New proxy data to constrain the early Cambrian greenhouse

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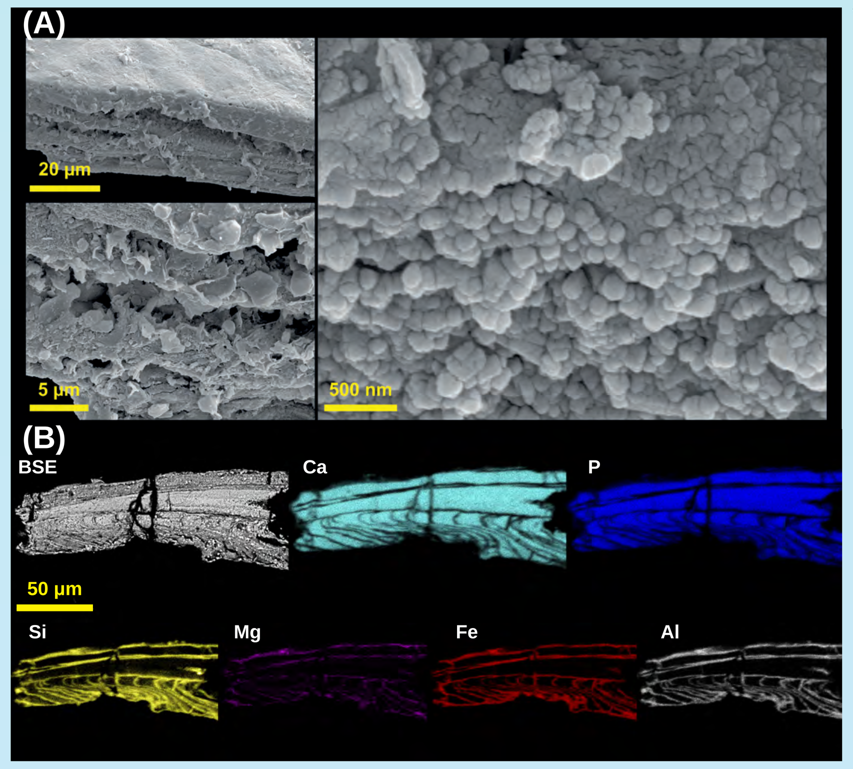
1. Introduction

