A Synthesis of Cambrian Phosphatocopid Distribution Patterns

The Leverhulme Trust

Rhicert William Reynolds[1*], Thomas W. Wong Hearing[2*], Mark Williams[2], Thomas H.P. Harvey[2], Ayari Yanagihara[2,3], Duncan J.E. Murdock[4], John E. Repetski[5], James D. Loch[6], Daniel J. Lunt[7] and Neil J. Gostling[8]

[1]University of Plymouth, UK; [2]University of Leicester, UK; [3]Kumamoto University, Japan; [4]Oxford University Museum of Natural History, UK; [5]United States Geological Survey, USA; [6]University of Central Missouri, USA; [7]University of Bristol, UK; [8]University of Southampton, UK. ***rhicert.reynolds@plymouth.ac.uk; twonghearing@gmail.com**

University of Plymouth, School of Geography, Earth and Environmental Sciences

University of Leicester

1. Introduction. We analyse the distribution patterns of phosphatocopids (**Fig. 1**), which are tiny (mm-scale) arthropods that lived in marine habitats worldwide from ~521 to 487 Ma (**Fig. 2**). Our dataset *[see 1]* includes 101 occurrences comprising 75 taxa (26 genera), distributed across nine palaeo-continental areas including Avalonia, Baltica, Gondwana, Laurentia, Siberia, South China and central Asian terranes (**Figs. 2 & 3**). Here we consider potential oceanographic controls on the spatial distribution of phosphatocopids, including sea temperature and oxygenation.

