<u>Session 3</u> - <u>Mass extinctions in Earth history</u>

Mass extinctions: discontinuities in the history of life

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Mass extinctions are large, geologically rapid reductions in biodiversity caused by increased rates of lineage termination. Global marine diversity compilations generally concur on which time intervals were characterized by elevated extinction. Depleted diversity was surely of ecological and evolutionary importance in the aftermath of an extinction, but on longer time scales (tens to hundreds of millions of years), mass extinctions are of particular interest because they preferentially extirpated members of certain clades or organisms with particular traits, swiftly and permanently changing the taxonomic and ecologic composition of the biosphere. The Earth's biota is thus a discontinuous function of time, not a smooth one. Change was also dramatic during recovery intervals following extinctions, characterized by preferential origination in some groups over others. Selectivity of extinction is not the same for all extinction events, but there may be groups of events that were similar in selectivity. Numerous events were similar in selectivity to the Permian-Triassic extinction, during which heavily calcified animals suffered preferentially, and these events appear to share physical correlates as well. Other events share patterns of selectivity that have been related to the onset of glaciation. Although extinction events disrupted evolutionary trends that occurred during background times, similar patterns of selectivity among different events suggest that their effects on the biosphere may not be entirely unpredictable and contingent. New field data from the Frasnian-Famennian (Late Devonian) boundary interval in the eastern U.S. will be presented that relate this extinction to other Phanerozoic events.

Newell, N. D. 1967. Revolutions in the history of life. In Albritton, C. C., Jr., ed. Pp. 63-91 *in* Uniformity and Simplicity: A Symposium on the Principle of Uniformity of Nature. Geological Society Special Paper 89.

Bush, A. M., and R. K. Bambach. 2011. Paleoecologic megatrends in marine metazoa. Annual Review of Earth and Planetary Sciences 39:241-269.

The Late Ordovician Mass Extinction: stable isotopes, sea level, stratigraphy and selectivity

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The Late Ordovician mass extinction was one of the largest extinction events of the past 500 million years, eliminating more than 50% of marine genera. The Late Ordovician event is unusual among major mass extinctions in being clearly linked to climate change: two major extinction pulses closely coincide with expansion and subsequent contraction of glaciers on the southern supercontinent Gondwana. However, many questions about the causal connection between climate change and marine extinction have remained unresolved. Recent work using new stable isotope and biomarker proxies, databases, and statistical methods has helped to clarify some of these issues and has implicated tropical cooling, changes in marine habitat area, paleoceanographic changes, and changes in continental configuration as important controls on the timing and selectivity of both the extinctions and the ensuing recovery. Despite massive species and genus losses relatively few higher taxa were eliminated, and relative to events of similar magnitude such as the Permo-Triassic or Cretaceous-Paleogene extinctions the Late Ordovician event had little long-term impact on the structure of marine ecosystems. Comparing these events may therefore help shed light on the ways in which the selective filters imposed by mass extinctions do and do not shape the subsequent development of ecosystems.

References for further reading:

Finnegan, S., K. Bergmann, et al. (2011). "The Magnitude and Duration of Late Ordovician-Early Silurian Glaciation." Science 331(6019): 903-906.

Finnegan, S., N. A. Heim, et al. (2012). "Climate change and the selective signature of the Late Ordovician mass extinction." Proceedings of the National Academy of Sciences.

End-Permian Mass Extinction in the Oceans: An Ancient Analog for the Twenty-First Century?

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The greatest loss of biodiversity in the history of animal life occurred at the end of the Permian Period (∼252 million years ago). This biotic catastrophe coincided with an interval of widespread ocean anoxia and the eruption of one of Earth's largest continental flood basalt provinces, the Siberian Traps. Volatile release from basaltic magma and sedimentary strata during emplacement of the Siberian Traps can account for most end-Permian paleontological and geochemical observations. Climate change and, perhaps, destruction of the ozone layer can explain extinctions on land, whereas changes in ocean oxygen levels, CO_2, pH, and temperature can account for extinction selectivity across marine animals. These emerging insights from geology, geochemistry, and paleobiology suggest that the end-Permian extinction may serve as an important ancient analog for twenty-first century oceans.

