



## Biography

Emily Wooton graduated from Harvard University in 2009 with an A.B. in Government and a secondary concentration in Earth and Planetary Sciences. She is a second year Ph.D. student at University of California, Riverside interested in resolving problems of community restructuring and environmental perturbation during the Late Devonian biotic crises. Between her undergraduate and graduate studies, Emily spent a year in the Summons Geobiology Lab at MIT, where she researched molecular fossils at the Permo-Triassic and Cretaceous-Paleogene

extinction boundaries. She is integrating her background in biomarker studies with inorganic redox proxies and a paleoecological approach to understanding paleoredox conditions. Her advisor is Dr. Mary Dorser.

## **A high resolution paleontological, ichnological, and biomarker chemostratigraphic study of the Late Devonian Bioevents in the Ardmore Basin, Oklahoma**

Mass extinctions fundamentally structure life on planet Earth. If we are to successfully mediate our ongoing environmental problems and the associated biodiversity crisis, it is critical to gain a better understanding of biotic thresholds and the mechanisms of ancient extinctions. One of the largest biodiversity crises in Earth's history occurred in the Late Devonian period, around 367 Ma. The diversity depletion was a cumulative effect of a series of stepwise events which resulted in the elimination of more than half of all extant genera (Sepkoski, 1986; Jablonski, 1991). Though traditionally considered a mass extinction, the Late Devonian biotic crises were fundamentally different from other mass extinctions in that all higher-level taxonomic groups recovered after the extinction pulses, but marine communities underwent a complete and permanent ecological restructuring (Droser et al., 2000).

The Late Devonian biodiversity crises remain enigmatic, with little consensus among researchers on mechanisms and environmental conditions. While it is gradually becoming accepted that the biological turnovers in the Late Devonian were a combination of targeted extinction and highly depressed origination rates (Bambach, 2004; Alroy, 2008a, 2008b), the traditional interpretation as a mass extinction has led to a plethora of posited causes for elevated extinction, ranging from the bolide impact hypothesis (McLaren, 1970), to climate change triggered by a combination of tectonic, sea level, and productivity cycles (Fischer, 1977; Johnson, 1974; Buggisch, 1991), to episodes of ocean anoxia affecting at least shallow shelf marine habitats (Joachimski and Buggisch, 1993; Bond et al., 2004). Though it is clear that environmental perturbation is key to this crisis, the breadth of postulated causes indicates how little is understood about the actual mechanisms of extrinsically-forced ecological change. This, in conjunction with the evolving understanding of the character of the Devonian turnover events, highlights the need for the collection new types of data at a new scale, specifically investigating the nature of the characteristically Devonian low oxygen facies.

This study focuses on understanding the dynamics of bottom water oxygen and its

potential influence on marine life, because most researchers agree that oxygen is limited in association with Late Devonian biotic crises and relative oxygen levels can be constrained in detail from the rock record. (Joachimski and Buggisch, 1993; Becker and House, 1994; Levman and von Bitter, 2002; Bond et al., 2004) Sequences of black shale are commonly preserved throughout the Devonian, including at intervals associated with biodiversity depletions; this sedimentary facies is indicative of anoxic or dysoxic conditions. Not all black shales represent deposition under anoxic conditions, however; fine-grained, organic-rich sediments classified as black shales may have been deposited under reduced but nonzero or fluctuating oxygen conditions (Arthur and Sageman, 1994). Increasingly, researchers are recognizing that black shales do not represent homogenous conditions but may in fact capture a range of bottom water redox conditions (Boyer et al., 2011). Potential evidence for rapid fluctuations justifies a high scale resolution study of the microstratigraphy and biological and geochemical characteristics of Devonian black shale units.

The purpose of this study is to correlate lipid biomarkers, trace fossils, and geochemical paleoredox proxies at a high-resolution to provide a more detailed reconstruction of depositional conditions in Late Devonian epeiric seas of Laurentia in order to constrain possible causes of the mass extinction events. To this end, extensive microstratigraphic analyses will be conducted across several bioevents of different magnitudes preserved in black shale intervals, including the Frasnian-Famennian boundary event. The chosen proxies complement each other well: the biological data allows for recognition of subtle variations in reduced but non-zero oxygen levels, while the geochemical proxies that are not as sensitive to fluctuations under dysoxic conditions can provide unambiguous evidence of anoxic and/or euxinic (not only anoxic but with dissolved sulfide in the water column) conditions. Although none of the proposed techniques are new, to my knowledge they have never been combined in a detailed investigation at such a refined scale. The broad dataset resulting from this project will allow for new insights into the mechanisms and outcomes of mass extinction and global environmental perturbation.

