Small Shelly Fossils: taking the temperature of the ‘Cambrian explosion’

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1. Background

The Cambrian ‘explosion’ was the first adaptive radiation of animals and happened between about 550 and 500 million years ago[1]. For the first time in Earth’s history animals burrowed down into the sea bed and could recylce nutrients that would previously have been locked away (Fig. 1).

Extraordinary discoveries of exquisitely preserved fossils have provided a lot of information about the biological changes in this interval. However, there are few constraints on the environment of this ecological revolution. Particularly, we lack reliable temperature data for the Cambrian Period[2] (Fig. 2).

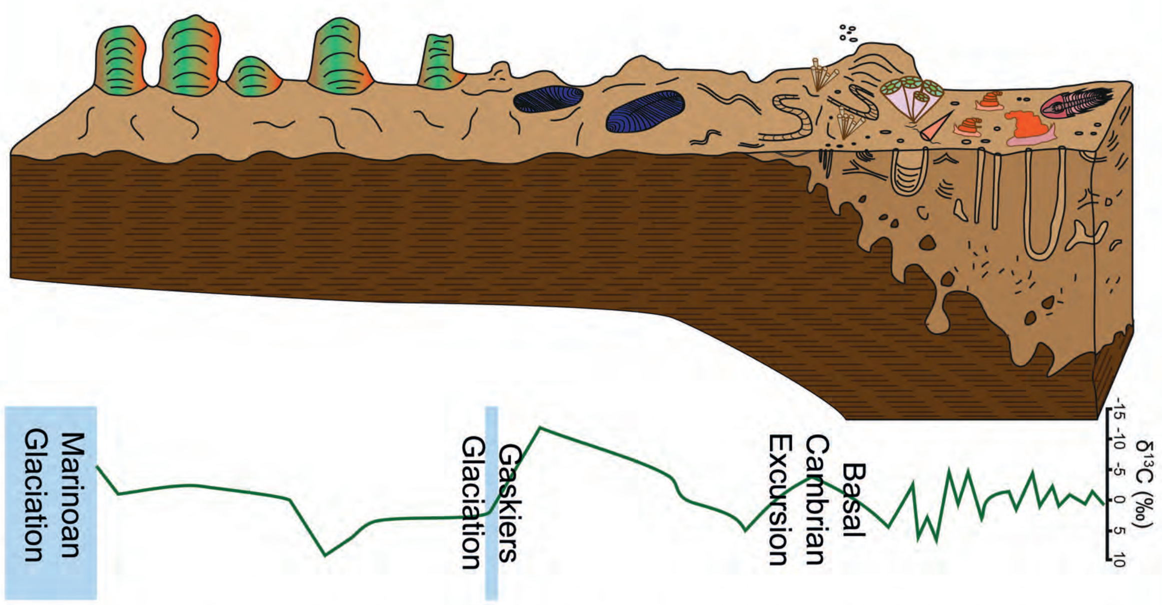

Fig. 1: The Cambrian ‘explosion’ is the transition from a microbial to animal-dominated world. Burrowing around the basal Cambrian enhances the sediment mixed layer and recycles nutrient including organic carbon as seen in the carbon isotope record. There is a transition from large amplitude low frequency cycles to low amplitude high frequency cycles. Adapted from[3&4].

