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Supplementary information

Manuscript: Changes in Latitudinal Diversity Gradient during the Great Ordovician Biodiversification Event

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Additional information on Data and Methods

PaleoBioDB collection data are attributed lithology and environment classes, which are used herein for estimating the relative number of carbonate/siliciclastic and shallow/deep collections. Carbonate depositional environment are all collections with primarily carbonate lithologies, siliciclastic environments include sandstone and siltstone, as well as e.g. ashes and slates. Shallow environments are all environments from shoreface and lagoonal, to shoal, and deep environments are collection classified as, e.g. offshore, shelf, slope or ramp. For estimation of environmental and lithological heterogeneity I used the PaleoBioDB primary lithology data and environment data on collections and excluded all collections with environment classes “marine indet.”, “terrestrial indet.” and “not reported. This resulted in 36 classes for the environment and 41 classes for primary lithology and a total of 23862, and 18581 classified collections respectively.

For comparison of the qualitative variation of occurrence environment and lithology I used the HRel index (Wilcox, 1973). HRel is an index of qualitative variation based on the Shannon entropy (H) and the number of classes (herein, environmental classes), similar to the Shannon evenness of ecology. HRel can be directly compared with the Shannon (or Pielou) evenness (see e.g. Magurran, 2004), where ln is used instead of $\log_2$ for the calculation and the number of classes is represented by the number of species or genera.

All estimates presented in this study have been calculated and generated with R statistical software. The HRel statistic was estimated using the Package qualvqr version 0.1.0 (https://cran.r-project.org/web/packages/qualvar/qualvar.pdf). The Shareholder Quorum Subsampling (Alroy, 2010) (herein: D_{SQS}), was calculated using Alroys R function version 3.3 (http://bio.mq.edu.au/~jalroy/SQS-3-3.R) and the Shannon Entropy Hill number (Jost, 2007; Chao et al., 2014) (herein D_{Chao}) was calculated using the R Package iNext version 2.0.12 (Hsieh et al., 2016).

The capture-mark-recapture approach (CMR) herein was used for diversity estimation. The method was transferred from ecology data to fossil data following suggestions from Liow and Nichols (2010), assuming that each genus is equivalent to a captured and recaptured organism, and that the total genus number is equivalent to the size of the population. A presence-absence matrix was constructed based on the PaleoBioDB genus occurrences for chronostratigraphic stages and Bergström et al. (2009) stage slices. This matrix served for the fitting of an explicit model for diversity estimation with time varying probabilities of survival, sampling/preservation, and origination. In this case I fitted the Jolly-Seber model following the POPAN formulation, also known as the "superpopulation approach" (Schwarz and Arnason, 1996) (herein: D_{CMR}). The CMR diversity estimates have been calculated with the program MARK (http://www.phidot.org/software/mark/) and the R Package RMark version 2.2 (Laake, 2013). The code is available for download under https://doi.org/10.5281/zenodo.197057.

Additional information on Results

The different diversity measures applied herein result in principally similar trends with most intense diversifications during the Middle Ordovician and in low latitudes (Fig. DR1). The diversity trends can be reproduced for subsets of different clades, such as brachiopods and mollusks (Fig. DR2). However, differences among clades occur. The low latitude diversification of graptolites took place earlier (during the Floian) and a strong high latitude diversification pulse is apparent in Middle Ordovician graptolites (Fig. DR3). This pattern is in general agreement to earlier estimations of graptolite diversity along paleolatitudes (Cooper et al. 2004).

The diversity estimates can be diagrammatically represented as trends per latitudinal zone (Fig. 2), and alternatively as gradients across latitudinal zones per time interval. Both representations have benefits and drawbacks depending on the context. Here, the latter representation is chosen (Fig. DR4) in order to emphasize the change in the LDG pattern through time. This change is most dramatic from Early to Middle Ordovician.

Although the Ordovician diversity trends over time are generally paralleled by sampling probabilities with peak values in Late Ordovician (Fig. DR5), the individual sampling probability trends per latitudinal zones do not reflect the diversity estimates (Fig. DR6).

The latitudinal changes in diversity over time do not reflect changes in environmental heterogeneity (Fig. DR7). Environmental heterogeneity, expressed as HRel statistics, herein, is generally not higher in the tropics and no significant Middle Ordovician increase in heterogeneity can be detected (Fig. DR5).

