

A new proxy data source to constrain Cambrian sea temperatures

Summary

The rapid appearance in the fossil record of most of the modern animal phyla in rocks of the lower Cambrian System is known as the Cambrian metazoan adaptive radiation (Fig. 1). The Cambrian Period is also the only Phanerozoic period lacking reliable oxygen isotope ($\delta^{18}\text{O}$) ocean temperature proxy data (Fig. 2). Calcitic brachiopods and phosphatic euconodonts, the usual biomineral sources of $\delta^{18}\text{O}$ data in rocks of Palaeozoic age, are not suitable for use in the Cambrian Period. Euconodonts are not known below uppermost Cambrian rocks and most calcitic brachiopods of this age have been diagenetically altered. Therefore, an alternative source of $\delta^{18}\text{O}$ data needs to be found. We have examined a selection of biophosphatic 'small shelly fossils' (SSFs) from the lower Cambrian of Britain (Fig. 3) following a rigorous protocol designed to test the preservation of phosphatic microfossils. Here we show that original biological ultrastructural (Fig. 4) and bulk chemistry (Fig. 5) are well-preserved in a subset of these microfossils. These biominerals have the potential to provide the first quantitative constraints on Cambrian sea temperatures.

The Cambrian Radiation

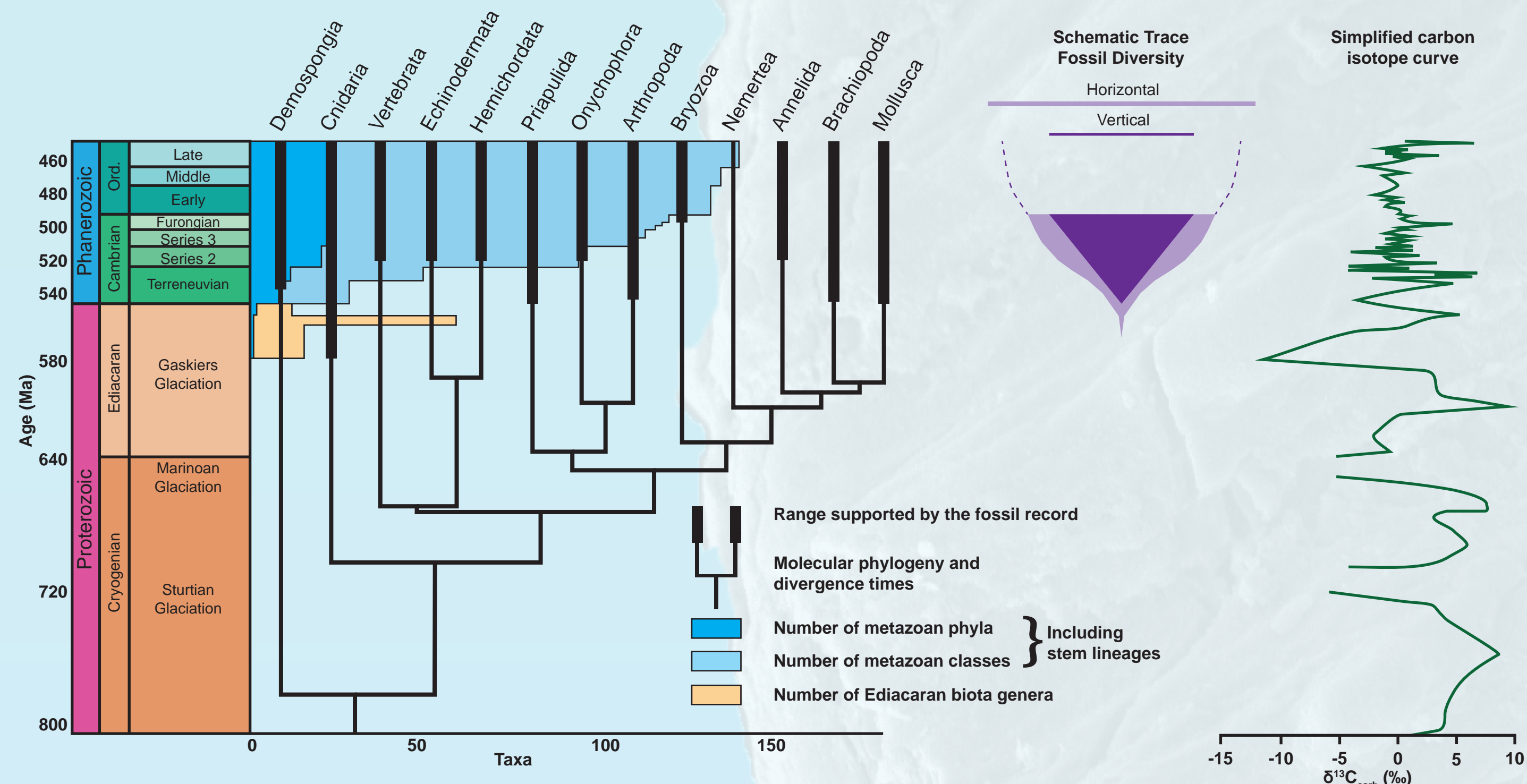


Fig. 1. The Cambrian radiation is seen as an increase in taxonomic diversity and disparity (adapted from Erwin et al., 2011), alongside increasing trace fossil penetration depth and complexity (adapted from Marshall, 2006). This is accompanied by a step-change in the amplitude and frequency of stable carbon isotope fluctuations (simplified from Saltzman & Thomas, 2012). Fossil and geochemical data across the Proterozoic—Phanerozoic transition record one of the greatest biological and environmental changes in Earth's history.

Selected 'small shelly fossils' (SSFs)

