Supplementary Information for

A high-resolution record of early Paleozoic climate

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This PDF file includes:
Figs. S1 to S8
Legends for Dataset S1 to S3
SI References

Other supplementary materials for this manuscript include the following:
Datasets S1 to S3
SI Dataset S1 (Dataset_S1.xlsx)
Clumped isotope replicate measurements for Svalbard samples.

SI Dataset S2 (Dataset_S2.xlsx)
Clumped isotope replicate measurements for Newfoundland samples.

SI Dataset S3 (Dataset_S3.xlsx)
Clumped isotope replicate measurements for brachiopod samples.

References
Fig. S1. Generalized stratigraphy and bulk and clumped isotopic measurements of Svalbard section. Stratigraphy adapted from (1). Symbol indicates mineralogy (see legend). Small black points are bulk isotope data from the same sections analyzed by (1). Error bars for clumped isotope measurements are standard error of multiple replicates. Error bars are not shown for bulk isotope measurements, but would be smaller than the symbols. A: Mineral δ13C. B: Mineral δ18O. C: Temperature calculated from Δ47 (closed symbols) and from bulk δ18O (open symbols). D: Fluid composition calculated from mineral δ18O and clumped isotope temperature.
Fig. S2. Generalized stratigraphy and bulk and clumped isotopic measurements of Newfoundland samples. Stratigraphy adapted from (2–4). Symbol indicates mineralogy (see legend). Small black points are bulk isotope data from the same succession analyzed by (5, 6). Error bars for clumped isotope measurements are standard error of multiple replicates. Error bars are not shown for bulk isotope measurements, but would be smaller than the symbols. A: Mineral $\delta^{13}$C. B: Mineral $\delta^{18}$O. C: Temperature calculated from $\Delta_{47}$ (closed symbols) and from bulk $\delta^{18}$O (open symbols). D: Fluid composition calculated from mineral $\delta^{18}$O and clumped isotope temperature. Abbreviations: CA - Cape Ann Member, BiC - Big Cove Member, MOW - Man o’ War Member, BaC - Barbase Cove Member, PH - Pigeon Head Member, PT - Pine Tree Member, CB - Costa Bay Member, Sl - Spring Inlet Member, CC - Cape Cormorant Formation, TC - Table Cove Formation.
Fig. S3. Bulk and clumped isotopic measurements of brachiopod samples, colored by location (see Figure 1) and labeled at bottom with preservation score (see methods) and at top with age. A: Mineral $\delta^{13}$C. B: Mineral $\delta^{18}$O. C: Temperature calculated from $\Delta_{47}$ (closed symbols) and from bulk $\delta^{18}$O (open symbols). D: Fluid composition calculated from mineral $\delta^{18}$O and clumped isotope temperature.
Fig. S4. (includes previous page) Oxygen isotope data ($\delta^{18}O$) plotted against time for each locality (see methods for data sources). Points are individual measurements, colored line and shaded region are moving median ±1 SD (see methods), and black line is global average of all locations. Larger outlined circles show $\delta^{18}O$ from our clumped-isotope measurements in Newfoundland and Svalbard. Outlined triangles are brachiopod data, where available. The dark brown dataset (Sweden) and the India dataset are omitted from global analysis (see Materials and Methods).
Fig. S5. Comparison matrix of regional $\delta^{18}O$ time series, using the 1 Myr moving median. Plots along the diagonal are histograms of each location. The scatterplots below the diagonal are scatterplots of two locations’ records, colored by age (see colorbar below). Entries above the diagonal give the Pearson correlation coefficient (R), statistical significance (p), and the number of overlapping timebins available for comparison (n). The color of the circle scales with the R value (blue for negative, red for positive), and the size with the p value. Empty entries indicate no overlap between two records.
Fig. S6. Global carbon and oxygen stable isotope records. Data are colored by location, as in Figure 1. Colored lines show the moving median from each location, with shaded regions indicating ± 1 SD. Triangles are brachiopod data from (7, 8); diamonds are conodont apatite data from (9–11). Carbonate data (bulk rock and brachiopod) are plotted on the left axis on the VPDB scale; apatite data (conodont) are plotted on the right axis on the VSMOW scale. The two axes are aligned such that calcite and apatite precipitated from the same seawater at the same temperature will coincide (see Materials and Methods for fractionation relations). Black triangles are brachiopod data without reported location information.
Fig. S7. Time-dependent seawater composition used for temperature calculations, due to ice-volume effects. Curve constructed using clumped isotope constraints from (7, 12). Dashed line shows constant seawater composition (-1.4 ‰).
Fig. S8. A. Red line shows the average of regional medians. Shaded regions denote the average of the deciles for each regional temperature record, showing the spread of the underlying data. Oxygen isotope composition on the right axis is for ice-free conditions (before 458 Ma); temperatures are calculated using time-dependent seawater composition after 458 Ma (see Figure S7). B. Same as A, but using constant seawater composition after 458 Ma.