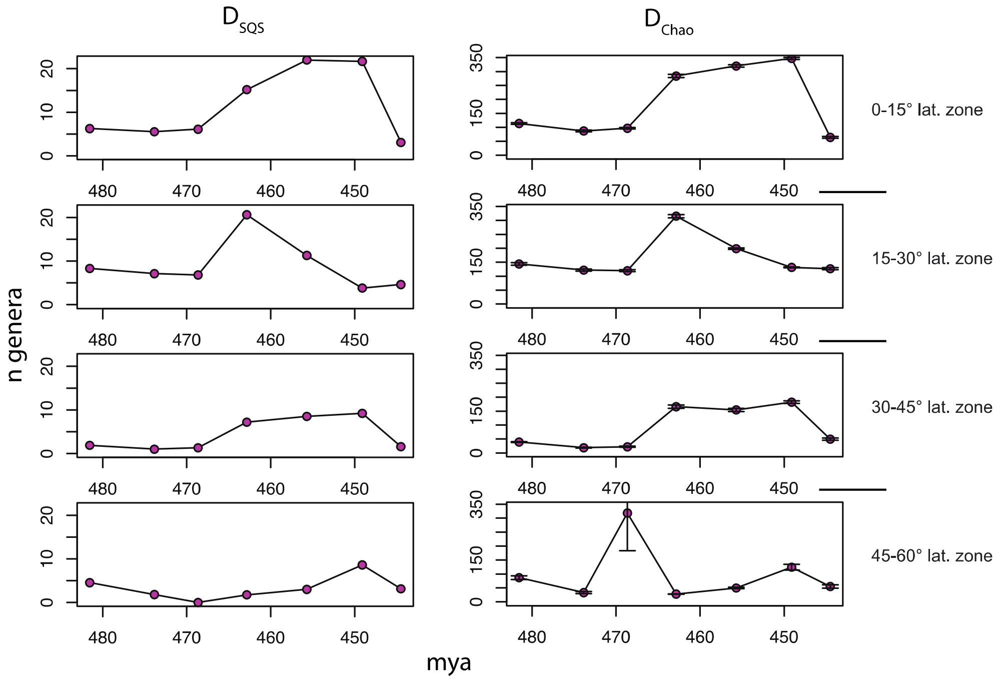


Figure DR1. Ordovician diversity trends of D_{SQS} and D_{Chao} within four paleolatitudinal zones. Note the relatively high degree of similarity between the curves, especially for low latitudes. Note also the high degree of similarity with D_{CMR} (compare with Fig. 2). D_{Chao} with 95% confidence intervals.

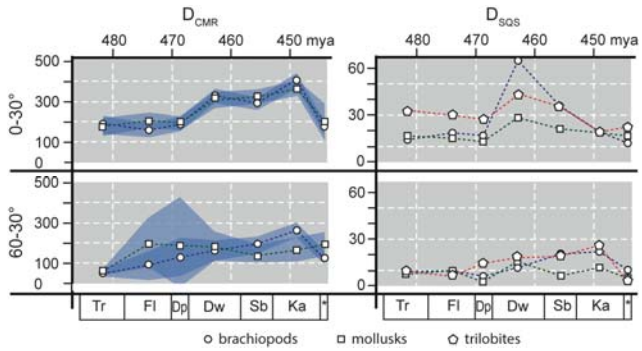


Figure DR2. Subsets of Ordovician diversity trends of D_{SQS} and D_{Chao} for different clades. D_{CMR} with 95% confidence intervals, shaded areas.

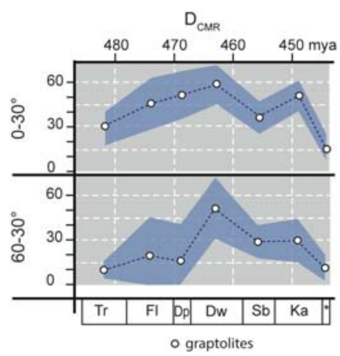


Figure DR3. Subsets of Ordovician diversity trends of D_{SQS} for graptolites. D_{CMR} with 95% confidence intervals, shaded areas.