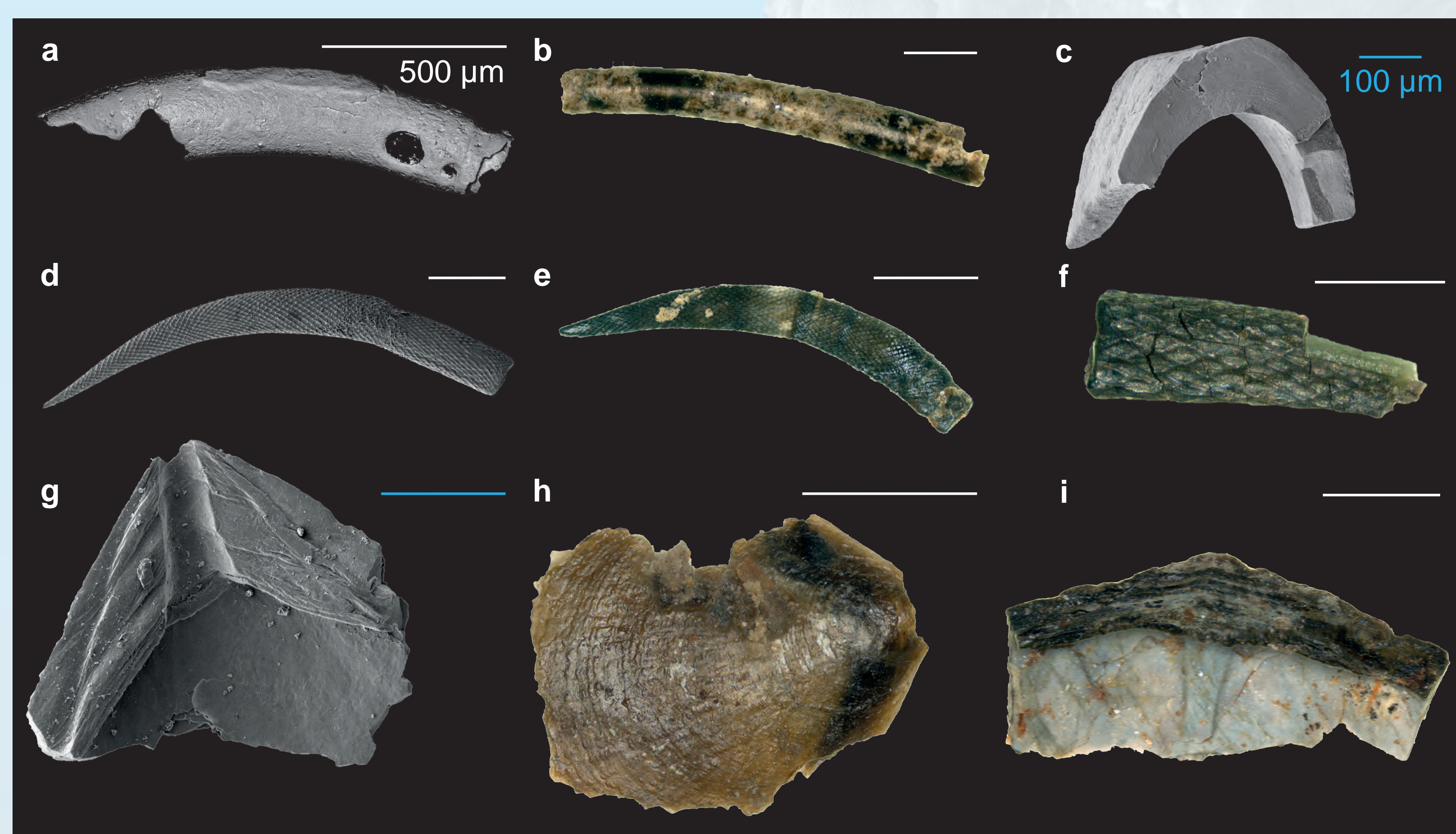


Fig. 3. SSFs from the Lower Comley Limestone, lower Cambrian of Shropshire, which was recently dated to $509.10 \pm 0.22 - 514.45 \pm 0.36$ Ma (Harvey et al., 2011). These include the tubular forms *Hyolithellus* (a, b) and *Torellella* (c), the enigmatic spinous genus *Rhombocorniculum* (d-f) and various lingulid brachiopods (g-i). Images from SEM (greyscale) and optical microscopy (colour).