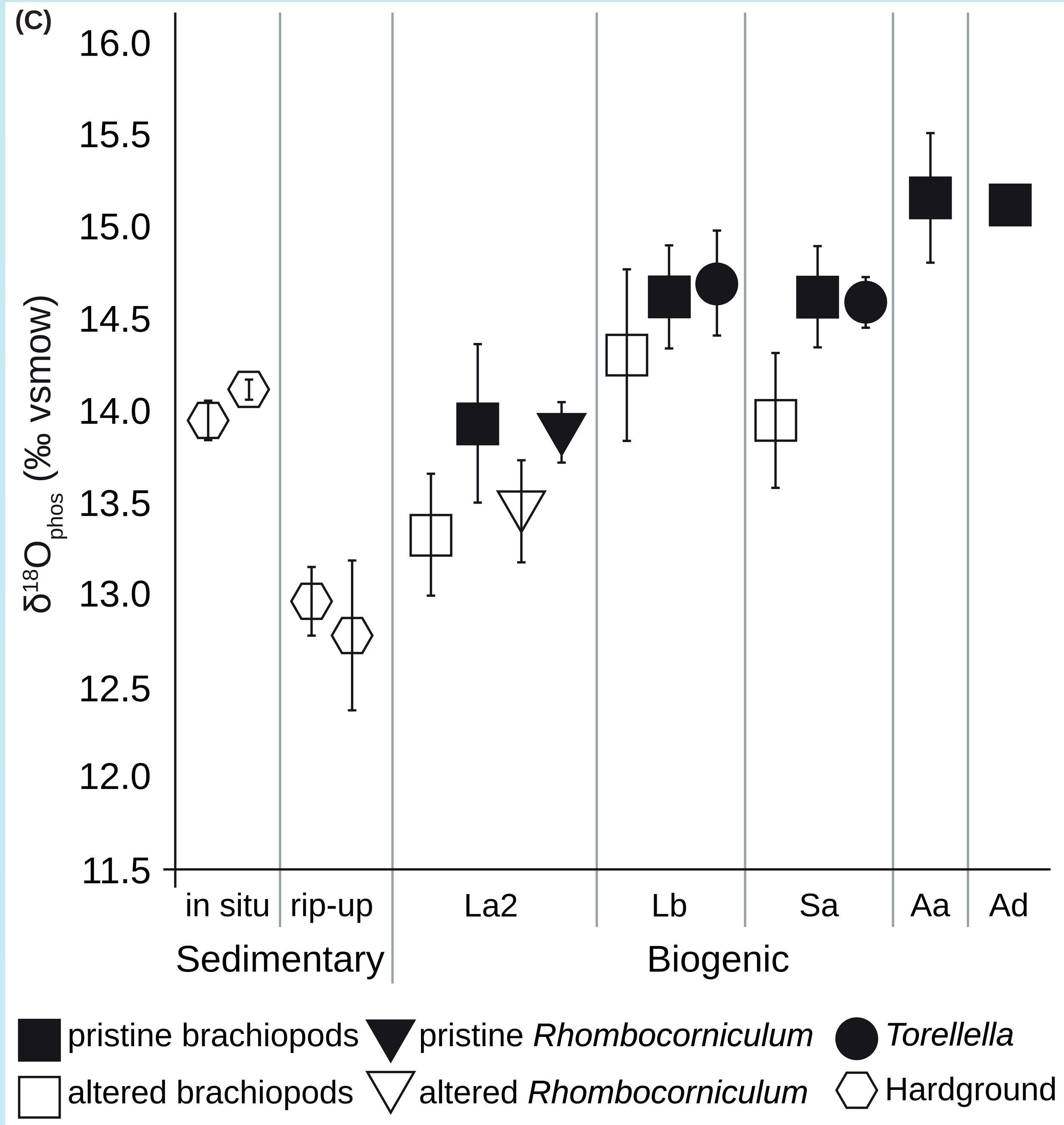
The Cambrian explosion was an ecological revolution that saw the development of the first animal-rich ecosystems, along with major biogeochemical restructuring of Earth's surface [1]. However, we have remarkably few quantitative environmental constraints for this interval. In particular, there is a 50 Myr gap at the base of the Phanerozoic stable oxygen isotope ($\delta^{18}O$) record [2], because calcareous brachiopods of this age have all so far been demonstrably diagenetically overprinted and phosphatic euconodonts are not known below uppermost Cambrian strata. The biogenic $\delta^{18}O$ record is the most widely used deep-time palaeothermometer, but a new $\delta^{18}O$ source is needed if we are to apply this proxy to the Cambrian Period.

