Geobiology 2013

Major Transitions in Earth History: Mass Extinctions & Radiations

The Permian-Triassic (P-T) boundary
The Triassic-Jurassic (T-J) boundary

Julio Sepúlveda

Outlook

- Definition of mass extinctions
- Mass extinctions over the Phanerozoic
- Triggering mechanisms
- The Permian-Triassic event
- The Triassic-Jurassic event

What are mass extinctions?

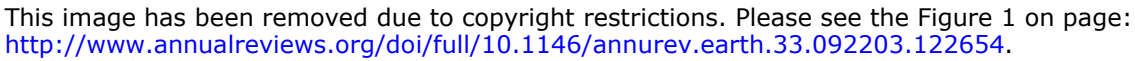
"A mass extinction is any substantial increase in the amount of extinction (i.e. lineage termination) suffered by more than one **geographically widespread** higher taxon during a relatively **short interval** of geologic time, resulting in an at least **temporary decline** in their standing diversity."

Jack Sepkoski (1986)

Mass Extinctions over the Phanerozoic

Mass Extinctions over the Phanerozoic

18 events with peaks of both magnitude and rate of extinction



What causes a mass extinction?

- Bolide Impact
- Long-Term Tectonic Processes
- Large Igneous Provinces
- Global Warming/Cooling
- Regression/Transgression
- Nutrient Collapse
- Hydrogen Sulfide Poisoning

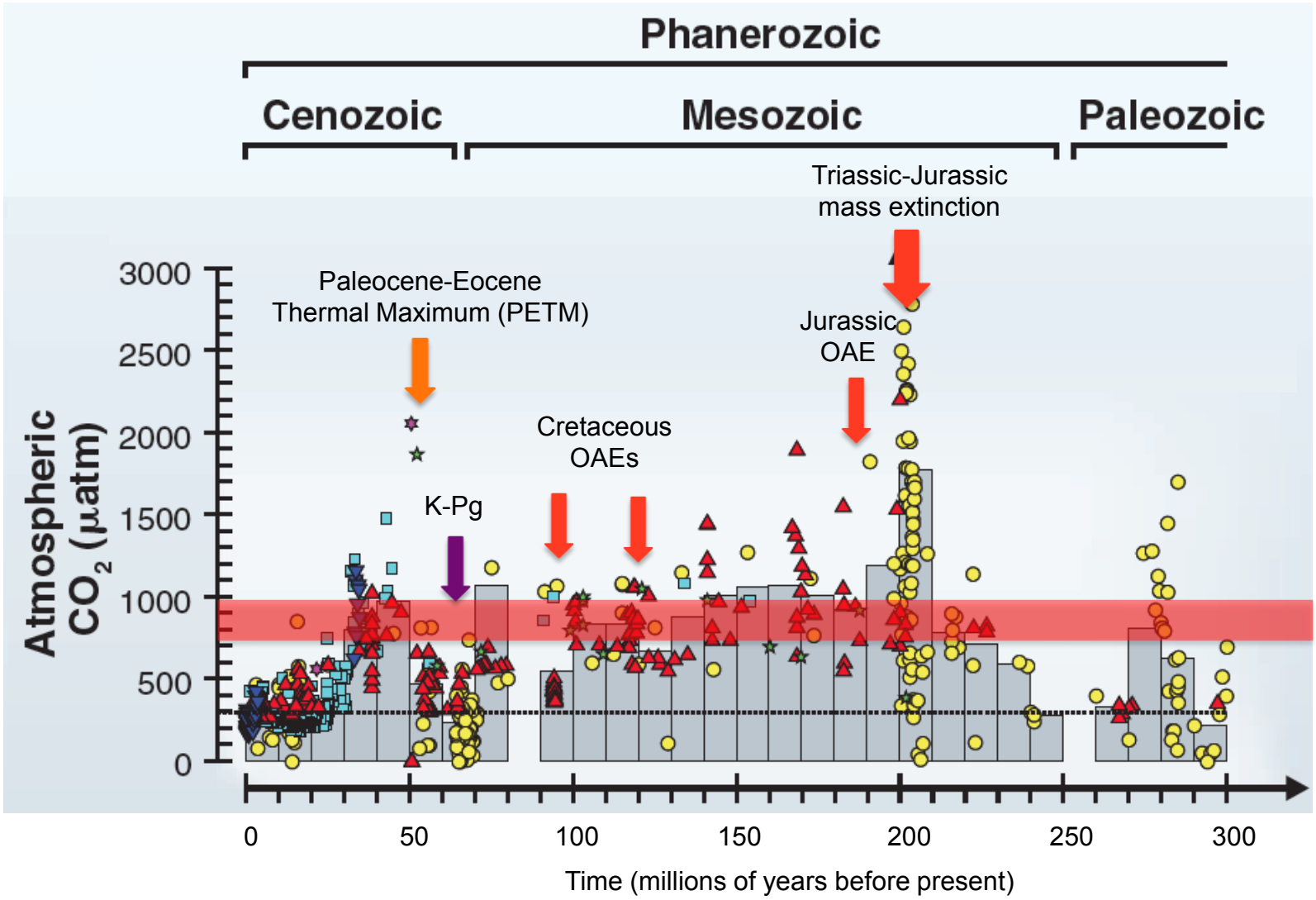
Google image hit #2

This image has been removed due to copyright restrictions. Please see the image on page: http://www gambassa.com/gambassafiles/images/images/deathgawd/mass_extinction_v1.jp.

Source: National Geographic

Anoxia, extinctions & black shales

CO_2 & planetary-scale critical transitions



Present-day mass extinction?

REVIEW

doi:10.1038/nature09678

Has the Earth's sixth mass extinction already arrived?

Anthony D. Barnosky[1,2,3], Nicholas Matzke[1], Susumu Tomiya[1,2,3], Guinevere O. U. Wogan[1,3], Brian Swartz[1,2], Tiago B. Quental[1,2]†, Charles Marshall[1,2], Jenny L. McGuire[1,2,3]†, Emily L. Lindsey[1,2], Kaitlin C. Maguire[1,2], Ben Mersey[1,4] & Elizabeth A. Ferrer[1,2]

REVIEW

doi:10.1038/nature11018

Approaching a state shift in Earth's biosphere

Anthony D. Barnosky[1,2,3], Elizabeth A. Hadly[4], Jordi Bascompte[5], Eric L. Berlow[6], James H. Brown[7], Mikael Fortelius[8], Wayne M. Getz[9], John Harte[9,10], Alan Hastings[11], Pablo A. Marquet[12,13,14,15], Neo D. Martinez[16], Arne Mooers[17], Peter Roopnarine[18], Geerat Vermeij[19], John W. Williams[20], Rosemary Gillespie[9], Justin Kitzes[9], Charles Marshall[1,2], Nicholas Matzke[1], David P. Mindell[21], Eloy Revilla[22] & Adam B. Smith[23]

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E., Smith, A.B., 2012. Approaching a state shift in Earth's biosphere. Nature 486, 52–58.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C., Ben Mersey, Ferrer, E.A., 2011. Has the Earth/'s sixth mass extinction already arrived? Nature 471, 51–57.

Large Igneous Provinces (LIPs)

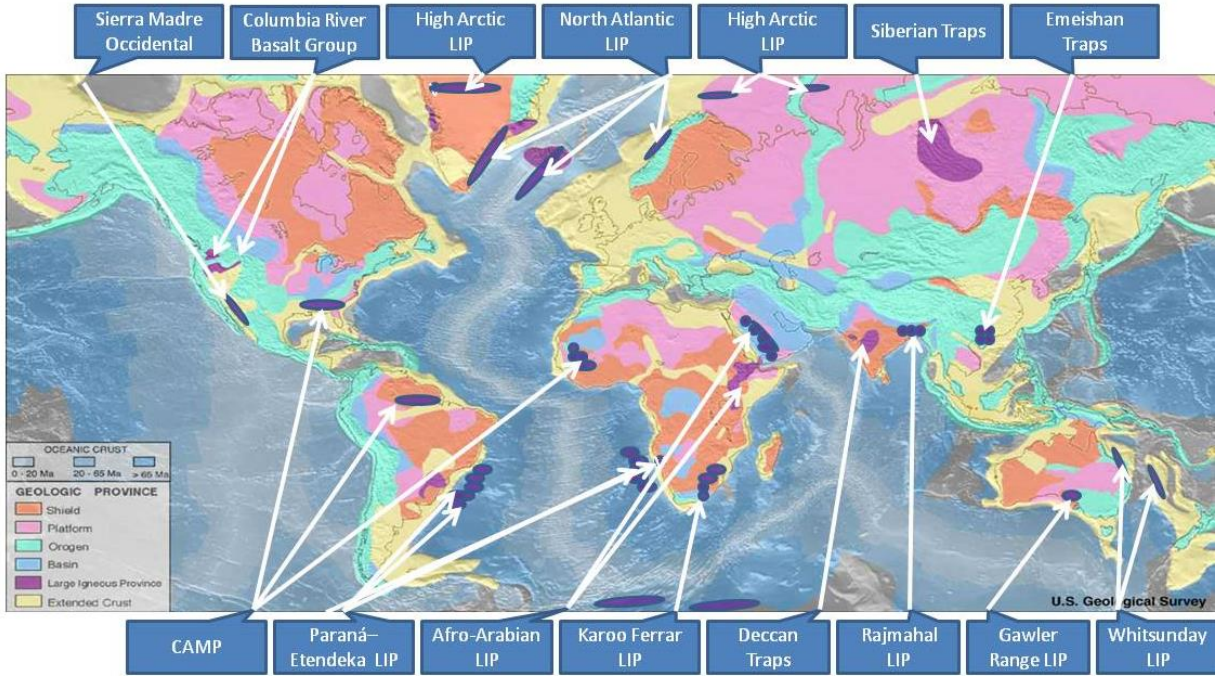
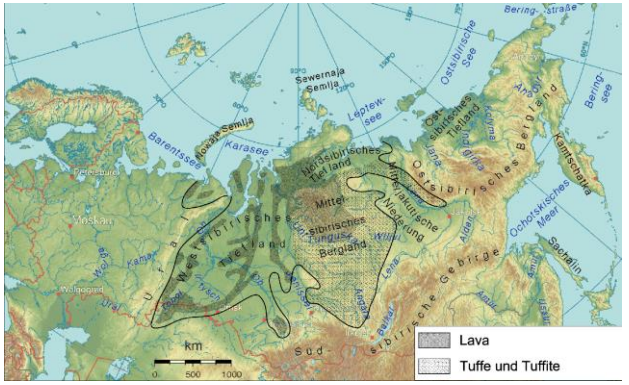


Image courtesy of USGS.

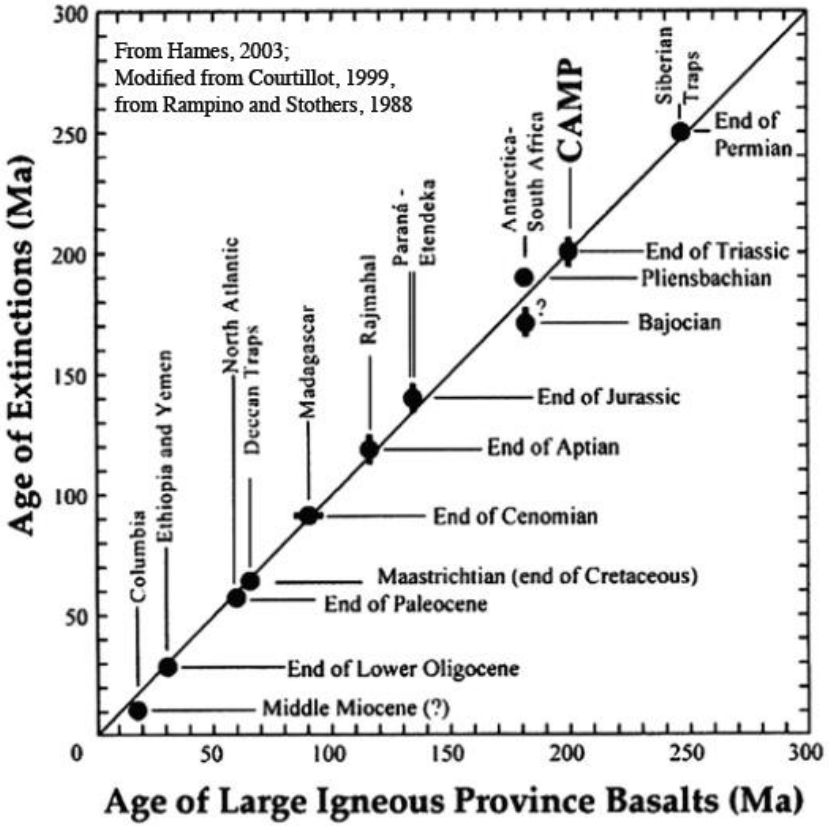
http://en.wikipedia.org/wiki/Large_igneous_province

