SUPPORTING INFORMATION APPENDIX FOR

THE END-DEVONIAN EXTINCTION AND A BOTTLENECK IN THE EARLY EVOLUTION OF MODERN JAWED VERTEBRATES

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I. Detailed Methods

A. Dataset Assembly Procedures

Diversity curves presented in this study are based on data from new comprehensive datasets of genus-level and species-level gnathostome vertebrate occurrences from the Givetian to Serpukhovian stages (391-318 million years ago) of the Devonian and Mississippian periods (Tables S1, S2, S3). This compilation was undertaken to address deficiencies in vertebrate sampling in both Sepkoski's marine dataset (1) and the Paleobiology Database – including lack of non-marine taxa (representing much of known vertebrate material) and undersampling of vertebrate museum collections. Agnathan occurrences are presently excluded due to the relative scarcity of macrofossil material in both the late Devonian and post-Devonian deposits. In the case of conodonts, there is an additional lack of relevant assemblage information and large taxonomic uncertainty related to element assignment. There is also strong indication that they tended to practice rapid within-group replacement after extinction intervals – obscuring any signal in analyses binned by stage or at higher taxonomic levels (1, 2, 3). However, it should be noted that there is recent evidence for acute extinction among conodonts during the Hangenberg event (3). Gnathostome occurrence data was taken from variety of sources in the literature including species descriptions and faunal lists. Genus-level diversity curves were generated from data binned by stage for each of the six traditional gnathostome divisions: Placodermi, Acanthodii, Actinopterygii, limbed Tetrapoda (including elpistostegalians), finned Sarcopterygii, and Chondrichthyes (Fig. 1 and Table S3).

Due to the high susceptibility of diversity curve analyses to sources of sampling bias, including (but not limited to) stage length, Lagerstätten, number of localities (4, 5), the paraphyly of some involved groups, and the limited temporal ranges of most vertebrate species and even genera, the occurrence data were subsampled to produce site-specific species lists for use in ecological analyses (Tables S1 and S2). Only macrofossil sites containing at least five named species in three groups in two divisions were eligible for inclusion in this smaller dataset. In addition, an attempt was made to sample each distinct fauna only once, resulting in the consolidation of taxa from multiple temporally concurrent deposits in the same environment into a single sample of the entire ecosystem (e.g. the Orcadian Lake). This culling of the dataset was performed in order to further circumvent the production of false signal due to poor sampling, unrepresentative preservation, and the taxonomic issues common to microfossil localities.

The aforementioned procedures produced a list of 66 eligible sites, including 11 sites from the Givetian, 14 from the Frasnian, 18 from the Famennian, 5 from the Tournaisian, 11 from the Viséan, and 7 from the Serpukhovian. Localities are referred to by their most common name, usually that of a nearby settlement or attraction (e.g. East Kirkton, Bearsden). The name of the formation or other geological trait is used when collections from multiple contemporaneous outcrops contain similar assemblages (e.g. Cleveland Shale), temporally, environmentally, and/or compositionally distinct assemblages are known from a single site (e.g. Rodebjerg, Aina Dal, and Britta Dal in East Greenland), or when no other name is available (e.g. Herbesskaya, Aztec).

Sites are widespread geographically (Fig. S1, Table S1) - although there is an overrepresentation of Euramerican ecosystems for historical reasons (e.g. proximity to workers and financial means) (6). However, this bias is consistent throughout the dataset (7), and visualization procedures, as explained below, should be able to differentiate between turnover signal stemming from geographic sampling and real faunal change. The chosen localities are all primarily aquatic, representing a variety of environments both marine and non-marine (defined here as having any freshwater influence, including marginal marine, brackish and estuarine localities). A bias towards the non-marine was noted for every stage except the Frasnian (Fig. S1 and Table S1). Site diversity ranges from 6 to 82 species, with a mean species count of 19.27 (SD: 13.01) for all sites, and a median of 15.00 (Table S4) – producing a left-skewed distribution with a long right tail representing Lagerstätten (Fig. S2). Analyses were run using both raw species counts and as well as counts converted to relative percentage of the overall faunal diversity. The latter was done in order to check sample size bias without the loss of signal expected to attend the exclusion of lagerstatten. Shannon-Weiner index values – the negative of the sum of the proportion of samples containing a species multiplied by the natural log of that proportion (8) – were calculated to measure the diversity at all sites (Table S4) along with taxonomic richness, which is a merely a count of occupied bins.

As demanded by the ecological analyses performed here, the sub-sampled data was arranged into matrix in which sites served as samples and species counts in taxonomic bins acting as variables (5). These bins represent major gnathostome clades and/or well-differentiated groups extant by the Frasnian. This binning scheme is preferable to the use of single taxonomic levels (such as families, genera, species) due to the high disagreement between classification schemes and usage among gnathostome groups, localities, and even workers. The validity of some well-known vertebrate divisions (e. g. Acanthodii, Placodermi) has recently come under fire due to potential paraphyly (9). While their higher-level standing is problematic, many of their lower-level taxonomic groups might be phylogenetically valid and monophyletic (e.g. Antiarcha and Arthrodira in Placodermi; Gyracanthida and Acanthodida in Acanthodii). Many of the remaining taxonomically problematic groups show enough morphological and/or ecological distinction in the Frasnian to warrant treatment as separate entities capable of responding independently to extinction or turnover. In addition, most of the groups diverged before the first event of interest. Use of these groups represents a conservative approach to measuring extinction – pseudoextinction is avoided but extinction with prompt replacement within divisions goes undetected. Only a high magnitude extinction event involving mostly monophyletic groups will show up in the results.

It should be noted here that it is common in ecological studies to use abundances rather than taxon counts, so as to prevent undue contribution from rare taxa (5). Unfortunately, few vertebrate sites have been subjected to abundance surveys (10), even though there is anecdotal evidence for the composition of many of them. The most likely effect of using diversity is lower sensitivity to real turnover – something that might be preferable when examining extinction events. For methods using presence-absence distance measures, the outcome should be identical.

B. Multivariate Ecological Methods and Outcomes

The faunal composition data was characterized and analyzed using the general statistics program R (version 2.8.1) (11), the ecological package vegan (version 1.15) (12), and the paleobiological statistics program PAST (version 2.98) (13). Ecological analyses used in this study included cluster analysis, canonical correspondence analysis (CCA), detrended correspondence analysis (DCA), factor analysis (FA), non-parametric multidimensional scaling (NMDS), one-tailed analysis of similarity (ANOSIM), and similarity percentage (SIMPER). The first five methods are ordination procedures that produce plots allowing visualization of the data. These procedures are useful for detecting true faunal breaks associated with mass extinction since they do not depend on *a priori* group assignment whether temporal or geographic. Despite commonalities, all the methods characterize different aspects of the data, and so their results can complement and support one another. Cluster analysis is useful for determining the degree and structure of relationships between individual faunas, while correspondence analysis reveals any major environmental and/or temporal gradients underlying the distribution of both sites and taxa, potentially revealing major assemblages. Detrended correspondence analysis corrects the latter for sample size if necessary and linearizes the data. Factor analysis reveals the most important taxa driving separation between different clusters of localities. NMDS is ordination along two axes based on distance metrics, and so can serve as the visual representation of statistical tests predicated on the same (such as ANOSIM). ANOSIM is a statistical permutation test of faunal similarities between *a priori groups* (unlike the previous methods), and SIMPER reveals the relative contribution of the changes to diversity of individual taxa to differentiation between those assigned groups. These methods will be explained in more detail below.

In order to control for sampling, analyses were performed using raw diversity, (with results presented in the text) and relative diversity in order to reveal any effects of sample size (Tables S1 and S2), as well as temporally restricted subsets containing Frasnian, Famennian, and Mississippian sites marked by environment (Table S1). The Tournaisian and Viséan were grouped together in order to correct for a lack of marine sites in the Tournaisian that would reduce statistical power. Since there was no significant difference between Tournaisian and Viséan sites in the overall analyses (Tables S12 and S16), this was unlikely to skew the results. A subset containing late Frasnian and early Famennian sites was analysed to further pinpoint the interval of faunal change (Fig. 2). Additional matrices comprising late Famennian and Tournaisian sites, and end-Famennian (those sites comformably overlain by Hangenberg and/or boundary deposits) and Tournaisian sites were analysed for the same reason (Fig. 2)

Some of the methods (cluster analysis, NMDS, and ANOSIM) require distance or similarity matrices. Distance and similarity metrics used here include: 1. Bray-Curtis distance (14), an abundance-sensitive distance measure representing the sum of absolute differences between sites divided by the sum of actual differences between sites (5); 2. Kulczynski similarity (15), a presence-absence measure modified from Jaccard similarity that groups subsets of faunas with larger biotas containing the same species; 3. Dice similarity (16), a presence-absence measure which puts greater weight on joint occurrences of taxa, and is calculated from twice the number of matches divided by the sum of twice the number of matches plus the number of dissimilar taxa; 4. Simpson similarity (17), a presence-absence measure which treats subsets of taxa as identical to large samples and is produced by the number of taxon matches divided by the minimum number of presences among two samples; 5. Chord distance (17) an abundance distance measure taken from relative species abundances (normalized to 1) rather than absolute numbers; 6. Morisita similarity (18), an abundance measure recommended by the authors of PAST (17); 7. Raup-Crick index (19), a presence-absence similarity measure which uses randomized pooled data from two sites to produce a distribution of co-occurrences and then compares these to the observed data.

The metrics are all based on different assumptions, and have different sensitivities to faunal differentiation. Using all of them will give information about the structure of the data, potentially avoiding errors. Agreement between such different measures is likely to provide especially compelling evidence of either extinction-related turnover or stasis. Presence-absence metrics do not take into account relative numbers of species, producing results based on faunal composition alone. They are therefore particularly useful for testing whether observed patterns of turnover are due to extinction rather than unrelated diversity changes. Use of these measures also corrects for the effects of oversampling of, or increased taxonomic work on, certain groups at a single locality.

Cluster analysis produces a hierarchical dendrogram of sites based on a distance or similarity matrix, with branching based on a chosen algorithm without *a priori* grouping by either age or environment (5). Dendrograms were produced using the *hclust* function in R based on average linkage clustering (UPGMA) (20), which averages all possible distances between groups. Clustering was performed for both raw and relative diversity datasets using both Bray-Curtis distances ("abundances" – actually species diversity here) and Kulczynski similarities (presence-absence) generated by using the *vegdist* function of the vegan package. Data was first square root transformed to correct for the effects of oversampled taxa. The cophenetic correlation, calculated in PAST, shows the relationship between true distances and those represented in the dendrogram. Sudden extinction and turnover is expected to show a large split between pre- and post-event faunas, while stasis and gradual change will result in sites from surrounding temporal intervals clustering together based on some other factor.

Canonical correspondence analysis (CCA) is an indirect ordination procedure that detects environmental (or temporal) gradients and distribution of sites from taxonomic composition without *a priori* group assignment. CCA visualizes the gradients as axes in a two-dimensional ordination plot of both taxa and sites (5, 21), revealing the correspondence between them, as well as any faunal associations. CCA plots were generated from the both the raw (Fig. 3) and relative diversity datasets (Fig. S6) using the *cca* function in the R package vegan. Detrended correspondence analysis is a related and popular technique that corrects for correlations between the first and second axes which often produce a horseshoe shaped distortion of the ordinations (5). Since primary gradient produced by CCA was temporal, while the second was environmental, there was little interplay between the two and DCA (generated by the *decorana* function in the R package vegan) proved an unnecessary step – turning out similar, but more condensed, plots. Mass extinction and turnover is assumed when a large temporal gap is observed between environmentally similar faunas. Gradual change or stasis is implied when sites form gradient along both correspondence axes and show overlap by environment or geography.

Factor analysis (FA) is a procedure similar to principal components analysis, in which a variance-covariance matrix is used to produce a visual ordination of samples (5). However, in FA, the axes are rotated to better explain the differentiation between clusters of samples that might otherwise fall diagonally (5). This technique was used by Sepkoski (22) to characterize his evolutionary faunas, and is another method for visualizing the main differences in taxon composition between sites. Factor analysis was performed on PAST using varimax rotation, which scales the loadings to maximizes sum of variance. Taxon loadings are produced for four axes. Large-scale differences between pre- and post-extinction faunas are expected to result in their placement primarily along distinct axes representing large amounts of variance. Stasis or gradual change is likely when faunas are ordinated along a single axis, or form a diagonal gradient.

NMDS is a visualization method which ordinates samples into a two-dimensional space while retaining the ranked distances found in an original multidimensional distance matrix data (5). It is often used for non-parametric data such as faunal distributions in place of principal components analysis (5). NMDS plots were produced using PAST, which chooses the best solution of 11 trials based on least "stress" – a value representing the difference between ranks within the distance matrix and in the ordination plot (5). PAST additionally generates a Shepard plot of obtained versus targeted ranks as visual representation of fit. NMDS plots were generated for all raw and relative diversity datasets based on both Bray-Curtis and Kulczynski distances. NMDS results are expected to appear similar to those of CCA depending on the patterns present in the data.

One-tailed ANOSIM is a non-parametric method similar to NMDS in that it depends on ranked distances. However, this is a statistical permutation test, a procedure much like bootstrapping which compares *a priori* group composition (5, 23). ANOSIM obtains these values by comparing within-in group and between-group ranks, under the assumption that the later must be larger than the former if two faunas are truly different. This generates the test statistic R, which can range from 1 (absolute dissimilarity) to 0 and even negative numbers (high similarity). Permutations of samples within groups are then used to determine the significance of differences between the groups themselves by producing pairwise p-values. As a non-parametric test, ANOSIM is a popular method for detecting significant differences in the faunal composition of modern and fossil ecosystems. ANOSIM p-values for all datasets were obtained for all seven distance measures using 1000000 permutations in PAST. Mean R statistics and p-values for raw diversity using all metrics are presented in the text. Means for all metrics, presence-absence, abundance, and individual metrics based on both raw and relative diversity data are additionally presented in the supporting tables S11-S18 for both extinction and selected background interval. Global mass extinction is expected to produce statistically significant ANOSIM p-values and high R statistics in pairwise comparisons of all environments and intervals around such an event using both kinds of metrics and diversity data. Stasis is expected to result in insignificant ANOSIM p-values and low R-statistics. Gradual and even sudden diversity changes without extinction are expected to produce insignificant p-values and low R in ANOSIM tests based on presence-absence metrics.

The final method used here, SIMPER, determines the relative contribution of taxa to dissimilarity between groups based on Bray-Curtis distances, as well as average dissimilarity (5). In other words, SIMPER reveals faunal patterns underlying turnover detected by ANOSIM, showing which groups underwent changes. SIMPER analysis was performed in PAST on both the restricted relative diversity datasets in order to determine the changes in faunal composition driving differentiation independent of environment. The main downside to this method is that the use of percentages might exaggerate the impact of rare taxa, while focusing on a narrow environment might obscure the signal for euryhaline species. However, it is still a useful technique for exploring ANOSIM results. In addition, the average dissimilarity metric can be used to relate SIMPER results from different comparisons.

II. Detailed Results

A. Total Faunal Dataset.

1. Cluster Analysis

The most basal division in all cluster dendrograms, whether based on abundance (Bray-Curtis) or presence-absence (Kulczynski) metrics or on raw or relative diversity, is between all Devonian sites and all Mississippian sites (Figs. S3, S4, S5). This split corresponds to the Hangenberg event at the Devonian-Mississippian boundary. A secondary deep division is observed among the Mississippian sites, falling between a cluster of majority marine sites and a cluster of mostly nonmarine localities. A similar environmental division is observed among the overall Mississippian cluster in dendrograms based on relative diversity and Kulczynski distances (Figs S4 and S5). Otherwise, sites mostly cluster by geography (e.g. Euramerican sites, Fig S1) or finer environmental designation in the (e.g. reef sites such as Gogo, Wildungen, and Wietrznia) (Figs. S3, S4, S5, Table S1). Few clusters of more than two localities, and none of more than four, belong to a single Mississippian or Devonian stage. Therefore, the dendrograms give little indication of any widespread faunal turnover around boundaries or extinction events apart from the Hangenberg.

2. Canonical Correspondence Analysis (CCA)

The correspondence axes generated for both raw and relative diversity are the same. Correspondence axis 1 (raw diversity eigenvalue=0.46, relative diversity eigenvalue=0.47) is purely temporal and does not represent a gradient so much as a split between the Devonian and Mississippian (Fig. 3*A* and S6*A*, Tables S5 and S7). Clusters of sites from all stages within the periods show extensive overlap, including those from around the Kellwasser extinction. There is a large gap between clusters containing all Devonian and all Mississippian localities along this axis. This shows deep dissimilarity between faunas before and after the end-Devonian Hangenberg extinction event, as was previously observed in the cluster dendrograms. A similar split is observed between taxa associated with sites from pre- and post-Hangenberg intervals, suggesting that acute faunal turnover as the cause of this pattern (Figs. 3*B* and S6*B*, Tables S6 and S8).

Correspondence axis 2 (eigenvalue=0.27) is associated with a salinity gradient evident in sites from both periods, with marine sites having more positive values (Figs. 3*A* and S5*A,* Tables S5 and S7). However, post-Hangenberg Tournaisian sites cluster tightly around the origin despite a worldwide geographic spread and differences in reported environment (Fig. S1 and Table S1). The spread of taxa along axis 2 shows that designations based on geological data can be corroborated by vertebrate faunal composition (Figs. *3B* and S6*B,* Tables S6 and S8). On the basis of these results, gnathostome assemblages might be used to determine the depositional environments of fossil sites from this interval in the absence of geological study. In addition, this data could be used to hypothesize the vertebrate faunas of new later Devonian and Mississippian localities with known environments.

3. Nonparametric Multidimensional Scaling (NMDS)

The first NMDS coordinate generated from both raw and relative data is associated with both time and to a lesser extent environment: Devonian and nonmarine sites have lower values than Mississippian and marine sites (Figs. 4*A* and S7). The temporal signal is much stronger; overlap between Mississippian and Devonian sites along the first coordinate is confined to Serpukhovian terrestrial freshwater sites (Dora, Niddrie) and late Famennian open marine deposits (Cleveland Shale, Tiflalt) in raw data analyses (Figs. 4*A,* S7*A,* S7*B).* This is likely due to underreporting of certain non-tetrapod taxonomic groups, such as actinopterygians, at those two sites, a situation common at Late Viséan and Serpukhovian terrestrial localities (e.g. Niddrie, Ducabrook, and previously East Kirkton). In fact, Dora is clustered with East Kirkton and other non-outliers in the cluster dendrograms (Figs. S3, S4, S5) and Niddrie lies well within a cluster of Tournaisian and other non-marine tetrapod site in the dendrogram based only on presence-absence of groups (Fig S5). This suggests that these sites should contain more actinopterygians and other typical Mississippian taxa. However, if this overlap is real, it either shows convergence (excluding extinct groups) between the faunas of two very different environments after a gap of 40 My, the existence of a marine refugium repopulating inland environments after the Hangenberg, and/or radical habitat shifts in the aftermath of extinction. However, it should be noted that there is no overlap along the first coordinate produced by NMDS ordination based on relative diversity (Figs. *S7C* and S7*D*). As in the CCA plots (Figs. 3 and S6), the second coordinate is strictly environmental – marine sites have more positive values.

4. Factor Analysis

Varimax factor analysis of all sites produces identical results from both raw and relative diversity data. Factor 1 (39.68% of variance) is positively associated Devonian non-marine taxa as designated by the CCA plots (Fig. 4*B* and Table S9). Factor 2 (22.10% of variance) is negatively correlated with Mississippian formss, largely actinopts and chondrichthyans (Table S9). Factor 3 (9.59% of variance) is negatively loaded by Devonian marine taxa, while Factor 4 (5.45% of variance) is positively associated with the same (Table S9). Overall, position along the main axes of variation are correlated with taxa abundant in either pre- or post-Hangenberg sites. This again illustrates the extreme differentiation of faunal composition of all environments around the Hangenberg event, but not the earlier Kellwasser extinction. The only overlap between pre and post-Hangenberg intervals on the non-environmental Mississippian axis (Factor 2) concerns the same two outlier terrestrial faunas seen on the first NMDS coordinate, and is likely caused the same factors (Fig. 4*B* and Table S10). All overlap on the other major factors is because Devonian environmental biotas (marine and non-marine) are distinct enough to be highly correlated with separate axes of variation (Tables S9 and S10). This causes contemporary sites representing the opposite environment to fall near the origin, alongside Mississippian localities. High correlation of the first factor with non-marine Devonian sites to exclusion of Mississippian non-marine faunas precludes a role for freshwater refugia in the Hangenberg event.

5. Analysis of Similarity (ANOSIM)

ANOSIM reveals a highly significant difference (α=0.05) between Devonian and Mississippian faunal composition, corresponding to the Hangenberg event (Tables S11-S18). In pairwise comparisons of various pre- and post- extinction stages, including the Famennian and Tournaisian, mean R statistics range from 0.74 to 0.81 and mean p-values range from 0* to <0.001* (Tables S11-S18). The R and p-values generated from tests based on different similarity metrics, including those based on abundance and presence-absence, are very consistent - the turnover signal is strong enough to be immune to minor methodological differences (Tables S11-S18). Crucially, this agreement indicates that faunal change at the Hangenberg was primarily due to whole-taxon extinction and basic compositional change rather than relative fluctuations in the diversity of co-existing groups.