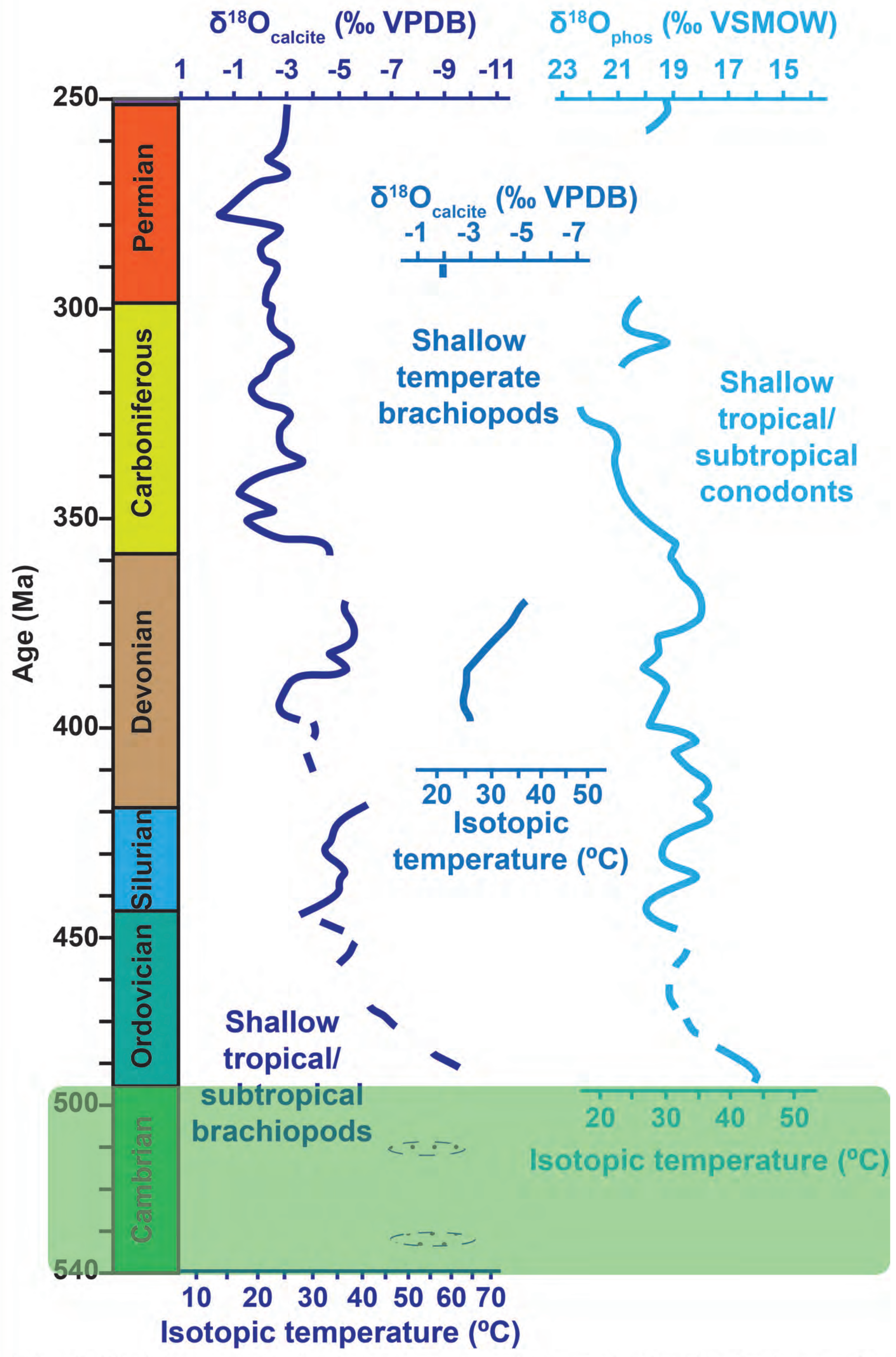

Fig. 2: Stable oxygen isotope temperature data for the Palaeozoic Era - the lower half of the Phanerozoic Eon. The best data come from well-preserved fossil skeletons. Simplified from[2].

2. Setting The Scene

Some rock types are ‘climatically sensitive’ – they only form in particular environments. In the early Cambrian Period (Fig. 3) these rocks indicate a world with warm shallow seas at high southern latitudes and little or no ice.