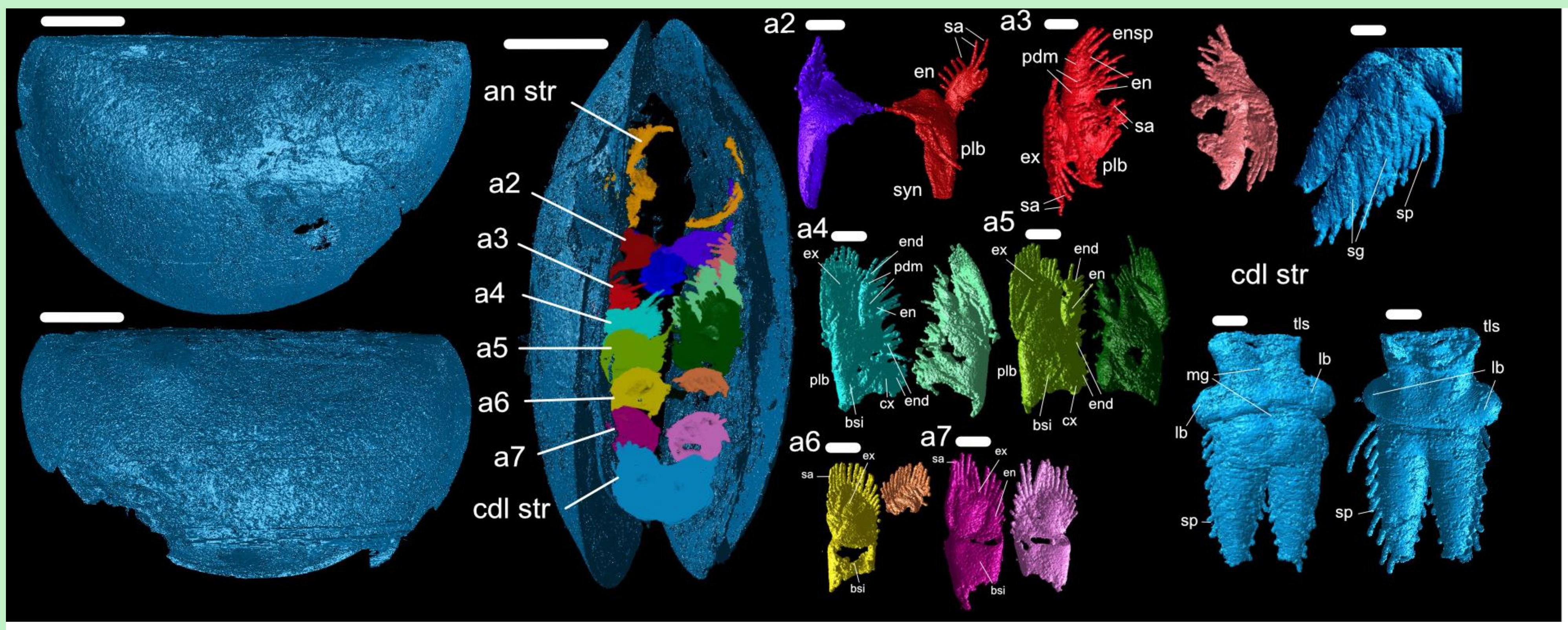


Figure 1. Morphology and anatomy of a typical Cambrian phosphatocopid, the species *Planamandibulus nevadensis [1]*. Virtual reconstructions of carapace with soft parts. **a2**: antenna; **a3**: mandibles; **a4**, **a5**, **a6**, **a7**: post-mandibular limbs. Abbreviations: **an str** = anterior structure; **cdl str** = caudal structure; **en** = endopod; **syn** = syncoxa; **plb** = proximal limb branch; **sa** = setae; **ensp** = endopodal spines; **ex** = exopod; **bsi** = basipod; **pdm** = podomeres; **end** = endite; **cx** = coxa; **tls** = telson; **mg** = medial groove; **lb** = lateral bulge ; **sg** = segment; **sp** = spine. Scale bars: whole animal (left) = 100 µm; individual limbs (right) = 50 µm.