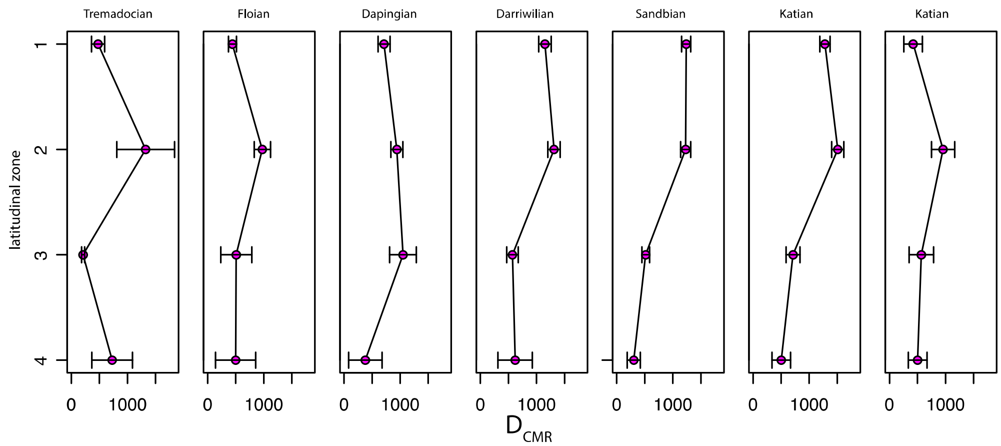


Figure DR4. Latitudinal diversity gradients (northern and southern hemisphere combined) for Ordovician chronostratigraphic stages. Latitudinal zones are: 1, 0-15°; 2, 25-30°; 3, 30-45°; 45-60°. With 95% confidence intervals, shaded areas.

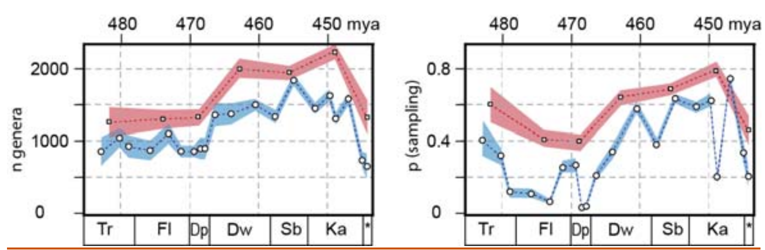


Figure DR5. Global genus-level diversity (D_{CMR}) trends for the Ordovician Period with stratigraphic resolution at stage level and stage slice level (Bergström et al., 2009), compared with sampling probabilities ($p_{(sampling)}$), with 95% confidence intervals (shaded areas). Stages: Tr, Tremadocian; Fl, Floian; Dp, Dapingian; Dw, Darriwilian; Sb, Sandbian; Ka, Katian, * Hirnantian.

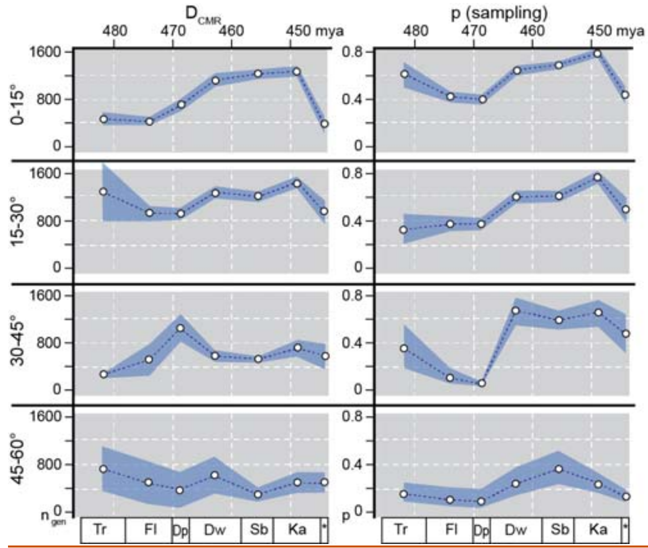
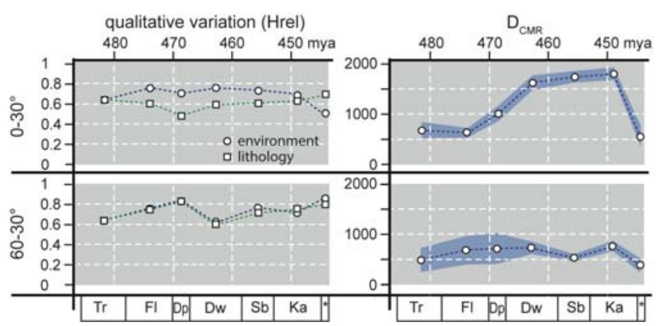


Figure DR6. Diversity trends (D_{CMR}) of each latitudinal zone compared with respective sampling probabilities ($p_{(sampling)}$), with 95% confidence intervals (shaded areas). Note the high sampling probabilities during the Late Ordovician. ngen, number of genera; p, sampling probability.



FigureDR7. Trend of qualitative variation (HRel index) of depositional environment (deep, shallow etc.) and lithology (carbonate, sandstone, etc) compared with diversity trends in two different latitudinal zones. D_{CMR} with 95% confidence intervals, shaded areas.

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