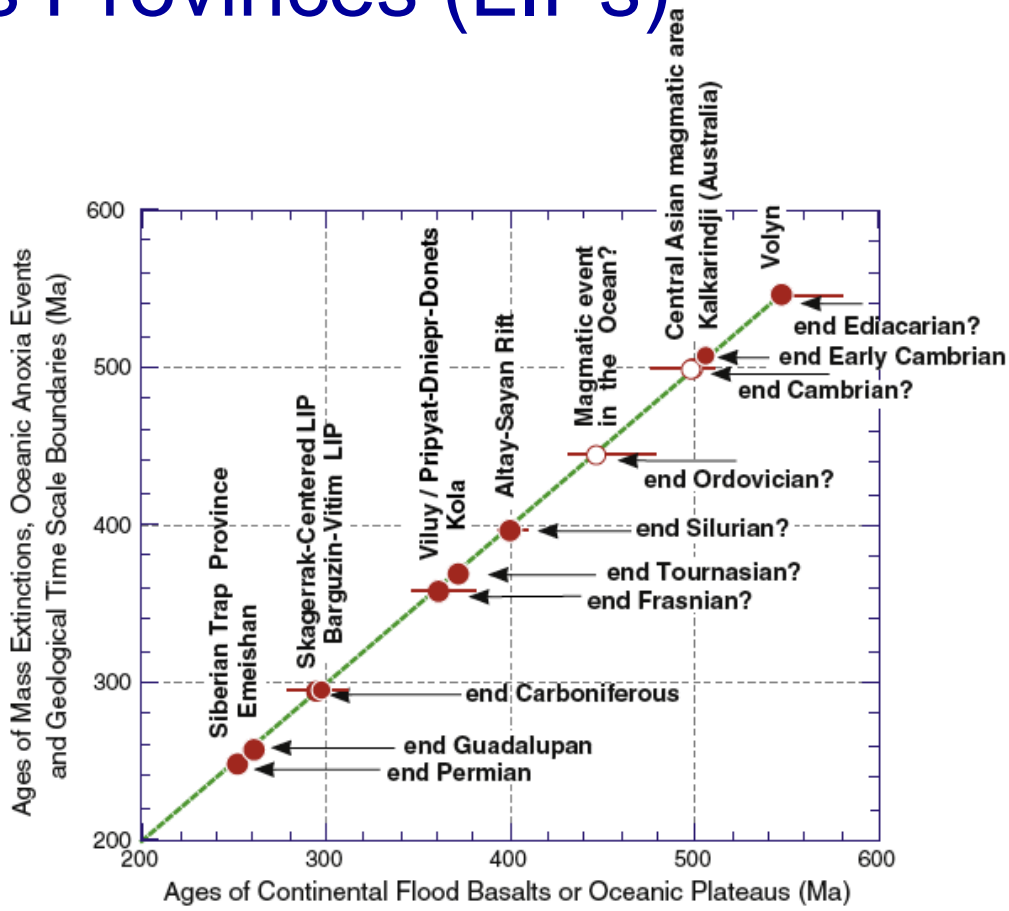
Siberian Traps



Extremely large accumulation (>100,000 km^2) of igneous rocks —intrusive, extrusive, or both— in the earth's crust, within an extremely short geological time interval—a few million years or less.

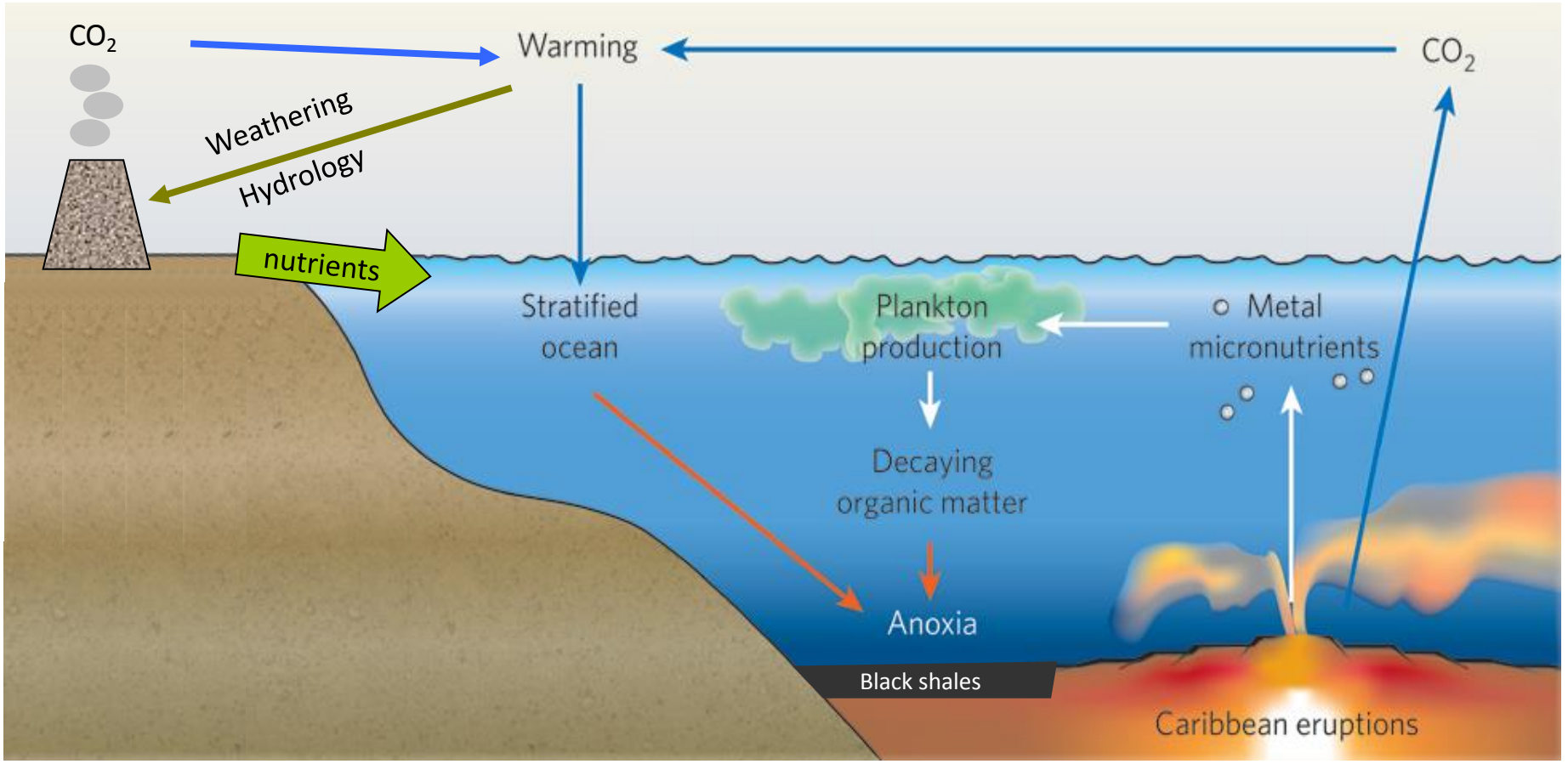
Large Igneous Provinces (LIPs)





Kravchinsky, V.A., 2012. Paleozoic large igneous provinces of Northern Eurasia: Correlation with mass extinction events. Global and Planetary Change 86-87, 31–36.

Mechanisms for ocean anoxia: Volcanism

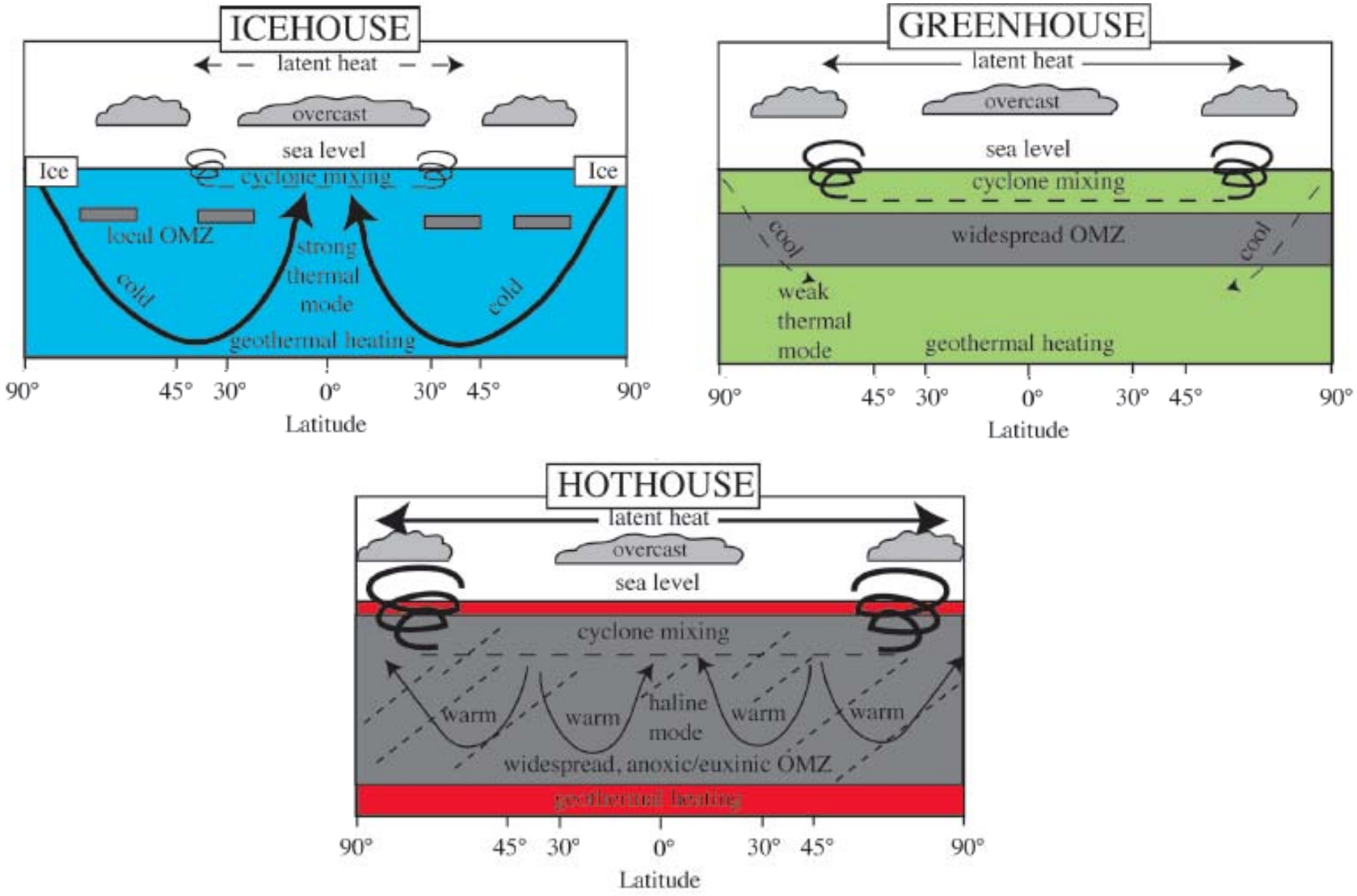


Bralower, T.J., 2008. Earth science: Volcanic cause of catastrophe. Nature 454, 285–287.
Turgeon, S.C., Creaser, R.A., 2008. Cretaceous oceanic anoxic event 2 triggered by a massive magmatic episode. Nature 454, 323–326.

Feedback mechanisms & deoxygenation

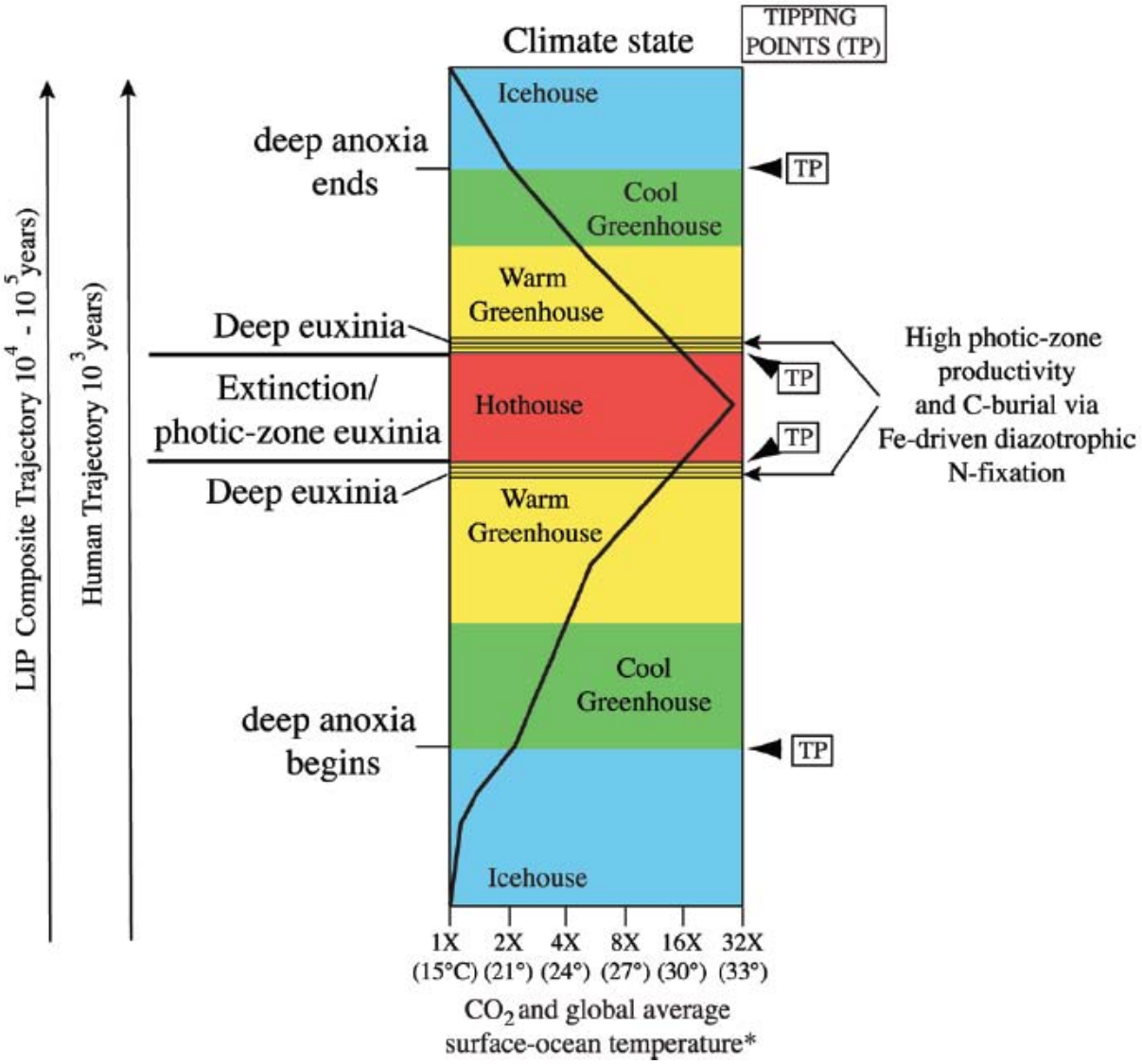
Meyer, K.M., Kump, L.R., 2008. Oceanic Euxinia in Earth History: Causes and Consequences. Annu. Rev. Earth Planet. Sci. 36, 251–288.