In contrast, the ANOSIM results for the Kellwasser extinction are mixed, with a bias towards insignficance (Tables S11-S18). Pairwise p-values for the Frasnian and Famennian based on abundance metrics show a significant difference between faunas before and after the event, despite low R-statistics indicating high faunal similarity (raw diversity abundance mean R=0.12, mean p=0.03*; relative diversity abundance mean R=0.13, mean p=0.03*) (Tables S11, S12, S15, S16). However, no significance is observed in tests based on presence-absence metrics, which have even lower R-statistics (raw diversity presence-absence mean R=0.07, p=0.08; relative diversity presence-absence mean R=0.08, p=0.08) (Tables S11, S12, S15, S16). This suggests that any faunal differentiation over the Frasnian-Famennian is due to relative changes in diversity, rather than turnover related to a first-order mass extinction. In addition, there is no significant difference in abundances in tests comparing the Givetian and Famennian, despite the longer interval and the inclusion of other geological events (raw diversity abundance mean R=0.12, mean p=0.05; relative diversity abundance mean R=0.10, p=0.08) (Tables S13, S14, S17, S18). The Frasnian-Famennian extinction has previously been considered an artefact of sampling, and the mixed signal observed here supports that claim. However, comparison of whole stages says nothing about the temporal spread, environmental extent, or the exact diversity changes underlying the abundance signal. These were examined in analyses of subsets of the data, results of which are presented below.

No significant difference was observed between faunas across other boundaries. This includes those thought to be associated with lesser extinction events, such as the Taghanic at the Frasnian-Givetian boundary (raw diversity mean R=-0.02, mean p=0.6; relative diversity mean R=-0.03, mean p=0.6) and the unnamed event of the early Serpukhovian (raw and relative diversity mean R=0.05, mean p=0.3) (Tables S13, S14, S17, S18). For both events and over Tournaisian-Viséan boundary, results from abundance metrics showed greater faunal differention than those based on presence-absence measures – the same signal observed for the Frasnian-Famennian (Tables S11, S12, S15, S16).

ANOSIM results suggest that changes in relative diversity of coexisting taxa are common over long intervals, but extinction and replacement of higher-level monophyletic or morphologically similar groups between two intervals is more rare. Therefore, the results generated for the Frasnian-Famennian are not exceptional compared to background. In contrast, the R-values generated from presence-absence metrics for the Hangenberg event are orders of magnitude larger than those for any other extinction or boundary examined here, while the p-values are orders of magnitude smaller. This shows the Devonian-Mississippian extinction to be a truly anomalous event in the mid-late Paleozoic.

6. Similarity Percentage (SIMPER)

SIMPER average dissimilarity for the Frasnian-Famennian is close to that for Givetian-Frasnian, and so is indistinguishable from background turnover (Table S19). It does appear from SIMPER comparison of the whole stages that arthrodires are lose half their diversity over the Kellwasser event, along with ptyctodonts, actinopterygians, climatiids, and other taxa designated as marine or euryhaline in the the CCA results (Fig. 3*B* and S5*B)*, although none go completely extinct (Table S20). This might suggest a marine-restricted turnover event. However, antiarchs more than double, as do the other Devonian non-marine taxa as sorted by the CCA (e.g. tristichopterids, osteolepidids, Table S22). Therefore, environmental sampling is likely behind significant values generated by ANOSIM using abundance metrics, rather than real diversity change, turnover, or extinction (Tables S11, S12, S15, S16). Indeed, there is more than double the number of marine sites known from the Frasnian than from the Famennnian (4 vs. 10) (Table S1), even though a greater number of Famennian localities were included in the overall dataset. Analyses performed using single environments in order to examine the impact of sampling, and the results are presented below.

SIMPER reveals the Famennian-Tournaisian average dissimilarity to be anomalously high (83.00), more than double the Tournaisian-Viséan (40.80) (Table S20). Comparisons based of relative diversity data show that 44% of all higher-level groups (all placoderms, many sarcopterygians and acanthodians) were completely lost over the Hangenberg event (Table S21). Increases in the relative diversity of most surviving taxa were as expected from the losses alone. However, actinopterygian species per site increases 20-fold in over the recovery interval, while holocephalans and gyracanthids show similar increases in mean relative abundance. However, these increases contribute less to overall faunal dissimilarity than extinctions, showing the latter to be the main driver of Devonian-Mississippian turnover.

B. Extinction Intervals: Marine and Non-marine Environments.

1. NMDS

Faunas of pre- and post-event stages were subjected to additional ordination analyses with sites marked by environment. Nearly all variation in the NMDS plots for Frasnian and Famennian sites is along the first coordinate (Figs. 4*C,* S7*A*, S8*A,* S9*A*), which represents a salinity gradient equivalent to CCA axis 2 (Figs. 3 and S6). No real difference is observed between plots generated by Bray-Curtis and Kulczynski metrics, nor from the raw and relative diversity datasets. As with the CCA (Figs. 3 and S6, Tables S5-S8), sites are distributed as expected from *a priori* assignments of environment (Figs. S8*A*, S9*A,* S10*A*). This once again shows that designations based on geological data can be confirmed by vertebrate faunal composition. Unlike the overall NMDS plots (Fig. S7), there appears to be no temporal gradient or gap – Frasnian and Famennian faunas overlap along both coordinates. Clustering of all sites is particularly tight along second axis. Differences between the spread of Frasnian and Famennian sites in the NMDS plots are due to differences in the number of marine and non-marine sites as well as geographic sampling (Figs. S8*A*, S9*A,* S10*A*). In summary, there is little evidence of any break in faunal composition associated with the Kellwasser event in either environment.

The coordinates generated by NMDS ordination of Famennian and Tournaisian-Viséan sites are very similar to the CCA and NMDS axes produced by the total datasets (Figs. 3*A*, S7, S8*A*, S9*A,* S10*A*) The only real difference is that positive values along axis 1 are associated with the Devonian rather than the Mississippian. Marine sites in the Devonian have more positive values on coordinate 2 than nonmarine sites, again as in CCA and the overall NMDS. Post-Hangenberg sites of all environments are tightly clustered on this coordinate, but marine and nonmarine sites are still well-sorted on the plot. Some other unknown coordinate must describe variation between environments during the recovery interval. These results again show that *a priori* environmental assignment in other analyses to be appropriate. No real difference in results is observed among plots generated by Bray-Curtis and Kulczynski metrics, nor from the raw and relative diversity datasets (Figs. S8*A*, S9*A,* S10*A*). All plots show a large gap between all Famennian sites and all Mississippian sites of the same environment. The closest approach between sites from pre- and post-Hangenberg intervals along coordinate 1 is again between Famennian open marine localities and an inland freshwater fauna from the late Viséan, some 30 million years later (Figs. S8*A*, S9*A,* S10*A*). This precludes the possibility of a single environment (e.g. freshwater) serving as an unaffected refugium during the extinction event – both the marine and nonmarine assemblages were changed.

2. Factor Analysis

Factor analyses plots generated from raw and relative diversity data are identical. Clusters of marine sites from before and after the Kellwasser event are overlapped on all major factors (Fig. S11*A* and Tables S22 and S23), as are nonmarine localities. Factors are completely environmental like the axes generated in NMDS (Table S22). Factor 1 (54.95% of variance) is positively associated with non-marine taxa from both stages (Figs. S11*A* and Table S22). Factor 2 (16.82% of variance) is positively associated with marine taxa (Fig. S11*A*), while factor 3 (6.06% of variance) and factor 4 (<5.00% of variance) are negatively loaded by the same (Table S22). These results once again show that the *a priori* environmental assignments used here are accurate. The plots of factors 1 and 2 show complete diagonal salinity gradient, with sites ranging from open marine to completely terrestrial (Fig. S11*A*). There is some geographic signal in the results – Middle Eastern sites from around the boundary are close, as are North American and European/German localities (Table S23). This suggests that both environmental and geographic sampling have a hand in any observed difference between Frasnian and Famennian faunas.

Factor analysis plots of peri-Hangenberg sites exhibit a large gap between all Devonian and all Mississippian sites from both environments (Fig. S11*C*). Plots generated from raw and relative diversity are completely identical. Factor 1 (42.92% of variance) is associated positive correlated with Mississippian taxa from all environment (Fig. S11*C* and Table S24). Factor 2 (25.88% of variance) is positively associated with Devonian non-marine taxa (Fig. S11*C* and Table S24). Factor 3 (9.85% of raw diversity variance) is positively correlated with Devonian marine groups (Table S24), as is Factor 4 (<5.00% of variance). All Mississippian sites fall near the origins of factors loaded by primarily Devonian taxa (Figs. S11*C*), and do not overlap with pre-Hangenberg localities on any major axis (Table S25).

3. ANOSIM

According to the ANOSIM results, faunas sampled from single environments exhibit great similarity across the Kellwasser event. (Tables S11, S12, S15, S16). Analyses of Frasnian and Famennian marine sites produced higher mean p-values (raw and relative diversity mean R=0.25, p=0.1) than pairwise comparisons of whole stages (Tables S11, S12, S15, S16). The mean values are similar to those obtained for non-extinction intervals in the overall analyses (Tables S13, S14, S17, S18). However, the results of individual metrics were highly mixed, likely due to the large difference in number of sites between intervals and geographical sampling. Insignificant values were obtained for non-marine faunas (raw diversity mean R=-0.08, p=0.7; relative diversity mean R=-0.07, p=0.7) - less saline biotas are largely unchanged over the boundary (Tables S11, S12, S15, S16). These results again show that environmental sampling, not mass extinction or major diversity change, is primarily responsible for the turnover signal observed in comparisons of entire stages.

In contrast to the Kellwasser results, ANOSIM comparisons of marine sites around the Hangenberg event indicate extreme dissimilarity of faunas. Marine R statistics are much higher than those generated for entire intervals, while p-values are higher only because of the relatively low number of Famennian and Tournaisian-Viséan marine sites (raw diversity mean R=0.90, mean p=0.03*, relative diversity mean R=0.91, mean p=0.03*) (Tables S11, S12, S15, S16). Non-marine values have greater significance (raw and relative diversity mean R=0.91, p=0* in 1000000 permutations) (Tables S11, S12, S15, S16). This suggests that analyzing the overall extinction interval was actually depressing the already strong signal. Results were consistent regardless of which similarity metric was used (Tables S11, S12, S15, S16). The Hangenberg turnover was not restricted to a single environment, but rather appears to have been global in effect.

4. SIMPER

In agreement with the ANOSIM results, average dissimilarities generated by SIMPER for Frasnian-Famennian marine (54.53) and non-marine (49.15) sites were lower than that generated from comparison of the overall stages and not much different from background comparisons (Tables S19, S26, S27). Marine faunal differentiation was driven primarily by increases in elasmobranchs and symmoriformes (Table S26), something which might partly be attributed to the greater representation of open marine shales in the Famennian (e.g. Cleveland Shale, *Cheiloceras* beds, and Tafilalt). These types of deposits exhibit better preservation of chondrichthyan remains. In contrast to the overall SIMPER results and previous assertions, marine arthrodires appear to pass through the boundary unscathed – their per site diversity is unaffected (Table S26). While there are some losses among groups in the purely marine results, these are all represented in marginal marine and estuarine environments of the Famennian – with many of these same taxa apparently rising from the dead (Table S27). This suggests that these might not represent real marine extinctions, but rather slight habitat shifts or changes in marine sampling owing to the paucity of nearshore reef sites documented elsewhere. The SIMPER results for nonmarine sites exhibit no real trends – some decreases in relative diversity are observed, but a greater number of groups are represented in Famennian environments (Table S27).

The average dissimilarities generated for SIMPER comparisons of pre- and post-Hangenberg marine and non-marine sites (80.74 and 81.73 respectively) were similar to the high value produced for the overall Famennian and Tournaisian (83.19) (Tables S19, S28, S29). Extinctions are observed in marine and non-marine faunas, with the composition of post-extinction faunas highly similar in both (Tables S28 and S29). This once again indicates that the Hangenberg extinction struck all environments equally.

B. Extinction Intervals: Restricted Timespans.

1. NMDS

Late Frasnian and early Famennian sites (Fig. 2) were analysed in order to determine whether any faunal change could be associated specifically with the Kellwasser event rather than longer-term phenomena. In NMDS plots of this restricted interval, constructed using both datasets and either Bray-Curtis or Kulczynski distances, coordinate 1 looks similar to that produced by analyses of the whole stages (Figs. *4A,* S8*B,* S9*B,* S10*B*). Negative values are associated with marine environments, while positive values are associated with nonmarine faunas. As was observed in the environmental analyses, most of the difference between stage clusters is caused by the relative number of sites from each environment. Pre- and post-extinction clusters are more extensively overlapped in plots based on presence-absence distances (Fig. S10*B*). Therefore, the overall composition of faunas changed less over the Frasnian-Famennian boundary than the relative diversity of coexisting groups. This agrees with the insignificant values generated using presence-absence metrics in ANOSIM. The second coordinate seems to be geographic and partly environmental. In addition, sites from the same biogeographic region event are adjacent in the ordination despite being separated by the Kellwasser event (e.g. Stolbovo and Tervete, Scaat Craig and Portishead).

NMDS plots of late Famennian and Tournaisian sites (Figs. 2, S8*D,* S9*D,* S10*D*) exhibit the major axes similar both the overall NMDS plots and the CCA (Figs. 3, 4*A*, S5). However, the first coordinate is arbitrarily flipped in when using Bray-Curtis distance and raw diversity (Fig. S8*D*). As with all other ordination plots involving Devonian and Mississippian localities, a large gap is seen between late Famennian and Tournaisian sites on the first axis - although this is not aligned near the origin in the raw diversity results (Figs. S8*D* and S10*D*). The second coordinate is environmental, with marine sites holding more positive positions. Distances between marine and non-marine sites across the boundary are about equal, again giving little evidence for freshwater refugia across the Hangenberg event. As in previous analyses, Tournaisian sites form the relatively tight cluster. NMDS plots constructed using only end-Famennian sites conformable with the Hangenberg event show the same exact pattern – no latest Devonian locality is more closely associated with Mississippian faunas than earlier localities (Fig. S12). This restricts the timing of the gap along axis 1, as well all associated extinctions, to the period between the beginning of the Hangenberg event and the deposition of Horton Bluff in the early-mid Tournaisian.

2. Factor Analysis

Factor analysis of late Frasnian and early Famennian sites produced the same factors as the overall stages using both raw and relative diversity data (Fig. S11*B* and Table S30). Factor 1 (56.84% of variance) was positively associated with non-marine taxa and sites. Factor 2 (19.86% of variance) was positively correlated with marine taxa. Factor 3 (6.04% of variance) and factor 4 (5.44% of variance) were both negatively loaded by marine groups (Tables S30). In the plots themselves, sites from similar environments but different stages overlap (Fig. S11*B*). Once again, there is no temporal signal or Kellwasser-associate faunal break observed in the data (Fig. S11*B* and Table S31). Environmental sampling, involving a paucity of marine sites in the early Famennian, plays a significant role in observations of faunal change around the stage boundary.

Factor analysis of late Famennian and Tournaisian sites generated factors slightly different from those of previous analyses of longer intervals, but still associated with the faunas of one period or the other (Figs. S11*D* and Table S32). Factor 1 (43.50% of variance based on both relative and raw data) is positively loaded by Famennian non-marine taxa, such as antiarchs (Tables S32). Factor 2 (22.78% of variance) is positively correlated with members of the Tournaisian biota, both marine and non-marine (Table S40). Factor 3 (12.45% of raw diversity variance) is negatively correlated with Famennian marine forms (Table S32). Factor 4 (5.11% of variance) is positively correlated with Famennian sarcopterygians and other estuarine taxa (e.g. those near the origin of correspondence axis 2 in CCA analysis (Figs. 3 and S6 and Table S32). There is no overlap between late Famennian and Tournaisian clusters on plots of factors 1, 2, and 3 (Figs. S11*D*), and no overlap along factor 2, the only factor associated with a single stage (Table S33).

Factor analysis of end-Famennian and Tournaisian sites linked the greatest part of the variance directly with changes observed in previous SIMPER analyses. Plots and scores were identical in analyses of both raw and relative diversity. Factor 1 (45.64% of variance) is more positively associated with all those taxa showing increases or little change in SIMPER comparison of the Famennian and Tournaisian (Tables S21 and S34) and less loaded or even negatively loaded by all groups facing extinction or decreases across the Hangenberg horizons (Tables S21 and S34). Factor 2 (24.04% of variance) is negatively correlated with components of the end-Famennian marine fauna (Table S34). Factor 3 (13.81% of variance) is positively associated with Famennian non-marine taxa, mostly sarcopterygians (Table S34). Factor 4 (5.95% of variance) is positively associated with chondrichthyans, and might represent a Tournaisian marine signal. As with the comparisons of longer intervals around the Hangenberg event, Tournaisian and end-Famennian clusters show little overlap in any plot of the major factors (Fig. S12*D*). The gap between all Tournaisian and all Famennian sites along factor 1 is very wide, much more so than on other factor plots involving many of the same sites (Fig. S12*D* and Table S35). Once again, the separation between end-Famennian and Tournaisian faunas, as well as associated higher-level group extinctions, is pinpointed to a short interval coincident with the Hangenberg event and its immediate aftermath.

3. ANOSIM

ANOSIM results for the late Frasnian and early Famennian show the same general pattern as comparisons of the entire stages (Tables S11, S12, S15, S16). The overall faunas are not significantly different (raw diversity mean R=0.19, mean p=0.1; relative diversity mean R=0.20, mean p=0.1) (Tables S11, S12, S15, S16). However, there is a significant difference in relative abundance of coexisting groups (raw diversity mean R=0.31, mean p=0.04*; relative diversity mean R=0.33, p=0.03*) which is not mirrored in values based on presence-absence metrics (raw and relative diversity mean R=0.10, p=0.2) (Tables S11, S12, S15, S16). Faunal differentiation between the late Frasnian and early Famennian is not driven by any fundamental change in faunal composition, such as extinction of higher-level groups at the Kellwasser event.

ANOSIM results for the late Famennian and Tournaisian are also nearly identical to those produced by analyses involving the entire Famennian (raw diversity mean R=0.71, mean p<0.001*; relative diversity mean R=0.72, mean p<0.001*) (Tables S11, S12, S15, S16). A consistent signal is once again seen in the values produced by all similarity metrics. Comparison of end-Famennian and Tournaisian sites also produced highly significant values despite the smaller number of samples, revealing the great strength of the Hangenberg extinction signal (raw diversity mean R=0.64, mean p=0.002*; relative diversity mean R=0.65, mean p=0.002*) (Tables S11, S12, S15, S16).

4. SIMPER

The results of SIMPER comparison for late Frasnian and early Famennian sites display the same environmental signal seen in comparisons of the entire stages (average dissimilarity=64.01) (Tables S19 and S36). Once again, antiarchs and non-marine Devonian sarcopterygians (tristichopterids and osteolepids) exhibit increases that exactly mirror the large decreases among the more marine arthrodires (Table S36). Only a single group is lost, Other Placodermi, but these reappear later in the Famennian and contribute little to larger patterns due to their overall rarity. Differences in environmental sampling are once again driving dissimilarity right around the Kellwasser horizon, while any evidence of high-level extinction is missing. This, along with all the other results of this study, casts doubt on the status of the Frasnian-Famennian mass extinction, as it seems to have had little real, demonstrable effect on the vertebrate biota.

SIMPER comparisons of Tournaisian, late Famennian, and end-Famennian sites show that all higher-level taxa are represented in Devonian deposits right through to the Hangenberg horizon (Tables S37 and 38). Therefore, extinction of these groups before the event is extremely unlikely. Between the start of the Hangenberg event and the earliest Tournaisian locality, the vertebrate biota experienced the complete extinction of 44% of gnathostome higher-level groups, involving the total loss of placoderms and several acanthodian and sarcopterygian monophyletic groups (Tables S37 and S38). There were attendent increases in the relative contribution of survivors to the Tournaisian fauna. Arthrodires remain the most taxonomically diverse segment of the Famennian vertebrate biota right up the boundary. In contrast, actinopterygians, a minor part of Devonian faunas, radiate far beyond what would be expected during the post-extinction interval, becoming the most taxonomically diverse segment of the Mississippian biota. This suggests that actinopterygians opportunistically replaced most of the dead in the Tournaisian recovery fauna (Tables S37 and S38). This acute faunal turnover, involving the extinction of multiple, large, mostly monophyletic groups - observed in all comparisons of of Devonian and Mississippian sites in this study - is the expected signal of a true mass extinction. Therefore, on the basis of all analyses, the Hangenberg extinction should be considered an anomalous event, with devastating effects on the worlwide vertebrate biota.

III. Site Descriptions and Faunal Lists

A. Givetian Sites

1. Orcadian Lake.

Stratigraphy/Location. Orcadian basin, Scotland. **Age.** early Givetian. **Environment.** Non-marine, Lacustrine/Fluvial.

