



Organismic and Evolutionary Biology

OEB/EPS 150 – Exceptional paleobiological insights into animal evolution

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Remote lecture time: Monday, Wednesday 1200-1315pm. See the course site for Zoom links.

Remote laboratory time: TBD.

Examination dates: Week 6, mid-term exam (TBD); May 10, 2021, final exam.

Notes: OEB 150 is also offered as E-PSCI 150. Students may not take both OEB 150 and E-PSCI 150 for credit.

Background and Rationale: The fossil record offers a unique deep time perspective into the evolution of animals, and critically informs about the major events that have defined the composition and ecological dynamics of the modern biosphere. Complementary to the shelly fossil record consisting of biomineralized hard parts, the study of so-called “sites of exceptional preservation” (or *Konservat-Lagerstätten*) has dramatically furthered our knowledge of extinct diversity and animal evolution by capturing delicate morphological information that would be lost to decay under normal conditions. In this course we will explore the importance of exceptional preservation in the fossil record through an overview of major Konservat-Lagerstätten around the world and throughout the Precambrian to Mid-Phanerozoic, with particular emphasis on the evolutionary history of invertebrate animals. Our aim is to produce a thorough understanding of the inherent biases of the fossil record, how exceptional deposits break with these limitations, and the contribution of exceptional paleontological data towards reconstructing the origin and early evolution of the major animal groups.

Format and Curriculum: The course is structured as biweekly lectures that provide a comprehensive overview of major sites of exceptional preservation, emphasizing the origin and early evolution of major groups of invertebrate animals. For most sessions, the lectures will be organized following a consistent core of topics in a format accessible to both biologists and geologists, including: 1) Spatiotemporal context within the history of the biosphere; 2) Major biological event(s) represented; 3) Fossil data and taphonomy; 4) Broader evolutionary significance/major contributions; 5) Fifteen-minute student chalk talk on selected publications.

Laboratory: The lectures will be complemented by a weekly laboratory session that will provide remote practical experience on the study and interpretation of exceptionally preserved fossils (Invertebrate Paleontology collections at MCZ) and/or analytical techniques used for their study.

Grading: Course assessment will be based on two exams (midterm and final, ca. 30% final grade each), student chalk talks during each session (ca. 20% final grade), and weekly laboratory practicals (ca. 20% final grade).

Week 1 – Introduction and nature of the fossil record

Jan 25, 2021 – S1: Course overview and the fossil record – Introduction to the general attributes of the fossil record, including most common modes of fossilization, biases, and major extinct groups represented.

Chalk talk: N/A

Jan 27, 2021 – S2: A primer on exceptional preservation – Addresses the phenomenon of exceptional preservation, decay biases, and the importance of understanding taphonomy for interpreting the animal fossil record.

Chalk talk: Sansom et al. 2010. *Nature* 463: 797

Recommended reading:

Parry et al. 2018. Soft-bodied fossils are not simply rotten carcasses—toward a holistic understanding of exceptional fossil preservation: exceptional fossil preservation is complex and involves the interplay of numerous biological and geological processes. *BioEssays* 40: 1700167.

Week 2 – Precambrian paleobiology, a world without animals

Feb 1, 2021 – S3: Origin of Life and the appearance of cellular complexity –Biogeochemical evidence for the origin of Life, and the early fossil record of prokaryote and eukaryotic cells.

Chalk talk: Nettersheim et al. 2019 *Nature Ecology and Evolution* 3: 577

Feb 3, 2021 – S4: Oxidation events, the Boring Billion and fossilized embryos – Overview of the oxidation of the atmosphere by photosynthetic autotrophs, the subsequent stability, and the significance of phosphatized embryos.

Chalk talk: Hultgren et al. 2011. *Science* 334: 1696

Lab: Nature of the fossil record and taphonomic biases. Assessing the potential of animal tissue preservation with decay experiments and diverse substrates in a controlled wet laboratory setting.

Recommended reading:

Butterfield 2015. The Neoproterozoic. *Current Biology*, 25: R859-R863.

Week 3 – Ediacaran paleobiology, the earliest macroscopic organisms

Feb 8, 2021 – S5: The Ediacaran biota, the first macroscopic animals – Diversity, distribution and preservation of Ediacaran assemblages around the world.

Chalk talk: Hoyal-Cuthill and Han 2018 *Palaeontology* 61: 813

Feb 10, 2021 – S6: Developmental biology and ecology in the Ediacaran biosphere – Overview of research that aims to resolve the phylogenetic affinities and mode of life of Ediacaran organisms based on analytical approaches.

Chalk talk: Mitchell and Kenchington 2018. *Nature Ecology and Evolution* 2: 1218

Lab: Precambrian fossil diversity and paleobiology.

Recommended reading:

Dunn, et al. 2018. Ediacaran developmental biology. *Biological Reviews*, 93: 914-932.

Mitchell, et al. 2015. Reconstructing the reproductive mode of an Ediacaran macro-organism. *Nature*, 524: 343.