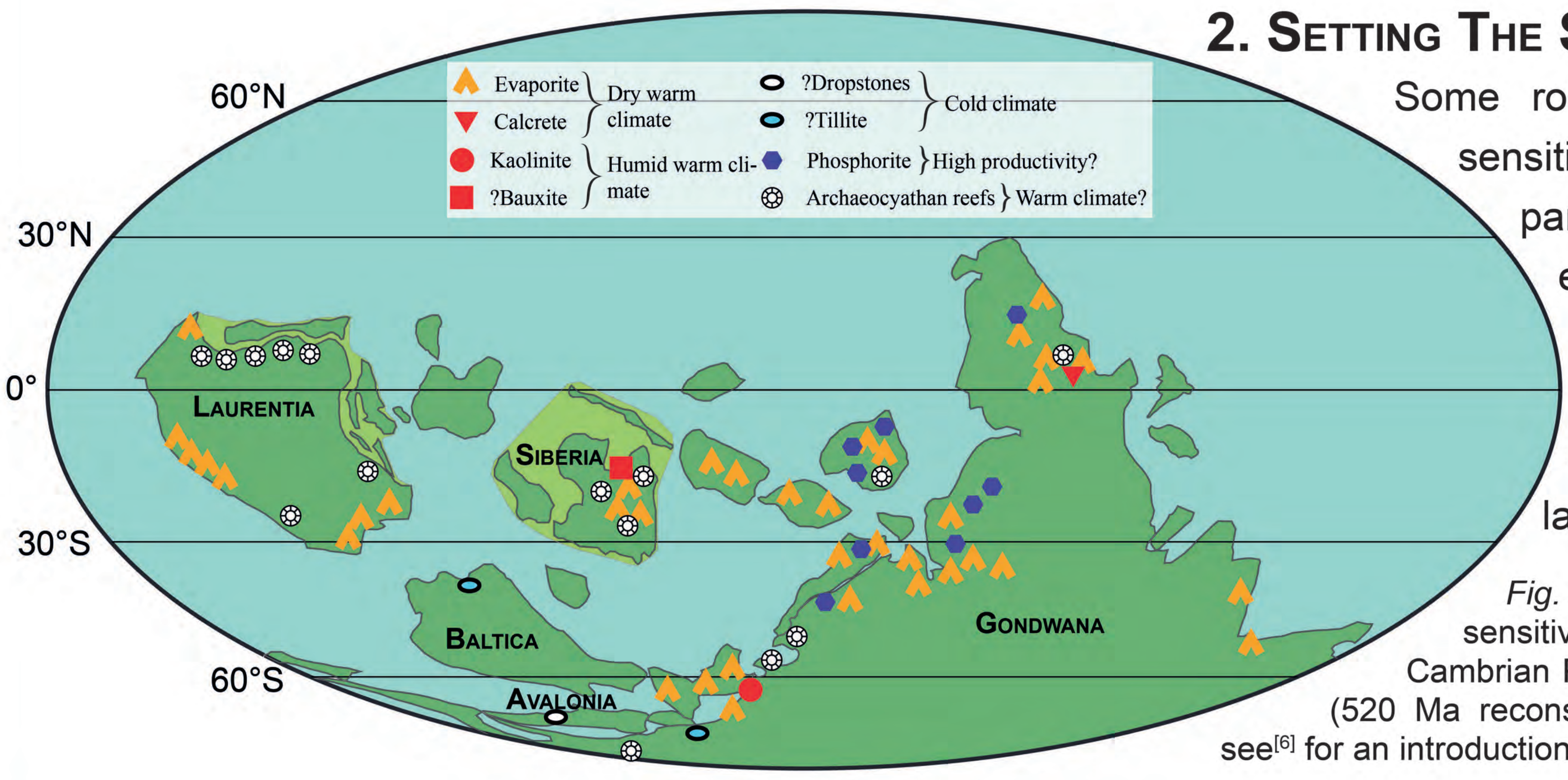

Fig. 3: Distribution of key climatically sensitive rock types in the early Cambrian Period. Base map redrawn from[5] (520 Ma reconstruction). Various data sources, see[6] for an introduction.

Fig. 4: A selection of small shelly fossils (SSFs) from the Comley Limestone, Shropshire, recently dated by bentonite beds to 514.45 ± 0.36—509.10 ± 0.22 million years ago[8]. SSFs comprise an eclectic group often classified by shape rather than biological affinity. There are many tubular forms, such as *Torellella* (a,i) and *Hyolithellus* (b,c). Spinous forms include the enigmatic genus *Rhombocorniculum* (d-f). There are several tommotiid s like *Lapworthella* (g,h). Small phosphatic brachiopods are some of the most common finds (j-m). Greyscale images from SEM; true colour images from optical microscopy.

3. The Problem

Temperature is one of the most important variables controlling environmental conditions. The dearth of Cambrian temperature data (Fig. 3) is because:

(a) of poor preservation of calcareous brachiopods of this age, and

(b) true conodonts are not known from before the Ordovician Period.