Climatic modes



Kidder, D.L., Worsley, T.R., 2012. GSA Today - A human-induced hothouse climate? GSA Today 22,

Tipping points



Kidder, D.L., Worsley, T.R., 2012. GSA Today - A human-induced hothouse climate? GSA Today 22, 4–11.

Permo-Triassic Boundary

Where is it and how is it defined?

1. Marine extinctions observed worldwide in the Upper Permian (Changhsingian)
2. Base Triassic (Griesbachian) defined at the Global Stratotype, Section and Point , Meishan, China at the first appearance of a specific marine taxon, the conodont *Hindeodus parvus*
3. Floral extinction: well defined ‘coal gap’ in terrestrial sediments worldwide
4. Terrestrial faunal extinction

Characteristics of Permian-Triassic Event

- Global regression of seal level; aggregation of supercontinent of Pangea; rarity of continuous sedimentation
- Massive volcanism and emplacement of Large Igneous Provinces (LIPS) - 400 to 3700m thick basalts over ca 5 Ma
- Uneven marine extinction; sessile animals worst hit
- Immediate radiation of different physiological groups (disaster species??) than before and then stabilization of the classic Mesozoic fauna and flora.
- More complex and sophisticated ecosystems

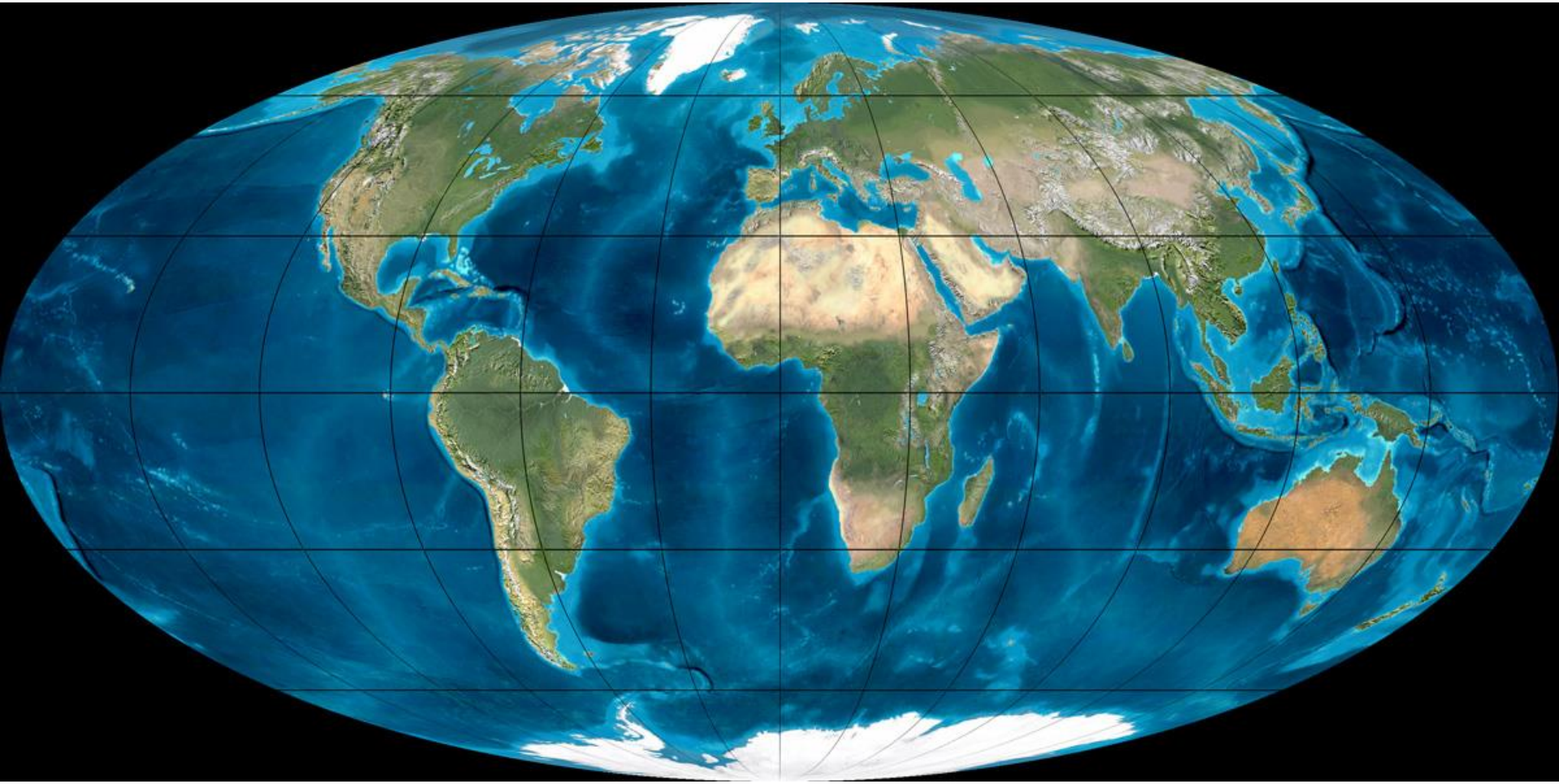
PTB Killing Mechanisms

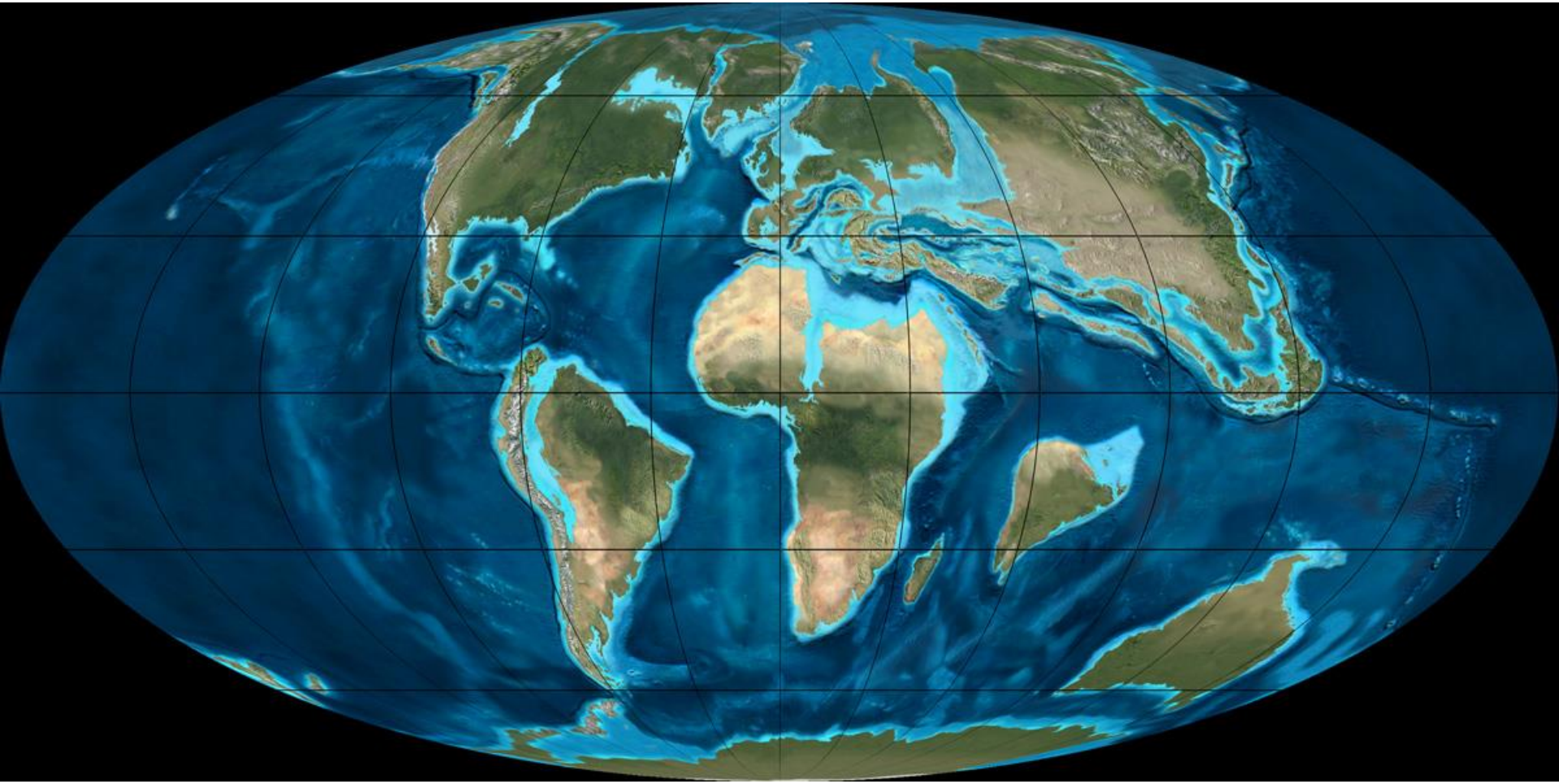
#1 Overturn of an anoxic ocean; CO_2 and H_2S poisoning (growing evidence)

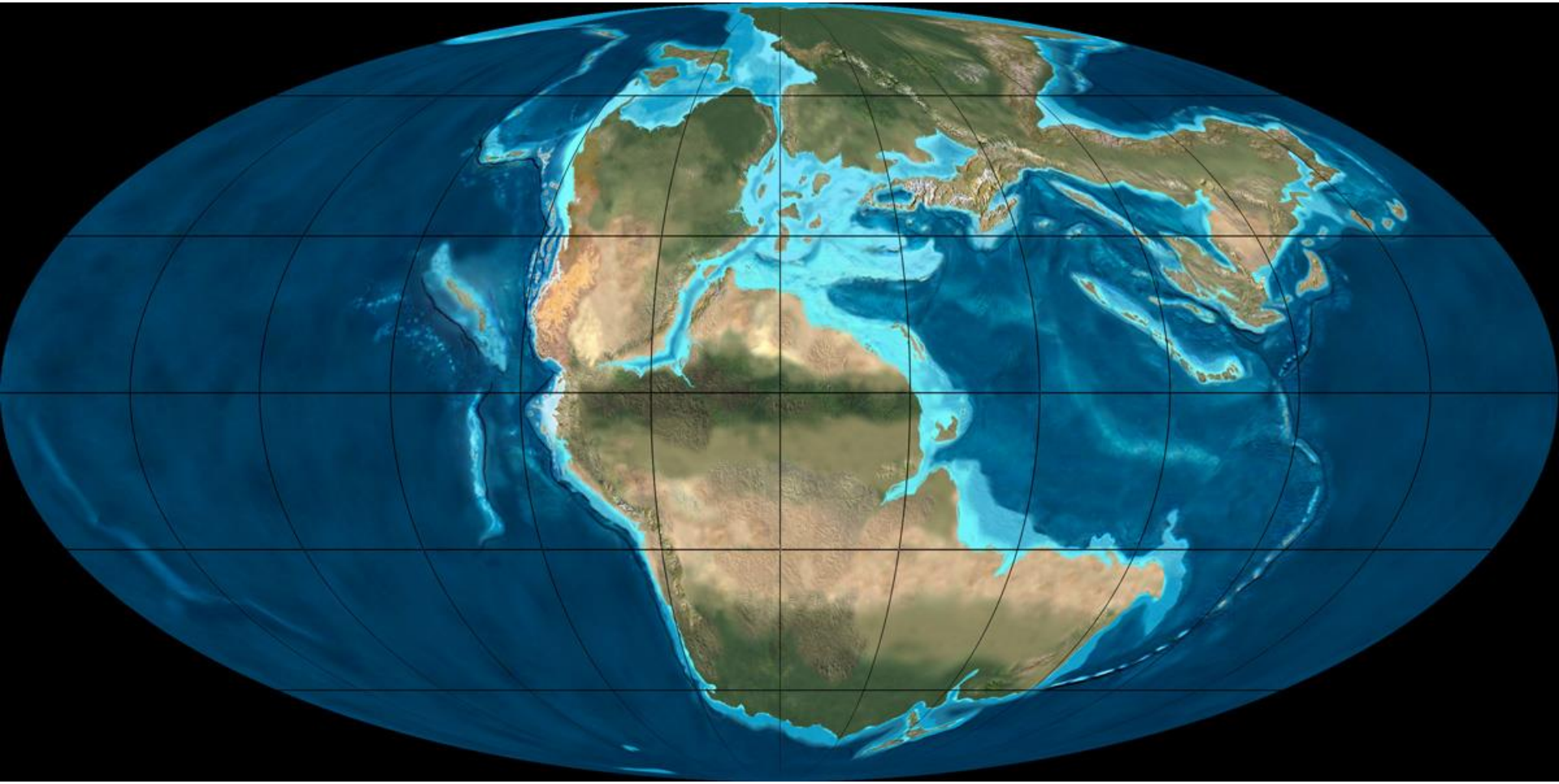
#2 Explosive volcanism and associated icehouse/greenhouse followed by productivity collapse (numerous authors)