2. Materials and Preservation

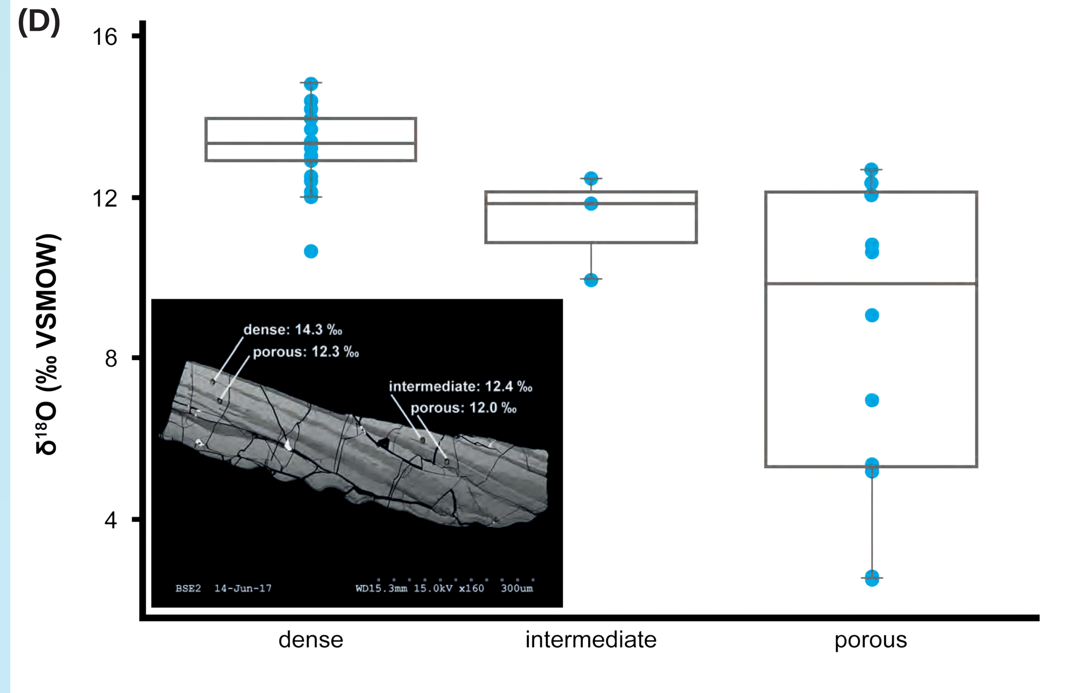


We investigated phosphatic small shelly fossils (SSFs), skeletal elements of some of the earliest earlbiomineralizing animals, from the Comley Limestones (Cambrian Stage 3/4, UK) to determine their potential as repositories of palaeo-environmental $\delta^{18}O$ data. We used optical (OM) and scanning electron (SEM) microscopy, with energy-dispersive X-ray spectroscopy (EDX) to examine SSF preservation. A subset of pristine SSFs was identified, preserving biological microstructure and ultrastructure. In phosphatic brachiopods, this means alternating compact and porous shell laminae, with the compact laminae comprising nanometer-scale mosaics of phosphatic spherules (A). EDX analysis shows that elements indicative of alteration, particularly Fe, are found only in the porous laminae of pristine specimens (B). Conversely, specimens identified by OM as diagenetically altered show prismatic micron-scale recrystallisation and infiltration of alteration elements (e.g. Fe) into the compact laminae.

