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

This image has been removed due to copyright restrictions. Please see the Figure 2 in the paper: RAUP, D. M., Sepkoski, J. J. “Mass Extinctions in the Marine Fossil Record.” *Science* 215, (1982): 1501–3.
Mass Extinctions over the Phanerozoic

18 events with peaks of both magnitude and rate of extinction

This image has been removed due to copyright restrictions. Please see the Figure 1 on page: http://www.annualreviews.org/doi/full/10.1146/annurev.earth.33.092203.122654.
What causes a mass extinction?

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

Source: National Geographic
Anoxia, extinctions & black shales

CO$_2$ & planetary-scale critical transitions

![Diagram showing atmospheric CO$_2$ levels over time for different geological periods: Paleocene-Eocene Thermal Maximum (PETM), Cretaceous OAEs, Triassic-Jurassic mass extinction, K-Pg extinction.](image-url)

© 2013 American Association for the Advancement of Science. All Rights Reserved. This content is excluded from our Creative Commons license. For more information, see [http://ocw.mit.edu/help/faq-fair-use/](http://ocw.mit.edu/help/faq-fair-use/).
Present-day mass extinction?

REVIEW

Has the Earth’s sixth mass extinction already arrived?


REVIEW

Approaching a state shift in Earth’s biosphere


Large Igneous Provinces (LIPs)

Extremely large accumulation (>100,000 km²) 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.

http://en.wikipedia.org/wiki/Large_igneous_province
Large Igneous Provinces (LIPs)


© Elsevier. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Mechanisms for ocean anoxia: Volcanism


© Nature. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Feedback mechanisms & deoxygenation

These images have been removed due to copyright restrictions. Please see the images in paper:

Climatic modes

Image courtesy of the Geological Society of America. Used with permission.

Tipping points


Image courtesy of the Geological Society of America. Used with permission.
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$_2$S 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 sediments deposited on N.-E. margin of Paleotethys equatorial latitudes, deepwater shales

http://www.scotese.com

© scotese.com. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Main extinction horizon in ash bed (Bed 25)
Composite $\delta^{13}C$ & Diversity Profiles

This image has been removed due to copyright restrictions. Please see the Figure 3 on page https://www.sciencemag.org/content/305/5683/506.full. Payne, J. L. “Large Perturbations of the Carbon Cycle During Recovery from the End-Permian Extinction.” Science 305, (2004): 506–9.
Overview of perturbations


This image has been removed due to copyright restrictions. Please see the Figure 1 on page http://www.annualreviews.org/doi/full/10.1146/annurev-earth-042711-105329.

Calibrating the End-Permian Mass Extinction

Most recent age: 252.28 ± 0.08 million years ago

**Biogeochemical Carbon Cycle in Modern Ocean**

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]  
**Photosynthesis**

\[ \text{H}_2\text{S} + 2\text{CO}_2 + 2\text{H}_2\text{O} \leftarrow \text{CH}_3\text{COOH} + \text{SO}_4^{2-} + 2\text{H}^+ \]  
**Sulfate Reduction**

\[ \text{hv} \]

**Respiration**
Links Between Carbon and Sulfur Cycles

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]  
Photosynthesis

\[ \text{H}_2\text{S} + 2\text{CO}_2 + 2\text{H}_2\text{O} \leftarrow \text{CH}_3\text{COOH} + \text{SO}_4^{2-} + 2\text{H}^+ \]  
Sulfate Reduction

respiration

sediment
Carbon Cycle in a Stratified Ocean

\[ \text{Photosynthesis} \]
\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

\[ \text{Sulfate Reduction} \]
\[ \text{H}_2\text{S} + 2\text{CO}_2 + 2\text{H}_2\text{O} \leftarrow \text{CH}_3\text{COOH} + \text{SO}_4^{2-} + 2\text{H}^+ \]

Euxinic Water Column
Green sulfur bacteria
Chlorobiaceae

\[ \text{Green-pigmented Chlorobiaceae} \]

\[ \text{Brown-pigmented Chlorobiaceae} \]

\[ \begin{align*}
\text{Anoxygenic photosynthesis} & \quad \text{requires reduced sulfur} \\
& \quad \text{requires light} \\
& \quad \text{strictly anaerobic}
\end{align*} \]

Biomarkers of Chlorobiaceae

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.
These images have been removed due to copyright restrictions.
Phytoplankton evolution and demise


© Annual Reviews. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Meishan sediments deposited on N.-E. margin of Paleotethys equatorial latitudes, deepwater shales

<table>
<thead>
<tr>
<th>Litho. Column</th>
<th>Age (Ma)</th>
<th>Pr/Ph</th>
<th>C_{27} HHI (%)</th>
<th>28,30-DNH/C_{29} Hapane (%)</th>
<th>Isorenieratane (ppm, TOC)</th>
<th>Total aryl isoprenoids C_{14-27} (ppm, TOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


![Graphical representation of plankton ecology data](http://www.sciencedirect.com)
Loci of Aryl Isoprenoid Occurrences
Hydrogen sulfide poisoning?

Kap Stosch
mid N. lat., paralic shales

Meishan
N.-E. margin Paleotethys equatorial, deepwater shale & carb.

Peace River Embayment
mid N. lat., Panthalassa, paralic shales

Great Bank of Guizhou
E. margin of Paleotethys equatorial, carbonates

Tibet
S. lat., Tethys carbonates

Perth Basin
High S. lat. Tethys, paralic shales

http://www.scotese.com

© scotese.com. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
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 $\delta^{13}C_{\text{carb}}$, $\delta^{13}C_{\text{org}}$, $\delta^{15}N_{\text{org}}$, $\delta^{34}S_{\text{pyrite}}$ 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:

Copyright © 2010 National Academy of Sciences, U.S.A. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.

Cartoon after:
Oxygen deficiency in shallow seas

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

Sylvain Richoz1,2, Bas van de Schootbrugge1*, Jörg Pross1,3, Wilhelm Püttmann4, Tracy M. Quan5, Sofie Lindström6, Carmen Heunisch7, Jens Fiebig8, Robert Maquil8, Stefan Schouten9, Christoph A. Hauzenberger10 and Paul B. Wignall11


Ecological perturbation in shallow seas


T-J Summary

• Globally widespread euxinia across the end-Triassic?
  – end-Triassic $\rightarrow$ CO$_2$ release $\sim$20 ky
  – end-Permian $\rightarrow$ CO$_2$ release $\sim$20-400 ky

• Environmental change preceded the extinction horizon and euxinia lasted for $\sim$0.5 Ma.

• Evidence for significant shifts in planktonic ecology and a delayed recovery $\rightarrow$ N nutrient limitation and HS$^-$ poisoning
Readings and Sources