In order to better understand an interconnected, possibly global mechanism for this extinction event, I will characterize, in high resolution, depositional conditions in two Laurentian basins that preserve sediments representative of an epeiric sea setting, the Appalachian and Ardmore Basins. I will be looking for correlative patterns to identify non-local signals. In both basins, distal, deep-water facies below storm-wave base will be sampled; this is the range of water depth where I expect to be able to find and test for anoxic conditions, and comparison will be made in similar facies.

These analyses require field collection of continuous sequences of black shales across Late Devonian bioevents. Last summer, I began this work in western and central New York State, sampling at eight localities containing black shale units from 5 distinct bioevents. My work in New York is being conducted in collaboration with Dr. Diana Boyer (SUNY Oswego) who has been investigating low oxygen facies through trace metal concentrations and other geochemical and paleontological proxies. Assisted by undergraduate students of Dr. Boyer, I logged stratigraphic sections, tracking lithological facies, body fossils, and trace fossil horizons at each locality. My field assistant and I then collected samples using rock hammers and other extraction tools; I am currently analyzing these samples at UC Riverside for paleontological and geochemical paleo-oxygen tracers. Each stratigraphic section was continuously sampled twice, once for trace fossil samples and once for biomarker/geochemical samples. The disparate nature of these analyses lends itself to different preparatory techniques: trace fossil samples are wrapped in duct tape, while biomarker samples, which are susceptible to contamination from hydrocarbons (like duct tape), are wrapped in tinfoil. Given the numerous locations throughout

western and central New York State and the intensive nature of the investigation of each visited unit, I spent 8 weeks engaged in the initial expedition.

A robust investigation of putatively global crises would necessarily involve field work in multiple sedimentary basins. In the summer of 2012, I will travel to Oklahoma, to the Woodford Shale of the Ardmore Basin, where Late Devonian black shales also crop out; this area is well-known for being highly oil-producing, thanks to the high organic content of the ubiquitous black shales. I have identified 4 localities in southern Oklahoma which are optimal for similar field exploration as performed in New York, and I will spend 4 weeks at these localities employing the same sampling procedures. This extension of the geographic range of my study across the North American continent will allow for the identification of non-local environmental trends and potentially provide further evidence for the global nature and ecological importance of the Late Devonian biodiversity crises.

The Late Devonian Woodford Shale was deposited in the Oklahoma Aulacogen on the southern margin of Laurentia and is found in disparate basins throughout Oklahoma, Texas, and New Mexico. Localities in the Ardmore Basin in Southern Oklahoma were selected for tight biostratigraphic constraint (Over, 2002). In the Ardmore Basin, the Woodford is fissile, spore-bearing, highly-radioactive black shale, sometimes interbedded with chert that is dark and rich in radiolarians and marine organic matter (Comer 1991). It is overlain by the Sycamore Formation, a poorly fossiliferous, fine-grained, silty limestone interbedded with dark shale ranging from Early to Middle Mississippian, and unconformably overlies the Lower Devonian Bois d'Arc Limestone of the Hunton Group. The F-F boundary is well-defined based on conodonts and in some localities a cryptic disconformity or phosphate nodule bed.

The Woodford Shale is a highly productive petroleum resource basin (Lambert, 1993; Wang and Philp, 1997); abundant organic geochemical maturity parameters suggest that the Ardmore Basin contains black shales with low maturity and high organic matter, perfect for biomarker studies. Vitrinite reflectance values in the basin vary between about 0.5-0.8% (Cardott, 2008); Rock-Eval Tmax values of ~430°C were calculated for samples in the Ardmore Basin (Jarvie, 2008). Both of these parameters are consistent with an early to peak-oil window thermal maturity of the bulk sedimentary organic matter (Comer and Hinch, 1987) which is ideal for lipid biomarker studies as the samples have not been metamorphosed.

Samples will be collected from field localities across each of the bioevents through the black shale horizons on a coarse meter scale for several meters above and below each turnover event (to characterize background conditions) and at a centimeter scale leading up to and through extinction events. High resolution intervals will be sampled continuously for geochemistry and paleontology over one to several meters. Sedimentology and stratigraphy of the exposed intervals will be described in detail.