3. Cambrian oxygen isotopes

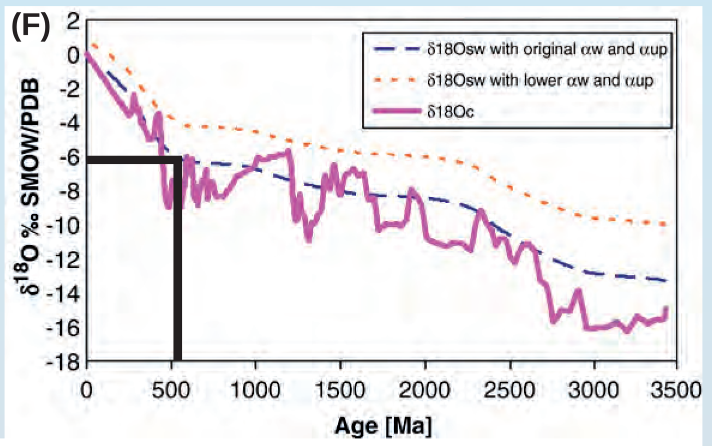


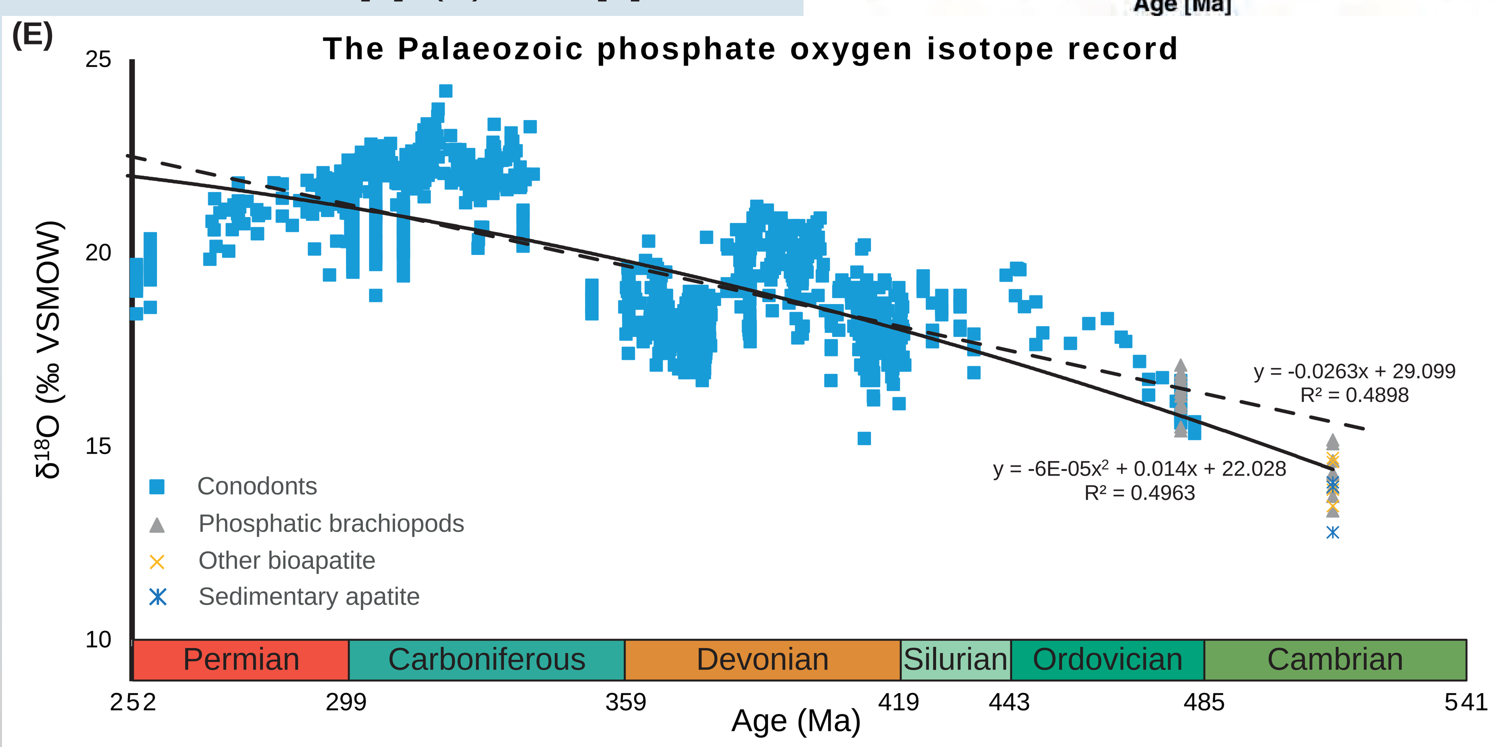
Bulk (trisilver phosphate) $\delta^{18}O$ data from specimens identified *a priori* as pristine were consistently heavier than diagenetically altered specimens from the same sample (C). SIMS (ion microprobe) $\delta^{18}O$ analyses also found that densely phosphatic brachiopod compact laminae were consistently heavier than porous laminae (D). Because the bulk $\delta^{18}O$ values approximate those of the dense laminae, it is likely that the dense laminae contribute most of the bulk signal.



4. Isotopic composition of Cambrian seas

An estimate of the isotopic composition of local sea water ($\delta^{18}O_{SW}$) is needed to convert measured $\delta^{18}O$ into sea temperature. Both data (E) and modelling (F) work support a secular trend in $\delta^{18}O$ of up to -1 ‰ per million years over the Palaeozoic Era. We use a modelled value of -6 ‰ [4] for global ocean $\delta^{18}O$. We also account for an additional -0.5 ‰ due to latitudinal precipitation/evaporation effects [5] at 65 – 70 °S [6]. We therefore use a local $\delta^{18}O_{SW}$ value of -6.5 ‰. (E) compiled from references in [2]; (E) after [4].