Bulk chemical screening

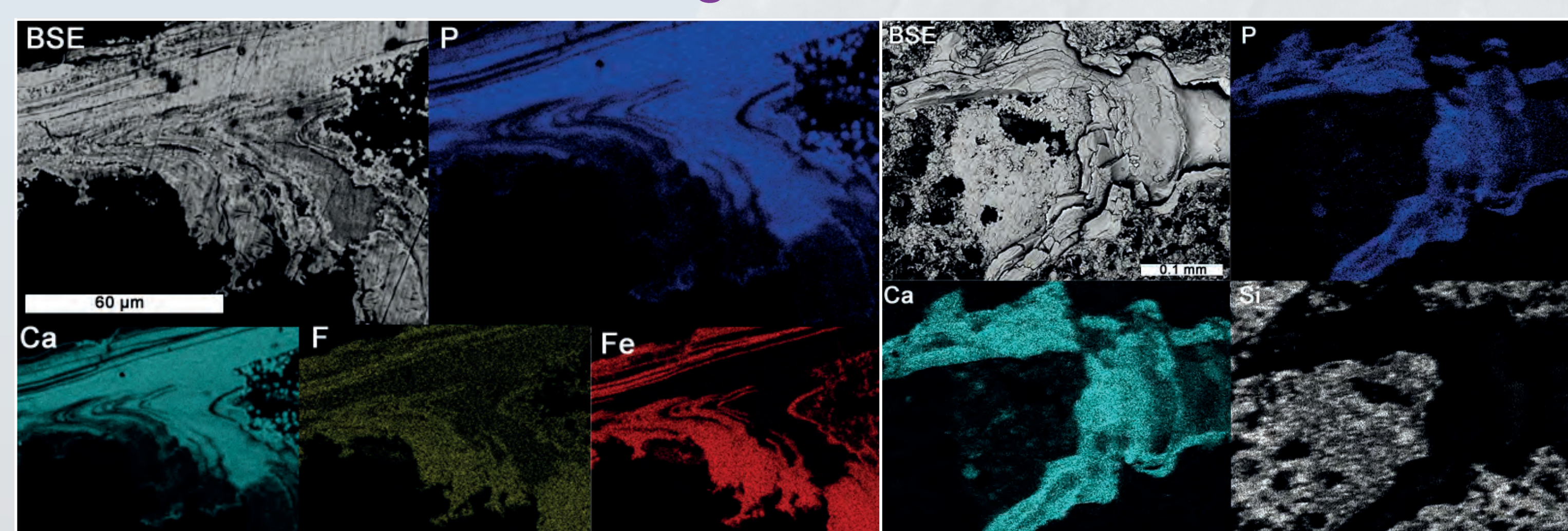


Fig. 5. Left: SEM-EDS analyses of a polished cross section of the hinge region of a lingulid brachiopod from the Comley Limestone. Right: SEM-EDS analyses of a fractured tomotioid (*Lapworthella*) specimen. BSE = back-scattered electron image. (P) EDS phosphorous map; (Ca) EDS calcium map; (F) EDS fluorine map; (Fe) EDS iron map. Ca and P are concentrated in the compact laminae of the lingulid brachiopod. F is diffuse throughout, but with greater concentration in the bacculate laminae and Fe is restricted to the more porous bacculate laminae.