Week 4 – Terreneuvian, at the beginning of the Phanerozoic biosphere, feat. Rudy Lerosey-Aubril

Feb 17, 2021 – S7: Terreneuvian trace fossils and the Cambrian Substrate Revolution – Addresses the fundamental ecological shift between the mat-ground dominated Ediacaran and the tiered Phanerozoic marine ecosystem.

Chalk talk: Vannier et al. 2010 *Geology* 38: 711

Feb 22, 2021 – S8: Small Shelly Fossils and the origin of animal biomineralization – Discusses the early evidence for animal biomineralization and diversification based on Tommotian microfossils and “reef-forming” organisms.

Chalk talk: Schiffbauer et al. 2020 *Nature Communications* 11, 205

Lab: Terreneuvian animal traces, Small Shelly Fossils and other biomineralized problematica.

Recommended reading:

Hua, et al. 2003. Borings in *Cloudina* shells: complex predator-prey dynamics in the terminal Neoproterozoic. *Palaios*, 18: 454-459.

Mangano and Buatois 2017. The Cambrian revolutions: trace-fossil record, timing, links and geobiological impact. *Earth-Science Reviews*, 173: 96-108.

Week 5 – Cambrian Konservat-Lagerstätten I, the gold standard for invertebrate body fossils

Feb 24, 2021 – S9: Burgess Shale-type preservation – Introduction to the mechanisms responsible for organic carbon film preservation in the Cambrian, including its spatiotemporal distribution and attributes.

Chalk talk: McMahon et al. 2016 *Geology* 44: 867

March 3, 2021 – S10: The Maotianshan Shales and other exceptional biotas from South China – Overview of early Cambrian biotas in South China, the earliest soft-bodied animal communities in the rock record.

Chalk talk: Yang et al. 2016 *PNAS* 11: 2988

Lab: Demonstration with MCZ museum specimens (Burgess Shale collection), and application of computed tomography to the study of Cambrian macrofossils from Chengjiang (temporary loan courtesy from Yunnan Key Laboratory for Palaeobiology, Yunnan University).

Recommended reading:

Fu et al. 2019. The Qingjiang biota—A Burgess Shale-type fossil Lagerstätte from the early Cambrian of South China. *Science*, 363: 1338-1342.

Gabbott et al. 2004. Preservation of Early Cambrian animals of the Chengjiang biota. *Geology*, 32: 901-904.

Week 6 – Cambrian Konservat-Lagerstätten II, exceptional preservation in North America

March 8, 2021 – S11: Burgess Shale biota, British Columbia – Overview of diversity, preservation and uniqueness of the Burgess Shale biota within the context of Cambrian exceptional deposits.

Chalk talk: Caron et al. 2006 *Nature* 442: 159

March 10, 2021 – S12: Exceptional insights from the mid-late Cambrian of USA – Overview of diversity, preservation and uniqueness of various USA Konservat-Lagerstätten within the context of Cambrian exceptional deposits.

Chalk talk: Ortega-Hernández et al. 2019 *Proceedings of the Royal Society B* 286, 20192370

Recommended reading:

Butterfield et al. 2007. Fossil diagenesis in the Burgess Shale. *Palaeontology*, 50: 537-543.

Lerosey-Aubril et al. 2018. The Weeks Formation Konservat-Lagerstätte and the evolutionary transition of Cambrian marine life. *Journal of the Geological Society*, 175: 705-715.

Week 6 – Midterm exam (30% final grade), Sessions 1 to 12.

Week 7 – Cambrian Konservat-Lagerstätten III, a microscopic perspective

March 15, 2021 – S13: Small Carbonaceous Fossils and the cryptic animal fossil record – Discussion of the significance of SCF's as a complementary view of Cambrian diversity with a broader spatiotemporal occurrence.

Chalk talk: Harvey & Butterfield 2008, *Nature* 452: 868

March 17, 2021 – S14: Orsten fossils from Sweden, the last Cambrian exceptional fossils – Overview of Orsten preservation in the Cambrian, with emphasis on the Furongian Swedish deposits.

Chalk talk: Waloszek & Dunlop 2002, *Palaeontology* 45: 421

Lab: Reconstructing the stem lineage of Euarthropoda combining Cambrian fossils and phylogenetics.

Recommended reading:

Butterfield and Harvey 2012. Small carbonaceous fossils (SCFs): a new measure of early Paleozoic paleobiology. *Geology*, 40: 71-74.

Maas, et al. 2006. The 'Orsten'—more than a Cambrian Konservat-Lagerstätte yielding exceptional preservation. *Palaeoworld*, 15: 266-282.

Week 8 – Ordovician, the establishment of the modern biosphere

March 22, 2021 – S15: The Fezouata biota and the Great Ordovician Biodiversification Event – Overview of the exceptionally preserved Fezouata biota from Morocco and its context within the GOBE.