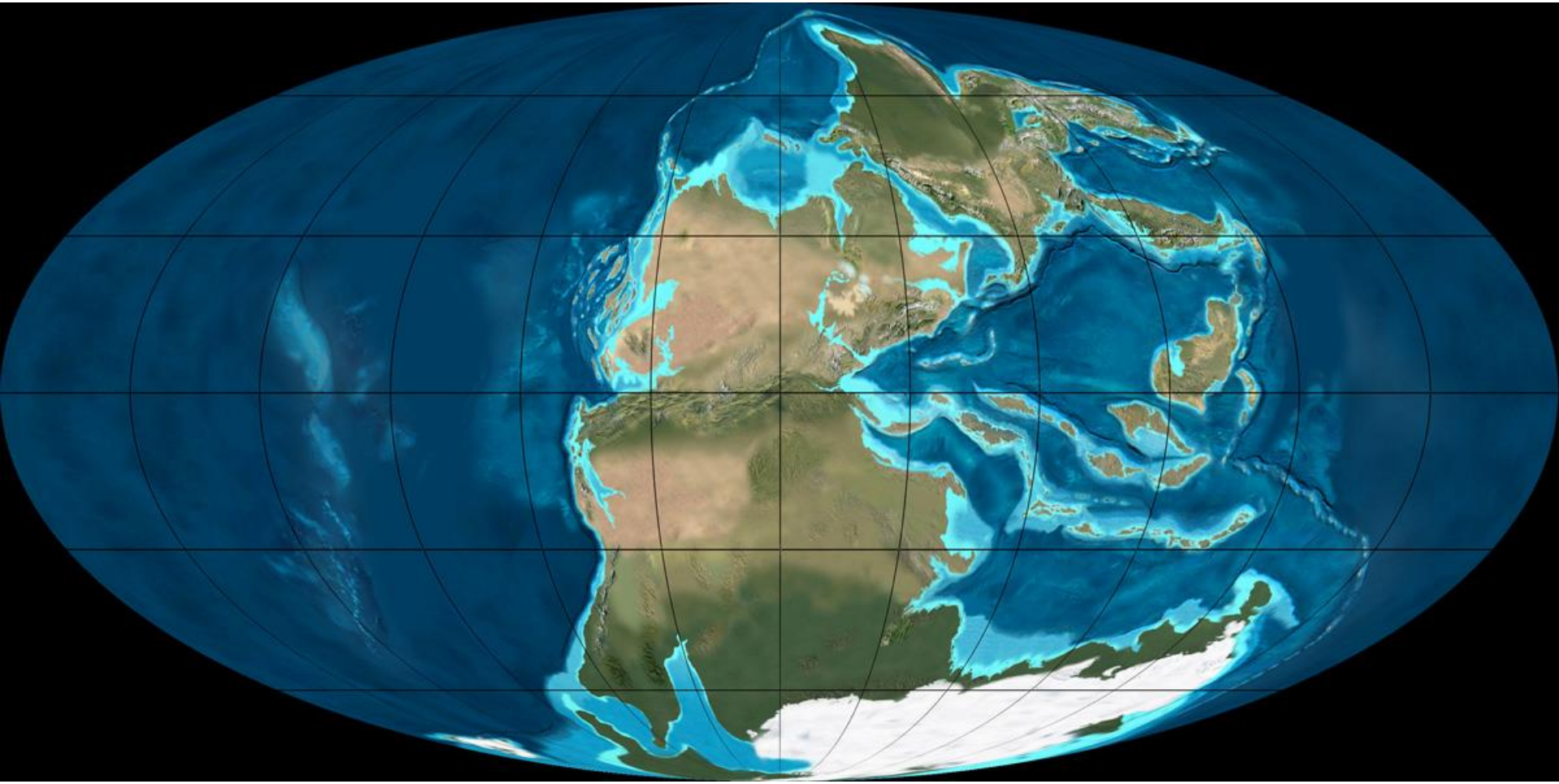
#3 Regression, catastrophic methane release and associated greenhouse (numerous authors)

#4 Impact (Becker and Poreda)

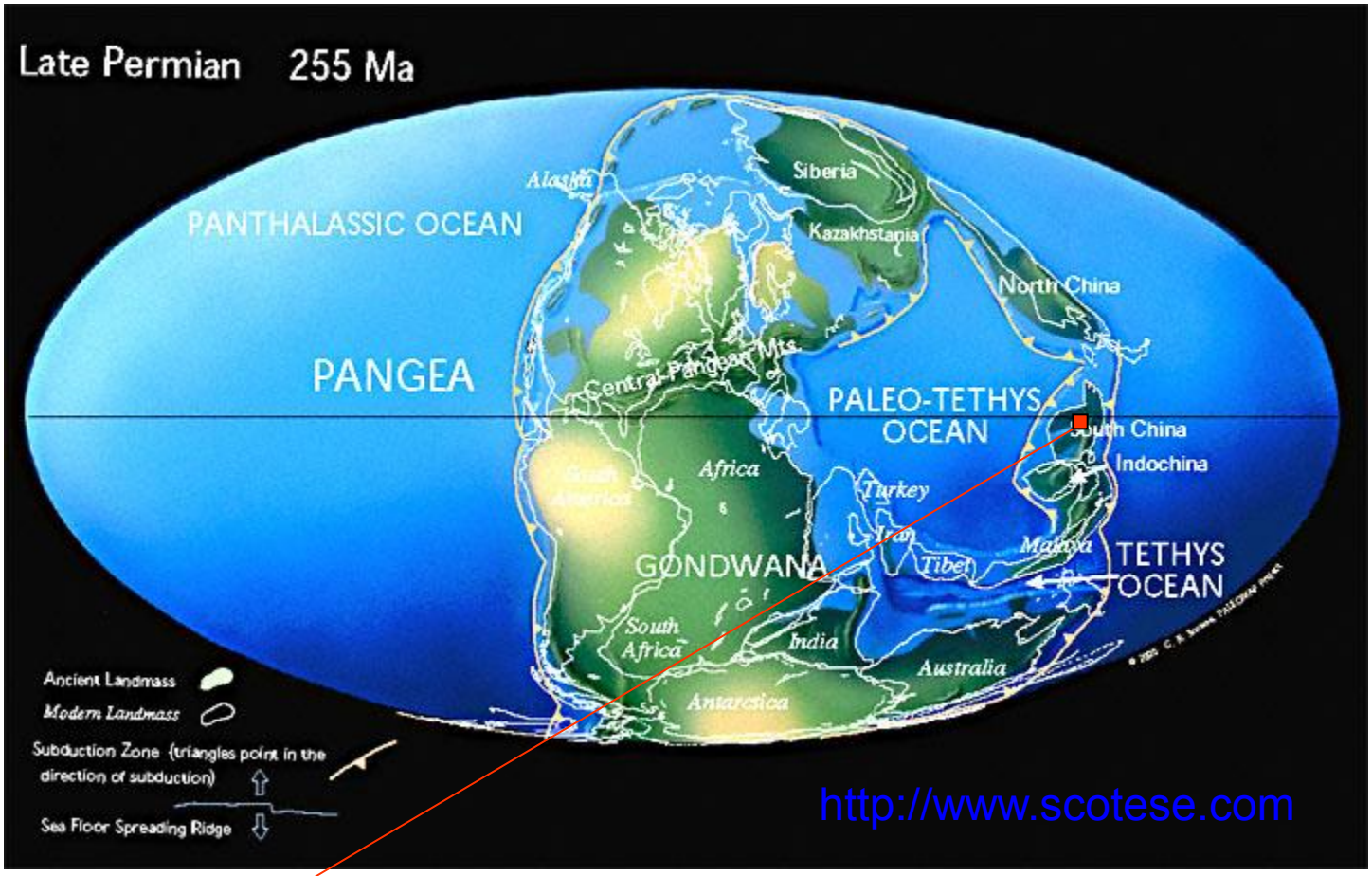








Meishan Section



Meishan sediments deposited on N.-E. margin of Paleotethys equatorial latitudes, deepwater shales

Litho- and Biostratigraphy of the Permian/Triassic Boundary Strata of Meishan Section D

This image has been removed due to copyright restrictions.

Main extinction horizon in ash bed (Bed 25)

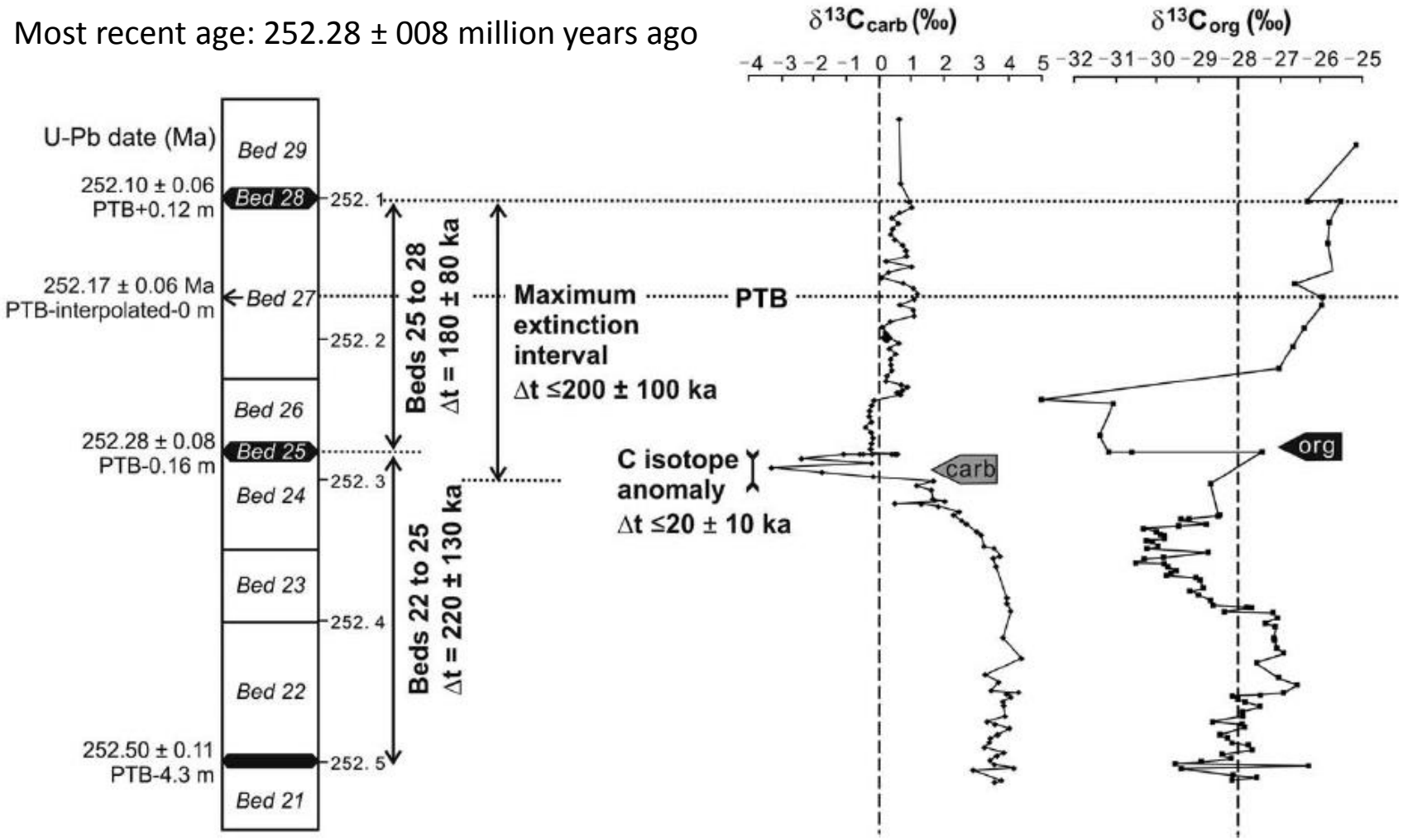
Composite $\delta^{13}C$ & Diversity Profiles

Overview of perturbations

Payne, J.L., Clapham, M.E., 2012. End-Permian Mass Extinction in the Oceans: An Ancient Analog for the Twenty-First Century? Annu. Rev. Earth Planet. Sci. 40, 89–111.