Further reading:

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

J.L. Payne, A.V. Turchyn, A.Paytan, D.J. DePaolo, D.J. Lehrmann, M. Yu and J. Wei Calcium isotope constraints on the end Permian mass extinction. (2010) www.pnas.org/cgi/doi/10.1073/pnas.0914065107

The comings after the goings: geography, timing and mechanisms of recovery from the KT mass extinction

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Approximately 65 million years ago, an asteroid impact on the Yucatan Peninsula caused the sudden mass extinction of late Cretaceous biota. The Cretaceous-Paleogene (K-Pg, formerly known as KT) mass extinction provides an unparalleled opportunity to examine the pattern and dynamics of profound biotic change, as it is the most recent and well resolved of the big five mass extinction events. In particular, the slow, multimillion year recovery from the K-Pg mass extinction promises insight into the long-term response of biota to biodiversity crises, like that facing species today. Three key patterns of open ocean recovery have emerged from recent research into post K-Pg recovery. At an ecosystem level, recovery was i) geographically heterogeneous, and ii) decoupled from the recovery of species richness in well-fossilized taxa, while at the taxonomic level iii) extinction and recovery patterns differed widely among taxa. Together, these patterns present a new picture of open ocean response to the end-Cretaceous extinction and challenge the current model of recovery, in which the slow, ~3 Ma year long, recovery of species richness and life history strategies is tied to the recovery of functioning ecosystems. Instead, it appears that biotic-abiotic interactions may have driven both the perception and pattern of recovery. Intriguingly, flood basalts offer one potential mechanism for the observed recovery patterns. The cessation and onset of eruptions of two large igneous provinces in the Paleocene (Deccan Phase 3 and North Atlantic Igneous Province Phase I, respectively) roughly correspond to the two recovery steps in open ocean species richness and life history strategies. While massive outpourings of lava have often been considered as possible drivers of mass extinction, they may also play a key role as a rare, extrinsic, intermediate-scale perturbations allowing for ecological reshuffling and evolutionary innovation. From the mass extinction at the K-Pg boundary to warming and acidification at the Paleocene-Eocene Thermal maximum or the onset of polar glaciation at the Eocene-Oligocene boundary, the deep sea record of the Cenozoic offers the exciting potential to understand the biotic sensitivity, resilience and response to global change.

Related References:

Hull PM and Norris RD. 2011. Diverse patterns of ocean export productivity change across the Cretaceous-Paleogene boundary: new insights from biogenic barium. *Paleoceanography* 26: PA3205.

Hull PM, Norris RD, Bralower TJ, and Schueth JD. 2011. A role for chance in marine recovery from the end-Cretaceous extinction. *Nature Geoscience* 4: 856-860.

The Late Quaternary Extinction

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Between fifty and two thousand years ago, most large mammals became extinct everywhere except Africa. With respect to ecological selectivity, slow-breeding animals were hit hard by this Late Quaternary Extinction (LQE) event, regardless of their body size, and slow-breeding survivors tend in live in closed habitats (where many are arboreal and/or nocturnal) or alpine habitats or at high latitudes. The major extinction pulse in each region occurred after the appearance of modern humans. Evidence from North America indicates that relative to earlier Cenozoic extinctions, the LQE was exceptionally selective on large-bodied animals, and that it was one of the two biggest extinctions of the last 55 million years.

These unusual ecological characteristics and the asynchronous timing of the extinction are consistent with different anthropogenic models (including but not exclusively those related to hunting), but they are difficult to explain with models that rely solely on environmental causes. It is an oversimplification, however, to say that an abrupt wave of hunting-induced extinctions swept continents right after first human contact. A more complicated portrait of the LQE is emerging from recent studies, including those using massive radiocarbon dating campaigns, reconstructions of population fluctuations from ancient DNA, new proxies for animal abundance, and other approaches. As a whole, these studies suggest that humans precipitated the extinction around the globe through direct (hunting) and indirect (competition, habitat alteration and fragmentation) impacts, but that late Quaternary environmental change influenced the timing, geography, mechanism, and perhaps magnitude of extinction. Put another way, without the various impacts of modern humans, there is no reason to expect a global mass extinction of large, slow-breeding animals in the late Quaternary, but absent the concurrent rapid climate shifts evident in many parts of the globe, the pattern of extinction might have differed in space and time. The unanswered questions now revolve around why some species succumbed to this combination of expanding human populations and climate change, whereas other species are currently unscathed. Such understanding is essential for informed predictions about the future of the surviving biota.

References:

Koch PL, Barnosky AD (2006) Late Quaternary extinctions: State of the debate. Annual Review of Ecology, Evolution, and Systematics 37: 215-250

Nogués-Bravo D, Ohlemüller R, Batra P, and Araújo MB (2010) Climate predictors of Late

Quaternary Extinctions. Evolution 64: 2442–2449