Palaeozoic $\delta^{18}\text{O}$ Record

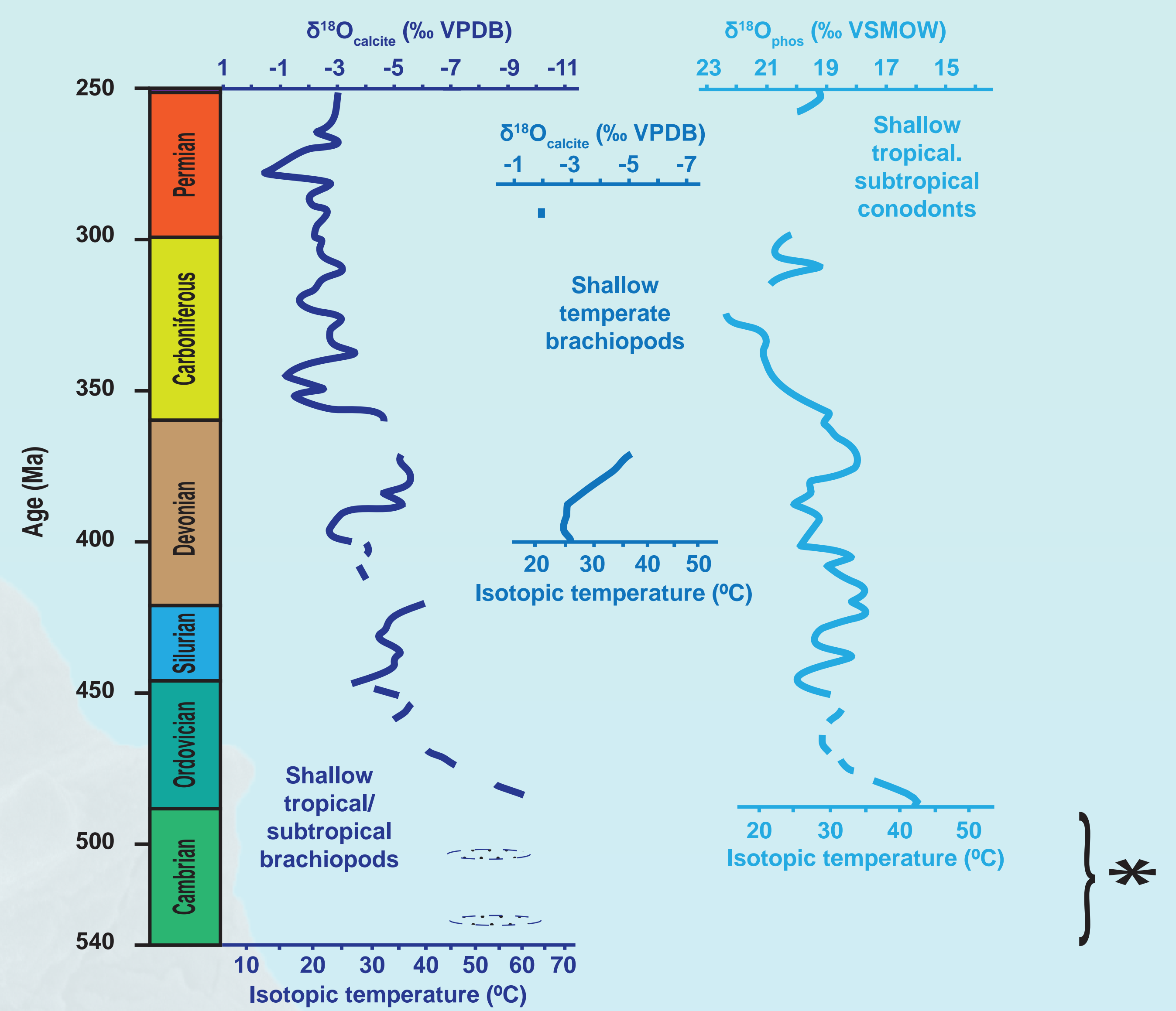


Fig. 2. Oxygen isotope data and isotopic temperatures for the Palaeozoic Era. *Note the death of data through the ~55 million year Cambrian Period. Simplified after Grossman (2012).

Methods

To have confidence that $\delta^{18}\text{O}$ data from biological material retains an original palaeo-environmental signal, we need to demonstrate that the fossils are well preserved; i.e. that the isotope signal has not been reset by diagenetic or other alteration. Taking fossils that have well-preserved gross morphology (Fig. 3), we examined their ultrastructure as a test for recrystallization (Fig. 4). Those with well-preserved ultrastructure were then examined by energy dispersive X-ray spectroscopy (EDS) which looks at bulk chemistry (Fig. 5). A subset of SSFs are found to have well-preserved bulk chemistry and warrant higher resolution chemical investigation. As isotopic alteration can be cryptic, affecting only the isotope ratios, the final test will utilise high resolution $\delta^{18}\text{O}$ analyses of individual SSFs.