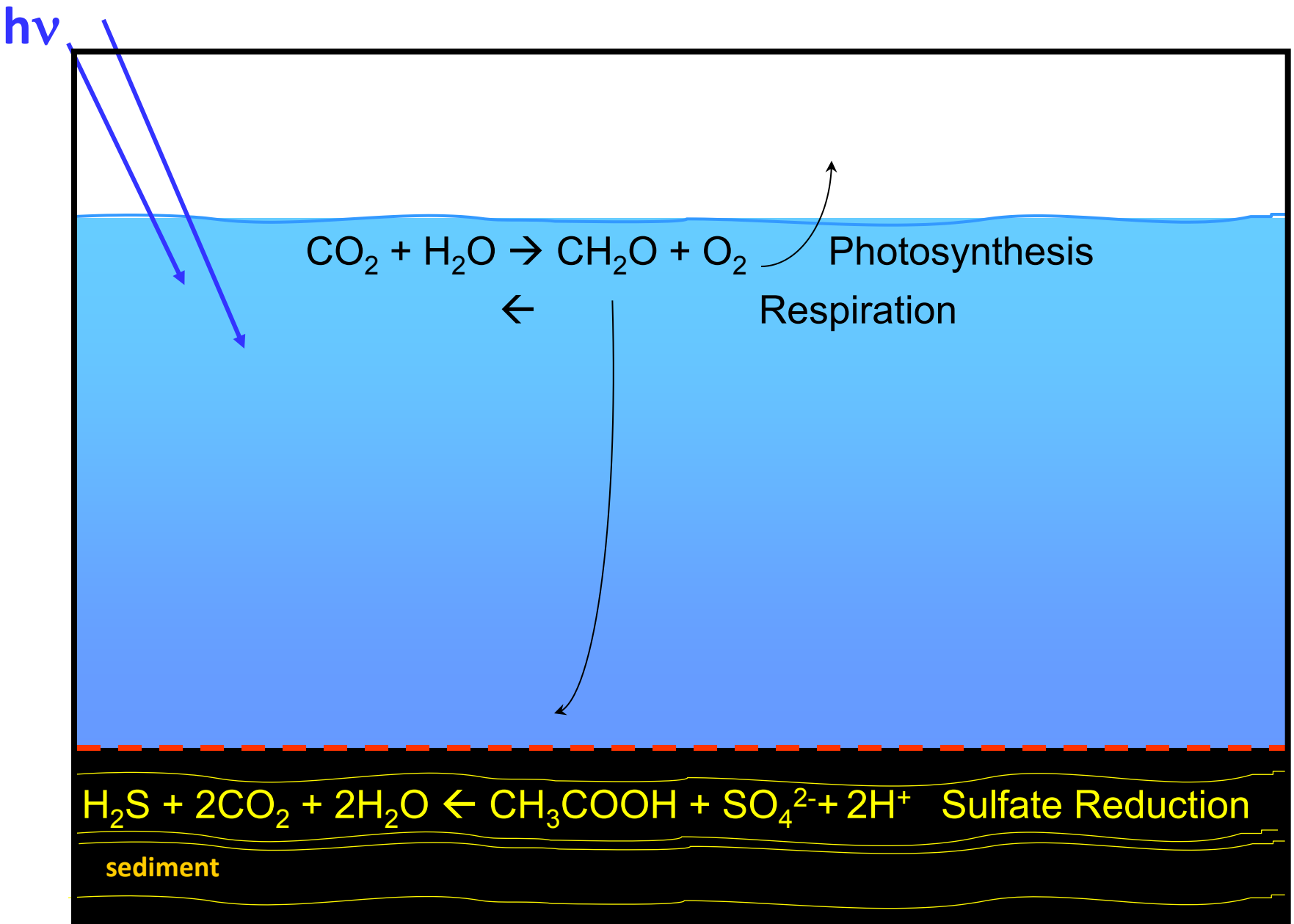
Calibrating the End-Permian

Most recent age: 252.28 ± 008 million years ago

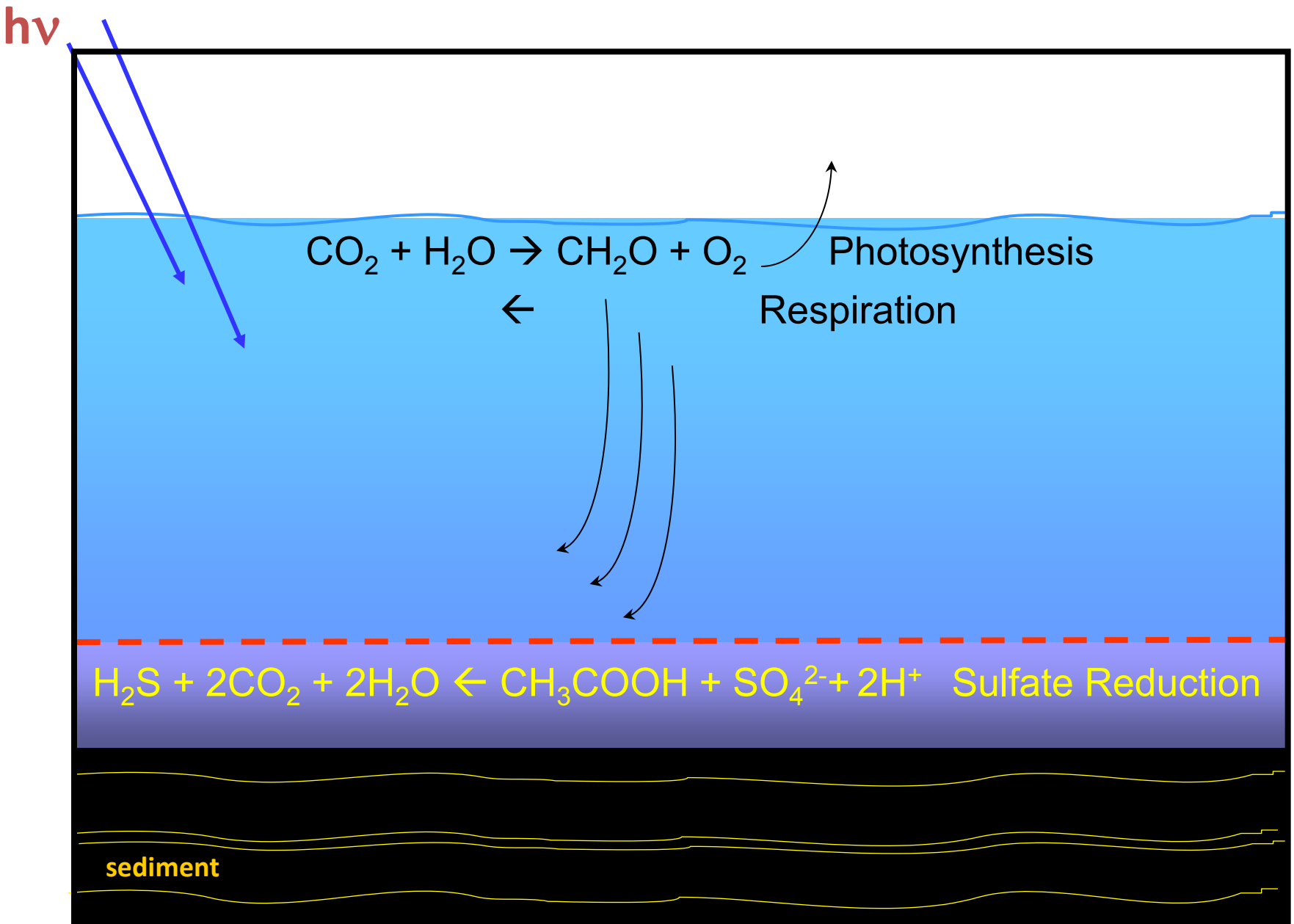


Shen, S.Z., Crowley, J.L., Wang, Y., Bowring, S.A., Erwin, D.H., Sadler, P.M., Cao, C.Q., Rothman, D.H., Henderson, C.M., Ramezani, J., Zhang, H., Shen, Y., Wang, X.D., Wang, W., Mu, L., Li, W.Z., Tang, Y.G., Liu, X.L., Liu, L.J., Zeng, Y., Jiang, Y.F., Jin, Y.G., 2011. Calibrating the End-Permian Mass Extinction. Science 334, 1367–1372.

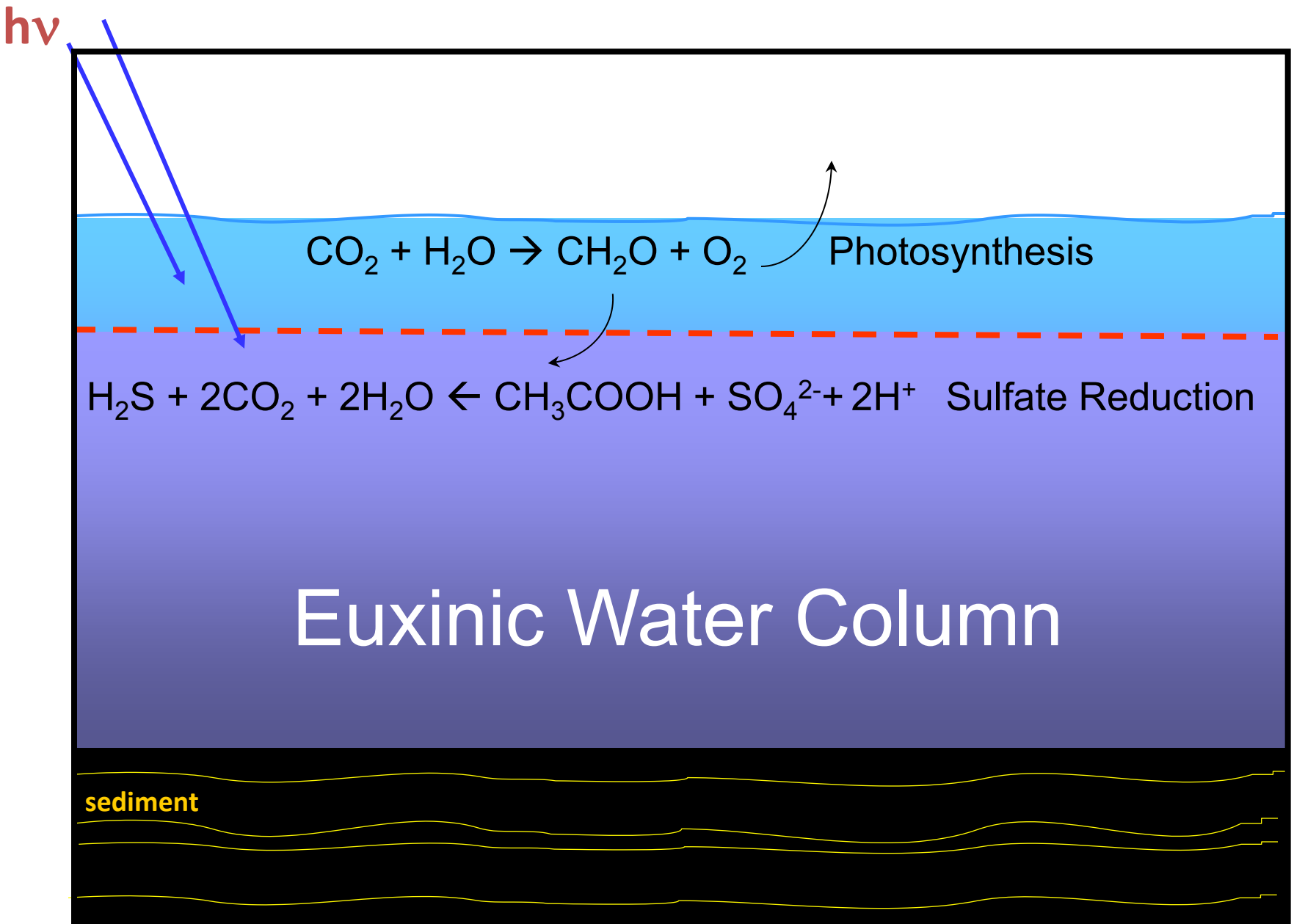
Biogeochemical Carbon Cycle in Modern Ocean



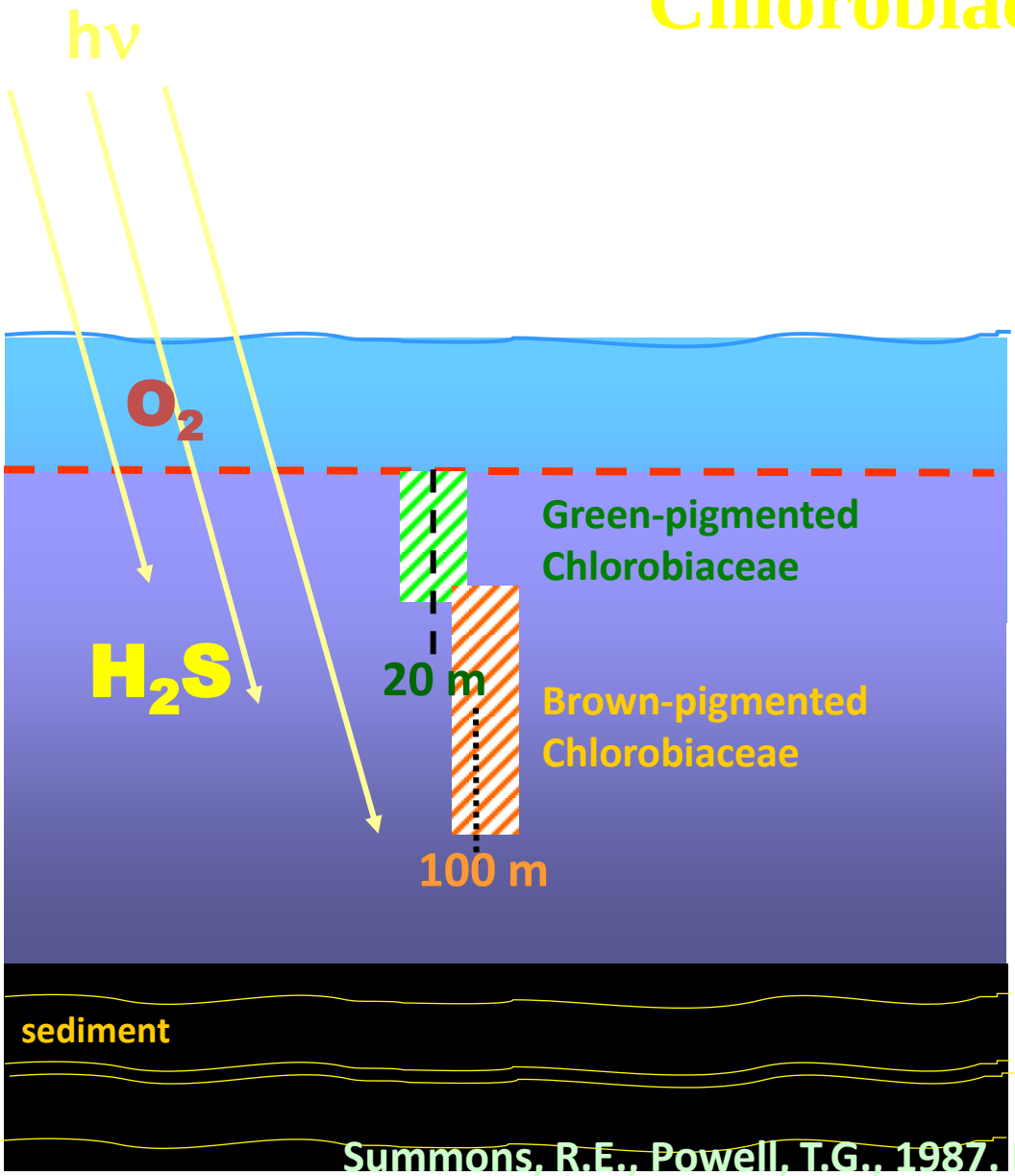
Links Between Carbon and Sulfur Cycles



Carbon Cycle in a Stratified Ocean



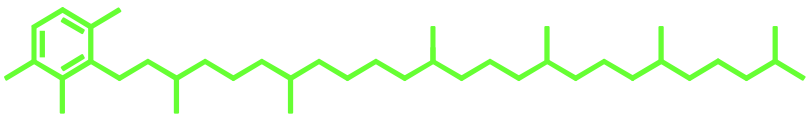
Green sulfur bacteria
Chlorobiaceae



H_2S

$h\nu$

SO_4^{2-}



chlorobactane

isorenieratane

Summons, R.E., Powell, T.G., 1987. Identification of aryl isoprenoids in

Biomarkers (chemical/molecular fossils)

- Biological sources
- Environmental conditions
- Sea surface temperature
- Carbon cycling
- Hydrology
- Nitrogen cycling

These images have been removed due to copyright restrictions.