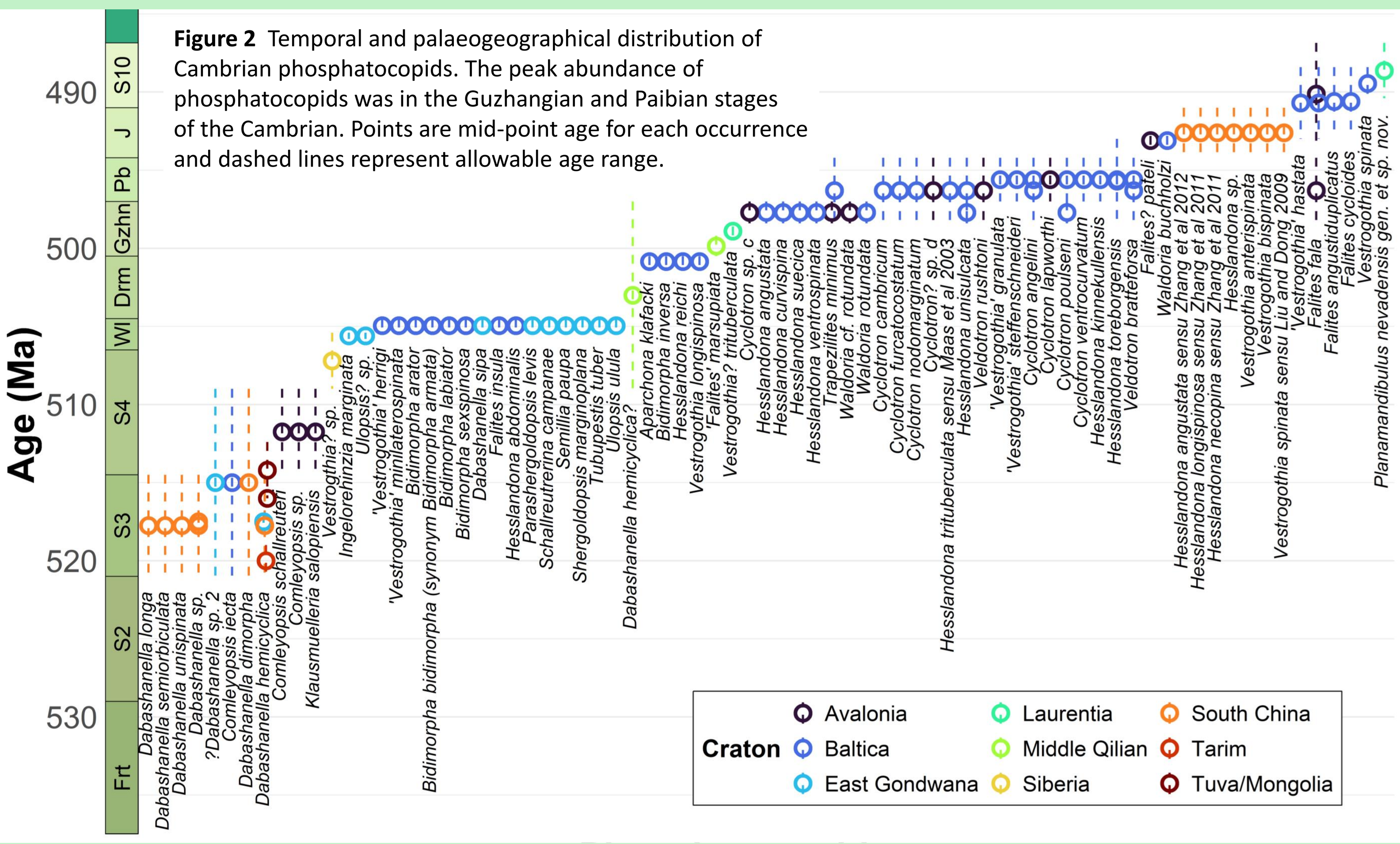
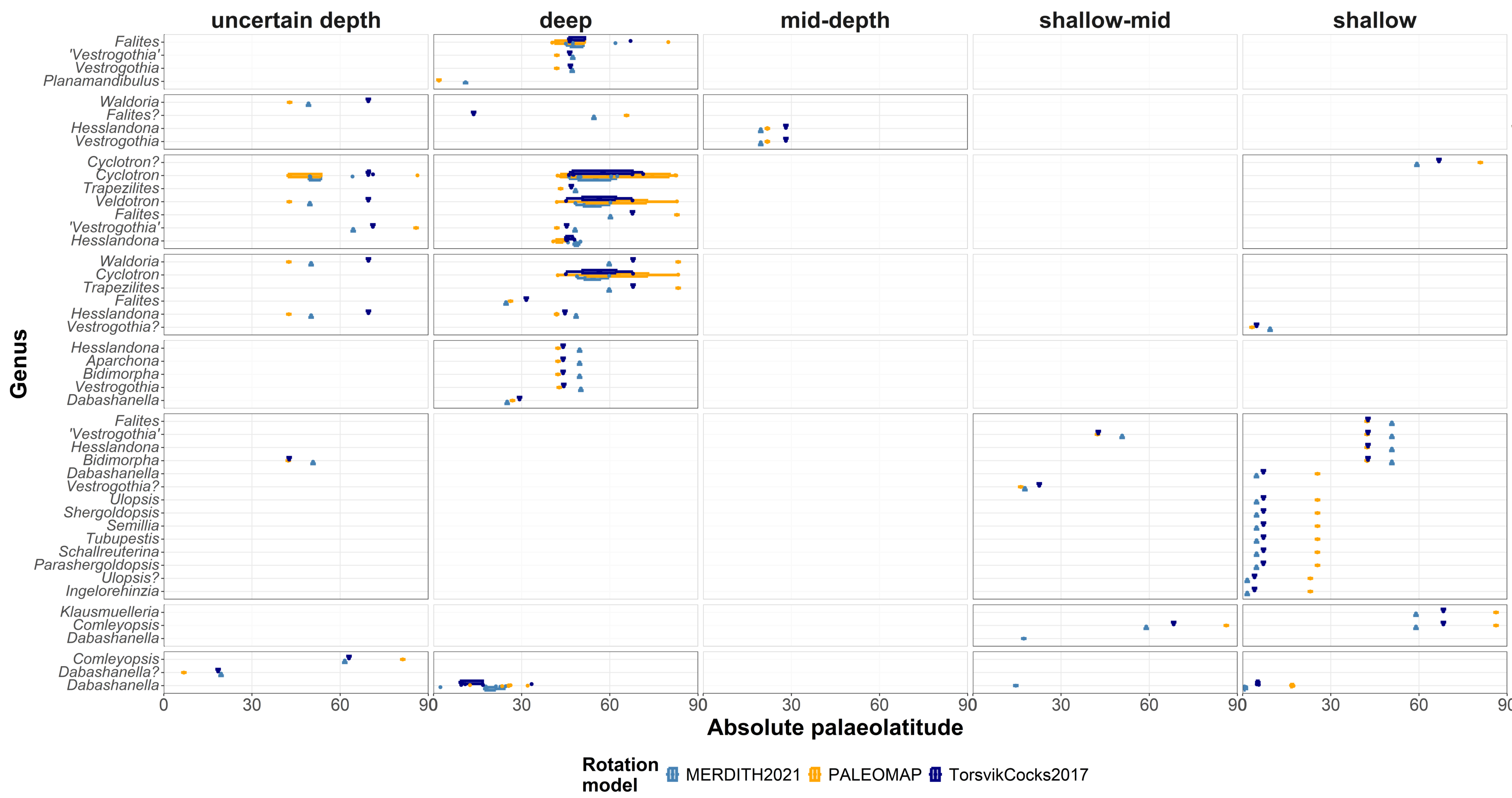


Figure 2 Temporal and palaeogeographical distribution of Cambrian phosphatocopids. The peak abundance of phosphatocopids was in the Guzhangian and Paibian stages of the Cambrian. Points are mid-point age for each occurrence and dashed lines represent allowable age range.