Hand samples through each interval will be brought back to the laboratory and cut perpendicular to bedding to expose fabric. Trace fossil data including relative amount of bioturbation, ichnogenetic diversity, as well as burrow width and depth of penetration will be measured. Ichnofabric indices, as a method to quantify the amount of bioturbation, with the ichnofabric index of 1 indicating laminated sediments, and 5 representing fully bioturbated sediments (Droser and Bottjer, 1986), will be determined through each cm of sampled sections. Maximum burrow width is specifically meaningful in that it preserves a record of the largest infaunal organism present at a given time, which is directly linked with relative oxygen levels correlated with body size based on physiological oxygen demands (Savrda, 1992). The appearance and disappearance of specific trace fossils and any cross-cutting relationships will be recorded, as well as the horizon of burrow origination as it reflect the actual oxygenation

“event.” From these data, a relative oxygen levels will be established.

Targeted samples will be analyzed for trace metal, iron speciation, and TOC from one detailed section from each stratigraphic interval in each basin (estimated 50-100 from each locality). Samples will be collected at a cm scale through selected turnover events. Geochemical data will be collected from hand samples to allow for precise correlation with biological and sedimentological data. Samples collected for whole-rock geochemical analysis will be sampled from chips removed along bedding planes in a thickness of no more than 3 mm.

Each locality will be sampled at high-resolution for biomarker analysis; samples will be taken at a cm resolution through the black shale units correlating to bioevent boundaries and then intermittently at a coarse resolution between selected stratigraphic intervals. Finer sampling will be undertaken where necessary as directed by our biomarker, paleontological and inorganic geochemical findings. Because 10-30 mg of rock bitumen from 5g of shale can be generated, I will be able to sample at a high resolution, cm scale. Care will be taken in sampling and packing procedures to minimize the amount of analytical contamination.

The new light being shed on Late Devonian biospheric and environmental evolution in North America will inform and direct future work in biogeochemistry, paleontology/paleobiology, evolutionary biology, and ocean-atmosphere evolution. Central to this research is a unique bridging of organic and inorganic geochemical methods with paleontology within a broad field-based template to yield high-resolution bio- and chemostratigraphic records that span the Late Devonian mass extinction events and their aftermath.

The widespread, global deposition of organic-rich Late Devonian petroleum source rocks, particularly in epeiric seas in the Frasnian, has been at the center of a primary productivity versus preservation controversy in petroleum geoscience. Algeo et al. (1995; 2001) suggested a link exists between the expansion of terrestrial vascular plants during the Middle-Late Devonian Period, increased continental weathering, and enhanced anoxia and preservation of organic matter in nearshore sediments. In contrast, Parrish (1995) argued that marine upwelling and enhanced productivity can account for about two-thirds of the Upper Devonian source rocks. This fine scale examination of source organism inputs and marine redox conditions which prevailed in the Devonian will shed new light on the main controlling factors affecting TOC content and petroleum/natural gas generation potential of Late Devonian sedimentary rocks.

## Reference List

- Algeo, T.J. et al. 1995. Late Devonian Oceanic Anoxic Events and Biotic Crises: “Rooted” in the Evolution of Vascular Land Plants? *GSA Today* 5(3): 45, 64-66.
- Algeo, T.J., Scheckler, S.E. and Maynard, J.B. 2001. Effects of the Middle to Late Devonian spread of vascular plants on weathering regimes, marine biotas, and global climate. In: *Plants Invade the Land: Evolutionary and Environmental Perspectives* (P.G. Gensel and D. Edwards, eds.), Columbia University Press, New York, pp. 213-236.
- Alroy, J. 2008a. Dynamics of origination and extinction in the marine fossil record. *PNAS* 105: 11536-11542.
- Alroy, J. et al. 2008b. Phanerozoic Trends in the Global Diversity of Marine Invertebrates. *Science* 321: 97-100.
- Arthur, M.A. and Sageman, B.B. 1994. Marine Black Shales: Depositional mechanisms and environments of ancient deposits. *Annual Reviews of Earth and Planetary Sciences* 22: 499-551.
- Bambach, R.K. et al. 2004. Origination, extinction, and mass depletions of marine diversity.