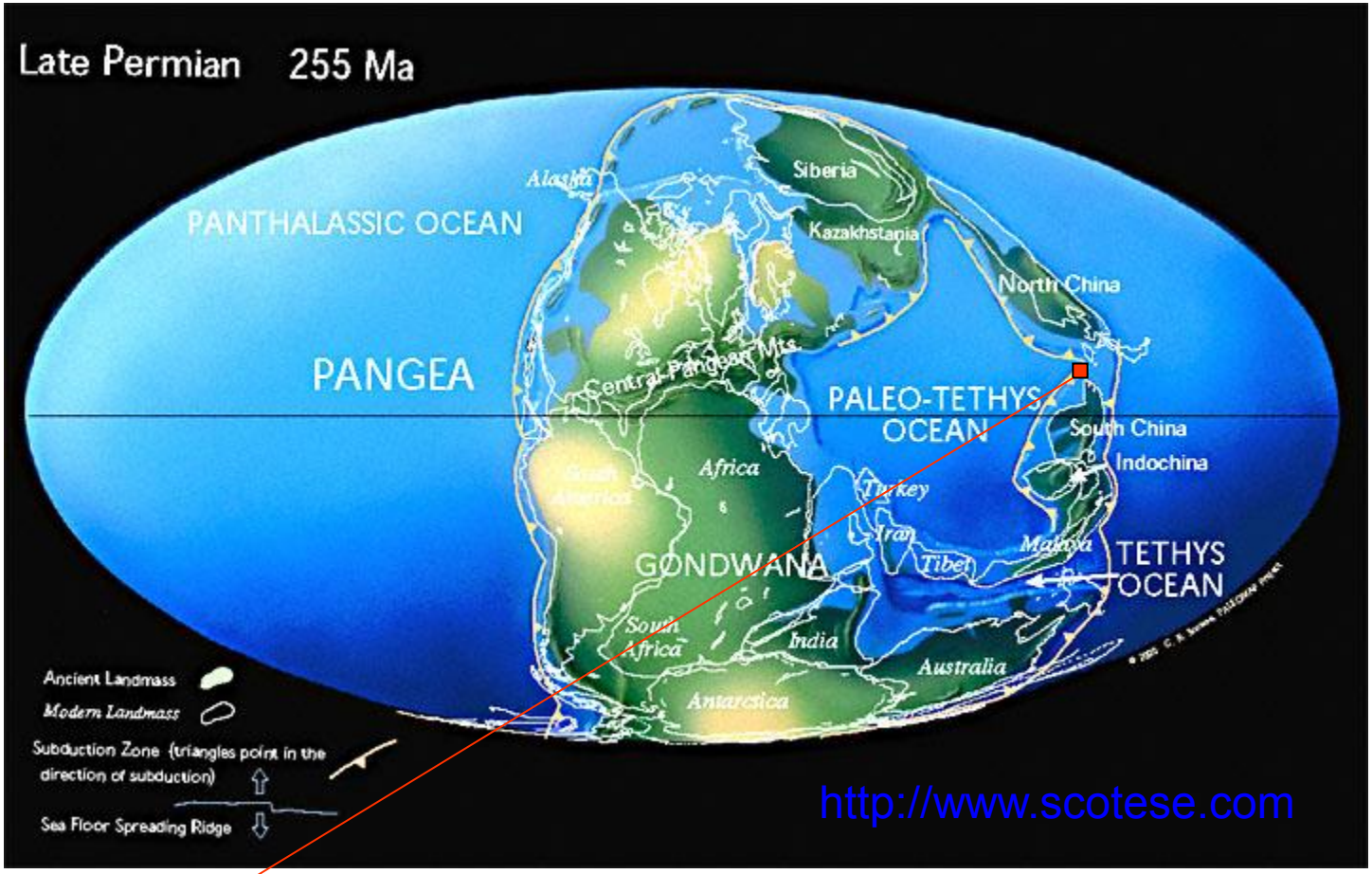
Tracing biology and carbon cycling

These images have been removed due to copyright restrictions.

Phytoplankton evolution and demise

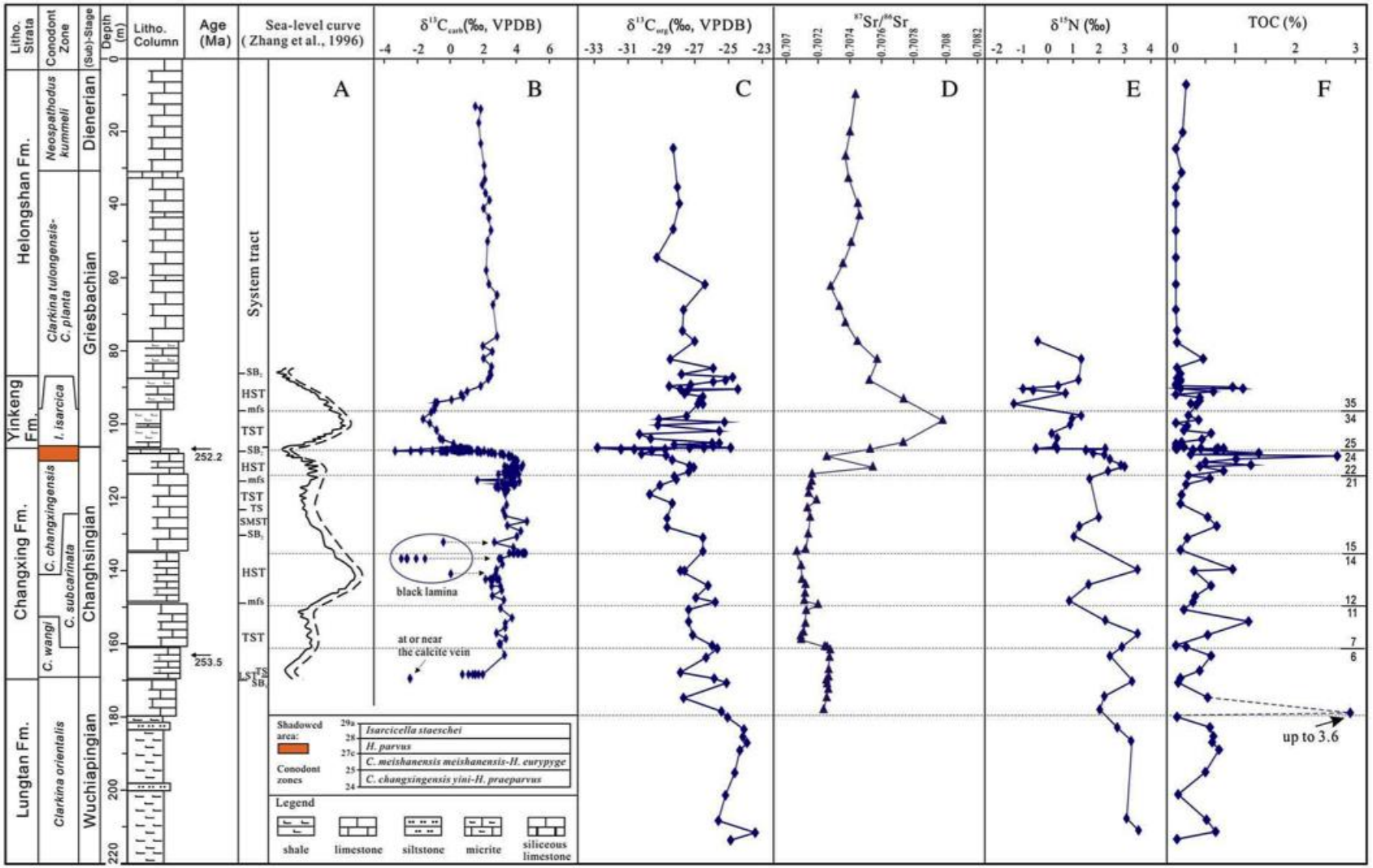
Katz, M.E., Finkel, Z.V., Grzebyk, D., Knoll, A.H., 2004. Evolutionary trajectories and biogeochemical impacts of marine eukaryotic phytoplankton. Annual review of Ecology, Evolution, and Systematics 35, 523–556.

Meishan Section



Meishan sediments deposited on N.-E. margin of Paleotethys equatorial latitudes, deepwater shales

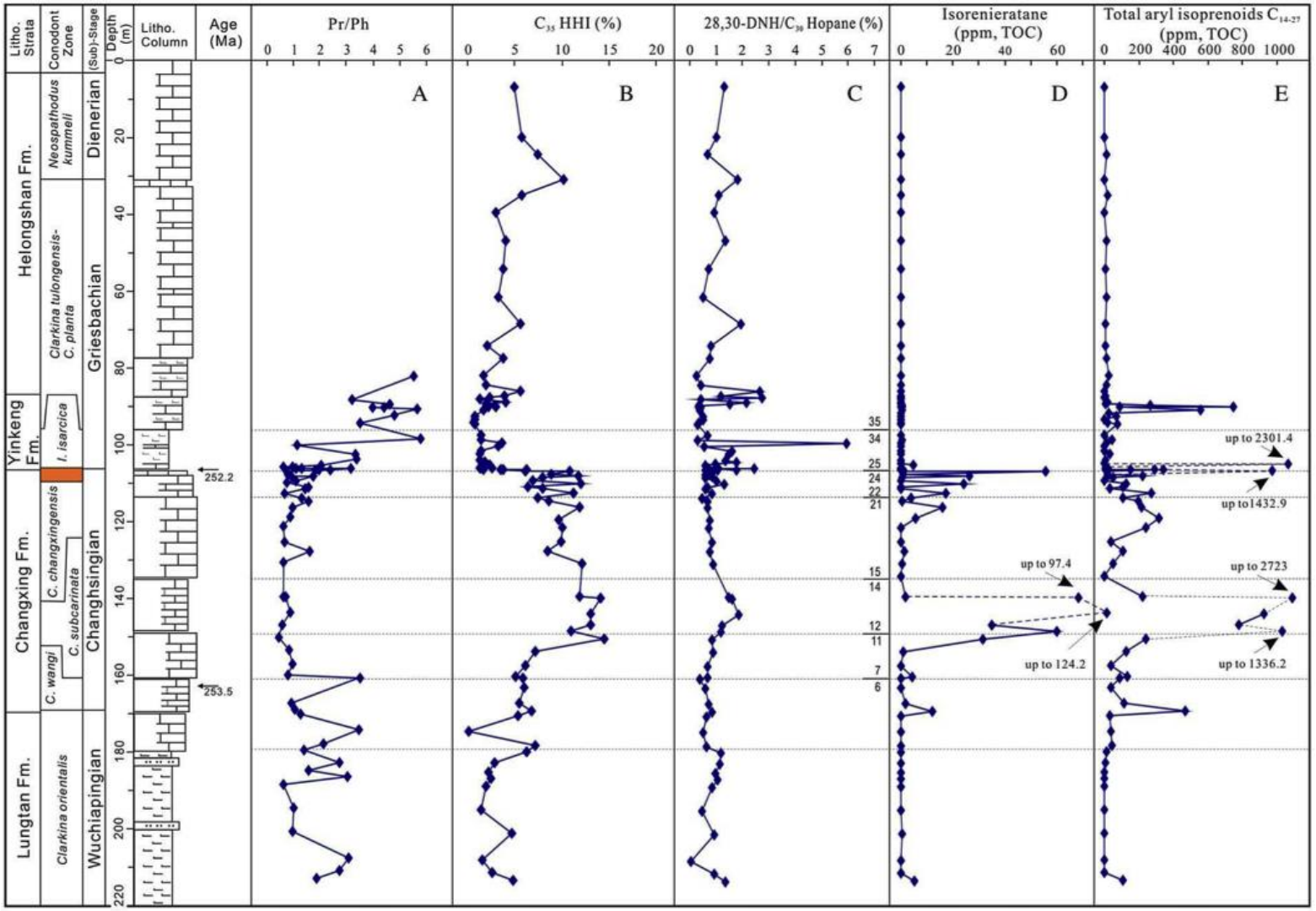
Meishan, southern China



Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

Cao, C., Love, G.D., Hays, L.E., Wang, W., Shen, S., Summons, R.E., 2009. Biogeochemical evidence for euxinic oceans and ecological disturbance presaging the end-Permian mass extinction event. Earth and Planetary Science Letters 281, 188–201.