Taxa. Actinopterygii: *Cheirolepis trailli*. Porolepiformes: *Holoptychius sp*., *Glyptolepis leptopterus*, *Glyptolepis paucidens*. Dipnoi: *Palaeospondylus gunni*, *Dipterus valenciennesi*, Unnamed lungfish. Osteolepididae: *Osteolepis macrolepidotus*, *Gyroptychius milleri*, *Gyroptychius agassizi*. Tristichopteridae: *Tristichopterus alatus*. Arthrodira: *Coccosteus decipiens*, *Homosteus milleri*. Antiarcha: *Pterichthyodes milleri*. Ptyctodontida: *Rhamphodopsis trieplandi*. Climatiida: *Diplacanthus striatus*, *Diplacanthus tenustriatus*, *Diplacanthus (Rhadinacanthus) longispinus, Diplacanthus crassisimus*. Acanthodida: *Mesacanthus peachi, Cheiracanthus murchisoni, Cheiracanthus latus, Acanthodes peachi*.

References. 6, 24, 25, 26.

2. Harma.

Stratigraphy/Location. Karski outcrop, Harma substage, Burtnieki regional stage, Estonia. **Age.** early Givetian. **Environment.** Non-marine, deltaic plain.

Taxa. Actinopterygii: *Cheirolepis sp*. Onychodontida: *Onychodus sp., Hamodus lutkevitshi*. Porolepiformes: *Glyptolepis karksiensis,* Holoptychiid. Osteolepididae: *Gyroptychius elgae*. Arthrodira: *Heterostius ingens, Coccosteus markae, Holonema harmae, Actinolepis magna, Homostius latus, Tropinema harmae*. Antiarcha: *Asterolepis dellei, Asterolepis sp*. Elasmobranchii: *Karksilepis parva,* Elasmobranchii gen et. sp. nov. Climatiidae: *Minioracanthus sp., Rhadinacanthus multisulcatus, Diplacanthus carinatus, Diplacanthus gravis, Diplacanthus sp., Ptychodictyon rimosum, Ptychodictyon sulcatum, Nostolepis gaujensis*. Acanthodida: *Markacanthus alius, Cheiracanthus brevicostatus, Cheiracanthus longicostatus, Cheiracanthus sp. nov. 1, Cheiracanthis sp. nov 2., Homacanthus gracilis, Homacanthus sp.,* Acanthodid gen. et. sp. nov.

References. 27, 28, 29, 30, 31, 32, 33. 34. 35, 36, 37.

3. Gerolstein.

Stratigraphy/Location. *Stringocephalus* beds, Eifel, Germany. **Age.** Early Givetian. **Environment.** Marine.

Taxa. Dipnoi: *Conchodus elkneri, Rhinodipterus sp., Archaeonectus pertusus*. Actinistia: *Euporosteus eifelianus*. Arthrodira: *Rhenonema eifeliense, Heterostius rhenanus*. Antiarcha: *Gerdalepis dohmi, Grossaspis carinata*. Ptyctodonta:

Desmoporella minor, Palaeomylus predator, Ptyctodus sp., Rhychodus rostratus, Goniosteus gerolstienensis. Other Placodermi: *Macropetalichthys pelmensis, Epipetalichthys minor*. Ischnacanthida: *Onchus sp*.

References. 27, 28, 29, 30, 38, 39, 40, 41. 42.

4. Rockport.

Stratigraphy/Location. Rockport formation, Traverse group, Michigan. **Age.** mid-Givetian. **Environment.** Marine, inland sea.

Taxa. Onychodontida: *Onychodus sp*. Dipnoi: *Cheirodipterus onawayensis*. Arthrodira: *Protitanichthys rockportensis, Dinomylostoma sp., Holonema rugosum, Holonema farrowi, Dinichthys sp., Mylostoma sp*. Antiarcha: *Bothriolepis sp.,* Ptyctodontida: *Eczematolepis sp*. Elasmobranchii: *Ctenacanthus sp., Acondylacanthus gracillimus*. Ischnacanthida: *Machaeracanthus sp*. Gyracanthida: *Gyracanthus sp*. Acanthodida: *Oracanthus sp*.

References. 27, 28, 43, 44, 45, 46, 47, 48, 49

5. Aztec.

Stratigraphy/Location. Aztec siltstone, Antarctica **Age.** Mid-Givetian. **Environment.** Non-marine, alluvial, lacustrine, fluvial.

Taxa. Actinopterygii: *Donnrosenia schaefferi*. Porolepiformes: Porolepiformes sp. Dipnoi: *Howidipterus sp.,* Ctenodontid sp., *Eoctenodus sp*. Osteolepididae: *Gyroptychius antarcticus, Koharalepis jarviki, Platyethmoidea antarctica*. Megalichthyidae: *Mahalalepis resima*. Rhizodontida: *Notorhizodon mackelveyi, Aztecia mahalae*. Actinistia: *Miguashaia grossi*. Arthrodira: *Antarctolepis gunni, Groenlandaspis antarcticus, Groenlandaspis sp., Boomeraspis goujeti,* Phlyctaeniid sp. nov. Antiarcha: *Bothriolepis antarctica, Bothriolepis alexi, Bothriolepis askinae, Bothriolepis barretti, Bothriolepis barretti, Bothriolepis karawaka, Bothriolepis kohni, Bothriolepis macphersoni, Bothriolepis mawsoni, Bothriolepis portalensis, Bothriolepis vuwae, Venezuelepis antartica, Pampulaspis antarctica*. Phyllolepida: *Austrophyllolepis quiltyi, Austrophyllolepis youngi, Placolepis tingeyi,* Phyllolepid sp., *Antarctaspis mcmurdoensis*. Elasmobranchii: *Mcmurdodus featherensis, Antarctilamna prisca, Anareodus statei, Aztecodus harmesenae, Portalodus bradshawae*. Climatiida: *Milescanthus antarctica, Culmacanthus antarctica, Nostolepis gaujensis, Pechoralepis juozasi, Antarctonchus glacialis*. Gyracanthida: *Gyracanthides warreni*. Acanthodida: *Cheiracanthus sp*.

References. 27, 28, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60.

6. Haikou.

Stratigraphy/Location. Haikou formaton, Yunnan, China, **Age.** Mid-Givetian. **Environment.** Marine.

Taxa. Porolepiformes: *Heimenia sp*. Arthrodira: *Jiuchengia longoccipita, Yinostius major, Kunmingolepis lucaowanensis, Quasipetalichthys haikouensis, Yangalepis jinningensis*. Antiarcha: *Bothriolepis tungseni, Dianolepis liui, Xichonolepis qujingensis, Hunanolepis tieni*. Other Placodermi: *Exutaspis megista*.

References. 61, 62, 63, 64, 65, 66, 67.

7. The Cletts.

Stratigraphy/Location. Caithness, Middle Old Red Sandstone, Scotland. **Age:** Late Givetian. **Environment.** Non-marine, fluvial/alluvial.

Taxa. Actinopterygii: *Stegotrachelus finlayi*. Dipnoi: *Pentlandia macroptera, Dipterus macropterus*. Tristichopteridae: *Tristichopterus sp*. Arthrodira: *Watsonosteus fletti, Coccosteus sp. nov*. Antiarcha: *Microbranchius dicki*.

Reference. 6.

8. Mt. Howitt.

Stratigraphy/Location. Mt. Howitt black shale, Victoria, Australia. **Age.** Late Givetian. **Environment.** Non-marine, lacustrine.

Taxa. Actinopterygii: *Howqualepis rostridens*. Dipnoi: *Howidipterus donnae, Barwickia* downunda. Osteolepididae: unnamed osteolepidid. Actinistia: *Gavinia syntrips*. Arthrodira: *Groenlandaspis sp*. Antiarcha: *Bothriolepis gipplandiensis, Bothriolepis cullodensis, Bothriolepis fergusoni*. Phyllolepida: *Austrophyllolepis ritchei* Acanthodida: *Howittacanthus kentoni,* unnamed acanthodid 1, unnamed acanthodid 2, unnamed acanthodid 3.

References. 58, 68, 69, 70, 71, 72, 73.

9. Abava.

Stratigraphy/Location. Abava substage, Burtnieki regional stage, Estonia. **Age.** Late Givetian. **Environment.** Non-marine, fluvially dominated basin.

Taxa. Actinopterygii. *Moythomasia sp*. Onychodontida: *Hamodus lutkevitshi*. Porolepiformes: *Laccognathus sp*. Dipnoi: Unnamed dipnoan. Arthrodira: *Livosteus grandis, Hybosteus mirabilis, Plourdosteus panderi*. Antiarcha: *Byssacanthus sp., Microbrachius dicki*. Elasmobranchii: unnamed elasmobranch. Acanthodida: *Cheiracanthus brevicostatus, Acanthodes sp. 1, Acanthodes sp. 2, Acanthodes sp. 3, Acanthodes sp. 4*. Tetrapoda: *Panderichthys sp*.

References. 27, 28, 29, 30, 32, 36, 37, 74.

10. Cedar Valley.

Stratigraphy/Location. Cedar Valley Limestone, Milwaukee formation, Iowa. **Age.** late Givetian. **Environment.** Marine, reef.

Taxa. Onychodontida: *Onychodus sigmoides*. Dipnoi: *Straitonia sp., Iowadipterus halli, Dipterus uddeni, Dipterus calvani*. Arthrodira: *Dinichthys pustulosus, Dinichthys tuberculatus*. Ptyctodontida: *Palaeomylus greeni*. *Ptyctodus ferox*, *Ptyctodus calceolus, Ptyctodus uddeni, Rhynchodus excavatus, Gamphacanthus politus, Ptyctodopsis mezelli*. Elasmobranchii: *Phoebodus macisaacsi*.

References. 27, 43, 75, 76, 77, 78, 79, 81, 82.

11. Gauja.

Stratigraphy/Location. Lode formation, Gauja, Latvia. **Age.** Latest Givetian. **Environment.** Non-marine, estaurine, deltaic.

Taxa. Actinopterygii: *Cheirolepis sp*. Onychodontida: *Strunius sp. nov*. Porolepiformes. *Laccognathus grossi, Laccognathus panderi*, *Glyptolepis baltica, Latvius sp*. Dipnoi: *Grossipterus crassus, Griphognathus minutidens*. *Rhinodipterus secans*. Osteolepididae: *Megadonichthys kurikae*. Tristichopteridae: *Eusthenopteron kurshi*. Actinistia: *Miguashaia grossi*. Arthrodira: *Asterolepis ornata, Plourdosteus livonicus, Plourdosteus panderi*. Antiarcha: *Bothriolepis curonica, Grossilepis spinosa, Taenolepis speciosa, Asterolepis ornata*. Ischnacanthida: *Devononchus concinnus*. Climatiida: *Nostolepis guajensis, Nodacosta pauli*. Acanthodida: *Acanthodes sp., Lodeacanthus gaujicus, Haplacanthus ehrmanensis*. Tetrapoda: *Panderichthys rhombolepis, Livoniana multidentata*.

References. 27, 28, 29, 30, 32, 36, 37, 42, 60, 74, 83, 84, 85, 86, 87, 88, 89.

B. Frasnian Sites.

12. Gladbach.

Stratigraphy/Location. Bergish Gladbach, Oberer Plattenkalk, Germany. **Age.** Earliest Frasnian. **Environment.** Marine.

Taxa. Actinopterygii: *Moythomasia nitida, Moythomasia striatus, Stegotrachelus sp*. Dipnoi: *Dipterus valenciennesi, Rhinodipterus ulrichi, Griphognathus sculpta*. Osteolepididae: *Gyroptychius sp., Thursius sp., Latvius niger*. Actinistia: *Holopterygius nudus, Diplocercides heiligenstockiensis*. Arthrodira: *Rachiosteus pterygiatus, Coccosteus sp., Gyroplacosterus sp., Plourdosteus sp*. Antiarcha: *Asterolepiformes sp*. Ptyctodontida: *Ptyctodus sp., Ctenurella gladbachensis*. Elasmobranchii: *Gladbachus adentatus*. Ischnacanthida: *Atopacanthus sp*. Acanthodida: *Protogonacanthus juergeni*.

References. 27, 28, 42, 74, 90, 91, 92, 93, 94, 95, 96.

13. Boghole.

Stratigraphy/Location. Boghole Beds, Upper Old Red Sandstone, Scotland. **Age.** Early Frasnian. **Environment.** Non-Marine, fluvial.

Taxa. Porolepiformes: *Holoptychius decorata, Holoptychius nobillissimus*. Tristichopteridae: *Eusthenopteron traquiari*. Rhizodontida: *Polyplocodus leptognathus*. Arthrodira*: Plourdosteus magnus*. Antiarcha: *Asterolepis alta*.

Reference. 6.

14. Gogo.

Stratigraphy/Location. Gogo Crossing, Victoria, Australia. **Age.** Early Frasnian. **Environment.** Marine, reef.

Taxa. Actinopterygii: *Gogosardinus coatesi, "Mimia" toombsi, Moythomasia durgaringa*. Onychodontida: *Onychodus jandemarrai*. Dipnoi: *Chirodipterus australis, "Griphognathus" whitei, Pillararhynchus longi, Holodipterus gogoensis, Holodipterus longi, Gogodipterus paddyensis, Holodipterus (Holodipteroides) elderae, Holodipterus meemanae, Adolopas moysmithae*. Tristichopteridae: *Gogonasus andrewsae*. Arthrodira: *Holonema westolli, Harrytoombsia elegans, Camuropiscis concinnus, Camuropiscis laidlawi, Tubonasus lennardensis, Rolfosteus canningensis, Kendrickichthys cavernosus, Bullerichthys fascidens, Bruntonichthys multidens, Incisoscutum ritchiei, Torosteus tiberculatus, Torosteus pulchellus, Compagopiscis croucheri, Gogopiscis gracilis, Kimberleyichthys cuspidatis, Kimberleyichthys whybrowi, Simosteus tuberculatus, Eastmanosteus calliaspis, Fallacosteus turnerae, Pinguosteus thulborni, Gogosteus sarahae, Mcnamaraspis kaprios*. Antiarcha: *Bothriolepis sp*. Ptyctodonta: *Campbellodus decipiens, Austroptyctodus gardineri, Materpiscis attenboroughi*. Elasmobranchii: Elasmobranchii gen. et sp. nov. Climatiidae: *Culmacanthus stewartii*.

References. 69, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125.

15. Chahriseh.

Stratigraphy/Location. Kuh-e-Kaftar, Chahriseh section, central Iran. **Age.** early Frasnian. **Environment.** Marine, shallow sea.

Taxa. Actinopterygii: *Moythomasia sp*. Onychodontida: *Strunius rolandi, Orvikuina sp*. Dipnoi: *Rhinodipterus sp., Dipterus sp*. Arthrodira: *Holonema sp*. Antiarcha: *Bothriolepis sp*. Symmoriformes: *Stethacanthus sp*. Elasmobranchii: *Manberodus fortis, Phoebodus latus, Protacrodus serra, Thrinacodus sp*. Climatiidae: *Nostolepis gaujensis, Iranolepis ginteri*.

References. 126, 127, 128, 129.

16. Kerman.

Stratigraphy/Location. Kerman, Tabas Region, eastern Iran. **Age.** Early Frasnian. **Environment.** Marine.

Taxa. Actinopterygii. *Moythomasia sp., "Rhadinichthys" devonicus*. Onychodontida: *Onychodus firouzi, Strunius rolandi*. Dipnoi: *Rhinodipterus sp., Dipterus sp., Chirodipterus sp., Iranorhynchus seyedemamii*. Osteolepididae: Osteolepidid sp.

Actinistia: *Diplocercides sp*. Arthrodira: *Aspidichthys ingens, Holonema radiatum, Eastmanosteus sp., Plourdosteus mironovi, Golshanichthys asiatica, Deirosteus sp*. Antiarcha: *Bothriolepis sp., Stegolepis sp., Byssacanthus dilatatus, Asterolepis sp*. Ptyctodontida: *Rhynchodus sp., Ptyctodus sp*. Other Placodermi: Unnamed Macropetalichthyid Elasmobranchii: *Cladodus sp., Phoebodus sp., Protacrodus* sp. Ischnacanthida: *Persacanthus kermanensis*. Climatiida: Unnamed Climatiid.

References. 27, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139.

17. North Evans.

Stratigraphy/Location. Genesee formation, North Evans/Geneseo, New York. **Age.** Early Frasnian. **Environment.** Marine.

Taxa. Actinopterygii: Unnamed actinopterygian. Onychodontida: Unnamed onychodont. Arthrodira: *Dunkleosteus newberryi, Dinichthys magnificus, Eastmanosteus aduncus, Eastmanosteus pustulosus, "Heintzichthys" denticulatus, Heintzichthys insignis, Dinomylostoma buffaloensis, Copanognathus crassus, Machaerognathus woodwardi, Acanthaspis sp., Aspidichthys notabilis, Coccosteus sp., Holonema* sp. Ptyctodontida: *Eczematolepis fragilis, Palaeomylus hussakofi, Palaeomylus lunaeformius, Palaeomylus minor, Ptyctodus compressus, Ptyctodus howlandi, Rhynchodus ornatus, Rhynchodus telleri*. Other Placodermi: *Oestophorus lilleyi*. Elasmobranchii: *Ctenacanthus sp., Coronodus reimanni*. Holocephalii: *Acmoniodus clarkei, Synthetodus calvini*. Ischnacanthidae: *Atopacanthus sp., Machaeracanthus retustus*. Gyracanthidae: *Gyracanthus sarlei, Gyracanthus sp*.

References. 27, 28, 39, 38, 43, 44, 140, 141, 142, 143, 144, 145, 146, 147, 148.

18. Miguasha.

Stratigraphy/Location: Miguasha, Escuminac formation, Quebec. **Age:** Early Frasnian. **Environment:** Non-marine, estuarine.

Taxa. Actinopterygii: *Cheirolepis Canadensis*. Porolepiformes: *Quebecia quebecensis, Holoptychius jarviki*. Dipnoi: *Fleurantia denticulate, Scaumenacia curta*. Tristichopteridae: *Eusthenopteron fordi*. Actinistia: *Callistiopterus macelveyi*. Arthrodira: *Plourdosteus canadensis*. Antiarcha: *Bothriolepis canadensis, Bothriolepis traquairi*. Climatiida: *Diplacanthus ellsi, Diplacanthus horridus*. Acanthodida: *Triazeugacanthus affinus, Homalacanthus concinnus*. Tetrapoda: *Elpistostege watsoni*.

References. 27, 28, 147, 148, 149, 150, 151, 152, 153.

19. Wietrznia.

Stratigraphy/Location. Zone II, Wietrznia, Kadzielnia, Holy Cross Mountains, Poland. **Age.** Early/mid-Frasnian. **Environment.** Marine.

Taxa. Actinopterygii: *"Rhadinichthys" devonicus*. Onychodontida: *Onychodus jaekeli*. Porolepiformes: *Holoptychius giganteus, Glyptolepis sp*. Dipnoi: *Holodipterusus santacrucensis, Conchodus elkneri, Dipterus murchisoni*. Tristichopteridae:

Eusthenopteron sp. Actinistia: *Diplocercides sp*. Arthrodira: *Deveonema obrucevi, Gyroplacosterus vialowi, Holonema radiatum, Oxyosteus sp., Plourdosteus grossi, Malerosteus gorizdroae*, *Eastmanosteus new sp., Brachydeirus scaber*, *Brachydeirus grandis*, *Pachyosteus bulla, Erromanosteus sp., Rhynchodus sp. 1, Rhynchodus sp. 2, Holonema sp., Gyroplacosteus sp., Plourdosteus sp., Dinichthys sp., Eastmanosteus sp. 2.* Antiarcha: *Bothriolepis panderi*. Ptyctodontida: *Ptyctodus czarnockii, Ptyctodus kielcensis, Ptyctodus obliquus, Rhynchodus marginalis, Rhychodus tetrodon*. Elasmobranchii: *Protacrodus vetestus, Phoebodus fastigatus*. Symmoriformes: *Stethacanthus resistens*.

References. 27, 154, 155, 156, 157, 158, 159.

20. Rodebjerg.

Stratigraphy/Location. Rodebjerg Formation/Snehvide Formation, Kap Kolthoff Group, Greenland. **Age.** Early/mid-Frasnian. **Environment.** Non-marine, alluvial, braidplain.

Taxa. Porolepiformes: *Holoptychius sp*. ,Dipnoi: *Spodichthys buetleri*. Osteolepididae: *Thursius minor*. Arthrodira: *Clarkosteus cf. halmodeus,* Unnamed arthrodire Antiarcha: *Remigolepis tuberculata, Asterolepis saevesorderberghi*. Tetrapoda: *Panderichthys sp*.

Reference. 160.

21. Rhinestreet.

Stratigraphy/Location. Rhinestreet shale, Portage formation, New York. **Age.** Late Frasnian. **Environment.** Marine, open marine.

Taxa. Actinopterygii: *“Rhadinichthys” devonicus*. Dipnoi: *Dipterus ithacensis*. Arthrodira: *Dunkleosteus magnificus, Dinomylostoma beecheri, “Heintzichthys” ringueberryi, Heintzichthys dilochocephalus, “Heintzichthys” mixeri, Callognathus serratus, Eastmanosteus pustulosus*. Antiarcha: *Asterolepis maxima*. Ptyctodontida: *Ptyctodus calceolus*. Elasmobranchii: *Cladoselache sp*. Ischnacanthida: *Atopacanthus dentatus, Atapeacanthus vetustus, Machaeracanthus retustus*. Acanthodida: *Gamphacanthus politus, Acanthodes pristis*.

References. 27, 43, 78, 140, 142, 143, 144, 161, 162.

22. Chemung.

Stratigraphy/Location. Chemung facies/Venago Formation, Warren, Pennsylvania. **Age.** Late Frasnian. **Environment.** Marine.