A new source of palaeoenvironmental proxy data is therefore needed. Phosphatic ‘small shelly fossils’ (SSFs), the remains of some of the earliest animals (Fig. 4), may be a suitable alternative, as phosphate is more robust to alteration than carbonate[e.g. 7].

4. Preservation

A lot can happen to a fossil in half a billion years and we have to be sure that the $\delta^{18}O$ values have not been altered by burial and post-burial processes.

To assess the preservation of these fossils we examine their microstructural texture (Fig. 5) and their chemistry (Fig. 6) for biological and alteration signals. We use scanning electron microscopy and spectroscopy techniques to investigate preservation.

We find that most specimens from the Comley Limestone are sufficiently well-preserved to analyse them for stable oxygen istope data.

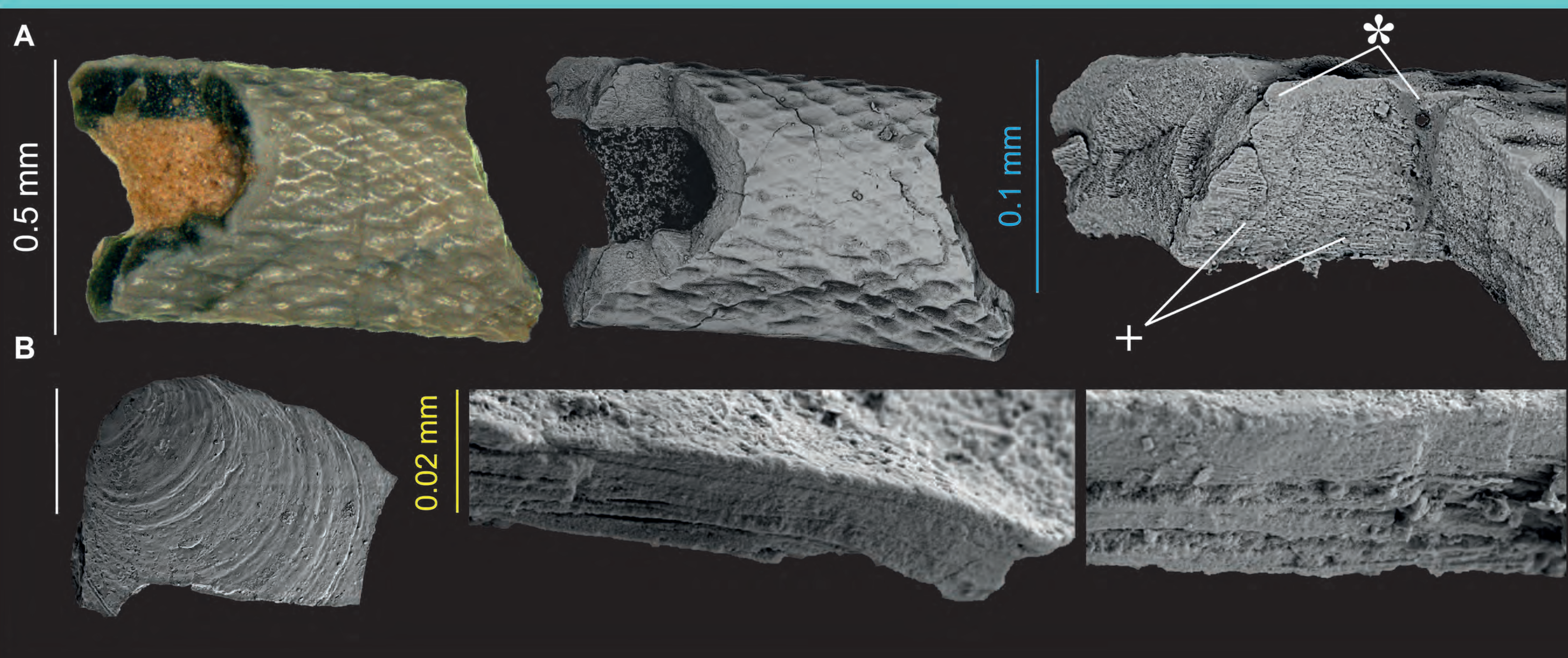

Fig. 5: (A) Biological layering of a thin outer microcrystalline layer (*) and inner net-like layer that emerges as prisms (+) are preserved in a fractured specimen of the spinous fossil *Rhombocorniculum*. (B) The compact and rubbly (more porous) laminae of phosphatic brachiopod shells are also commonly preserved.