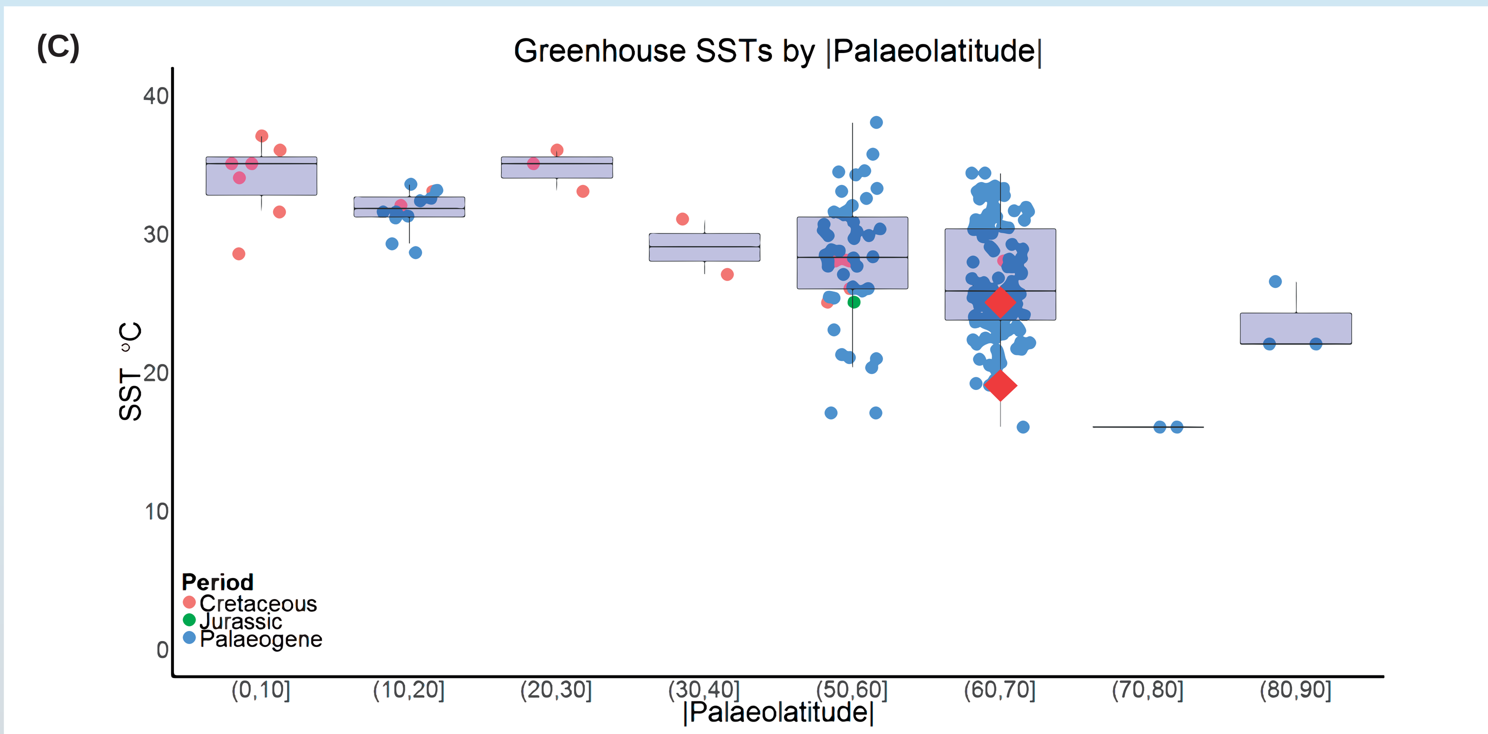


5. Cambrian ocean temperature

Pristine $\delta^{18}O_{phos}$ = 13.9 – 15.2 ‰ Cambrian $\delta^{18}O_{SW}$ = -6.5 ‰

[7] $T\,(°C) = (117.4 \pm 9.5) - (4.50 \pm 0.43)*(\delta^{18}O_{phos} - \delta^{18}O_{SW})$