Taxa. Actinopterygii: Unnamed actinopterygian. Onychodontida: *Onychodus hopkinsi*. Porolepiformes: *Holoptychius sp*. Dipnoi: *Ganorhynchus sp., Dipterus nelsoni, Heliodus lesleyi*. Arthrodira: *Deirosteus abbreviata, Holonema rugosus, Coccosteus macromus*. Other Placodermi: *Oestophorus lilleyi*. Elasmobranchii: *Ctenacanthus chemungensis, Ctenacanthus randalli*. Holocephali: *Helodus gibberulus*. Ischnacanthida: *Onchus rectus*. Acanthodida: *Homacanthus acinaciformis*.

References. 27, 28, 39, 46, 75, 78, 80, 140, 142, 163, 164, 165.

23. Wildungen.

Stratigraphy/Location. Bad Wildungen, Kellwasserkalk, Germany. **Age.** Late Frasnian. **Environment.** Marine.

Taxa. Actinopterygii: *Moythomasia laevigata*. Onychodontida: *Onychodus sp*. Dipnoi: *Chirodipterus wildungensis*. Tristichopteridae: *Devonosteus proteus*. Actinistia: *Nesides heiligenstockiensis*. Arthrodira: *Wildungenichthys grossi, Aspidichthys ingens, Pholidosteus friedeli, Coccosteus bickensis, Brachydeirus carinatus, Brachydeirus bicarinatus, Brachydeirus gracilis, Brachydeirus grandis, Brachydeirus magnus, Brachydeirus minor, Belosteus major, Synauchenia coalescens, Leptosteus bickensis, Pholidosteus laevior, Tapinosteus heintzi, Hadrosteus rapax, Erromenosteus (Leiosteus) lucifer, Erromenosteus brachyrostris, Erromenosteus concavus, Erromenosteus (Paraleiosteus) diensti, Erromenosteus platycephalus, Belosteus elegans, Brachyosteus deitrichi, Cyrtosteus inflatus, Parabelosteus pusillus, Parabelosteus acuticeps, Parabelosteus tuberculatus, Trematosteus fontanellus, Braunosteus schmidti, Enseosteus jaekeli, Enseosteus hermanni, Enseosteus pachyostoides, Microsteus angusticeps, Pachyosteus bulla, Rhinosteus traquairi, Rhinosteus parvulus, Rhinosteus tuberculatus, Ottonosteus hermanni, Walterosteus pachyosteoides*. Antiarcha: *Lepadolepis stensioei*. Ptyctodontida: *Rhynchodus tetrodon, Rhynchodus eximius, Rhynchodus wildungensis*. Other Placodermi: *Jagorina pandora, Epipetalichthys wildungensis*. Elasmobranchii: *Cladoselache hassiacus, Protacrodus vetustus, Cladodus wildungensis*. Acanthodida: *Homacanthus jaekeli*.

References. 1, 2, 27, 28, 30, 49, 138, 148, 166.

24. Scaat Craig.

Stratigraphy/Location. Scaat Craig beds, Upper Old Red Sandstone, Highland, Scotland. **Age:** Late Frasnian. **Environment:** Non-marine, alluvial, fluvial.

Taxa: Porolepiformes: *Holoptychius giganteus, Holoptychius nobillisimus*. Dipnoi: *Conchodus ostreiformis*. Rhizodontida: Unnamed rhizodont. Arthrodira: *Cosmacanthus malcolmsoni*. Antiarcha: *Bothriolepis paradoxa*. Tetrapoda: *Elginerpeton pancheni*.

References. 6, 24, 27, 148.

25. Stolbovo.

Stratigraphy/Location. Stolbovo, Syas River, Dubniki beds, Sargayevian region stage, main Devonian field, northwestern Russia. **Age.** Late Frasnian. **Environment.** Non-marine, alluvial.

Taxa. Porolepiformes: *Holoptychius sp*. Dipnoi: *Rhinodipterus stolbovi, Conchodus jerofjewi, Dipterus sp*. Osteolepididae: *Latvius sp*. Tristichopteridae: *Jarvikina sp., Platycephalichthys bishoffi*. Arthrodira: *Holonema sp., Gyroplacosteus sp., Plourdosteus sp., Eastmanosteus sp*. Antiarcha: *Asterolepis sp., Bothriolepis trauscholdi*.

Ischnacanthida: *Persacanthus sp*. Acanthodida: *Acanthodes sp*. Tetrapoda: *Parapanderichthys stolbovi*.

References. 28, 30, 36, 37, 56, 74, 167.

C. Famennian Sites.

26. Canowindra.

Stratigraphy/Location. Mandangery Sandstone, Canowindra, New South Wales, Australia. **Age.** Early Famennian. **Environment.** Nonmarine, shallow/seasonal basin.

Taxa. Dipnoi: *Chirodipterus potteri*. Osteolepididae: *Canowindra grossi*. Tristichopteridae: *Mandageria fairfaxi, Cabonnichthys bursi*. Rhizodontida: *Gooloogongia loomesi*. Arthrodira: *Groenlandaspis sp*. Antiarcha: *Remigolepis walkeri, Bothriolepis yeungae*.

References. 27, 56, 168, 169, 170, 171, 172, 173.

27. Rosebrae.

Stratigraphy/Location. Rosebrae beds, Upper Old Red Sandstone, Morayshire, Scotland. **Age.** Early Frasnian. **Environment.** Non-marine, freshwater.

Taxa. Porolepiformes: *Holoptychius nobillisimus*. Dipnoi: *Phaneropleuron sp., Rhynchodipterus elginensis, Conchodus sp*. Osteolepididae: *Glyptopomus elginensis*. Tristichopteridae: *Eusthenopteron cf. traquairi* Antiarcha: *Bothriolepis alvesiensis, Bothriolepis cristata, Bothriolepis laverocklochensis*.

Reference. 6, 174.

28. Dura Den

Stratigraphy/Location. Dura Den, Upper Old Red Sandstone, Fifeshire, Scotland. **Age.** Early Famennian. **Environment.** Non-marine, freshwater lake.

Taxa. Porolepiformes: *Holoptychius flemingii*. Dipnoi: *Phaneropleuron andersoni*. Tristichopteridae: *Heddleichthys dalgleisiensis*. Antiarcha: *Bothriolepis hydrophilus, Bothriolepis cristata*.

References. 6, 24, 174, 175. 176.

29. *Cheiloceras* Beds

Stratigraphy/Location. *Cheiloceras* beds, Holy Cross Mountains, Poland. **Age.** Early Famennian. **Environment.** Marine.

Taxa. Dipnoi: *Holodipterus kiprijanowi*. Actinistia: *Diplocercides kayseri, Diplocercides sp*. Arthrodira: *Dunkleosteus denisoni, Dunkleosteus sp., Titanichthys kozlowskii, Pachyosteus bulla, Sentacanthus zelichowskae*. Antiarcha: *Bothriolepis jazwicensis*. Elasmobranchii: *Phoebodus gothicus, Phoebodus limpidus, Phoebodus australiensis,* *Dittodus sp., Cladodus sp., Jalodus australiensis, Ctenacanthus sp*. Symmoriformes: *Danaea sp*.

References. 1, 2, 27, 39, 41, 155, 156, 165, 177, 178, 179, 180, 181, 182, 183.

30. Tervete.

Stratigraphy/Location. Skujaine river, Tervete formation, Latvia. **Age.** Early Famennian. **Environment.** Non-marine, brackish basin.

Taxa. Porolepiformes: *Holoptychius sp*. Dipnoi: *Dipterus sp., Conchodus sp*. Tristichopteridae: *Platycephalichthys skuensis*. Arthrodira: *Dunkleosteus sp*. Antiarcha: *Bothriolepis ornata, Bothriolepis jani*. Phyllolepida: *Phyllolepis tolli*. Ptyctodontida: *Chelyophorus sp*. Acanthodida: *Homacanthus sweetensis, Devononchus tenuispinus*. Tetrapoda: *Obruchevichthys gracilis*.

References. 27, 28, 36, 184, 185.

31. Oryol.

Stratigraphy/Location. Tugenevo beds/Dankoc-Lebedyan beds, Zadonckian/Plavsk regional stage, central Devonian field, Oryol, Metsensk district, Russia. **Age.** Mid Famennian. **Environment.** Non-marine, deltaic.

Taxa. Actinopterygii: *Moythomasia sp*. Onychodontida: *Strunius rolandi, Pycnacanthus fischeri*. Porolepiformes: *Glyptolepis dellei*. Dipnoi: *Holodipterus kiprijanowi, Conchodus sp., Jarvikia lebedevi, Orlowichthys limnatus*. Osteolepididae: *Glyptopomus bystrowi, Cryptolepis grossi, Thaumatolepis edelsteini*. Arthrodira: Unnamed pachyosteomorph. Antiarcha: *Bothriolepis siberica, Remigolepis armata, Livnolepis zadonica, Rossolepis brodensis*. Ptyctodontida: *Chelyphorus verneuli*, *Ptyctodus major*. Elasmobranchii: *Tuberospina nataliae*. Symmoriformes: *Symmorium glabrum*. Ischnacanthida: Unnamed Ischnacanthid. Acanthodida: *Devononchus sp*., *Acanthodes lopatini*. Tetrapoda: *Jakubsonia livnensis*.

References. 1, 27, 28, 29, 36, 93, 186, 187, 188.

32. Portishead.

Stratigraphy/Location. Woodhill Bay Fish Bed, Upper Old Red Sandstone, Portishead, Avon, England. **Age.** Mid Famennian. **Environment.** Non-marine, alluvial plain.

Taxa. Porolepiformes: *Holoptychius giganteus, Holoptychius nobilissimus*. Dipnoi: *Conchodus sp*. Osteolepididae: *Glyptopomus kinnairdi*. Rhizodontida: *Sauripterus anglicus*. Arthrodira: *Groenlandaspis disjectus*. Antiarcha: *Bothriolepis hydrophila, Asterolepis maxima*. Phyllolepida: *Phyllolepis concentrica*.

References. 6.

33. Aina Dal

Stratigraphy/Location. Aina Dal Formation, Celsius Bjerg Group, East Greenland. **Age.** Late Famennian. **Environment.** Non-marine, fluvial.

Taxa. Porolepiformes: *Holoptychius sp.,* Dipnoi: *Jarvikia arctica*, *Soederberghia groenlandica*. Tristichopteridae: Unnamed tristichopterid Arthrodira: Unnamed arthrodire. Antiarcha: *Remigolepis tuberculata, Bothriolepis nielseni, Remigolepis kullingi, Remigolepis kochi, Remigolepis cristata*. Phyllolepida: *Phyllolepis nielseni*. Acanthodida: Unnamed acanthodid. Tetrapoda: *Acanthostega gunnari, Ichythyostega stensioei,* Tetrapoda nov. gen. et. sp.

Reference. 160.

34. Britta Dal

Stratigraphy/Location. Britta Dal Formation, Celsius Bjerg Group, East Greenland. **Age.** Late Famennian. **Environment.** Non-marine, fluvial.

Taxa. Porolepiformes: *Holoptychius sp*. Dipnoi: *Jarvikia arctica, Oervigia nordica*, Unnamed dipnoan. Tristichopteridae: *Eusthenodon waengsjoei*. Arthrodira: *Groenlandaspis mirabilis,* Unnamed arthrodire 1, Unnamed arthrodire 2 Antiarcha: *Remigolepis kochi, Remigolepis cristata, Remigolepis acuta, Remigolepis incisa*. Elasmobranchii: Unnamed elasmobranch. Acanthodida: Unnamed acanthodid. Tetrapoda: *Acanthostega gunnari, Ichthyostega eigili,* Tetrapoda nov. gen. et. sp.

Reference. 160.

35. Grenfell

Stratigraphy/Location. Hunter Siltstone, Hervey Group, Grenfell, New South Wales, Australia. **Age.** Late Famennian. **Environment.** Non-marine, lacustrine.

Taxa. Dipnoi: *Adelargo schultzei*. Osteolepididae: *Grenfellia meemanae*. Tristichopteridae: *Eusthenodon gavini, Yambira thomsoni*. Arthrodira: *Groenlandaspis sp*. Antiarcha: *Bothriolepis grenfellensis, Remigolepis redcliffensis,* Grenfellaspis *branagani*. Acanthodida: *Grenfellacanthus zerinae*.

References. 189, 190, 191, 192, 193.

36. Hyner

Stratigraphy/Location. Red Hill, Duncannon Member, Catskill Formation, Hyner, Pennsylvania. **Age.** Late Famennian. **Environment.** Non-marine, fluvial.

Taxa. Actinopterygii: *Limnomis delaneyi*. Porolepiformes: *Holoptychius sp*. Dipnoi: Unnamed dipnoan 1, Unnamed dipnoan 2. Osteolepididae: *Glyptopomus sayerei* Tristichopteridae: *Hyneria lindae*. Megalichthyidae: Megalichthyid sp. nov. Rhizodontidae: Rhizodontidae gen. et sp. nov., *Sauripterus taylori*. Arthrodira: *Groenlandaspis pennsylvanica, Turrisaspis elektor*. Antiarcha: *Bothriolepis minor,* *Bothriolepis nitida*. Phyllolepida: *Phyllolepis rossimontina, Phyllolepis concentrina, Phyllolepis woodwardi, Phyllolepis nielseni, Phyllolepis undulata*. Elasmobranchii: *Ageolodus pectinatus, Ctenacanthus nodocostatus*. Gyracanthida: *Gyracanthus sherwoodi*. Tetrapoda: *Hynerpeton bassetti, Densignathus rowei*.

References. 27, 39, 75, 163, 194, 195, 196, 197, 198.

37. Evieux

Stratigraphy/Location. Evieux Formation, Famenne, Belgium. **Age.** Late/end Famennian. **Environment.** Non-marine, coastal alluvial plain.

Taxa. Actinopterygii: *Osorioichthys marginus*. Porolepiformes: *Holoptychius sp., Glyptolepis sp*. Dipnoi: *Jarvikia sp., Soederberghia sp*. Osteolepididae: *Glyptopomus sp*. Tristichopteridae: *Langliera socqueti, Eusthenodon waengsjoei, Platycephalichthys sp*. Megalichthyidae: *Megalichthyes sp*. Rhizodontida: *Strepsodus sp*. Arthrodira: *Dunkleosteus belgicus, Ardennosteus ubaghsi, Deirosteus omaliusi, Groenlandaspis thorezi,* Unnamed coccosteid. Antiarcha: *Bothriolepis lohesti, Bothriolepis sp*. Phyllolepida: *Phyllolepis konincki*. Elasmobranchii: *Goodrichthys sp*. Ischnacanthida: *Onchus latus*. Tetrapoda: Unnamed Ichthyostegid.

References. 27, 199, 200, 201, 202, 203, 204, 205, 206.

38. Ketleri

Stratigraphy/Location. Ketleri outcrop, Ketleri Formation, Venta River, Latvia. **Age.** Late/end Famennian. **Environment.** Non-marine, shallow tidal.

Taxa. Onychodontida: *Onychodus sp*. Porolepiformes: *Holoptychius nobilissimus*. Dipnoi: *Orlovichthys limnatus, Latvius obrutus*. Osteolepididae: *Glyptopomus bystrowi, Cryptolepis grossi*. Tristichopteridae: *Ventalepis ketleriensis*. Arthrodira: *Stenosteus sp*. Antiarcha: *Bothriolepis ciecere*. Acanthodida: *Devononchus ketleriensis, Devononchus tenuispinus*. Tetrapoda: *Ventastega curonica*.

References. 27, 28, 32, 36, 184, 185, 195, 207, 208.

39. Tafilalt

Stratigraphy/Location. Tafilalt Basin Limestone, Anti-Atlas Mountains, Southern Morocco. **Age.** Late/end Famennian. **Environment.** Marine, open marine.

Taxa. Actinopterygii: Unnamed actinopterygian. Tristichopteridae: Unnamed eusthenopterid. Actinistia: Unnamed actinistian. Arthrodira: *Dunkleosteus marsaisi, Tafilalichthys lavocati*, *Titanicthys termieri*. Elasmobranchii: *Cobelodus sp., Thrinacodus tranquillus, Protacrodus, Jalodus sp., Siamodus janvieri*. Symmoriformes: *Stethacanthus resistens, Denaea sp*.

References. 27, 31, 183, 209, 210, 211, 212.

40. Andreyevka-2

Stratigraphy/Location. Andreyevka-2, Khovanshshina Beds, Zovalzkh Formation, Tula, Siberia. **Age.** Late/end Famennian. **Environment.** Nonmarine, estuarine, epicontinental brackish basin.

Taxa. Actinopterygii: *Moythomasia sp*. Onychodontida: *Strunius sp*. Porolepiformes: *Holoptychius nobilissimus*. Dipnoi: *Andreyevichthys epitomus*. Osteolepididae: *Chrysolepis orlensis*. Tristichopteridae: *Eusthenodon sp. nov*. Megalichthyidae: *Megistolepis sp*. Antiarcha: *Remigolepis armata, Bothriolepis sp*. Holocephali: Unnamed eugeneodont. Ischnacanthida: *Onchus latus*. Acanthodida: *Devononchus laevis, Devononchus concinnus, Cheiracanthus sp*. Tetrapoda: *Tulerpeton curtum*.

References. 27, 28, 36, 213, 214, 215.

41. Cleveland Shale

Stratigraphy/Location. Cleveland Shale Member, Ohio Shale, Cleveland, Ohio. **Age.** Late/end Famennian. **Environment.** Marine, open marine.

Taxa. Actinopterygii. *Tegeolepis clarki, Kentuckia hlavini*. Dipnoi: *Proceratodus wagneri*. Arthrodira: *"Hoplonchus" sp., Coccosteus cuyahogae, Gorgonichthys clarki, Heintzichthys gouldii, Holdenius holdeni, Hussakofia minor, Gymnotrachelus hydei, Paramylostoma arcualis, Selenosteus brevis*, *Stenosteus angustopectus*, *Stenosteus glaber, Mylostoma variabile, Mylostoma eurhinus, Mylostoma newberryi, Titanichthys agassizi, Titanichthys attenuatus, Titanichthys clarkii, Titanichthys hussakofi, Titanichthys rectus, Titanichthys sp., Bungartius perissus, Callognathus regularis, Diplognathus mirabilis, Glyptaspis verrucosa, Trachosteus clarki, Dinognathus eurhinus*, *Dunkleosteus terrelli* , *Brontichthys clarki*. Elasmobranchii: *Cladoselache fyleri, Cladoselache clarki, Cladoselache kepleri, Cladoselache pattersoni, Ctenacanthus compressus, Ctenacanthus clarki, Tamiobatus vestustus, Phoebodus heslerorum*, *Diademodus hydei, Diademodus utahensis, Orodus sp., Phoebodus politus*. Symmoriformes: *Stethacanthus sp*.

References. 27, 75, 148, 165, 216, 217, 218, 219, 220.

42. Chaffee

Stratigraphy/Location. Fossil Ridge, Parting Formation, Chaffee Group, Gunnison County, Colorado. **Age.** Late/end Famennian. **Environment.** Marine, shallow continental shelf.

Taxa. Onychodontida: Unnamed onychodont. Porolepiformes: *Holoptychius giganteus*. Dipnoi: *Dipterus johnsoni, Conchodus parvulus, Soederberghia sp*. Osteolepididae: *Gyroptychius sp., Litoptychius bryanti*. Arthrodira: *Aspidichthys sp., Dinichthys tuberculatus,* Unnamed arthrodire. Antiarcha: *Bothriolepis coloradensis*. Elasmobranchii: *Ctenacanthus sp*. Holocephalii: *Sandalodus minor*.

References. 27, 221, 222, 223, 224. 225.

43. Witpoort

Stratigraphy/Location. Witpoort Formation, Witteberg Group, Cape Supergroup, Grahamstown, South Africa. **Age.** Late/end Famennian. **Environment.** Non-marine, estuarine, brackish lagoon.

Taxa. Actinopterygii: Unnamed actinopterygian. Dipnoi: *Andreyevichthys sp*. Tristichopteridae: *Eusthenodon sp*. Actinistia: *Diplocercides sp*.. Arthrodira: *Groenlandaspis riniensis, Africanaspis doryssa, Tiaraspis sp*. Antiarcha: *Bothriolepis africana*. Ptyctodontida: Unnamed ptyctodontid. Other Placodermi: Unnamed macropetalichthyid. Elasmobranchii: *Plesioselachus macracanthus*. Climatiida: *Diplacanthus acus*. Gyracanthida: *Gyracanthides warreni*. Tetrapoda: Unnamed elpistostegelian.

References. 226, 227, 228, 229, 230, 231.

D. Tournaisian Sites

44. Horton Bluff

Stratigraphy/Location. Horton Bluff and Albert Formations, Bay of Fundy, Canada. **Age**. Early/mid-Tournaisian. **Environment.** Non-marine, lacustrine with marine influence.

Taxa. Actinopterygii: *Elonichthys ellsi, Elonichthys browni, Elonichthyes sp., Rhadinichthys alberti, Rhadinichthys sp., Acrolepis hortonensis, Palaeoniscus sp*. Dipnoi: Unnamed ctenodont. Rhizodontida: *Letognathus hardingi*. Symmoriformes: *Stethacanthus sp*. Gyracanthida: *Gyracanthides sp*. Acanthodidae: *Acanthodes sp*. Tetrapoda: Unnamed anthracosaur.