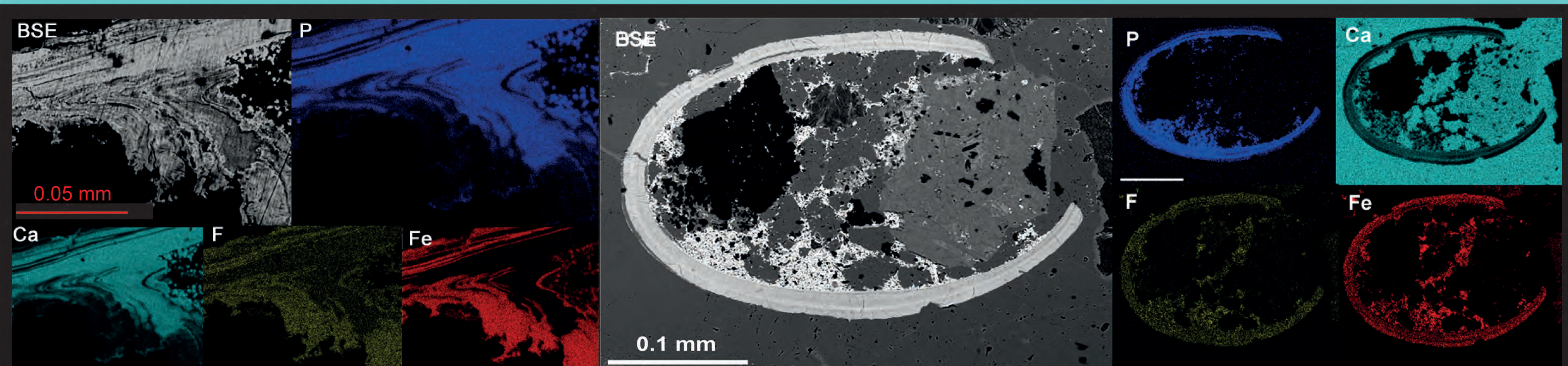

Fig. 6: Cross-sections through a phosphatic brachiopod hinge (left) and specimen of *Torellella* (right). Imaging by scanning electron microscopy (SEM). Backscattered electron images (BSE) and energy dispersive X-ray spectroscopy (EDS) maps showing the distribution of the elements phosphorous (P), calcium (Ca), fluorine (F) and iron (Fe). The brachiopod maps indicate that the compact laminae are well-preserved, with less fluorine that the more porous laminae and little or no iron away from fractures. The maps of *Torellella* show that iron pervades the skeletal (tube) phosphate and the secondary phosphate that has grown inside the tube, possibly from decaying organic matter. This brachiopod may be suitable for isotope analysis but the *Torellella* specimen would be considered altered and not suitable.

Summary

We currently have little quantitative information about the environments the earliest animals evolved in. This is an important interval in the history of Earth and saw the establishment of animal-dominated ecosystems. When carefully screened, ‘small shelly fossils’ may be a source of quantitative data to constrain early Cambrian environments.

References

[1]**Erwin & Valentine, 2014**: The Cambrian explosion. [2]**Grossman, 2012**: in Gradstein et al. (eds.), The Geologic Timescale 181–206. [3]**Brasier et al., 2010**: in Allison & Bottjer (eds.), Taphonomy: Process and Bias Through Time, 519–567. [4]**Saltzman & Thomas, 2012**: in Gradstein et al. (eds.), The Geologic Timescale 221–246. [5]**Torsvik & Cocks, 2013**: in Harper & Servais (eds.), Early Palaeozoic Biogeography and Palaeogeography. Geol. Soc. Mem. 38, 5–24. [6]**Boucot et al., 2014**: Phanerozoic Paleoclimate. [7]**Veizer et al., 2000**: Nature 408, 698–701. [8]**Harvey et al., 2011**: J. Geol. Soc. 168, 705–716.