2. Spatial analysis. At the genus level, most taxa are found at either low (<30 °N/S) or mid- to high (>45 °N/S) palaeolatitudes (**Fig. 3**). *Hesslandona* and *Vestrogothia* are exceptions which span low to mid-palaeolatitudes. There is a temporal trend in palaeolatitude throughout the Cambrian, with a lower palaeolatitude dominance in Stage 3 and the Wuliuan Stage changing to a mid- to high palaeolatitude dominance from the Guzhangian (**Fig. 3**). There is also a temporal trend in water depth preference, with a shallower water dominance in Stage 3 to the Wuliuan changing to a deeper water dominance from the Drumian (**Fig. 3**). Phosphatocopids commonly, though do not exclusively, occur in facies indicative of low environmental oxygen levels (**Fig. 3**). In total 60 % of occurrences are from settings indicative of low oxygen concentration, with only 15 % from settings that are unlikely to be characterized as low-oxygen.



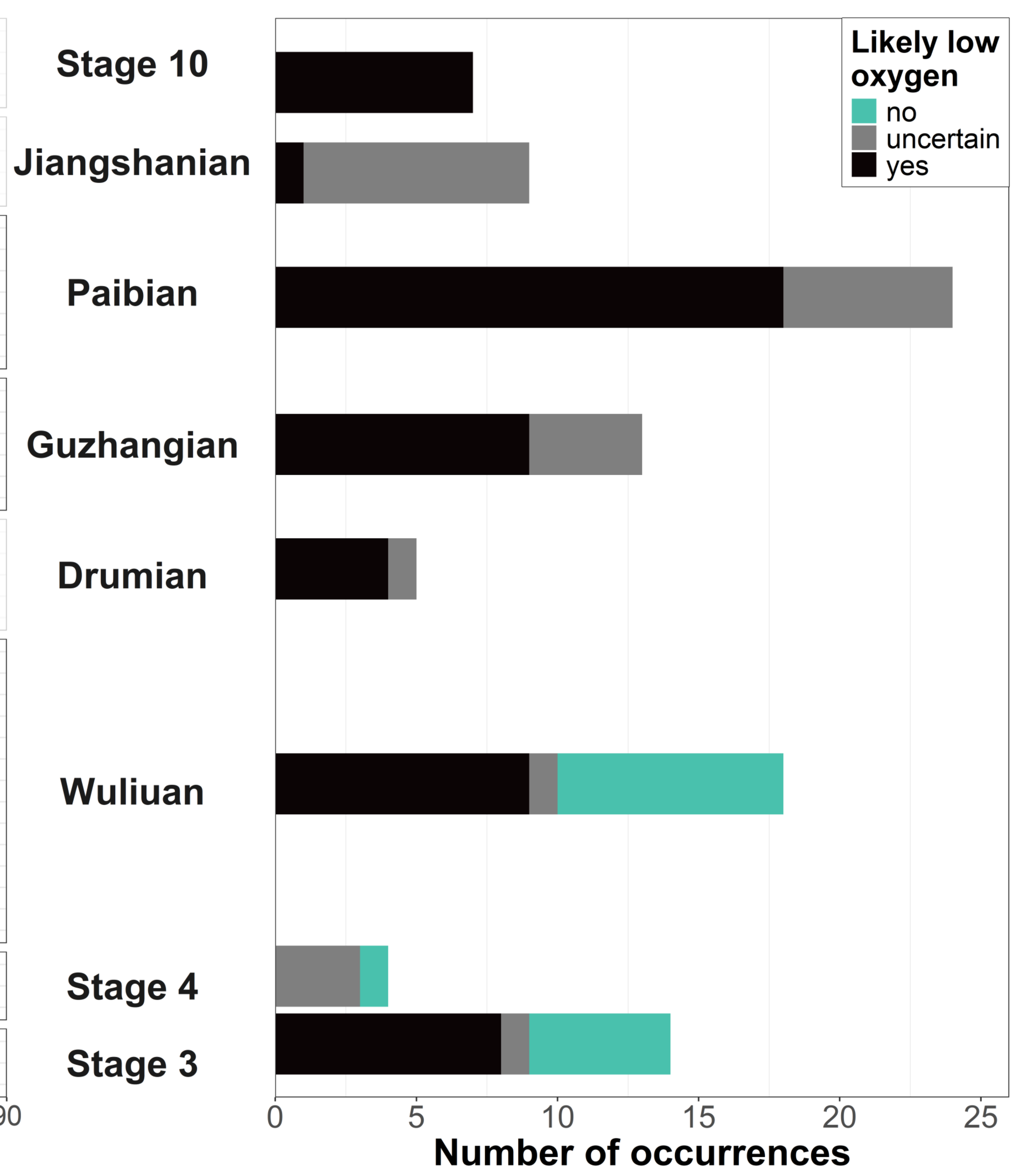
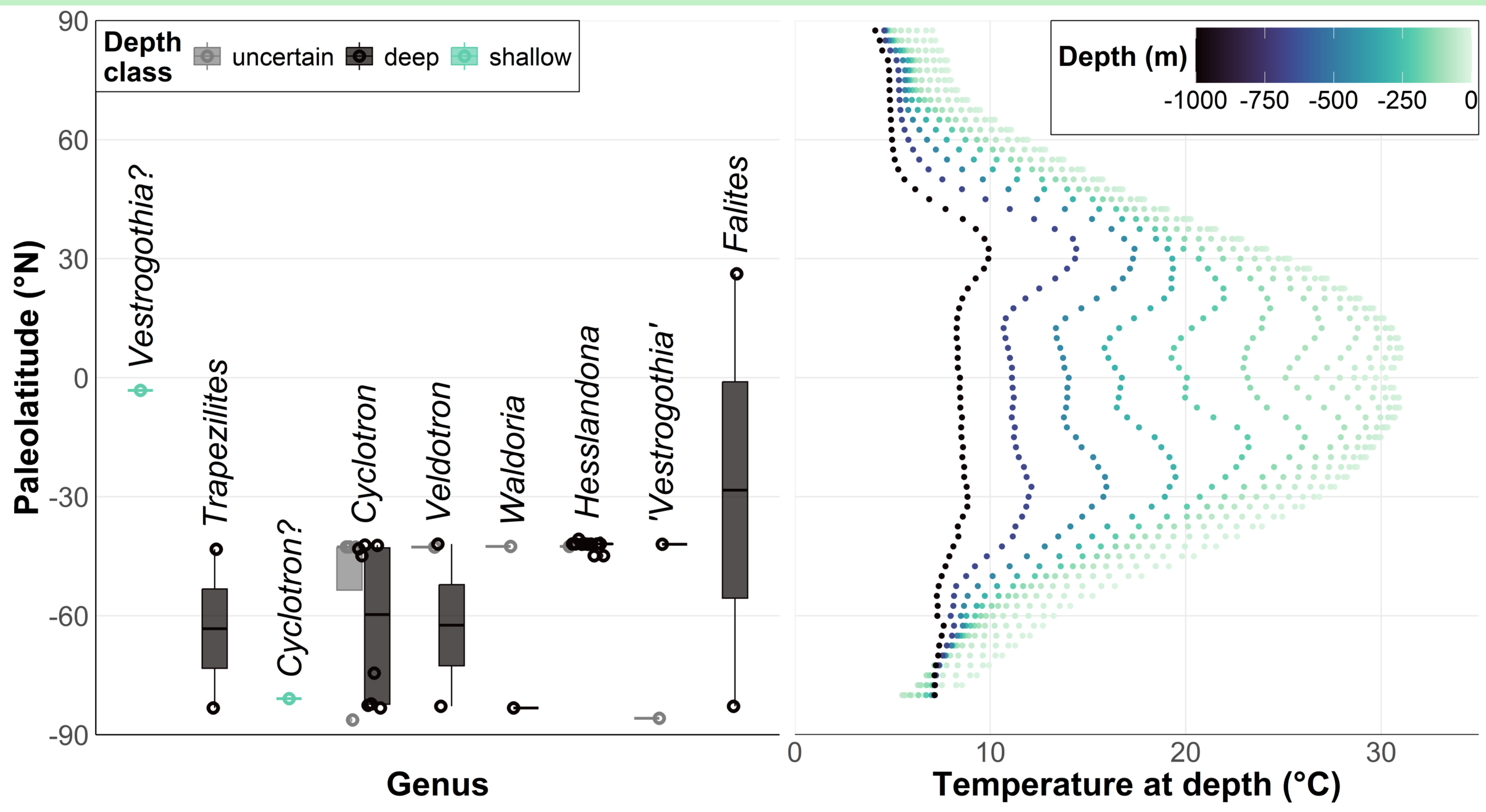