- Paleobiology* 30(4): 522-542.
- Becker, R.T., and House, M.R. 1994. Kellwasser events and goniatite successions in the Devonian of the Montagne Noire with comments on possible causations. *Courier Forschung-Institut Senckenberg* 16: 45-77.
- Bond, D. et al. 2004. Extent and duration of marine anoxia during the Frasnian-Famennian (Late Devonian) mass extinction in Poland, Germany, Austria and France. *Geological Magazine* 141(2): 173-193.
- Boyer, D.L. et al. 2011. Joining forces: Combined biological and geochemical proxies reveal a complex but refined high-resolution palaeo-oxygen history in Devonian epeiric seas. *Palaeogeography, Palaeoclimatology, Palaeoecology* 306: 134-146.
- Buggisch, W. 1991. The global Frasnian-Famennian "Kellwasser Event." *Geologische Rundschau* 80:49-72.
- Cardott, B.J. 2008. Overview of Woodford Gas-Shale Play in Oklahoma, 2008. Proc. of Oklahoma Geological Survey, Gas Shales Workshop, October 2008.
- Comer, J.B. 1991. Stratigraphic analysis of the Upper Devonian Woodford Formation, Permian Basin, West Texas and Southeastern New Mexico: Texas Bureau of Economic Geology Report of Investigations 201.
- Comer, J.B. and Hinch, H.H. 1987. Recognizing and Quantifying Expulsion of Oil from the Woodford Formation and Age-Equivalent Rocks in Oklahoma and Arkansas. *AAPG Bulletin* 71(7): 844-858.
- Droser, M.L. et al. 2000. Decoupling of taxonomic and ecologic severity of Phanerozoic marine mass extinctions. *Geology* 28: 675-678.
- Droser, M.L. and Bottjer, D.F. 1986. A semiquantitative field classification of ichnofabric. *Journal of Sedimentary Research* 56: 558-559.
- Fischer, A.G. and Arthur, M.A. 1977. Secular variations in the pelagic realm. *Society of Economic Paleontologists and Mineralogists Special Publication* 25:19-50.
- Jablonski, D. 1991. Extinctions: A paleontological perspective. *Science* 253:754-757.
- Jarvie, D. 2008. Geochemical Characteristics of the Devonian Woodford Shale. Proc. Of Oklahoma Geological Survey, Gas Shales Workshop, October 2008.
- Joachimski, M.M. and Buggisch, W. 1993. Anoxic events in the late Frasnian. Causes of the Frasnian-Famennian faunal crisis? *Geology* 21: 675-678.
- Johnson, J.G. 1974. Extinction of perched faunas. *Geology* 2:479-482.
- Lambert, M.W. 1993. Internal Stratigraphy and Organic Facies of the Devonian-Mississippian Chattanooga (Woodford) Shale in Oklahoma and Kansas: Chapter 11. In *Source Rocks in a Sequence Stratigraphic Framework*, pp. 163-176. *AAPG Special Volumes SG 37*.
- Levman, B.G., and von Bitter, P.H. 2002. The Frasnian-Famennian (mid-Late Devonian) boundary in the type section of the Long Rapids Formation, James Bay Lowlands, northern Ontario, Canada. *Canadian Journal of Earth Sciences* 39: 1795-1818.
- McLaren, D.J. 1970. Time, life, and boundaries. *Journal of Paleontology* 44:801-815.
- Over, D.J. 2002. The Frasnian-Famennian boundary in central and eastern United States. *Palaeogeography, Palaeoclimatology, Palaeoecology* 181: 153-169.
- Parrish, J.T. 1995. Paleogeography of Corg-rich rocks and the preservation controversy. In: *Paleogeography, Paleoclimate, and Source Rocks* (A.-Y. Huc, ed.), American Association of Petroleum Geologists, Tulsa, OK, pp. 1-20.
- Savrda, C.E. 1992. Trace fossils and benthic oxygenation. In: C.G. Maples, and West, R. R. (Editor), *Trace Fossils, Short Courses in The Paleontological Society*, pp. 172-196.
- Sepkoski, J.J., Jr. 1986. Phanerozoic overview of mass extinctions. In D. M. Raup and D.

Jablonski, eds., *Patterns and Processes in the History of Life*, pp. 277-295. Berlin: Springer-Verlag.

Wang, H.D. and Philp, R.P. 1997. Geochemical Study of Potential Source Rocks and Crude Oils in the Anadarko Basin, Oklahoma. *AAPG Bulletin* 81(2): 249-275.