References. 232, 233, 234, 235, 236.

45. Izkchul Village

Stratigraphy/Location. Izkchul Village Fish Horizon, Lower Os'kin/Bystraya/Bystr'anskaya Formation, Minussinsk Depression, Siberia. **Age.** Early/mid-Tournaisian. **Environment.** Non-marine, brackish lagoon or lake.

Taxa. Actinopterygii: *Oxypteriscus minimus, Ministrella longicaudata, Palaeobergia microlepis, Bishofia lucida, Aetheretmon sp., Ganolepis gracilis, Gyrolepidotus schmidtii, Grassator bidens*. Megalichthyidae: *Rhizodopsis savenkovi, Greiserolepis minusensis*. Rhizodontida: *Pyncnotenion sibiriacus*. Elasmobranchii: *Ctenacanthus peregrinus, Cladodus sp*. Acanthodida: *Acanthodes lopatini*.

References. 29, 30, 39, 237, 238, 239, 240.

46. Mansfield

Stratigraphy/Location. Broken River fish fauna, Devil's Plain Formation, Mansfield Group, Mansfield Basin, Victoria, Australia. **Age.** Early/mid-Tournaisian. **Environment.** Non-marine, fluvial, floodplain.

Taxa. Actinopterygii: *Novogonatodus kasantsevae, Mansfieldiscus sweeti, Mansfieldiscus gibbus*. Dipnoi: *Delatitia breviceps*. Rhizodontida: *Barameda decipiens*. Elasmobranchii: *Tristychius sp., Ctenacanthus sp., Ageleodus altus*. Gyracanthida: *Gyracanthus murrayi*. Acanthodida: *Acanthodes australis, Eupleurogmus cresswelli*.

References. 71, 241, 242, 243, 244, 245

47. Foulden

Stratigraphy/Location. Foulden fish beds, Cementstone Group, Berwickshire, Scotland. **Age.** Mid/late Tournaisian. **Environment.** Non-marine, brackish alluvial, lacustrine.

Taxa. Actinopterygii: *Styracopterus fulcratus, Phanerosteon ovensi, Strepheoschema fouldensis, Aetheretmon valentiacum, Cosmoptychius striatus, Rhadinichthys sp*. Dipnoi: Unnamed dipnoan. Rhizodontida: *Strepsodus aulaconamensis, Strepsodus nov. sp*. Actinistia: *Rhabdoderma sp*. Holocephalii: *Lophosteus sp*. Gyracanthida: *Gyracanthides sp*. Acanthodida: *Acanthodes ovensi*. Tetrapoda: Unnamed anthracosaur.

References. 6, 24, 246, 247. 248.

48. Herbesskaya

Stratigraphy/Location. Senek and Ortokhodan Creeks, Herbesskaya Formation, Shagonar City, Tuva, Western Siberia. **Age.** Late Tournaisian. **Environment.** Marine, shallow sea.

Taxa. Actinopterygii: *Senekichthys hirundo, Ganolepis sp., Actinopterygii nov. gen. et sp., Grassator sp*. Megalichthyidae: *Rhizodopsis savinkovi*. Rhizodontida: *Pycnotenion sibiriacus*. Elasmobranchii: *Psammodus linearis, Lagarodus angustus, "Ctenacanthus" (Hybodus) panderi, Cladodus sp*. Holocephali: *Helodus antiquissimus, Helodus contractus, Psephodus dentatus*. Acanthodida: *Acanthodes lopatini*.

References. 39, 147, 239, 249.

E. Viséan Sites

49. Waaipoort

Stratigraphy/Location. Waaipoort Formation, Lake Mentz Subgroup, Witteberg Group, Cape Supergroup, South Africa. **Age.** Early Viséan. **Environment.** Non-marine, lacustrine.

Taxa. Actinopterygii: *Adroichthys tuberculatus, Mentzichthys walshi, Mentzichthys jubbi, Mentzichthys maraisi, Mentzichthys theroni, Aestaurichthys fulcratus,* *Soetendalichthys cromptoni, Australichthys longidorsalis, Willomorichthys striatulus, Sundayichthys elegantulus, Dwykia analensis*. Elasmobranchii: Unnamed protoacrodontid. Gyracanthida: *Gyracanthides sp*., *Gyracanthus sp*. Acanthodida: *Acanthodes sp*.

References. 230, 250, 251, 252.

50. Glencartholm

Stratigraphy/Location. Glencartholm Fish Bed, Dumfiresshire, Scotland. **Age.** Mid Viséan. **Environment.** Marine, nearshore marine.

Taxa. Actinopterygii: *Protoeurynotus traquairi, Paramesolepis tuberculatus*, *Platysomus superbus*, *Cheirodopsis geikiei, Rhadinichthys canobiensis, Rhadinichthys macconochii*, *Rhadinichthys fusiformis*, *Rhadinichthys formosus*, *Rhadinichthys tuberculatus*, *Rhadinichthys sp*., *Cycloptychius concentricus, Mesopoma politum, Mesopoma pulchellum, Mesopoma crassum, Mesopoma macrocephalum, Canobius ramseyi, Canobius elegantulus, Canobius sp., Elonichthys serratus, Elonichthys pulcherrimus, Acrolepis ortholepis, Phanerosteon mirabile, Holurus parki, Styracopterus fulcratus, Tarrasius problematicus*. Megalichthyidae: *Megalichthys sp*. Rhizodontida: *Archichthys portlocki, Strepsodus saurroides*. Actinistia: *Dumfregia huxleyi*. Elasmobranchii: *Goodrichichthys eskdalensis, Onychoselache traquairi, Sphenacanthus costellatus*. Holocephalii: *Deltoptychius armigerus, Antliodus scoticus, Chondrenchelys problematica*. Acanthodida: *Acanthodes nitidus*.

References. 1, 6, 10, 24, 39, 148, 253, 254, 255.

51. Burdiehouse

Stratigraphy/Location. Burdiehouse limestone, Edinburgh, Scotland. **Age.** Mid Viséan. **Environment.** Non-marine, lacustrine, alluvial.

Taxa. Actinopterygii: *Elonichthys robinsoni, Elonichthys bucklandi, Elonichthys striatulus, Rhadinichthys ornatissimus, Nematoptychius greenocki*, *Gonatodus punctatus, Eurynotus crenatus, Elonichthys ovatus, Elonichthys striolatus*. Dipnoi: *Uronemus lobatus, Ctenodus sp*. Megalichthyidae: *Megalichthys laticeps*. Rhizodontida: *Rhizodus hibberti, Screbinodus ornatus*. Elasmobranchii: *Cladodus hibberti, Cladodus parvus, Diplodus minutus, Ptyctacanthus sublaevis, Sphenacanthus serratulus, Ageolodus pectinatus*. Gyracanthida: *Gyracanthides rectus*. Acanthodida: *Acanthodes sulcatus*. Tetrapoda: *Pholidogaster pisciformis, Dolichopareias disjectins*.

References. 6, 24, 41, 148, 256, 257, 258. 259, 260.

52. Ducabrook (**Note:** Locality does not meet the dataset criteria, but is included here due to its high profile and importance to tetrapod workers)

Stratigraphy/Location. Middle Paddock Tetrapod Unit, Ducabrook Formation, Drummond Basin, Queensland, Australia. **Age.** Mid-Viséan. **Environment.** Non-marine, estuarine.

Taxa. Actinopterygii: *Elonichthys sp.,* Unnamed actinopterygian. Dipnoi: *Ctenodus sp.* Rhizodontida: *Strepsodus sp.* Elasmobranchii: Unnamed xenacanth, Unnamed hybodont, *Ageolodus sp., Psammodus sp.* Gyracanthida: *Gyracanthides hawkinsi.* Tetrapoda: *Ossinodus pueri.*

References. 260, 261, 262, 263, 264, 265, 266.

53. Wardie

Stratigraphy/Location. Wardie Shales, Lower Lothian Group, Lothian, Scotland. **Age.** Late Viséan. **Environment.** Non-marine, brackish lagoon.

Taxa. Actinopterygii: *Cosmoptychius striatus, Nematoptychius greenocki, Elonichthys robinsoni, Elonichthys striatulus, Gonatodus punctatus, Eurynotus crenatus, Wardichthys cyclosoma, Rhadinichthys brevis, Rhadinichthys carinatus, Rhadinichthys ferox, Rhadinichthys orenatissimus, Chirodus sp.* Dipnoi: Unnamed dipnoan. Megalichthyidae: *Megalichthys sp.* Rhizodontida: *Rhizodus hibberti.* Elasmobranchii: *Onychoselache traquari, Sphenacanthus serrulatus, Ctenacanthus sp., Diplodoselache woodi.* Acanthodida: *Acanthodes sulcatus.* Tetrapoda: *Lethiscus stocki.*

Reference. 6.

54. Cheese Bay

Stratigraphy/Location. Cheese Bay Shrimp Bed, Gullane Formation, Lower Oil Shale Group, Calciferous Sandstone Series, East Lothian, Scotland. **Age.** Late Viséan. **Environment.** Non-marine, brackish pools.

Taxa. Actinopterygii: *Gonatodus punctatus, Elonichthys robinsoni, Elonichthys intermedius, Cosmoptychius striatus, Nematoptychius greenocki, Rhadinichthys brevis, Rhadinichthys elegantulus, Rhadinichthys formosus, Rhadinichthys ornatissimus, Wardichthys cyclosoma.* Rhizodontida: *Rhizodus hibberti.* Actinistia: *Rhabdoderma sp.* Acanthodida: *Acanthodes sp.* Tetrapoda: *Casineria kiddi.*

References. 6, 267.

55. East Kirkton

Stratigraphy/Location. East Kirkton Limestone, West Lothian Oil Shale Formation, Bathgate, Lothian, Scotland. **Age.** Late Viséan. **Environment.** Non-marine, lacustrine.

Taxa. Actinopterygii: *Elonichthys robinsoni, Cosmoptychius sp., Watsonichthys sp., Rhadinichthys carinatus, Mesopoma sp., Eurynotus sp.,* Unnamed actinopterygian. Rhizodontida: Unnamed rhizodont. Elasmobranchii: *Tristychius arcuatus, Diplodocanthus woodi.* Gyracanthida: Unnamed gyracanthid. Acanthodida: *Acanthodes sp.* Tetrapoda: *Eucritta melanolimnetes*, *Balanerpeton woodi*, *Ophiderpeton kirktonense*, *Eldeceeon rolfei*, *Silvanerpeton miripedes*, *Westlothiana lizziae.*

References. 6, 268, 269.

56. Gilmerton

Stratigraphy/Location. Gilmerton Blackband Ironstone, Gilmerton, Scotland. **Age.** Late Viséan. **Environment.** Non-marine, lacustrine, alluvial.

Taxa. Actinopterygii: *Elonichthys robinsoni, Pseudogonatodus macrolepis, Eurynotus crenatus*. Dipnoi: *Uronemus splendens, Ctenodus interruptus, Sagenodus quinquecostatus*. Megalichthyidae: *Megalichthys sp*. Rhizodontida: *Screbinodus ornatus, Rhizodus hibberti*. Holocephali: *Harpacanthus fimbriatus*. Acanthodida: *Acanthodes sp*. Tetrapoda: *Crassigyrinus scoticus, Eoherpeton watsoni, Loxomma allmanni, Pholidogaster pisciformis*.

References. 6, 24, 235, 259, 260, 269, 270, 271, 272.

57. Ardross Castle

Stratigraphy/Location. *Crangopsis* Beds, Calciferous Sandstone Series, Ardross Castle, Fife, Scotland. **Age.** Late Viséan. **Environment.** Marine, marine forms stranded in a saline lagoon.

Taxa. Actinopterygii: *Rhadinichthys carinatus, Rhadinoniscus wrighti, Elonichthys robinsoni, Watsonichthys pectinatus, Chirodus crassus*. Actinistia: *Rhabdoderma ardrossense, "Coelacanthopsis" curta*. Elasmobranchii: *Euphyacanthus semistriatus*. Holocephali: *Deloptychius armigerus, Eucentrurus paradoxus,* Unnamed helodont. Acanthodida: *Acanthodes sulcatus*.

Reference. 6.

58. Abden

Stratigraphy/Location. Abden Bone Bed, Calciferous Sandstone Series, Fife, Scotland. **Age.** Late Viséan. **Environment.** Marine, open marine.

Taxa. Actinopterygii: *Chirodus crassus, Eurynotus crenatus, Nematoptychius greenocki, Elonichthys robinsoni*. Rhizodontida: *Archichthys (Strepsodus) portlocki*. Actinistia: *Diplocercides davisi*. Elasmobranchii: *Tristychius arcuatus*. Holocephalii: *Deltoptychius armigerus*. Acanthodida: *Acanthodes sp*.

References. 6, 24, 235, 272.

59. Inchkeith

Stratigraphy/Location. Inchkeith, Upper Oil Shale Group, Firth of Forth, Fife, Scotland. **Age.** Late Viséan. **Environment.** Non-marine, lacustrine.

Taxa. Actinopterygii: *Psuedogonatodus sp., Elonichthys robinsoni, Nematoptychius sp., Eurynotus sp*. Dipnoi: *Sagenodus sp., Uronemus sp*. Rhizodontida: *Strepstodus sp., Rhizodus hibberti*. Elasmobranchii: *Ageleodus sp., Cynopodius crenulatus, Pleuracanthus sp*. Gyracanthida: *Gyracanthus sp*. Tetrapoda: *Doragnathus woodi, Palaeomolgophis*.

References. 6.

F. Serpukhovian Sites

60. Bearsden

Stratigraphy/Location. Manse Burn Formation, Bearsden, Scotland. **Age.** Early Serpukhovian. **Environment.** Marine, coastal.

Taxa. Actinopterygii: *Mesopoma carricki, Mesopoma smithsoni, Mesopoma pancheni, Frederichthys musadentatus, Melanecta anneiae, Woodichthys bearsdeni*, *Chirodus crassus,* Actinopterygii gen. et sp. nov., *Watsonichthys sp.,* Unnamed actinopterygian 1(MIC pers. obs.), Unnamed actinopterygian 2 (MIC pers. obs.). Rhizodontida: Unnamed rhizodont. Actinistia: Unnamed coelacanth. Elasmobranchii: *Tristychius arcuatus, Onychoselache traquairi*. Symmoriformes: *Akmonistion zangerli* Holocephali: *Deltoptychius sp.,* Unnamed menaspid. Acanthodida: *Acanthodes sulcatus*.

References. 6, 273, 274, 275, 276, 277.

61. Chokier

Stratigraphy/Location. Chokier Formation, Belgium. **Age.** Early Serpukhovian. **Environment.** Marine, open marine.

Taxa. Actinopterygii: *Elonichthys robinsoni, Mesonichthys aitkeni, Rhadinichthys raineri*. Actinistia: *Rhabdoderma corneti, Rhabdoderma stensioei*. Holocephali: *Physonemus konincki*.

References. 205, 206.

62. Loanhead

Stratigraphy/Location. Burghlee Ironstone, Limestone Coal Group, Loanhead, Midlothian, Scotland. **Age.** Mid Serpukhovian. **Environment.** Non-marine, lacustrine.

Taxa. Actinopterygii: *Cryphiolepis striatus, Drydenius insignis*, *Elonichthys robinsoni, Protohaplolepis scotica, Nematoptychius greenocki, Pseudogonatodus parvidens, Eurynotus crenatus, Blairolepis loanheadensis, Watsonichthys pectinatus*. Dipnoi: *Ctenodus sp., Uronemus splendens, Sagenodus quinquecostatus*. Megalichthyidae: *Rhizodopsis sp*. Rhizodontidae: *Rhizodus hibberti, Screbinodus ornatus, Strepsodus sauroides , Strepsodus striatulus*. Elasmobranchii: *Pleuracanthus gracillimus, Pleuracanthus horridulus, Pleuracanthus elegans, Cynopodius crenulatus, Dicentrodus bicuspidatus, Diplodus parvulus*. Holocephali: *Euctenius elegans, Euctenodopsis tenuis*. Gyracanthida: *Aganacanthus striatulus, Gyracanthus nobilis, Gyracanthus youngi*. Acanthodida: *Acanthodes sp*. Tetrapoda: *Caerorhachis bairdi,* Unnamed aistopod, *Eoherpeton watsoni, Acheroniscus caledoniae, Adelogyrinus sp*., *Doragnathus woodi, Loxomma sp., Papposaurus traquair, Spathicephalus mirus*.

References. 6, 24, 28, 41, 148, 259, 260, 262, 271, 277, 278, 279, 280, 281, 282.

63. Niddrie

Stratigraphy/Location. Niddrie Colliery Shale overlying South Parrot Coal Seam, Upper Limestone Group, Niddrie, Lothian, Scotland. **Age.** Mid Serpukhovian. **Environment.** Non-marine, lacustrine, coal swamp.

Taxa. Dipnoi: *Ctenodus interruptus*. Rhizodontida: *Strepsodus sauroides, Rhizodus hibberti, Archichthys sulcidens*. Gyracanthida: *Gyracanthus youngi*. Tetrapoda: *Adelogyrinus sp., Doracanthus woodi*. Unnamed anthracosaur.

References. 6, 260, 262, 281.

64. Millstone Grit

Stratigraphy/Location. Millstone Grit, Summit, Lancashire, England. **Age.** Late Serpukhovian. **Environment.** Marine, coastal marine.

Taxa. Actinopterygii: *Rhadinichthys planti, Rhadinichthys microdon, Rhadinichthys monensis, Rhadinichthys elegans, Elonichthys aitkeni, Elonichthys caudalis, Elonichthys oblongus, Acrolepis hopkinsi, Elonichthys obliquus, Elonichthys ornatus, Platysomus sp*. Dipnoi: *Sagenodus inequalis*. Megalichthyidae: *Megalichthys hibberti, Rhizodopsis sauroides*. Rhizodontida: *Archichthys sulcidens*. Actinistia: *"Coelacanthus" sp. nov*. Elasmobranchii: *Cladodus mirabilis, Acondylacanthus sp., Euctenodopsis tenuis, Ctenacanthus major*. Symmoriiformes: *Falcatus falcatus*. Holocephalii: *Psephodus minuta, Poecilodus jonesii, Janassa linguaeformis*. Gyracanthida: *Marsdenius summiti, Oracanthus milleri*. Acanthodida: *Acanthodes wardi, Acanthodes striatus*.

References. 283, 284, 285, 286.

65. Dora

Stratigraphy/Location. Dora Bone Bed, Limestone Bone Bed, Cowdenbeath, Fife, Scotland. **Age.** Late Serpukhovian. **Environment.** Non-marine, lacustrine, coal swamp.

Taxa. Actinopterygii: *Psuedogonatodus sp*. Rhizodontida: *Strepsodus sp*. Elasmobranchii: *Dicentrodus bicuspidatus*, *Diploselache parvulus, Xenacanthus elegans*. Gyracanthida: *Gyracanthus young, Aganacanthus striatulus*. Tetrapoda: *Eoherpeton watsoni, Proterogyrinus sp., Crassigyrinus scoticus, Doragnathus woodi, Adelogyrinus sp., Spathicephalus mirus,* Unnamed anthracosaur.

References. 6, 42, 235, 260, 281, 287, 288.

66. Bear Gulch

Stratigraphy/Location. Bear Gulch Limestone, Heath Formation, Big Snowy Group, Montana. **Age.** Late Serpukhovian. **Environment.** Marine, reef.

Taxa. Actinopterygii: *Paratarrasius hibbardi, Kalops monophrys, Kalops diophrys,* Unnamed tarrasiiform, *Aesopichthys erinaceus*, *Proceramala montanensis, Cyranorhis bergeraci, Discoserra pectinodon, Wendichthys dicksoni, Wendyichthys lautreci,* *Guildayichthys carnegiei,* Unnamed actinopterygian "*copiosus",* Unnamed actinopterygian *"brevis",* Unnamed actinopterygian *"prolatus*", *Cornuboniscus sp*., Unnamed actinopterygian "gulo", *Phanerosteon sp.,* Unnamed actinopterygian "lundae", Unnamed actinopterygian "worm tail", Unnamed actinopterygian "round tail", Unnamed actinopterygian "spike", Unnamed actinopterygian "BGLP", Unnamed actinopterygian "big antorbital", Unnamed actinopterygian "deep belly", Unnamed actinopterygian "short vertical cheek", Unnamed actinopterygian "nude cheek", Unnamed actinopterygian "horizontal cheek", Unnamed actinopterygian "fat fish", Unnamed actinopterygian "deep scale", Unnamed actinopterygian "long pelvic", Unnamed actinopterygian "barred scale", Unnamed actinopterygian "tube bod", Unnamed actinopterygian "pseudo", *Beagiascus pulcherrimus, Lineagruan snowyi, Lineagruan judithi, Platysomus sp*. Rhizodontida: *Strepsodus sp*. Actinistia: *Allenypterus montanus, Caridosuctor populosum, Hadronector donbairdi, Lochmocercus aciculodontus, Polyosteorhynchus beargulchensis,* Actinistia gen. et sp. nov. Elasmobranchii: *Heteropetalus elegantulus., Squatactinus montanus, Orodus daedalus, Orodus springeri, Orodus sp., Thrinacoselache gracia, Listracanthus sp.,* Symmoriiformes: *Damocles serratus, Falcatus falcatus, Orestiacanthus fergusi, Stethacanthus altonensis, Stethacanthus productus*. Holocephali: *Bellbonn rogaire, Gregorius rexi, Srianta dawsoni, Srianta iarlis, Srianta srianta, Debeerius ellefseni, Belantsea montana, Ctenopetalus serratus, Janassa clarki, Netsepoye hawesi, Petalorhynchus beargulchensis, Polyrhizodus digitatus, Sikisika ottae, Venustodus arguatus, Harpacanthus fimbriatus, Lisgodus sp., Delphyodontos dacriformes, Harpagofututor volsellorhinus, Echinochimaera meltoni, Echinochimaera snyderi, Traquairius agkistrocephalus, Traquairius nudus, Traquairius nitidus, Rainerichthys zengeri, Papillionichthys stahlae*. Acanthodida: *Acanthodes lundi*.