Chalk talk: Van Roy et al. 2015 *Nature* 522: 77

March 24, 2021 – S16: Trilobite legs from New York– Overview of exceptional localities with soft tissue preservation in New York stage, including Beecher's trilobite bed (pyritization) and Walcott-Rust Quarry (calcite replication).

Chalk talk: Hegna et al. 2017 *Geology* 45: 199,

Lab: Demonstration with MCZ museum specimens (Walcott-Rust, Beecher's and Fezouata collections).

Recommended reading:

Farrell et al. 2009. Beyond Beecher's Trilobite Bed: Widespread pyritization of soft tissues in the Late Ordovician Taconic foreland basin. *Geology*, 37: 907-910.

Van Roy et al. 2015. The Fezouata fossils of Morocco; an extraordinary record of marine life in the Early Ordovician. *Journal of the Geological Society*, 172: 541-549.

Week 9 – Silurian, the initial transition to land

March 29, 2021 – S17: Herefordshire, a unique three-dimensional view of extinct marine diversity – Overview of the unique Herefordshire biota and its three dimensionally preserved diversity of marine organisms.

Chalk talk: Sutton et al. 2012 *Nature* 490: 94

April 5, 2021 – S18: The first terrestrial ecosystems – Overview of evidence for the earliest terrestrial incursions based on animal traces, body fossils and plant compressions.

Chalk talk: Wendruff et al 2020 *Scientific Reports* 10: 14

Lab: Demonstration with MCZ museum specimens (Herefordshire nodules provided by Oxford Museum of Natural History), and virtual models of three-dimensional preserved animals (courtesy of Mark Sutton, Imperial College London).

Recommended reading:

Siveter et al. 2019. The Herefordshire Lagerstätte: fleshing out Silurian marine life. *Journal of the Geological Society*, 2019-110.

Week 10 – Devonian, early terrestrial ecosystems

April 7, 2021 – S19: Rhynie Chert, a terrestrial ecosystem frozen in time – Discussion of the Rhynie Chert as a particularly comprehensive insight into an early terrestrial community preserved through silicification.

Chalk talk: Engel & Grimaldi 2004 *Nature* 427: 627

April 12, 2021 – S20: Hunsrück Slate of Germany, a marine fauna with echoes from the past – Highlights the contrast between ‘modern’ groups preserved through whole body pyritization, with the last occurrence of Cambrian-type animals.

Chalk talk: Kuhl et al. 2009 *Science* 323: 771

Lab: Demonstration with MCZ museum specimens (Hunsrück Slate collection).

Recommended reading:

Garwood et al. 2019. An introduction to the Rhynie chert. *Geological Magazine*, pp.1-18.

Week 11 – Carboniferous, terrestrial animals take to the skies

April 14, 2021 – S21: Montceau-les-Mines, terrestrial animals in three dimensions – Overview of Montceau-les-Mines in France as a deposit with three-dimensional preservation of semiaquatic animals.

Chalk talk: Garwood et al. 2016 *Proceedings of the Royal Society B* 283: 20160125

April 19, 2021 – S22: Mazon Creek, Wamsutta Formation and the origins of flight – Discussion on the significance of the fossil record understanding the origin of flight in insects.

Chalk talk: McCoy et al. 2016 *Nature*, 532: 496

Lab: Demonstration with MCZ museum specimens (Mazon Creek and Wamsutta Sandstone collections), and virtual models of three-dimensional preserved animals (courtesy of Russell Garwood, University of Manchester).

Recommended reading:

Heyler, D. and Poplin, C.M., 1988. The fossils of Montceau-les-Mines. *Scientific American*, 259(3), pp.104-111.

Knecht, R.J., Engel, M.S. and Benner, J.S., 2011. Late Carboniferous paleoichnology reveals the oldest full-body impression of a flying insect. *Proceedings of the National Academy of Sciences*, 108: 6515-6519.

Week 12 – Exceptional preservation beyond the Paleozoic

April 21, 2021 – S23: Amber deposits – Characteristics, spatiotemporal distribution and significance of living organisms preserved as amber inclusions.

Chalk talk: Yu et al. 2019 *PNAS*, 116: 11345

April 26, 2021 – S24: Last but not least – Overview of other modes of exceptional preservation not already covered in the course, such as preservation of color/melanosomes, and lithographic limestones, and ancient DNA.

Chalk talk: Lindqvist et al. 2010 *PNAS*, 107: 5053

Lab: Demonstration with MCZ museum specimens (Entomology and Invertebrate Paleontology collections).

Recommended reading:

Colleary et al. 2015. Chemical, experimental, and morphological evidence for diagenetically altered melanin in exceptionally preserved fossils. *Proceedings of the National Academy of Sciences*, 112, 12592-12597.

McCoy, V.E., Soriano, C., Pegoraro, M., Luo, T., Boom, A., Foxman, B. and Gabbott, S.E., 2018. Unlocking preservation bias in the amber insect fossil record through experimental decay. *PloS one*, 13, e0195482.

May 10, 2021 – Final exam (30% final grade), Sessions 13 to 24.