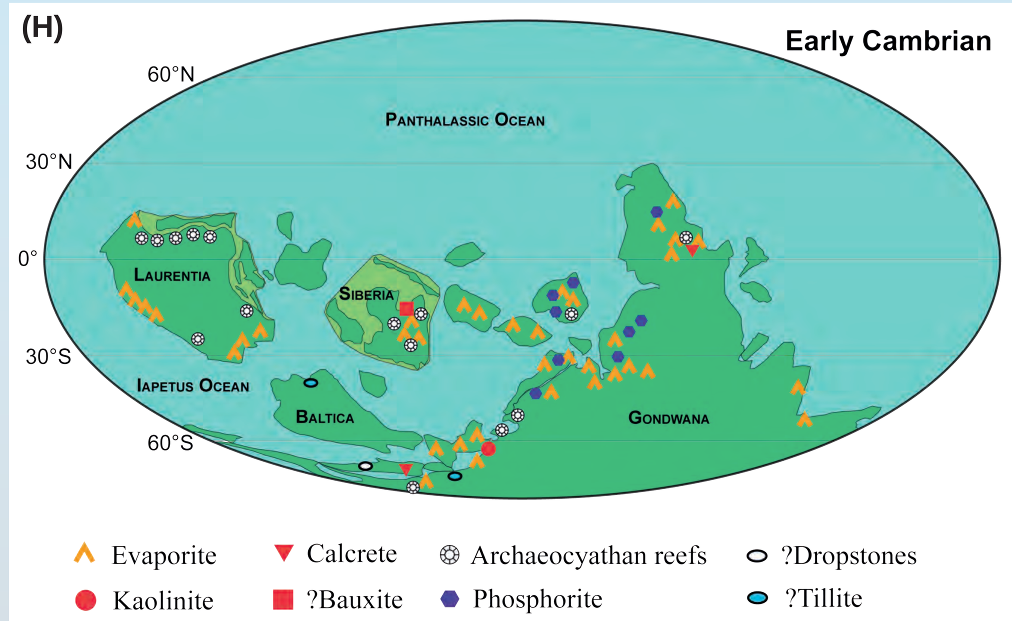
T = 19 – 25 °C



Sea surface temperatures (SSTs) of 19 – 25 °C at 65 – 70 °S fall within the typical range of more recent greenhouse climate states (G; our data = red rhombs). Palaeozoic $\delta^{18}O$ studies commonly assume $\delta^{18}O_{SW}$ = -1 ‰. This has led to unfeasible Ordovician temperature estimates [8] and would increase our temperature estimates by ca. 25 °C. However, accounting for $\delta^{18}O_{SW}$ secular variation has been shown to improve Palaeozoic data – model agreement [9].

6. Cambrian climates

Geological evidence generally supports a greenhouse climate state during the Cambrian Period (H) [but see 10]. Rocks characteristic of warm environments were deposited over a wide palaeolatitudinal range in the early Cambrian, signifying a shallow latitudinal temperature gradient. Our new $\delta^{18}O$ data support a Mesozoic- or early Cenozoic-style greenhouse climate state during the early Cambrian when the first animal-rich ecosystems were evolving.



Acknowledgements

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[1] **Erwin, D. H. & Valentine, J. W., 2013**: *The Cambrian Explosion, Roberts & Co.* [2] **Grossman, E. L. 2012**: *in* Gradstein F. M., et al., *The Geologic Timescale*, 181–206. [3] **Harvey T. H. P. et al., 2011**: *J. Geol. Soc.* 168, 705–716. [4] **Jaffrés, J. et al., 2007**: *ESR.* 83(1–2), 83–122. [5] **Tindall, J. et al., 2010**: *EPSL.* 292(3), 265–273. [6] **Torsvik T. H. & Cocks, L. R. M., 2013**: *Geol. Soc. Lond. Mem.* 38(1), 5–24. [7] **Lécuyer, C. et al., 2013**: *Chem. Geol.* 347, 217–226. [8] **Trotter, J. A. et al., 2008**: *Science* 321(5888), 550–554. [9] **Nardin, E. et al., 2011**: *GSA Bull.* B30364.1. [10] **Landing, E. & MacGabhann, B. A., 2010**: *Palaeogeog. Palaeoclim. Palaeoecol.* 285(3–4) 174–185.