References. 44, 289, 290, 291, 292, 293, 294, 295, Carnegie Museum of Natural History Collections.

IV. Supporting Figures

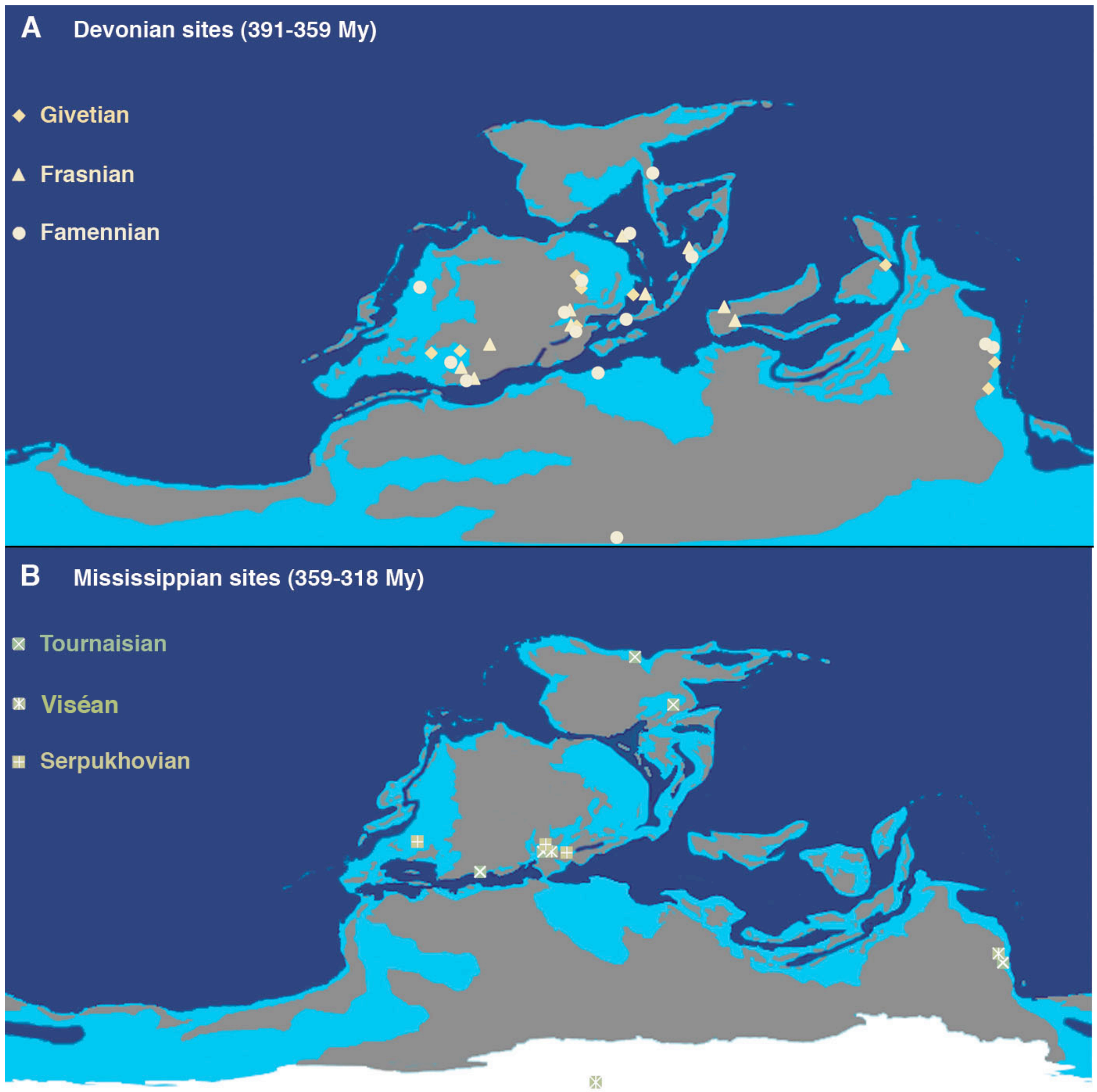

Fig. S1. Paleogeography of sampled vertebrate sites (N=66). (*A*) Devonian (~370 Ma, N=43) (*B*) Mississippian (~340 Ma, N=23). (After Blakey, 2007).

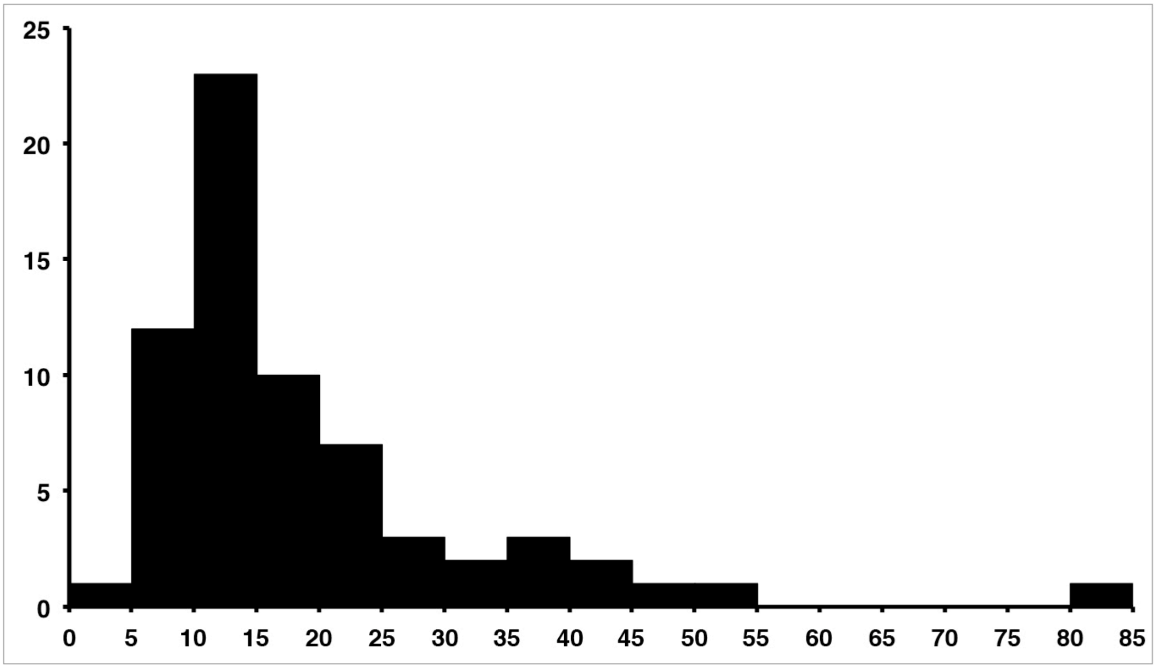

Fig. S2. Histogram of site species-level diversity (N=66, Mean=19.27, SD= 13.10, Median=15). See Table S1 for more details.

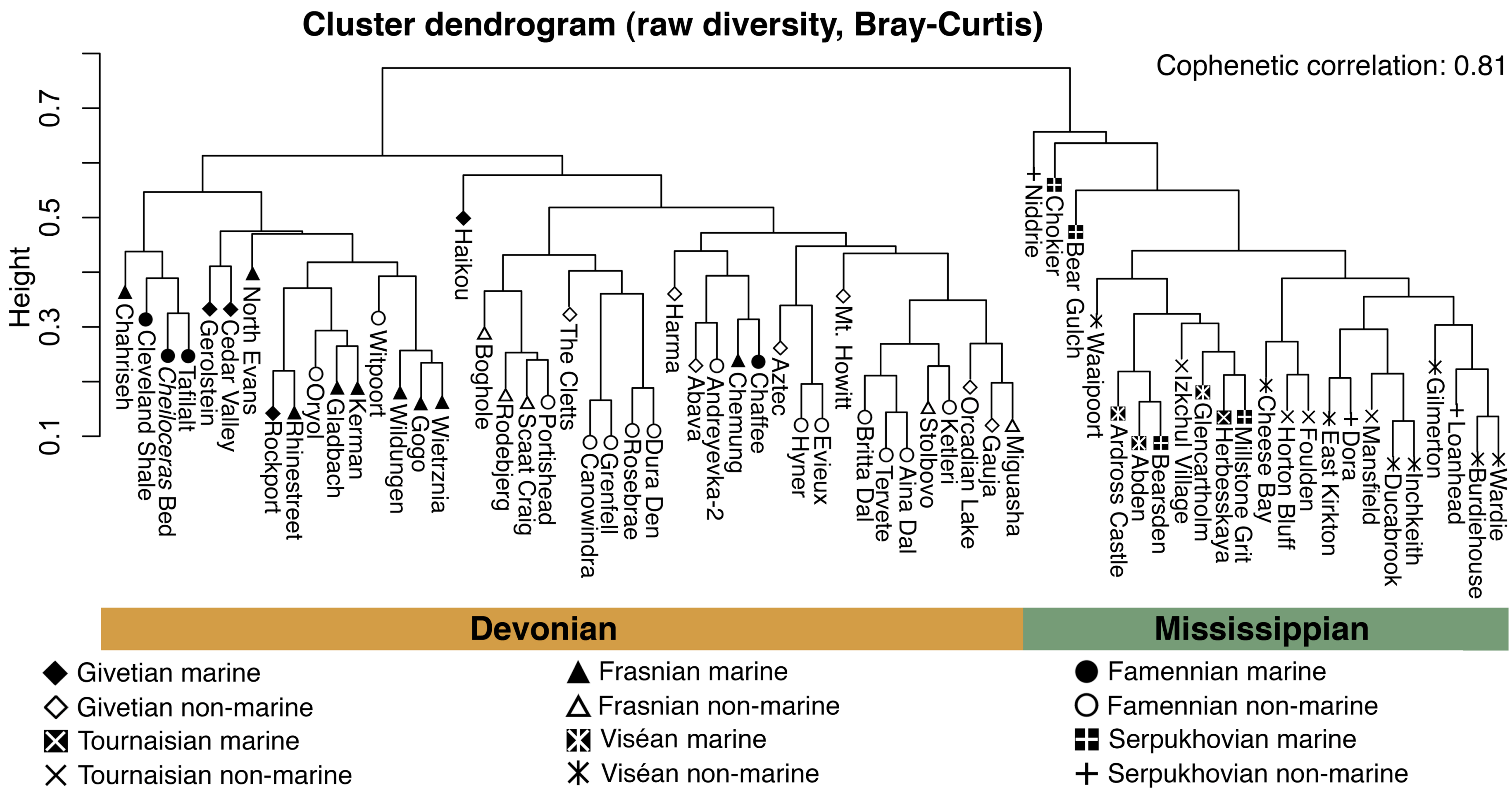

Fig. S3. Cluster dendrogram: Bray-Curtis, raw diversity. Cluster dendrogram of 66 vertebrate sites generated from the raw diversity dataset (Table S1). Sites are coded according to stage and environment. Bars mark clusters associated with geologic period.

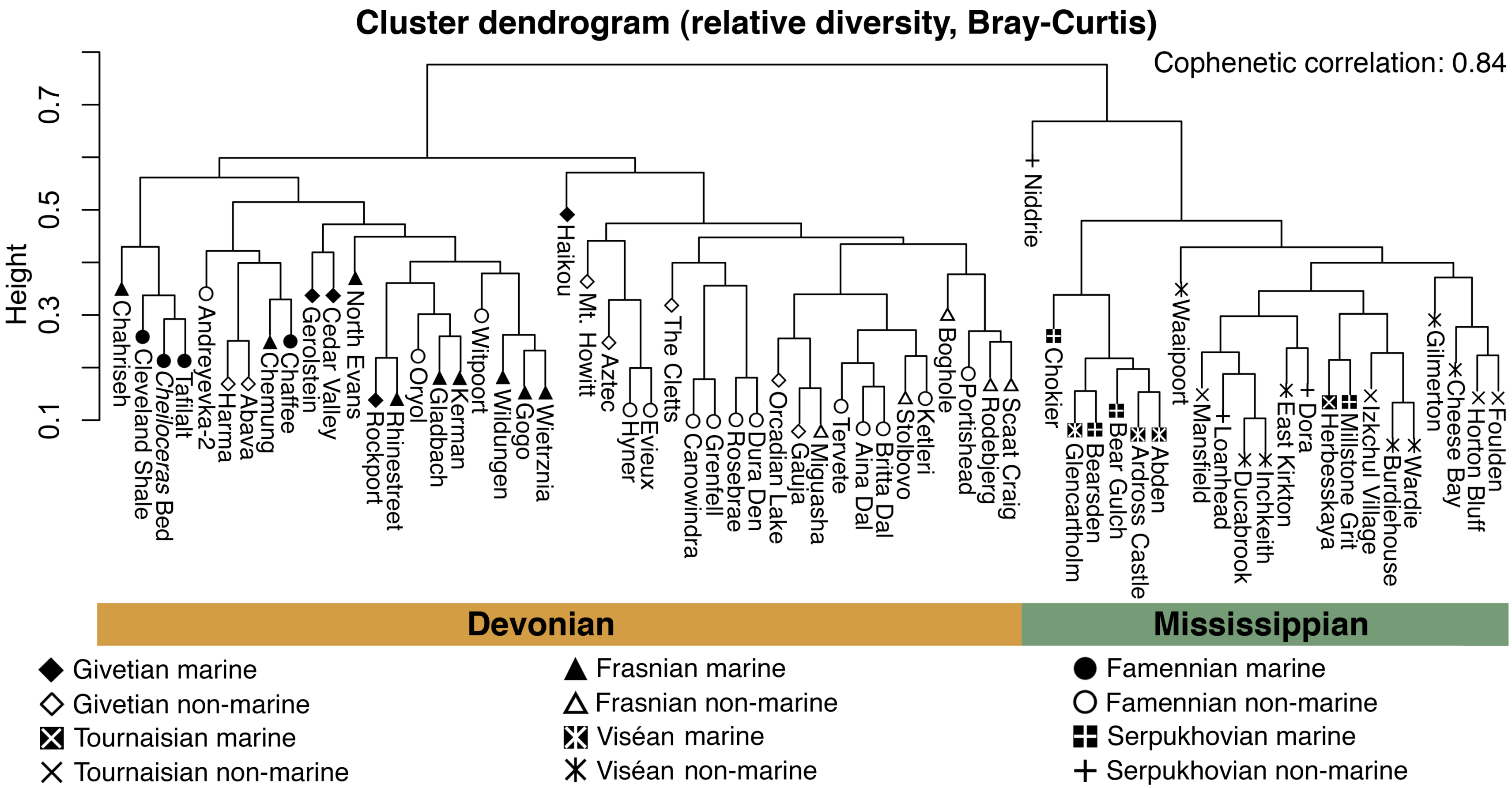

Fig. S4. Cluster dendrogram: Bray-Curtis, relative diversity. Cluster dendrogram of 66 vertebrate sites generated from the relative diversity dataset (Table S2). Sites are coded according to stage and environment. Bars mark clusters associated with geologic period.

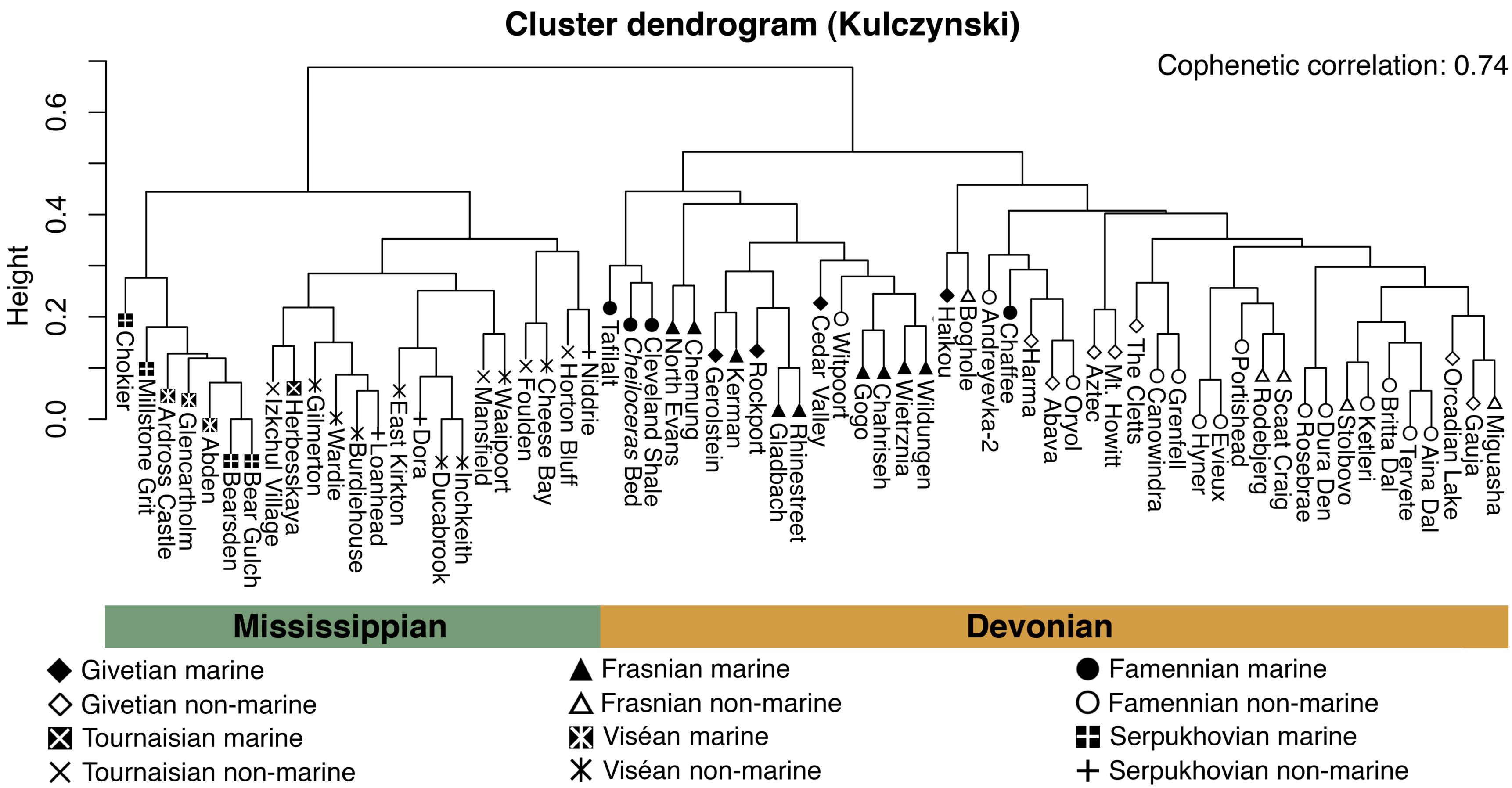

Fig. S5. Cluster dendrogram: Kulczynski similarity. Cluster dendrograms generated from raw and relative diversity were identical since they were constructed from a presence-absence metric. Sites are coded according to stage and environment. Bars mark clusters associated with geologic period.