Screening for biological ultrastructures

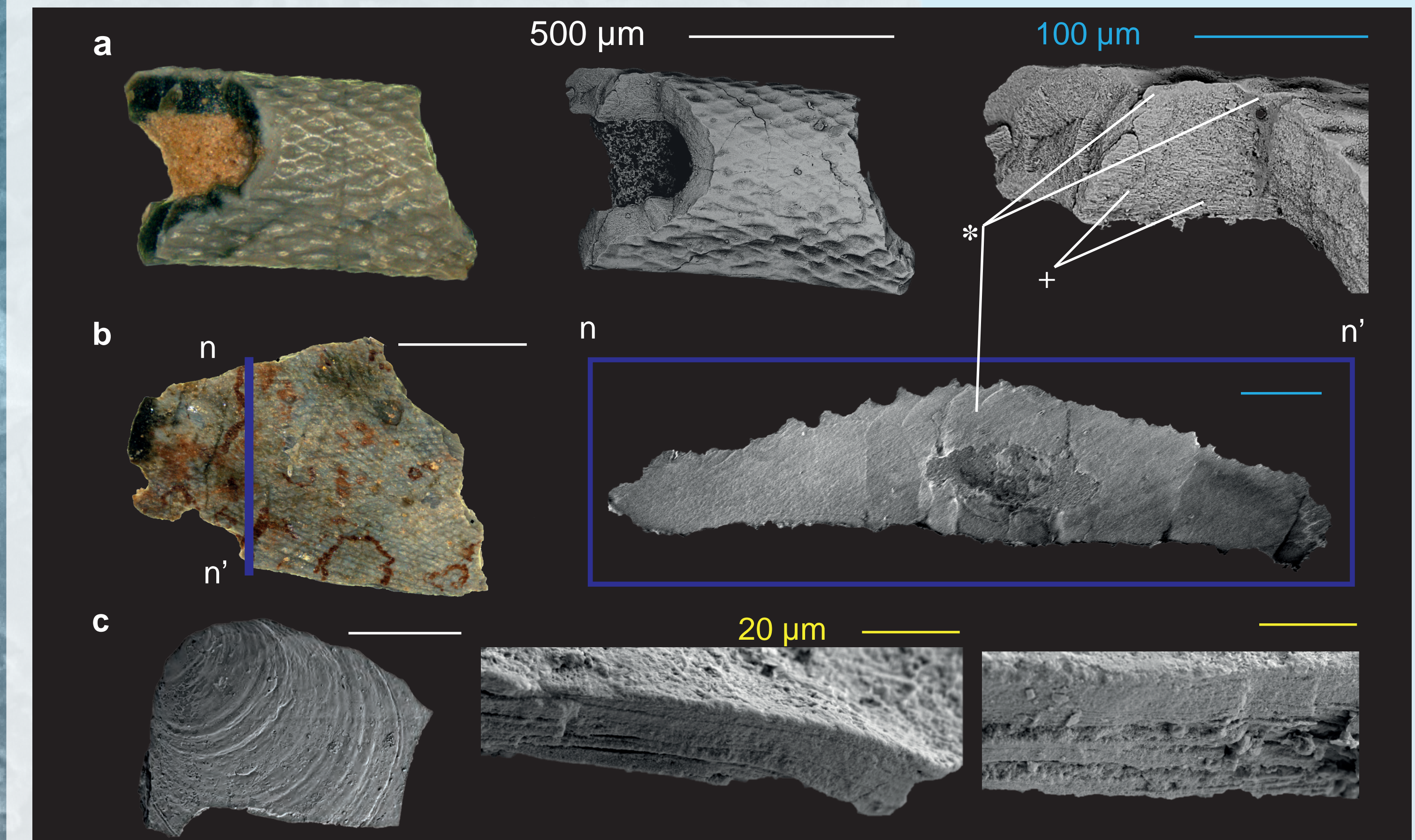


Fig. 4. (a, b) *Rhombocorniculum* colour appears to distinguish between phosphate ultrastructure: dark colour = prismatic (+); light colour = massive and sugary (*). (c) biogenic compact and bacculate laminae are preserved in lingulid brachiopods.

Conclusions

A subset of phosphatic SSFs from the Lower Comley Limestone, lower Cambrian of Shropshire, have so far passed the preservation tests of our strict new protocol. These fossils are thus far considered to be suitable for isotope analyses. Ongoing high resolution chemical analyses are the next stage of the screening protocol. As a word of caution, in addition to inherent uncertainties in the isotope data, including unconstrained biological ('vital effect') fractionation, the $\delta^{18}\text{O}$ composition of Cambrian sea water is required to calculate an isotopic temperature. There is ongoing debate as to whether sea water $\delta^{18}\text{O}$ changes substantially over geological time. Despite these complicating factors, preliminary $\delta^{18}\text{O}$ data are comparable with that of early Ordovician conodonts (Trotter et al., 2008) and fall within a realistic range for warm Cambrian sea surface temperatures.

Background image: *Lapworthella* from the Comley Limestone, ~450 μm vertical height. Erwin, D.H., et al., 2011: *Science* 34, 1091–1097. Grossman, E.L. 2012: in Gradstein, F.M., et al. (eds.), *The Geologic Timescale*, 181–206. Harvey T.H.P. et al., 2011: *J. Geol. Soc.* 168, 705–716. Kouchinsky A. et al., 2012: *Geol. Mag.* 149(2), 221–251. Marshall, C.R. 2006: *Annu. Rev. Earth Planet. Sci.* 34, 355–84. Saltzman, M.R. & Thomas, E. 2012: in Gradstein, F.M., et al. (eds.), *The Geologic Timescale*, 207–232. Trotter, J.A. et al., 2006: *Science* 321, 550–554.