

Using machine learning tools to understand the Cambrian Explosion of animal skeletons

Supervisory Team

- Luke Parry (Earth Sciences) luke.parry@earth.ox.ac.uk
- Julie Cosmidis (Earth Sciences) julie.cosmidis@earth.ox.ac.uk
- Duncan Murdock (OUMNH)
- Imran Rahman (NHM, London)
- Philip Donoghue (Bristol)

Key Words

Palaeobiology, Synchrotron tomography, Cambrian, Biomineralisation

Overview

Skeletons are vital for providing structural support, gathering/processing food, and defence against predators in a variety of animals. During the latest Ediacaran and Cambrian (~550–485 million years ago), virtually all the animal groups that produce biominerals first appear in the fossil record, with multiple lines of evidence suggesting they acquired biomineralized skeletons independently (Murdock 2020). Consequently, skeletal diversification is central to hypotheses of the drivers of the Cambrian explosion (e.g. an evolutionary arms race between predators and prey), as well as proposed feedbacks between the earth and life that shaped the evolution of mineralised hard parts (Porter 2007). Studies of the genetic machinery of skeletal development have suggested that distantly related animal groups co-opted a common genetic toolkit, with biomineralized skeletons evolving from common organic precursors.

Processes of growth and development of individual skeletal elements are recorded in exquisite detail in the microstructures preserved in fossilized animal hard parts, revealing information about the skeleton forming tissue, the site of formation and how/if hard parts were remodelled over time. Many of the earliest animal skeletons are exceptionally well preserved in “small shelly fossil” assemblages from the early Cambrian, allowing their microstructures to be observed and reconstructed in fine detail using electron microscopy and synchrotron tomography. These early fossils reveal the oldest

records of groups that persist to the present day (e.g. echinoderms, molluscs and brachiopods), as well as a wealth of extinct groups with bizarre body plans and controversial affinities (Skovsted *et al.* 2008; Liu *et al.* 2020; Guo *et al.* 2022).

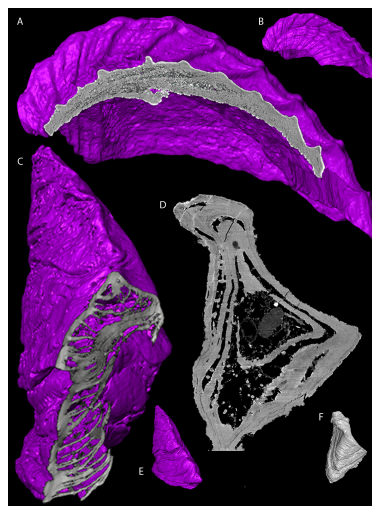


Figure showing synchrotron tomographic models of tommotiids, iconic early Cambrian skeletal microfossils (see Murdock 2020 for details).

It has been hypothesised that the first animal skeletons showed less biologically controlled secretion and greater disparity than their recent counterparts, with canalisation and increasing entrenchment of skeletal microstructures occurring in tandem with an increased skeletal complexity. Counterparts of extant taxa in the Cambrian show microstructures that do not exist in the Recent, and some iconic complex structures (e.g. molluscan nacre) appear to have evolved convergently through a repeated pattern of increasing complexity and control after the Cambrian. Similarly, biomineralogy appears to

have been less constrained in the early Palaeozoic than the recent, such as the widespread use of phosphorus in the skeletons of sessile animals like cnidarians, which become less available through the Phanerozoic (Kraft & Mergl 2022).

This project aims to test hypotheses surrounding the origin of skeletal microstructures in deep time, particularly if greater disparity was present in Cambrian animal skeletons compared to the Recent and how this varied between major groups, thereby revealing how skeletons have diversified over the past 500 million years of evolutionary history.

Methodology

The student will develop methods for automatically recognising microstructural fabrics and features from 3D tomographic data (i.e. lab microCT and synchrotron tomography) animal skeletal hard parts. These data will be used to quantify how growth and development of skeletons has changed over the past 500 million years in different groups and to develop metrics for microstructural complexity. This framework will be used to test the hypothesis that skeletons showed higher initial disparity and were less constrained earlier in their history. The initial focus of this work will be on the echinoderms, a clade with a complex calcitic skeleton and a fossil record stretching back to the early Cambrian (~520 Ma), for which large amounts of tomographic data have already been collected. This dataset will be used for methods development and to establish a quantitative framework for studying microstructural data in a phylogenetic context. Reference scans will be manually segmented and used to train neural networks, which will be used to automatically segment subsequent scans. Properties such as wall thickness, porosity and pore connectivity will be quantified to compare samples from the Cambrian and the recent. This approach will then be extended to other relevant animal groups, such as brachiopods and molluscs. These new data will be used in conjunction with an emerging phylogenetic framework for early animals to understand how skeletons have evolved over time using phylogenetic comparative methods.

Timeline

Year 1: Doctoral training courses (10 weeks), literature review, initial data exploration and beamtime applications.

Years 2 and 3: Tomographic dataset preparation and segmentation, tomographic data collection, presentation at national conferences.

Year 4: Data integration, thesis completion, papers for international journals/conference presentation.

Training & Skills

The supervisory team at Oxford includes expertise in early animal evolution (L. Parry), early skeletonization (D. Murdock) and biomineralization (J. Cosmidis) and external collaborators with complementary skills in 3D morphology and macroevolutionary analysis (I. Rahman, P. Donoghue). The student will learn how to prepare fossils for 3D scanning, automation of processing of tomographic data and integrating observations of extant and extinct taxa in comparative analyses.

References & Further Reading

D. J. Murdock, The 'biomineralization toolkit' and the origin of animal skeletons. *Biological Reviews* **95**, 1372-1392 (2020).

S. M. Porter, Seawater chemistry and early carbonate biomineralization. *Science* **316**, 1302-1302 (2007).

J. Guo *et al.*, A Cambrian tomotiid preserving soft tissues reveals the metameric ancestry of lophophorates. *Current Biology* **32**, 4769-4778. e4762 (2022).

C. B. Skovsted, *et al.* The scleritome of *Eccentrotheca* from the Lower Cambrian of South Australia: Lophophorate affinities and implications for tomotiid phylogeny. *Geology* **36**, 171-174 (2008).

F. Liu, *et al.* Are hyoliths Palaeozoic lophophorates? *National Science Review* **7**, 453-469 (2020).

P. Kraft, M. Mergl, Struggle for phosphorus and the Devonian overturn. *Trends in Ecology & Evolution*, (2022).

Further Information

Contact: Luke Parry, luke.parry@earth.ox.ac.uk (Associate Professor of Earth Sciences)