Figure 3. **Left:** Point and boxplots showing the distribution of phosphatocopid genera (y-axis) by palaeolatitude (x-axis), water depth (x-facets), and chronostratigraphic stage (y-facets), on three different hypotheses of plate rotation (colour). Empty facets (i.e. water depth-stage combinations with no occurrences) are faded out. Rotation models: MERDITH2021 *[2]*; PALEOMAP *[3]*; TorsvikCocks2017 *[4]*. Rotations calculated using *rgplates [5]*. There is a general division between shallower water + lower palaeolatitude occurrences before the Drumian and deeper water + higher palaeolatitude occurrences after the Drumian. Note that Stage 10 occurrences span low to high palaeolatitudes in deep water settings.

Right: Number of occurrences by Cambrian stage and identified marine oxygenation conditions (colour) based on their geological context. Most occurrences (60 %) are from likely low-oxygen settings; 15 % are from settings identified as unlikely to be low-oxygen; 25 % are from settings with uncertain oxygenation state. Stage 3 to Wuliuan occurrences are from both well-oxygenated and low-oxygen settings. Drumian to Stage 10 occurrences are from uncertain or low oxygen settings.



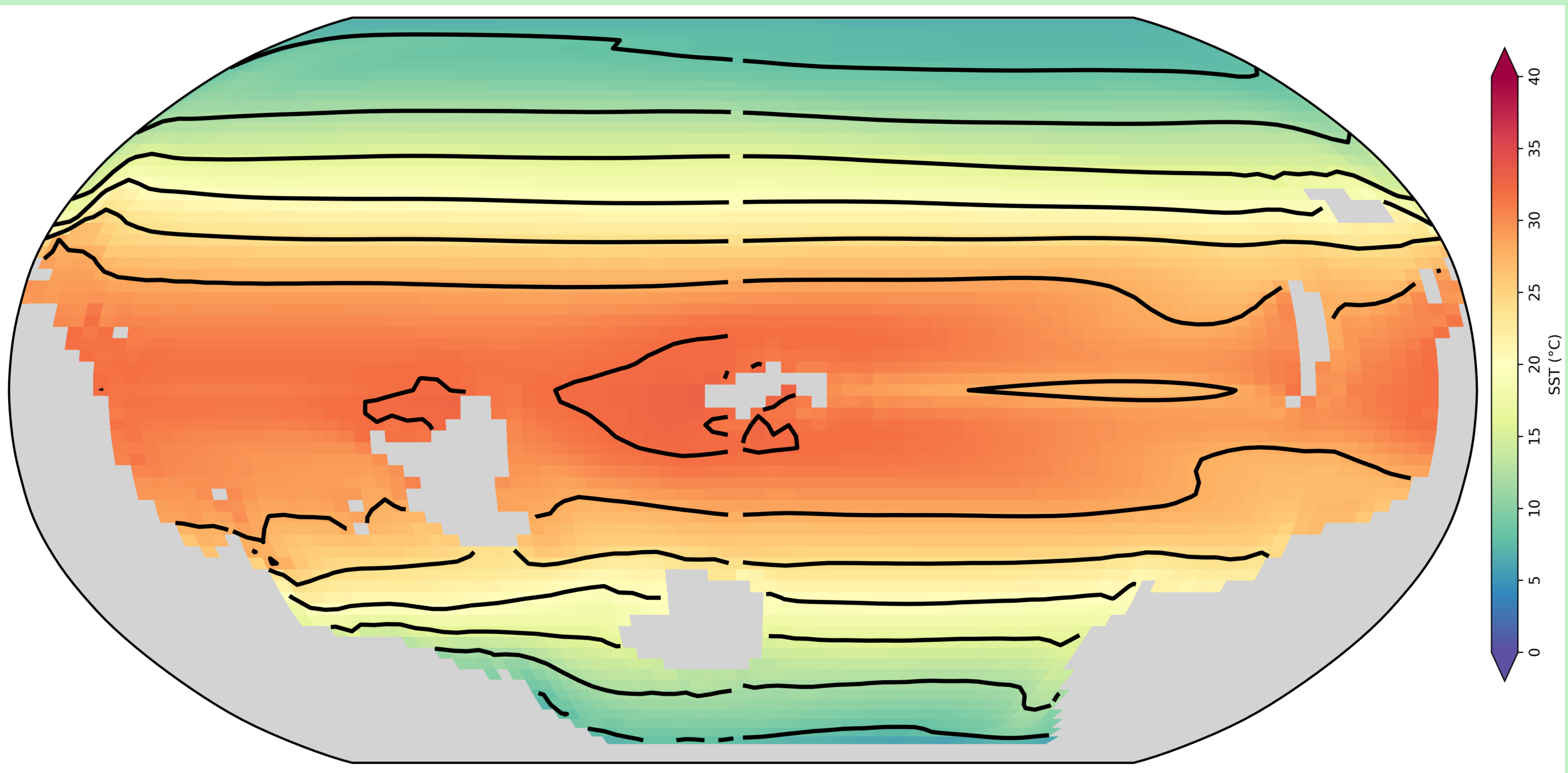


Figure 4. Left: Comparison between Guzhangian + Paibian phosphatocopid occurrences and modelled zonal average sea temperatures with depth (see *[6]*). There are no 'shallow-mid' or 'mid-depth' depth occurrences for the Guzhangian or Paibian. Colours represent water depth categories.

Right: Modelled sea surface temperatures from the HadCM3L 'tfks' series (see *[6]*) at 500 Ma on the PALEOMAP *[3]* continental configuration.

