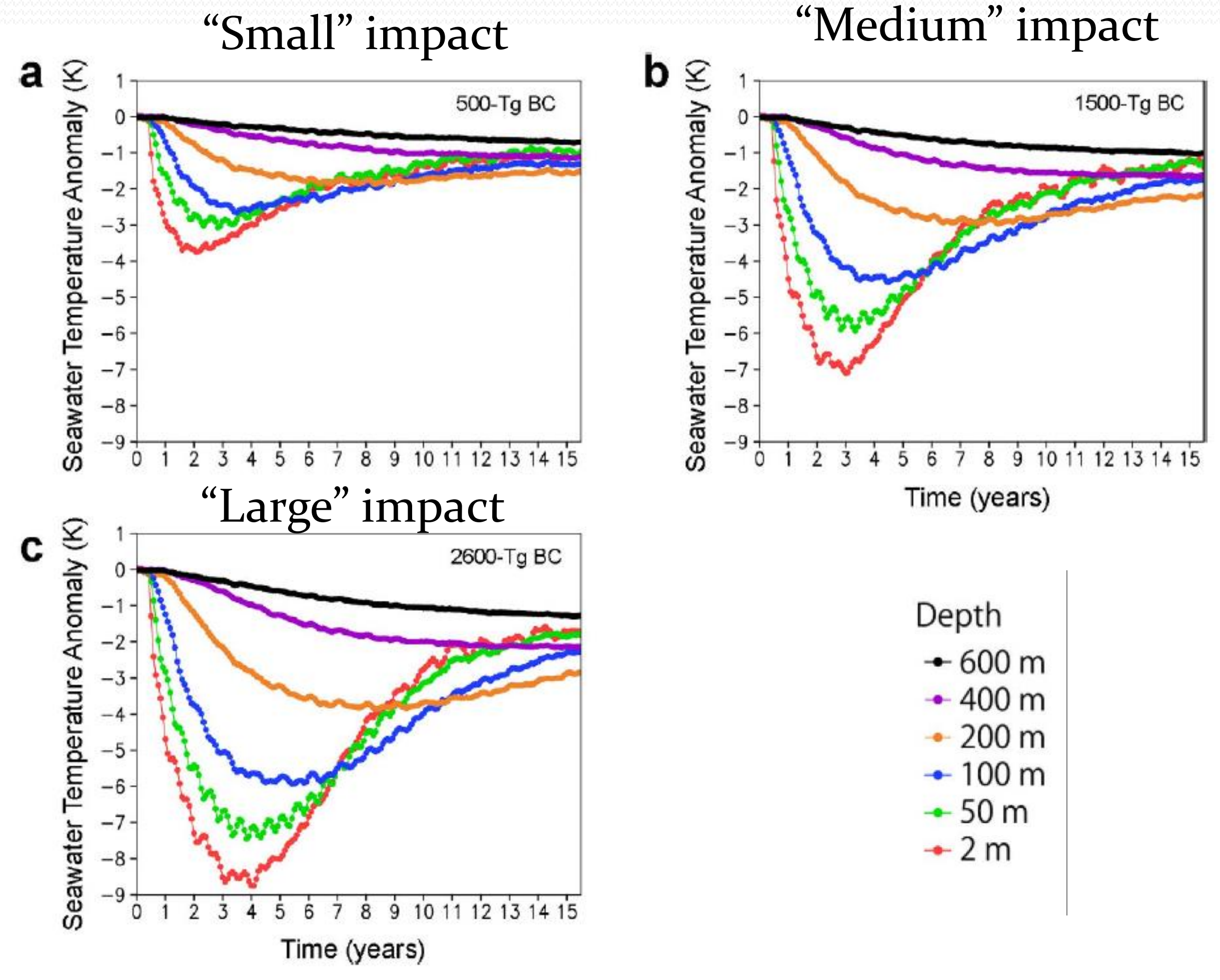
Environmental Changes (short-term)

- Dust cloud from vaporized rock spread across the planet leading to temporary global decrease in sunlight and temperature
  - Rapid but short-lived global cooling
- Impact vaporized gypsum deposits ($CaSO_4$) that would have introduced sulfates into the air and also helped push temperatures down temporarily
  - Sulfates cause acid rain and ocean acidification

Collisions Effect on Precipitation for 3.5 years following impact



Collisions Effect on SST for 3.5 years following impact



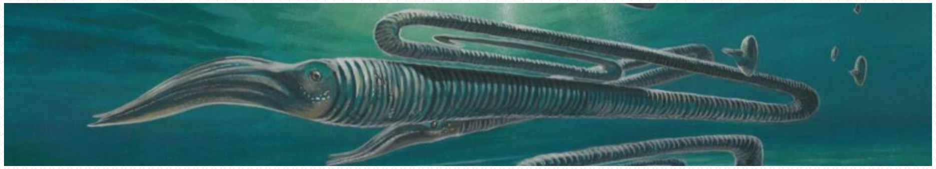
Long-Term Effects

- Impact also vaporized large amounts of carbonates (tropical ocean impact site) in combination with burning forests (instant CO_2 release and loss of photosynthetic sink) led to rapid warming afterward