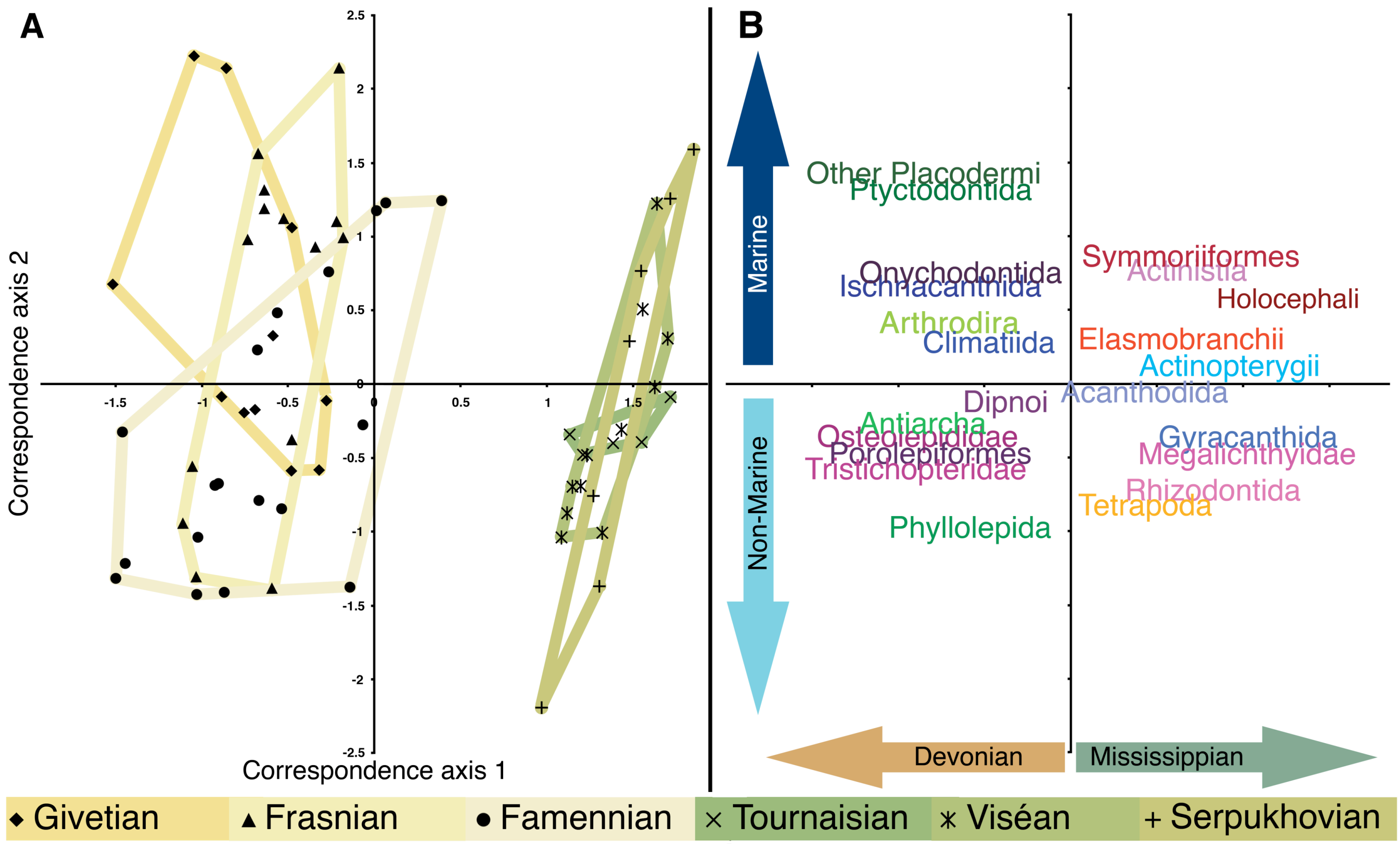

Fig. S6. CCA of relative diversity. (*A*) Site ordination plot (N=66). (*B*) taxon ordination and axis gradients (N=22). See Tables S7 and S8 for scores.

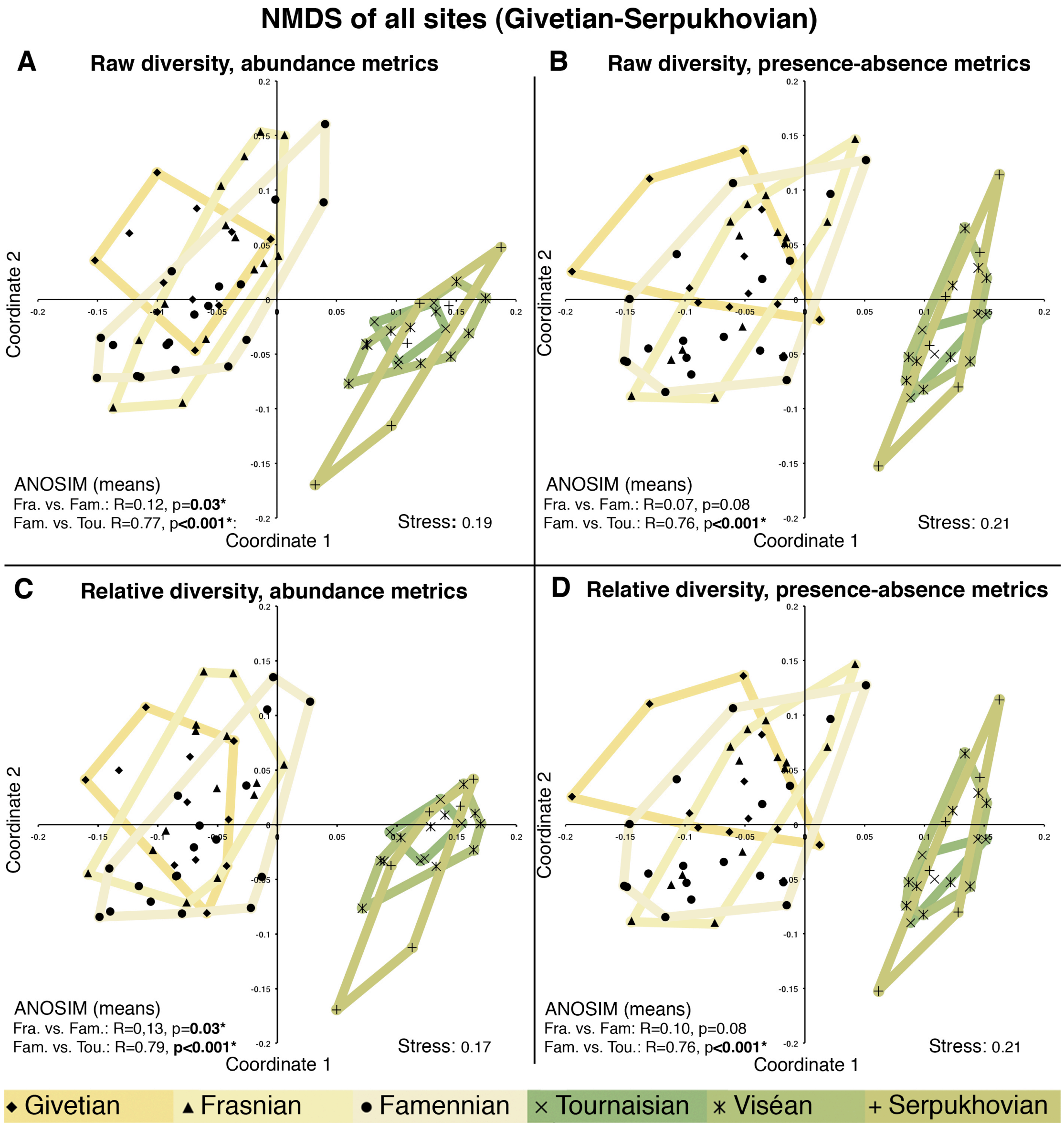

Fig. S7. NMDS plots of all sites. (*A*) NMDS plot generated from the raw diversity dataset based on Bray-Curtis distances (N=66). ANOSIM p-values for stages surrounding extinction events are the mean of those produced by all abundance-based distance measures from the appropriate dataset. Stress is a measure of difference between the rank-order of sites in the distance matrix and the rank-order generated by NMDS. This panel also appeared as text Fig. 4*A*, but is placed here for comparison to other results. (*B*) NMDS plot generated from the raw diversity dataset based on Kulczynski similarity (N=66). ANOSIM p-values for stages surrounding extinction events are the mean of those produced by all presence-absence-based distance measures from the appropriate dataset. However, the ANOSIM p-values are not, showing some further variability in the Frasnian-Famennian signal. (*C*) NMDS plot generated from the relative diversity dataset based on Bray-Curtis distances (N=66). (*D*) NMDS plot generated from the relative diversity dataset based on Kulczynski similarity. It is identical to S7*B* (N=66).

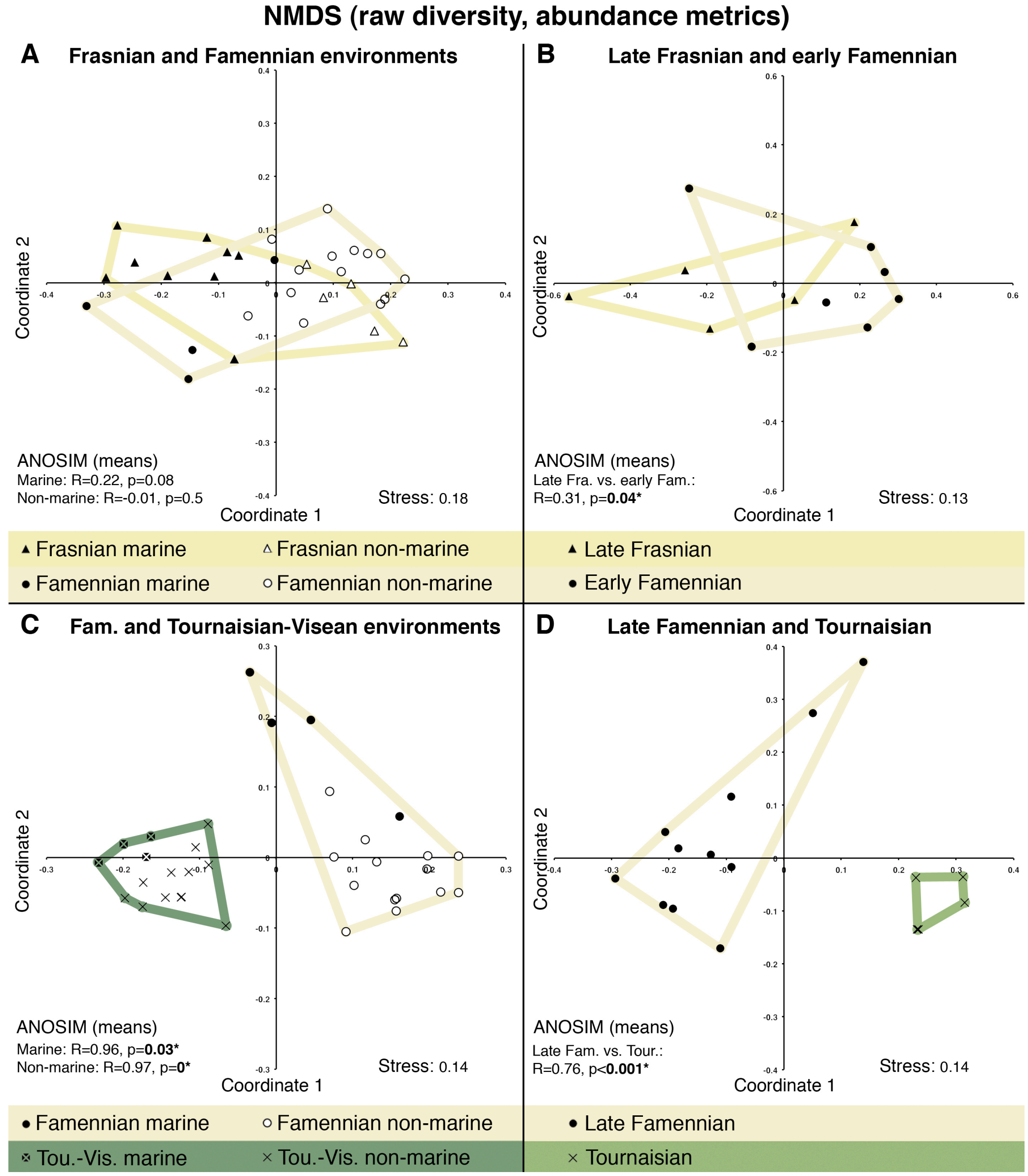

Fig. S8. NMDS of restricted intervals: Bray-Curtis distances, raw diversity. ANOSIM values are the mean of all abundance metric values (Tables S11 and S12). (*A*) NMDS plot of Frasnian and Famennian sites marked by environment (N=32). This panel also appeared as Fig. 4*C*, and is included here for comparison (*B*) NMDS plot of late Frasnian and early Famennian sites (N=13). (*C*) NMDS plot of Famennian and Tournaisian-Viséan sites marked by environment (N=34). (*D*) NMDS plot of late Famennian and Tournaisian sites (N=16). This panel also appeared as Fig. 4*D* and is included here for comparison.

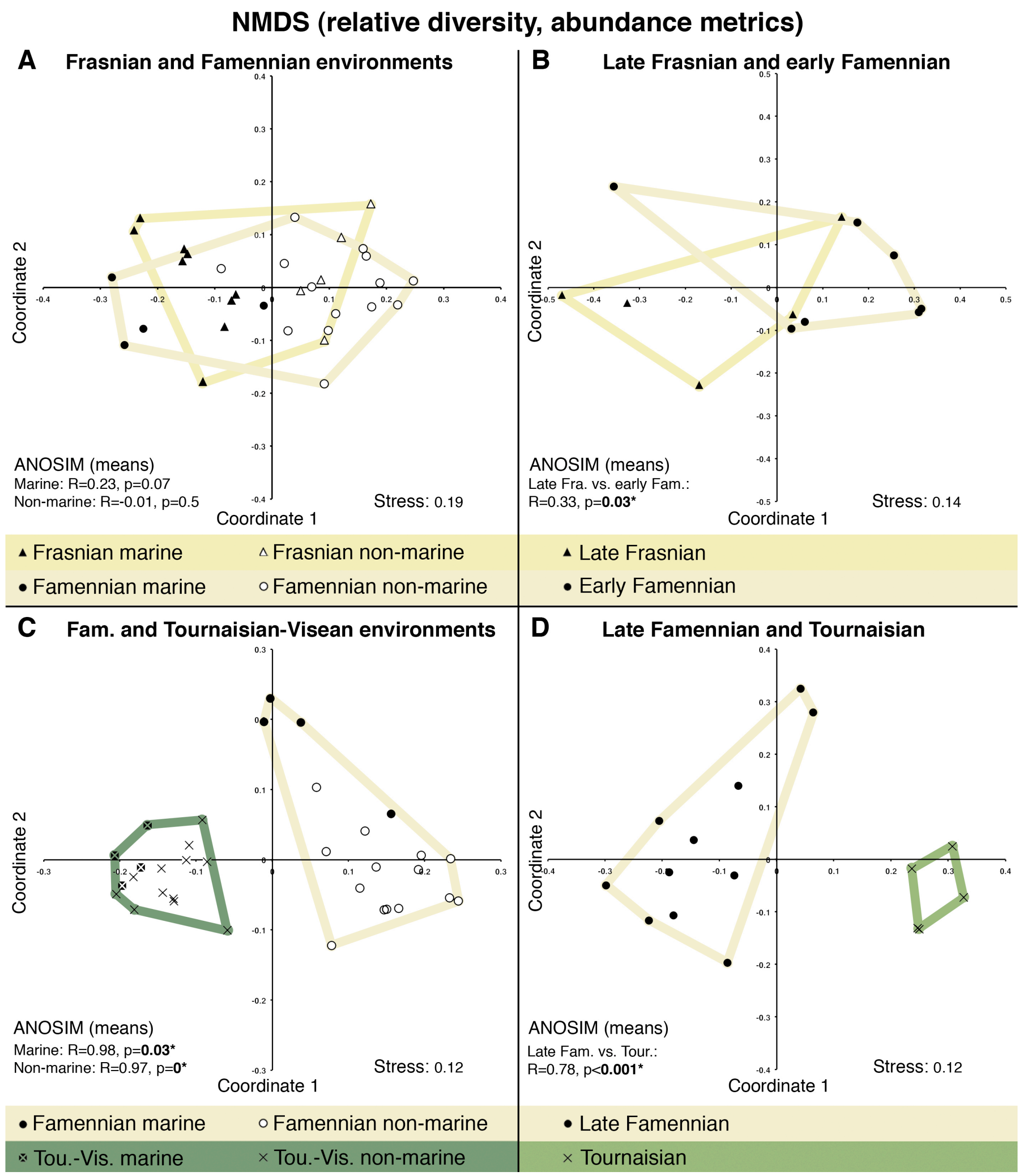

Fig. S9. NMDS of restricted intervals: Bray-Curtis distances, relative diversity. ANOSIM values are the mean of all abundance metric values (Tables S15 and S16). (*A*) NMDS plot of Frasnian and Famennian sites marked by environment (N=34). (*B*) NMDS plot of late Frasnian and early Famennian sites (N=13). (*C*) NMDS plot of Famennian and Tournaisian-Viséan sites marked by environment (N=34). (*D*) NMDS plot of late Famennian and Tournaisian sites (N=16).

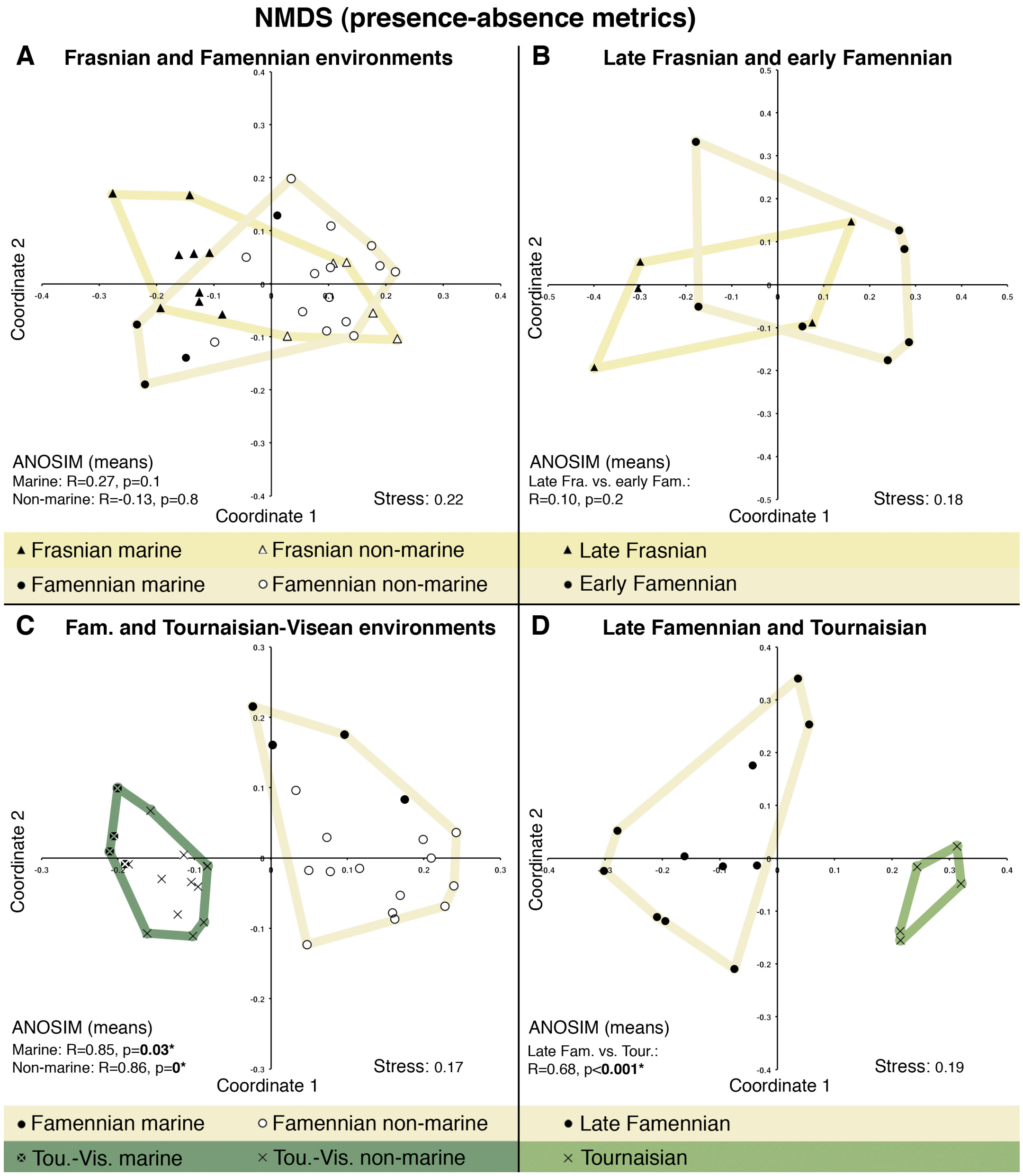

Fig. S10. NMDS of restricted intervals: Kulczynski similarity. ANOSIM values are the mean of all presence-absence metric values from raw diversity. Raw and relative diversity produced identical NMDS plots and similar if not identical ANOSIM values (Tables S11, S12, S15, S16). (*A*) NMDS plot of Frasnian and Famennian sites marked by environment (N=34). (*B*) NMDS plot of late Frasnian and early Famennian sites (N=13). (*C*) NMDS plot of Famennian and Tournaisian-Viséan sites marked by environment (N=36). (*D*) NMDS plot of late Famennian and Tournaisian sites (N=16).