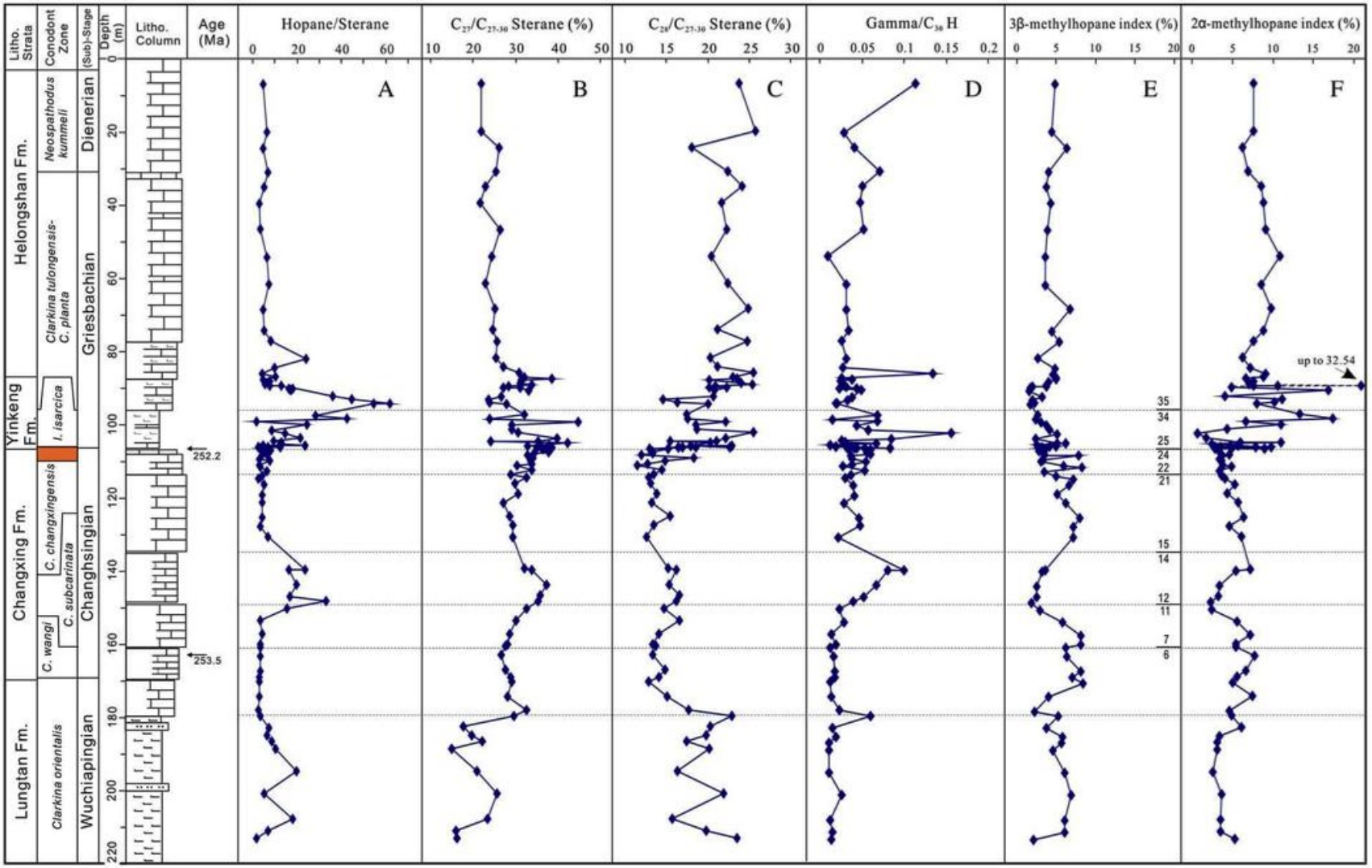
Meishan, redox, anoxia & euxinia



Courtesy Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

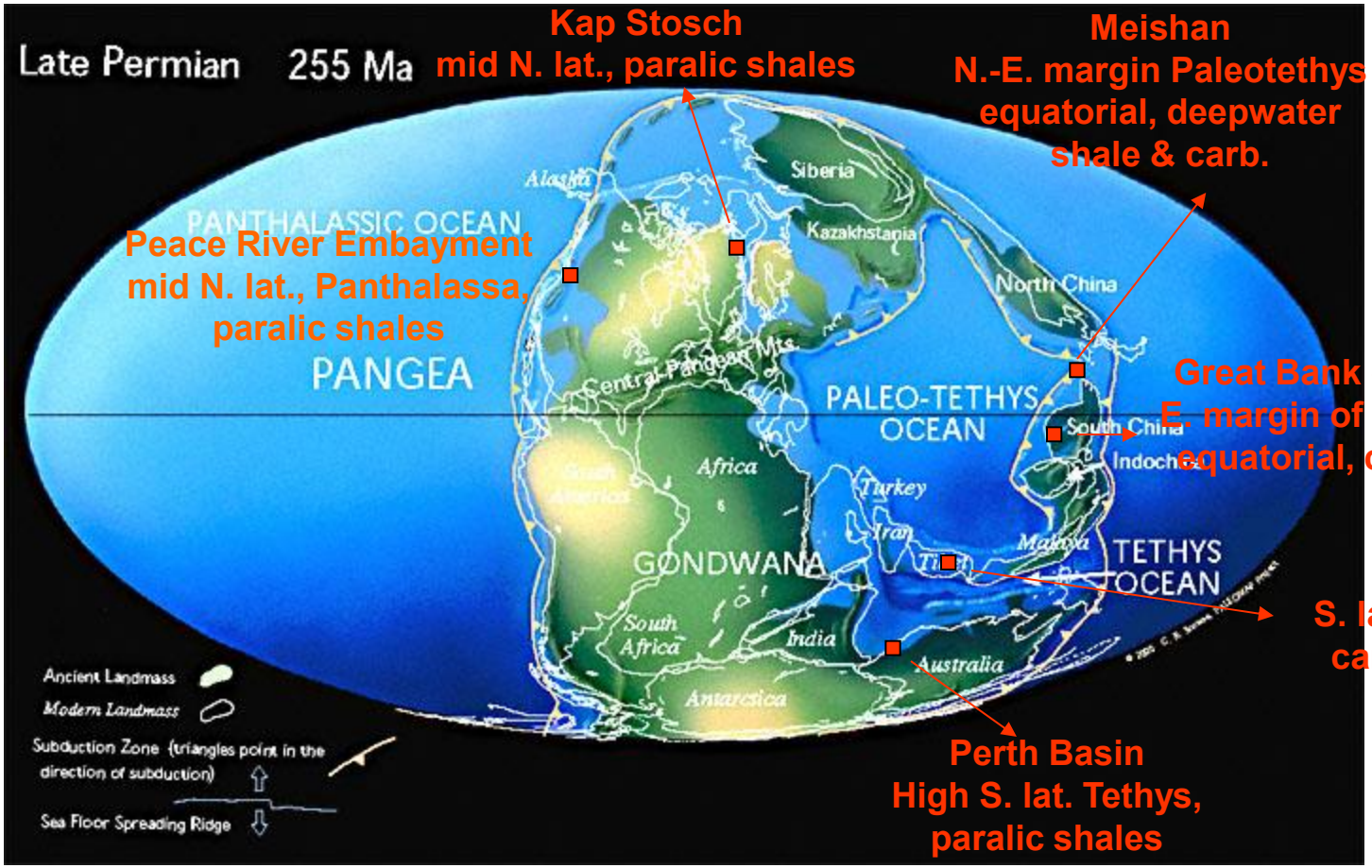
Cao, C., Love, G.D., Hays, L.E., Wang, W., Shen, S., Summons, R.E., 2009. Biogeochemical evidence for euxinic oceans and ecological disturbance presaging the end-Permian mass extinction event. Earth and Planetary Science Letters 281, 188–201.

Meishan, plankton ecology



Cao, C., Love, G.D., Hays, L.E., Wang, W., Shen, S., Summons, R.E., 2009. Biogeochemical evidence for euxinic oceans and ecological disturbance presaging the end-Permian mass extinction event. Earth and Planetary Science Letters 281, 188–201.

Loci of Aryl Isoprenoid Occurrences
Hydrogen sulfide poisoning?

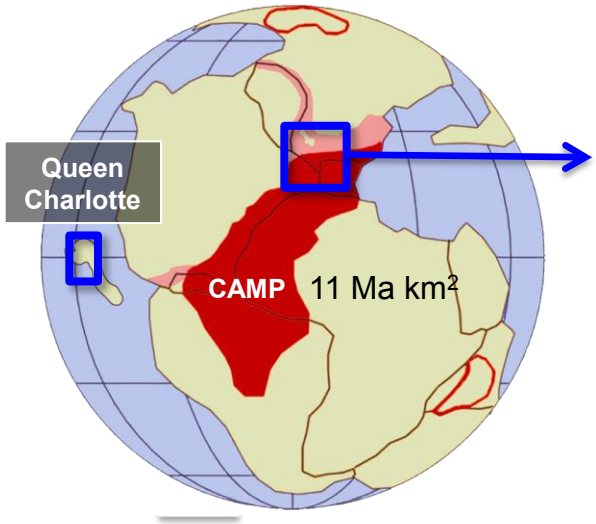


http://www.scotese.com

PTB Summary

- Extinction selectively killed sessile organisms with calcareous skeletons; vertebrates less affected
- Recovery was very protracted > 10 million years
- Biomarker and isotopic evidence for deep ocean euxinia across P-T
- Multiple excursions in $\delta^{13}C_{carb}$, $\delta^{13}C_{org,}$ $\delta^{15}N_{org,}$ $\delta^{34}S_{pyrite}$ *near* boundary
- These anomalies indicate there were major, long-term changes in the redox state of the ocean and a long-term disruption of the C-cycle
- Evidence for near-surface euxinia at PTB from 5 localities → Tethys and Panthalassic were euxinic → compelling extinction mechanism

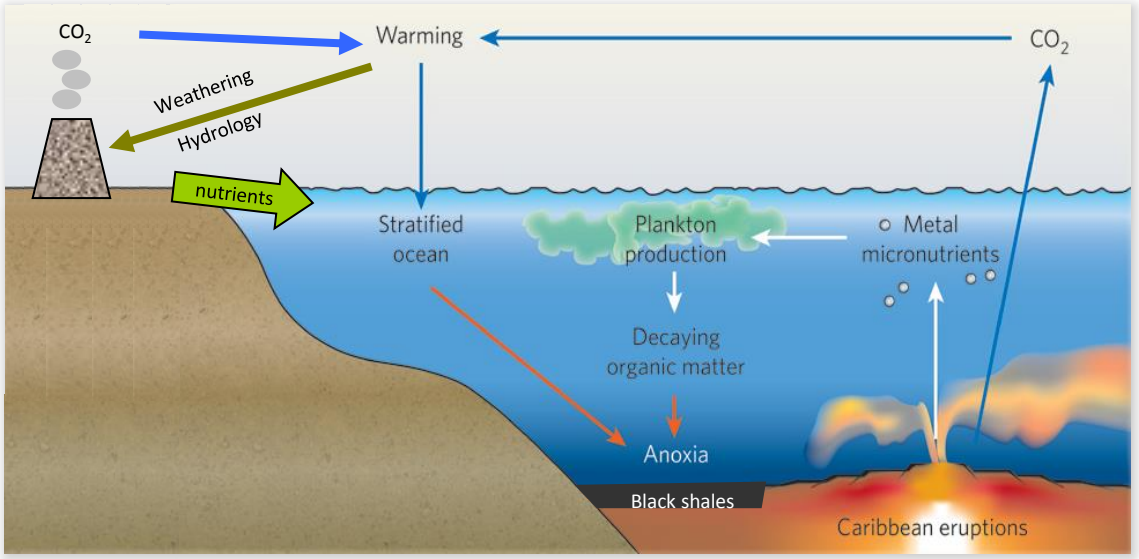
End Triassic: Volcanism & Euxinia?