3. Two clear patterns emerge that suggest phosphatocopids are useful markers of temperature and oxygenation patterns in Cambrian seas. (1) Ocean temperature. *Dabashanella* (e.g., *D. hemicyclica*) are found across low palaeolatitude (<35 ° N/S) regions (East Gondwana [Australia], South China, central Asian terranes), but are absent from mid- and high palaeolatitudes, suggesting a warmer water preference (>20 °C). Similarly, a warm-water preference is inferred for endemic taxa of East Gondwana (e.g., *Ulopsis*, *Parashergoldopsis*). In contrast, the mid- to high palaeolatitude Baltica and Avalonia are characterized by *Veldotron*, *Cyclotron*, *Bidimorpha*, *Waldoria*, *Vestrogothia*, *Falites* and *Trapezilites* species which occur in deep shelf, cooler water settings. *Hesslandona* species occur in mid-depth (likely above storm wave base) tropical marine waters (>20 °C) but are typically found in the cooler waters of deeper shelf and mid- to high palaeolatitude (>35 °N/S) settings. **(2) Dysoxic conditions.** As well as individual occurrence data (**Fig. 3**), phosphatocopid occurrences peak around the Guzhangian and Paibian stages. This is the interval of the Steptoean Positive Carbon Isotope Excursion (SPICE) which is associated with the expansion of anoxic water masses onto shallow marine shelves *[e.g. 7]*. Our data compilation and data–model comparison supports the environmental preference of phosphatocopids for low oxygen, but not anoxic water masses.

References. ***[1]*** Reynolds, R.W., et al., *in press. Journal of Paleontology* (doi: 10.1017/jpa.2025.10180).
[2] Merdith A.S., *et al.*, 2021. *Earth-Science Reviews*, 214, e103477 (doi: 10.1016/j.earscirev.2020.103477).
[3] Scotese, C.R., & Wright, N., 2018. *PALEOMAP Project*.
[4] Torsvik T.H., & Cocks L.R.M., 2016. *Earth History and Palaeogeography.* Cambridge University Press.
[5] Kocsis, A.T., *et al.*, 2024. *rgplates*: R Interface for the GPlates Web Service and Desktop Application (doi: 10.5281/zenodo.13711982).
[6] Judd, E.J., *et al.*, 2024. *Science*, 385, eadk3705, (doi: 10.1126/science.adk3705).
[7] Saltzman, M.R., *et al.*, 2000. *Palaeogeography, Palaeoclimatology, Palaeoecology* 162, 211–223 (doi: 10.1016/S0031-0182(00)00128-0).