- Collapse of photosynthetic-based food webs (oceans and land)
  - Acidification of oceans due to initial sulfate flux would also help destroy ocean food webs that rely on invertebrates to produce $CaCO_3$ based shells

Organisms Most Affected (other than non-avian dinosaurs)

- Ammonites*



- Birds

- Mammals

- Marine Reptiles

- Pterosaurs

*A handful of ammonites likely survived, but went extinct almost immediately afterward

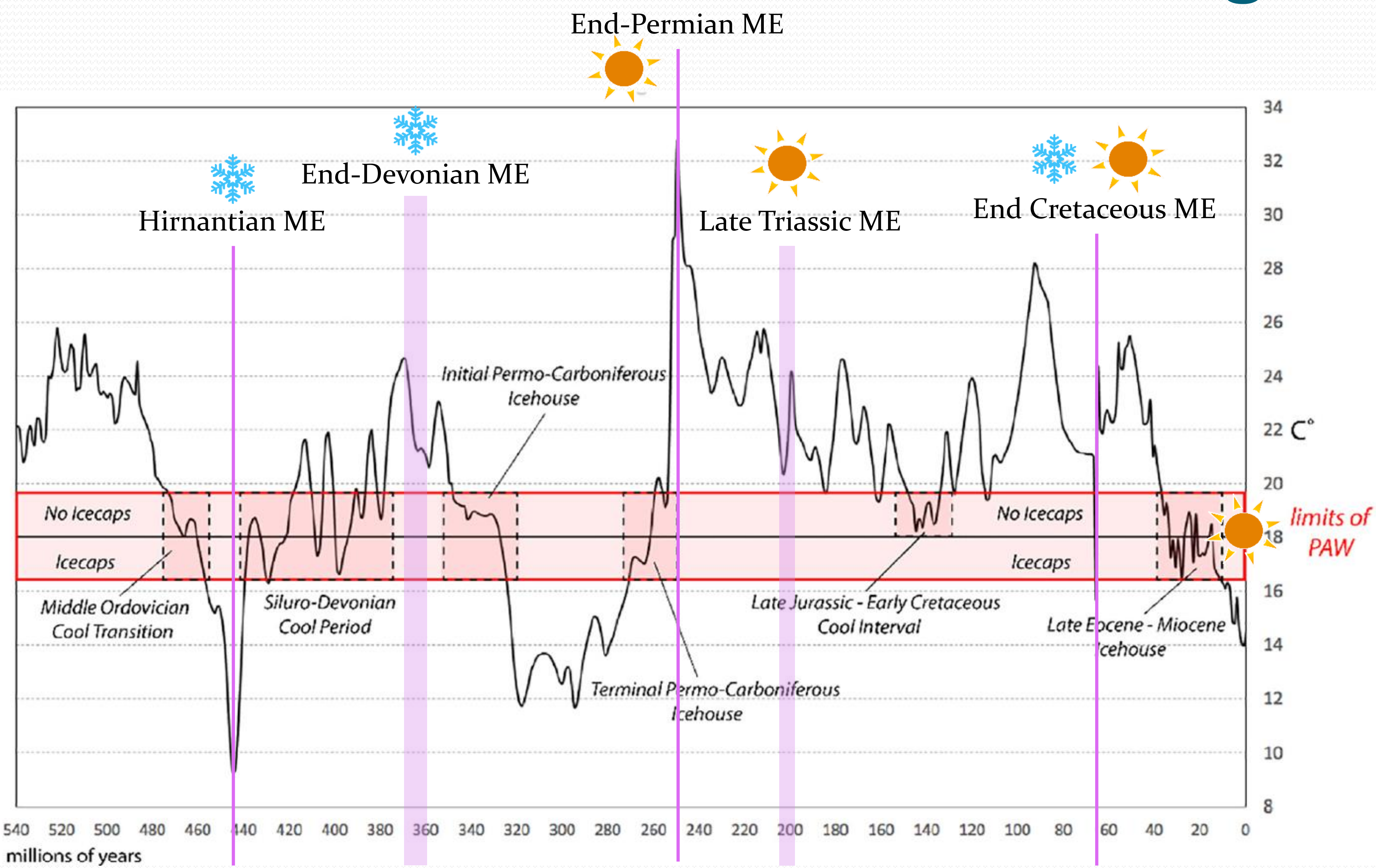
Extinction Events Summary

- Late Ordovician: rapid cooling and glaciation triggered thermohaline circulation and sea level drop, both of which destroyed lots of habitat. Then rapid warming destroyed newly create habitats.

- Late Permian: rapid warming from massive volcanism and bad luck of burning through limestone and coal deposits, led to extreme temperatures, seasonal extremes, and ocean acidification

- End-Cretaceous: meteorite impact struck shallow warm oceans injecting dust, sulfates, and CO_2 into the atmosphere. Triggered short but intense global cooling, forest fires, and ocean acidification initially. But CO_2 increase then led to rapid warming

Mass Extinctions & Climate Change



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