Oxygen deficiency over epicontinental seas

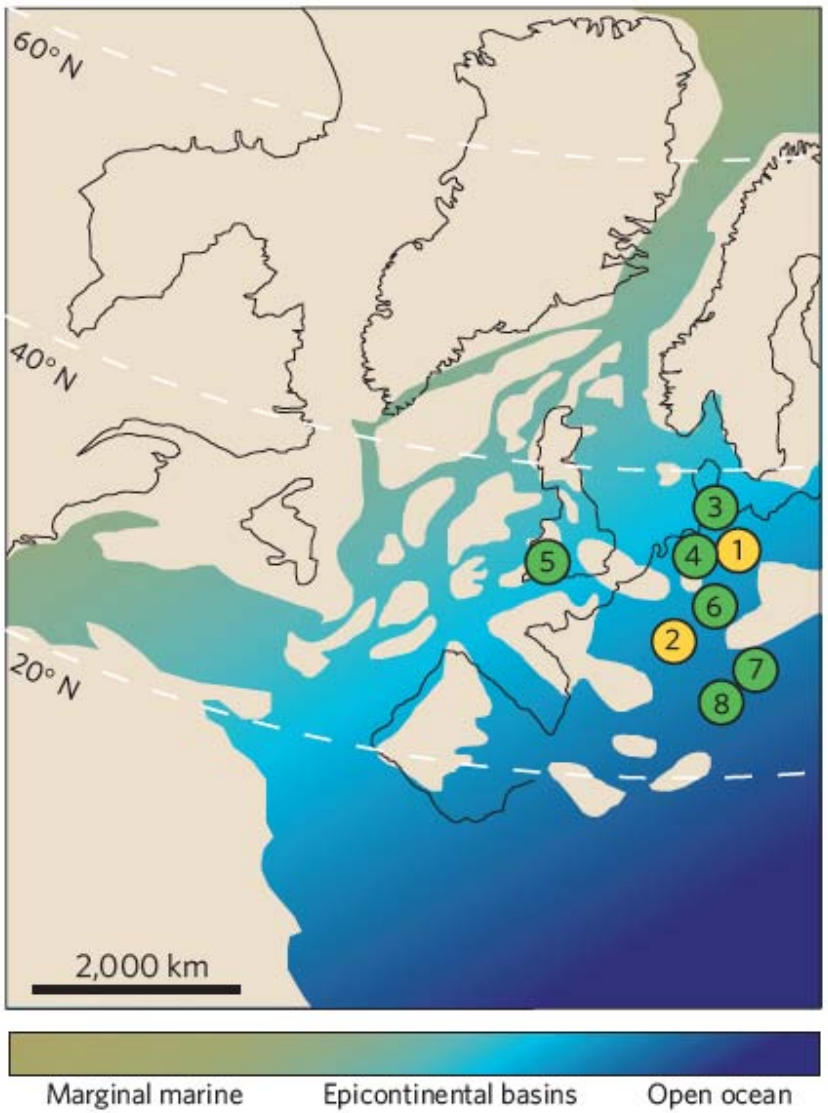
Global signature?

Map:
Whiteside, J.H., Olsen, P.E., Eglinton, T., Brookfield, M.E., Sambrotto, R.N., 2010. Compound-specific carbon isotopes from Earth's largest flood basalt eruptions directly linked to the end-Triassic mass extinction. Proceedings of the National Academy of Sciences 107, 6721-6725.



Cartoon after:
Bralower, T.J., 2008. Earth science: Volcanic cause of catastrophe. Nature 454, 285–287.
Turgeon, S.C., Creaser, R.A., 2008. Cretaceous oceanic anoxic event 2 triggered by a massive magmatic episode. Nature 454, 323–326.

Oxygen deficiency in shallow seas



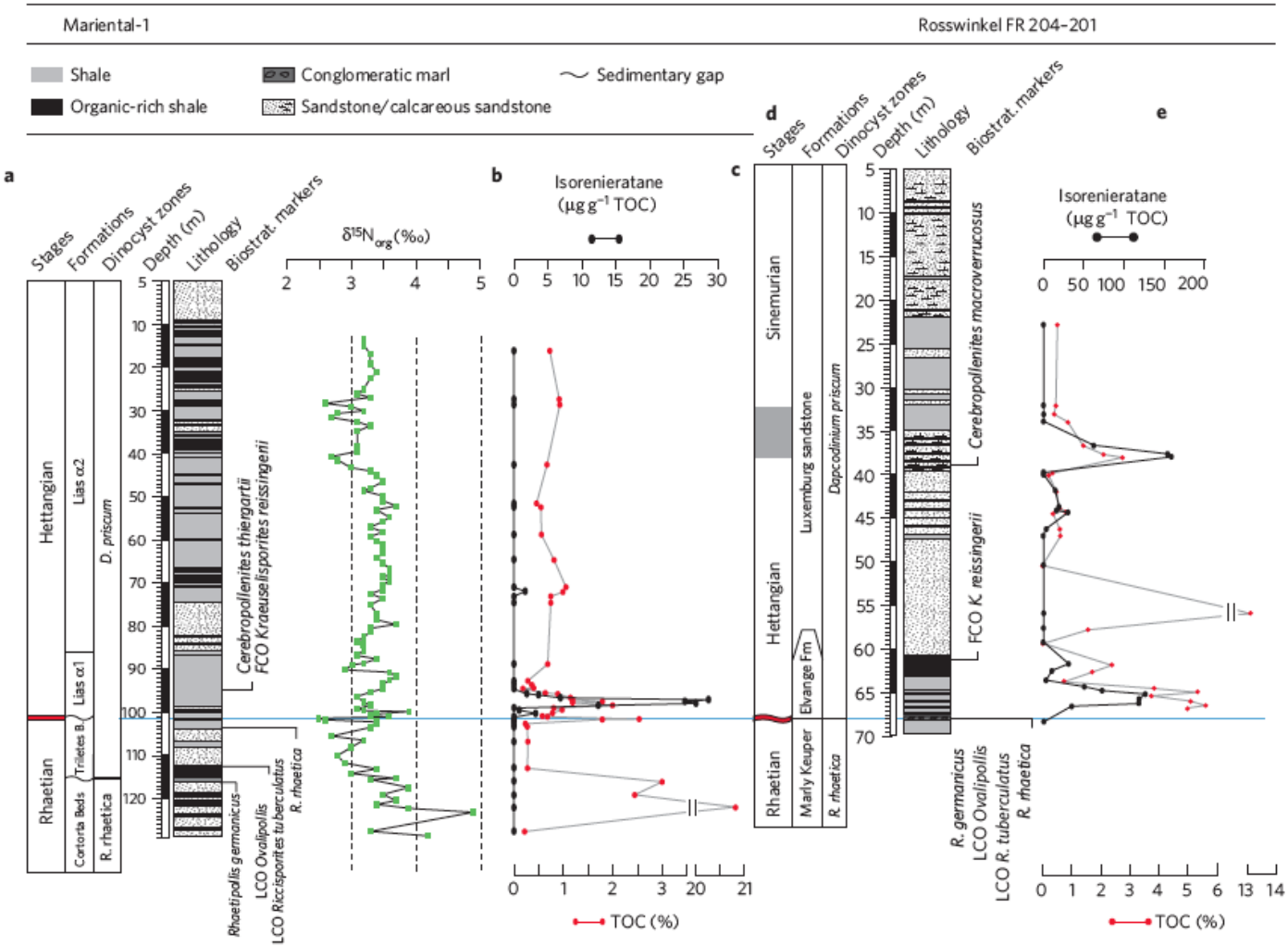
ARTICLES
PUBLISHED ONLINE: 12 AUGUST 2012 | DOI: 10.1038/NGEO1539
nature geoscience

Hydrogen sulphide poisoning of shallow seas following the end-Triassic extinction

Sylvain Richoz[1,2], Bas van de Schootbrugge[1]*, Jörg Pross[1,3], Wilhelm Püttmann[4], Tracy M. Quan[5], Sofie Lindström[6], Carmen Heunisch[7], Jens Fiebig[1], Robert Maquil[8], Stefan Schouten[9], Christoph A. Hauzenberger[10] and Paul B. Wignall[11]

Richoz, S., van de Schootbrugge, B., Pross, J., Püttmann, W., Quan, T.M., Lindström, S., Heunisch, C., Fiebig, J., Maquil, R., Schouten, S., Hauzenberger, C.A., Wignall, P.B., 2012. Hydrogen sulphide poisoning of shallow seas following the end-Triassic extinction. Nature Geoscience 5, 662–667.

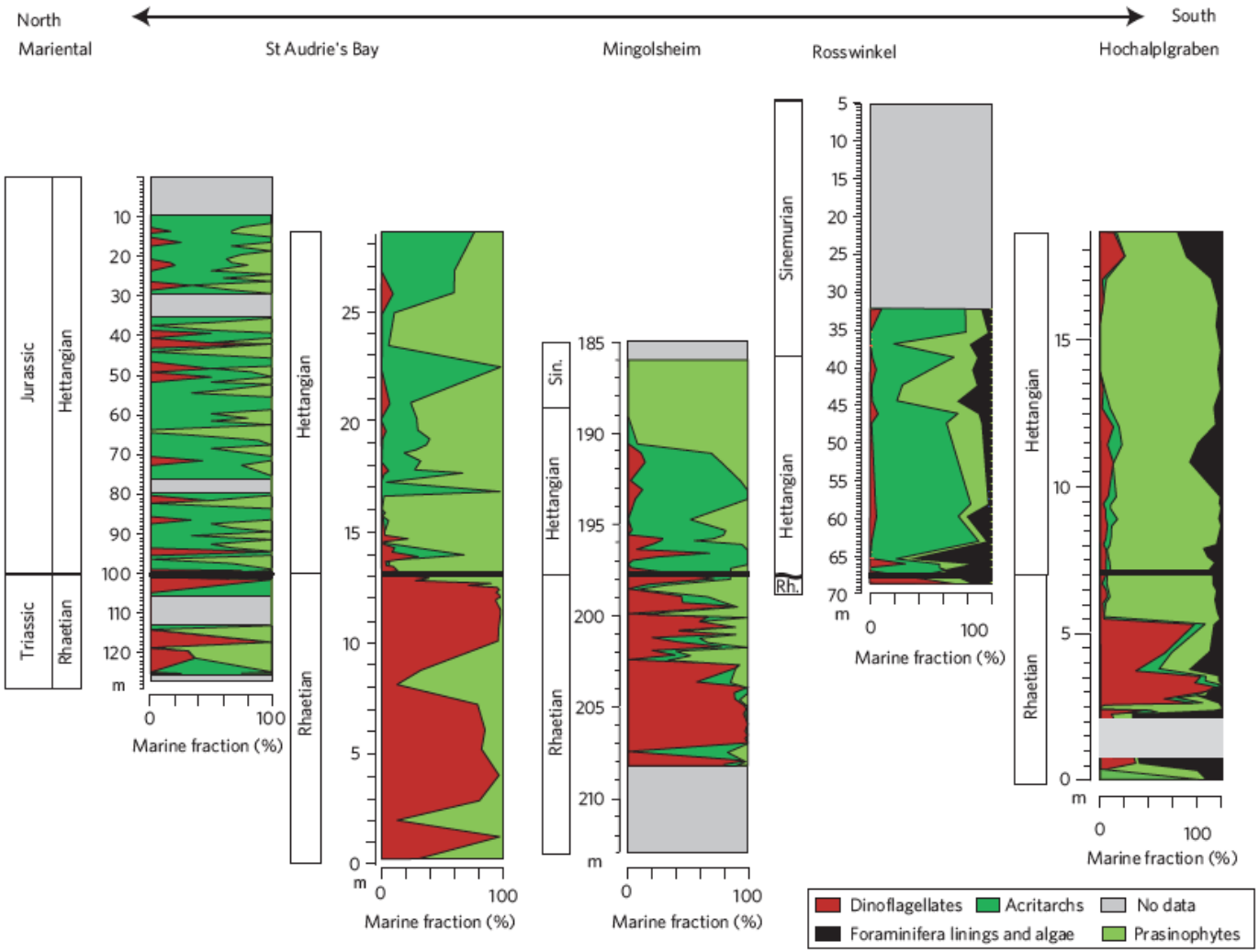
Meishan, plankton ecology



Reprinted by permission from Macmillan Publishers Ltd: Nature Geoscience. Source: Richoz, S., B. van de Schootbrugge, et al. Hydrogen Sulphide Poisoning of Shallow Seas Following the End-Triassic Extinction. *Nature Geoscience* 5 (2012): 662–7. © 2012.

Cao, C., Love, G.D., Hays, L.E., Wang, W., Shen, S., Summons, R.E., 2009. Biogeochemical evidence for euxinic oceans and ecological disturbance presaging the end-Permian mass extinction event. Earth and Planetary Science Letters 281, 188–201.

Ecological perturbation in shallow seas



Richoz, S., van de Schootbrugge, B., Pross, J., Püttmann, W., Quan, T.M., Lindström, S., Heunisch, C., Fiebig, J., Maquil, R., Schouten, S., Hauzenberger, C.A., Wignall, P.B., 2012. Hydrogen sulphide poisoning of shallow seas following the end-Triassic extinction. Nature Geoscience 5, 662–667.

T-J Summary

- Globally widespread euxinia across the end-Triassic?
  - end-Triassic → CO_2 release ~20 ky
  - end-Permian → CO_2 release ~20-400 ky
- Environmental change preceded the extinction horizon and euxinia lasted for ~0.5 Ma.
- Evidence for significant shifts in planktonic ecology and a delayed recovery → N nutrient limitation and HS^- poisoning

Readings and Sources

- Bambach, R.K. (2006) Phanerozoic Biodiversity Mass Extinctions. Annu. Rev. Earth Planet. Sci. 34,127–55
- Cao C., et al., (2009) Biogeochemical Evidence for a Euxinic Ocean and Ecological Disturbance Presaging the end-Permian Mass Extinction Event. Earth and Planetary Science Letters 288, 188-201
- Erwin D.H. (1996) The Mother of All Mass Extinctions Scientific American, 72.
- Erwin D.H. (2006) Extinction, Princeton
- Greene, S., et al., 2012. Recognizing ocean acidification in deep time: An evaluation of the evidence for acidification across the Triassic-Jurassic boundary. Earth-Science Reviews 113, 72-93.
- Grice et al. (2005) Photic Zone Euxinia During the Permian-Triassic Superanoxic Event. Science 307, 706
- Knoll A.H., et al. (1996) Comparative Earth History and Late Permian Mass Extinction. Science 273, 455.
- Payne, J.L., Clapham, M.E. (2011) End-Permian Mass Extinction in the Oceans: An Ancient Analog for the Twenty-First Century? Annu. Rev. Earth Planet. Sci. 2012.40.
- Richoz, S., et al., 2012. Hydrogen sulphide poisoning of shallow seas following the end-Triassic extinction. Nature Geoscience 5, 662-667.
- Ward, P., et al., 2001. Sudden Productivity Collapse Associated with the Triassic-Jurassic Boundary Mass Extinction. Science 292, 1148-1151.

12.007 Geobiology

Spring 2013