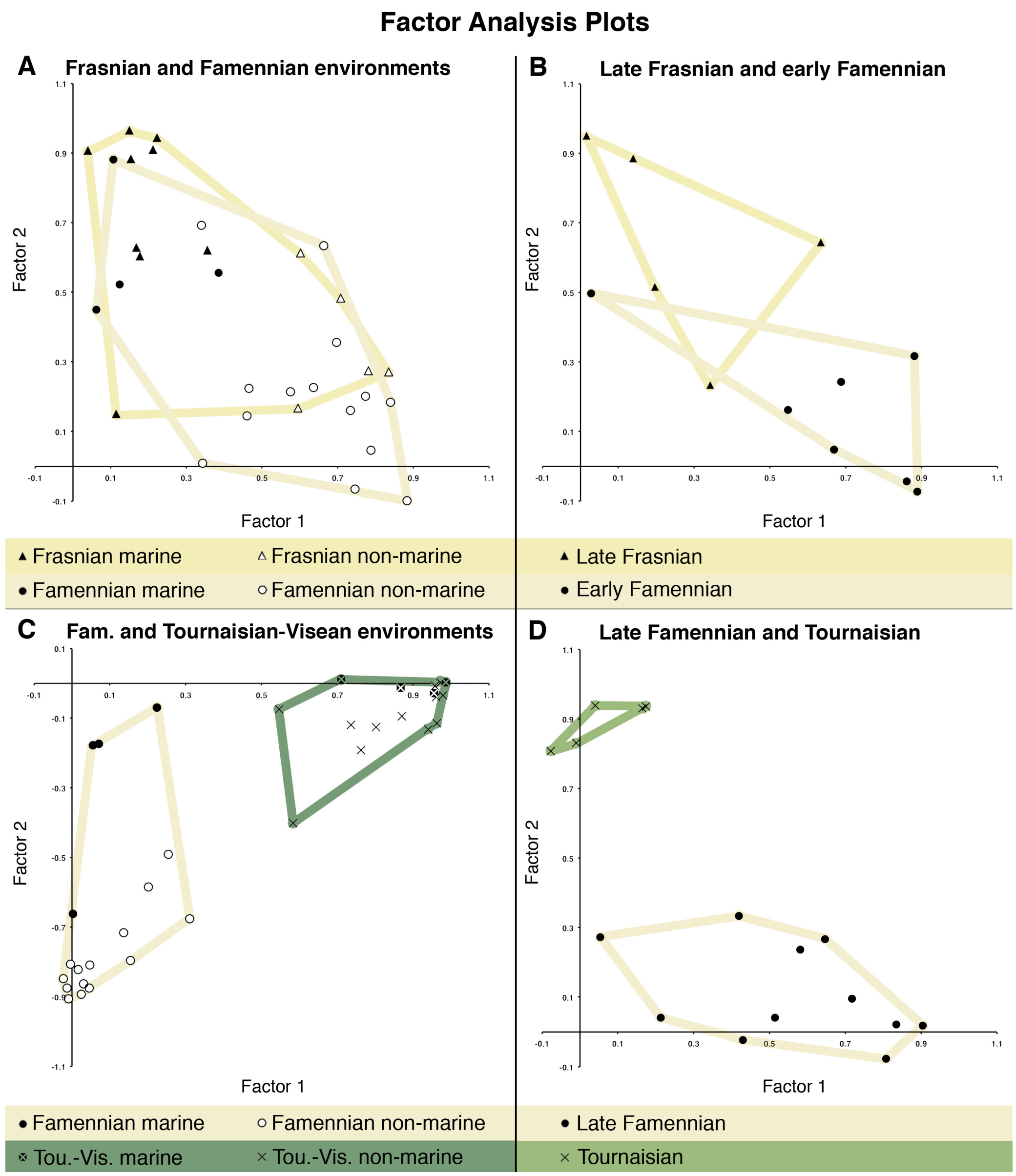

Fig. S11. Factor analysis of restricted intervals (*A*) Frasnian and Famennian sites marked by environment (N=32) (Tables S24 and S25). Factor 1 (55.17% of variance) is positively loaded by Devonian non-marine taxa as indicated in the CCA plot (Fig. 3*B*). Factor 2 (16.92% of variance), is positively loaded by Devonian marine taxa. Site placement also displays some paleogeographic signal. (*B*) Late Frasnian and early Famennian sites (N=13) (Tables S36 and S37). Factors 1 (56.84% of variance) and 2 (19.86% of variance) are highly similar to those generated in analysis of all Frasnian and Famennian sites. (*C*) Famennian and Tournaisian-Viséan sites marked by environment (N=34) (Tables S28 and S29). Factors are very similar to those produced by factor analysis of all sites (Figs. 4*B*), except factors 1 (42.92% of variance) and 2 (5.88% of variance) are switched. (*D*) Late Famennian and Tournaisian sites (N=16) (tables S40 and S41). Factor 1 (43.51% of variance) is positively loaded by Devonian non-marine forms, just as in the overall factor analysis plot (Fig. 4*B*). Factor 2 (22.77%) is strongly loaded by actinopterygians and other Mississippian taxa.

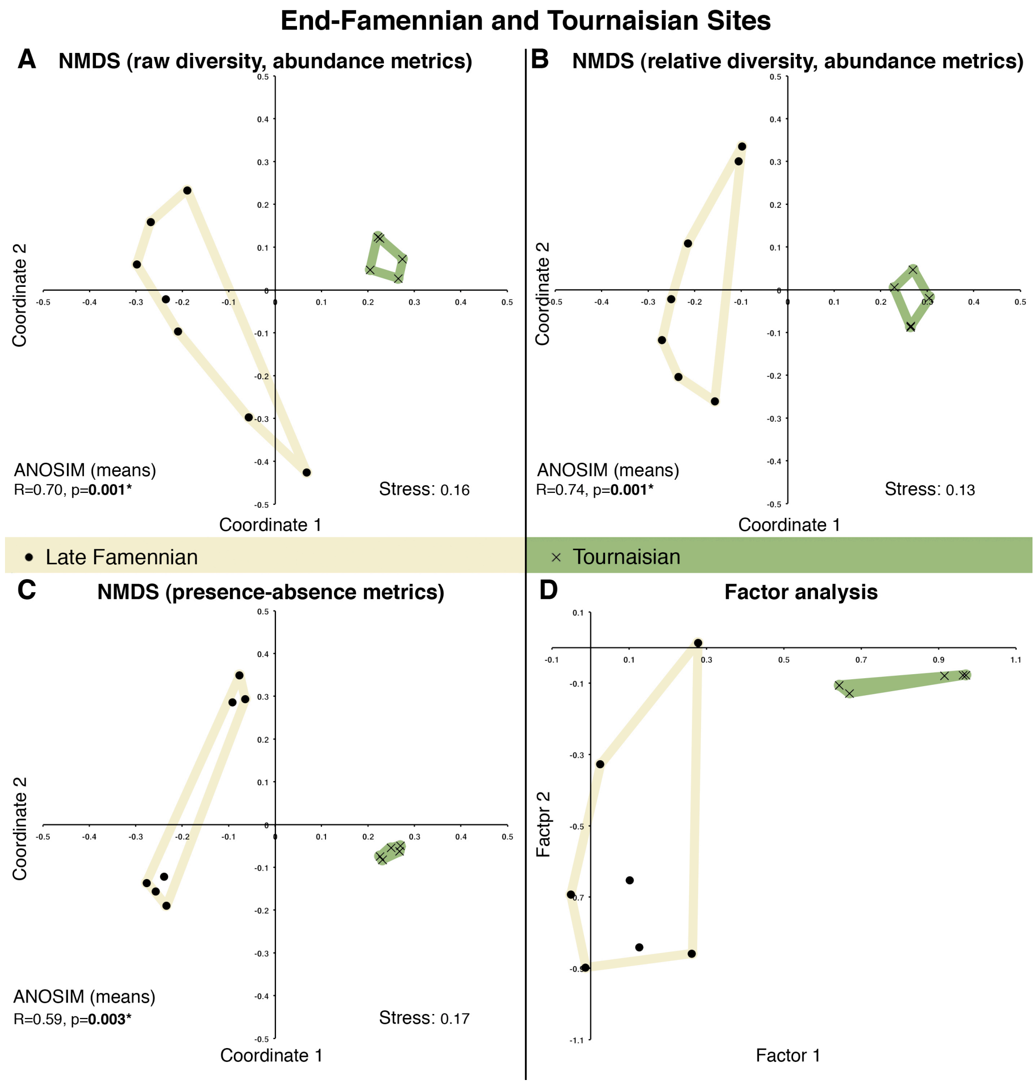

Fig. S12. Ordination plots of end-Famennian and Tournaisian sites (N=12). (*A*) NMDS plot of end-Famennian and Tournaisian relative site diversities based on Bray-Curtis distance. (*B*) NMDS plot of end-Famennian and Tournaisian raw site diversities based on Bray-Curtis distance (*C*) NMDS plot of end-Famennian and Tournaisian raw and relative site diversities based on Kulczynski similarity. (*D*) Factor analysis plot of end-Famennian and Tournaisian sites. Position along factor axis 1 (45.70% of variance) is positively influenced by Tournaisian taxa, such as actinopterygians. Factor 2 (24.02% of variance) is negatively loaded by Devonian freshwater taxa. Plots were the same for both raw and relative diversity data.

V. Supporting Tables

Table S1. Raw diversity data. See separate file in PNAS supporting information.

Table S2. Relative diversity data. See separate file in PNAS supporting information.

Table S3. Genus-level gnathostome occurrences. Raw genus counts for six major divisions of vertebrates binned by stage for the Givetian-Serpukhovian.

Division	**Givetian**	**Frasnian**	**Famennian**	**Tournaisian**	**Viséan**	**Serpukhovian**	***Total***
Actinopterygii	6	8	11	25	41	46	*137*
Sarcopterygii	40	48	56	14	16	18	*192*
Placodermi	83	106	53	0	0	0	*242*
Acanthodii	29	21	11	8	7	6	*82*
Chondrichthyes	11	20	36	66	94	77	*304*
Tetrapoda	2	7	10	4	22	17	*62*
Total	*171*	*210*	*177*	*117*	*180*	*164*	*1019*

Table S4. Descriptive statistics for faunal composition. Species counts, Shannon-Weiner diversity, and taxonomic richness for both the overall raw diversity dataset and each stage. Species counts range from 6-82.

Stage	**Species Count**			**Shannon-Wiener Diversity**			**Taxonomic Richness**		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Giv.	20.64	11.24	16.00	1.85	0.38	1.90	8.45	3.17	9.00
Fra.	22.21	14.29	16.50	1.85	0.32	1.76	8.86	2.07	9.00
Fam.	15.61	8.81	13.50	1.89	0.42	1.91	8.28	2.99	8.00
Tour.	14.00	2.24	14.00	1.61	0.23	1.67	6.60	1.14	7.00
Vis.	17.09	7.69	15.00	1.42	0.31	1.46	6.09	1.14	6.00
Serp.	27.86	26.51	18.00	1.46	0.35	1.35	6.43	2.57	7.00
Overall	*19.27*	*13.01*	*15.00*	*1.73*	*0.40*	*1.74*	*7.74*	*2.61*	*7.00*

Table S5. CCA of raw diversity: site scores. Eigenvalue of correspondence axis 1: 0.46. Eigenvalue of correspondence axis 2: 0.27. See Fig. 3*A* for plot.

Site	CA1	CA2
Orcadian	-0.95	-0.40
Harma	-0.69	0.00
Gerolstein	-1.16	2.00
Rockport	-0.58	0.94
Aztec	-0.35	-0.82
Haikou	-1.57	0.56
Cletts	-0.78	-0.22
MtHowitt	-0.51	-0.85
Abava	-0.34	-0.25
CedarValley	-0.99	1.95
Gauja	-0.75	-0.43
Gladbach	-0.43	0.75
Boghole	-0.98	-1.35
Gogo	-0.82	0.86
Chahriseh	-0.27	0.81
Kerman	-0.75	1.11
NorthEvans	-0.31	2.06
Miguasha	-0.53	-0.63
Wietrznia	-0.72	1.10
Rodebjerg	-1.11	-1.10
Rhinestreet	-0.61	0.99
Chemung	-0.29	1.01
Wildungen	-0.78	1.48
ScaatCraig	-0.54	-1.44
Stolbovo	-1.07	-0.71
Canowindra	-0.99	-1.12
Rosebrae	-1.43	-1.42
DuraDen	-1.49	-1.48
Cheiloceras	-0.02	1.20
Tervete	-0.93	-0.91
Oryol	-0.62	0.30
Portishead	-0.99	-1.61
AinaDal	-0.86	-1.61
BrittaDal	-0.68	-0.91
Grenfell	-1.48	-0.50
Hyner	-0.12	-1.51
Evieux	-0.54	-0.97
Ketleri	-0.95	-0.89
Tafilalt	0.32	1.27
Andreyevka-2	-0.09	-0.47
Cleveland	-0.07	1.25
Chaffee	-0.71	0.11
Witpoort	-0.35	0.60
Horton	1.23	-0.43
Izkchul	1.53	-0.39

Mansfield	1.10	-0.32
Foulden	1.39	-0.37
Herbesskaya	1.72	-0.02
Waaipoort	1.55	0.02
Glencartholm	1.69	0.34
Burdiehouse	1.19	-0.68
Ducabrook	1.15	-0.64
Wardie	1.22	-0.49
Cheesebay	1.42	-0.34
EastKirkton	1.33	-1.00
Gilmerton	1.14	-1.05
Ardross	1.58	1.19
Abden	1.54	0.51
Inchkeith	1.13	-0.82
Bearsden	1.53	0.80
Chokier	1.78	1.56
Loanhead	1.29	-0.74
Niddrie	1.08	-2.12
Millstone	1.46	0.32
Dora	1.33	-1.34
BearGulch	1.71	1.32

Table S6. CCA of raw diversity: taxon scores. See Fig. 3*B* for plot.

Taxon	**CA1**	**CA2**
Actinopterygii	0.86	0.11
Onychodontida	-0.60	0.60
Porolepiformes	-0.77	-0.63
Dipnoi	-0.34	-0.16
Osteolepididae	-0.74	-0.48
Tristichopteridae	-0.82	-0.50
Megalichthyidae	0.89	-0.51
Rhizodontida	0.86	-0.65
Actinistia	0.49	0.66
Arthrodira	-0.63	0.42
Antiarcha	-0.76	-0.34
Phyllolepida	-0.51	-1.15
Ptyctodontida	-0.73	1.16
OtherPlacoderms	-0.77	1.31
Elasmobranchii	0.43	0.29
Symmoriiformes	0.58	0.86
Holocephali	1.20	0.60
Ischnacanthida	-0.65	0.54
Climatiida	-0.61	-0.03
Gyracanthida	0.91	-0.33
Acanthodida	0.21	-0.16
Tetrapoda	0.37	-0.87

Table S7. CCA of relative diversity: site scores. Eigenvalue of correspondence axis 1: 0.47. Eigenvalue for correspondence axis 2: 0.27. See Fig. S6*A* for plot.

Site	CA1	CA2
Orcadian	-0.89	-0.08
Harma	-0.59	0.33
Gerolstein	-1.05	2.23
Rockport	-0.48	1.06
Aztec	-0.32	-0.58
Haikou	-1.52	0.68
Cletts	-0.76	-0.19
MtHowitt	-0.48	-0.58
Abava	-0.28	-0.11
CedarValley	-0.86	2.14
Gauja	-0.69	-0.17
Gladbach	-0.34	0.93
Boghole	-1.03	-1.30
Gogo	-0.73	0.99
Chahriseh	-0.18	0.99
Kerman	-0.64	1.33
NorthEvans	-0.20	2.15
Miguasha	-0.48	-0.37
Wietrznia	-0.64	1.20
Rodebjerg	-1.11	-0.93
Rhinestreet	-0.52	1.13
Chemung	-0.22	1.11
Wildungen	-0.67	1.57
ScaatCraig	-0.59	-1.37
Stolbovo	-1.05	-0.55
Canowindra	-1.03	-1.04
Rosebrae	-1.45	-1.22
DuraDen	-1.50	-1.32
Cheiloceras	0.06	1.23
Tervete	-0.91	-0.68
Oryol	-0.56	0.49
Portishead	-1.03	-1.42
AinaDal	-0.87	-1.41
BrittaDal	-0.67	-0.79
Grenfell	-1.46	-0.32
Hyner	-0.14	-1.37
Evieux	-0.54	-0.84
Ketleri	-0.92	-0.68
Tafilalt	0.39	1.25
Andreyevka-2	-0.07	-0.27
Cleveland	0.01	1.18
Chaffee	-0.68	0.24
Witpoort	-0.26	0.76
Horton	1.21	-0.48
Izkchul	1.55	-0.39

Mansfield	1.13	-0.34
Foulden	1.39	-0.40
Herbesskaya	1.72	-0.09
Waaipoort	1.63	-0.02
Glencartholm	1.70	0.31
Burdiehouse	1.20	-0.69
Ducabrook	1.15	-0.69
Wardie	1.24	-0.48
Cheesebay	1.44	-0.31
EastKirkton	1.32	-1.00
Gilmerton	1.09	-1.04
Ardross	1.64	1.22
Abden	1.56	0.51
Inchkeith	1.12	-0.87
Bearsden	1.55	0.77
Chokier	1.86	1.59
Loanhead	1.27	-0.76
Niddrie	0.97	-2.20
Millstone	1.48	0.29
Dora	1.31	-1.37
BearGulch	1.72	1.26

Table S8. CCA of relative diversity: taxon scores. See Fig. S6*B* for plot.

Taxon	**CA1**	**CA2**
Actinopterygii	0.91	0.10
Onychodontida	-0.51	0.71
Porolepiformes	-0.81	-0.57
Dipnoi	-0.34	-0.14
Osteolepididae	-0.78	-0.37
Tristichopteridae	-0.85	-0.49
Megalichthyidae	0.91	-0.48
Rhizodontida	0.75	-0.75
Actinistia	0.61	0.76
Arthrodira	-0.61	0.40
Antiarcha	-0.79	-0.27
Phyllolepida	-0.57	-0.99
Ptyctodontida	-0.65	1.30
OtherPlacoderms	-0.71	1.39
Elasmobranchii	0.51	0.29
Symmoriiformes	0.55	0.82
Holocephali	1.18	0.56
Ischnacanthida	-0.62	0.65
Climatiida	-0.52	0.26
Gyracanthida	0.97	-0.39
Acanthodida	0.26	-0.08
Tetrapoda	0.33	-0.84

Table S9. Factor analysis of all sites: taxon loadings. See Fig. 4*B* for plot of factors 1 and 2.

Taxon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Actinopterygii	0.06	-4.43	-0.04	0.37
Onychodontida	0.20	0.00	-0.29	-0.05
Porolepiformes	1.56	0.12	0.23	0.07
Dipnoi	2.03	-0.09	-0.48	-0.78
Osteolepididae	0.99	-0.02	0.03	0.27
Tristichopteridae	1.05	0.09	0.03	0.12
Megalichthyidae	0.09	-0.21	0.05	-0.14
Rhizodontida	0.35	-0.29	0.28	-1.51
Actinistia	0.08	-0.58	-0.24	0.47
Arthrodira	0.45	0.33	-4.20	0.57
Antiarcha	3.12	0.21	0.25	0.29
Phyllolepida	0.49	0.06	0.14	-0.23
Ptyctodontida	0.01	0.02	-0.92	0.28
OtherPlacoderms	0.00	0.01	-0.26	0.06
Elasmobranchii	-0.73	-0.65	-1.55	-2.71
Symmoriiformes	-0.10	-0.10	-0.20	-0.16
Holocephali	0.01	-0.78	-0.06	0.30
Ischnacanthida	0.19	-0.03	-0.34	0.22
Climatiida	0.39	-0.09	-0.14	0.18
Gyracanthida	-0.13	-0.27	-0.11	-0.99
Acanthodida	1.27	-0.79	0.13	0.61
Tetrapoda	0.81	0.07	0.51	-3.03
Variance Explained	*39.68%*	*22.10%*	*9.59%*	*5.45%*

Table S10. Factor analysis of all sites: site scores. See Fig. 4*B* for plot of factors 1 and 2.

Site	Factor 1	Factor 2	Factor 3	Factor 4
Orcadian	0.66	-0.18	-0.25	0.10
Harma	0.40	-0.16	-0.44	0.09
Gerolstein	0.42	0.01	-0.46	0.05
Rockport	0.25	-0.01	-0.93	-0.08
Aztec	0.70	-0.07	-0.33	-0.14
Haikou	0.53	0.09	-0.65	0.14
Cletts	0.59	-0.23	-0.59	0.02
MtHowitt	0.78	-0.19	-0.09	0.09
Abava	0.57	-0.24	-0.42	-0.03
CedarValley	0.22	0.00	-0.47	-0.07
Gauja	0.87	-0.13	-0.30	-0.04
Gladbach	0.43	-0.42	-0.64	0.05
Boghole	0.61	0.04	-0.24	-0.03
Gogo	0.29	-0.06	-0.89	0.05
Chahriseh	0.22	-0.26	-0.46	-0.42
Kerman	0.51	-0.20	-0.75	-0.09
NorthEvans	0.07	-0.05	-0.89	0.05
Miguasha	0.82	-0.25	-0.17	-0.03
Wietrznia	0.23	0.00	-0.94	0.06
Rodebjerg	0.77	0.07	-0.47	-0.11
Rhinestreet	0.28	-0.11	-0.86	0.09
Chemung	0.37	-0.26	-0.70	-0.18
Wildungen	0.13	0.03	-0.93	0.09
ScaatCraig	0.70	0.03	-0.23	-0.31
Stolbovo	0.73	0.04	-0.59	-0.04
Canowindra	0.75	0.03	-0.24	-0.04
Rosebrae	0.89	0.03	-0.02	-0.05
DuraDen	0.88	0.04	0.02	0.00
Cheiloceras	0.06	-0.10	-0.78	-0.37
Tervete	0.86	-0.03	-0.22	-0.10
Oryol	0.74	-0.16	-0.28	-0.21
Portishead	0.81	0.04	-0.19	-0.06
AinaDal	0.87	0.03	-0.06	-0.26
BrittaDal	0.79	0.02	-0.40	-0.33
Grenfell	0.78	0.05	-0.22	0.07
Hyner	0.52	-0.15	-0.27	-0.45
Evieux	0.61	-0.09	-0.63	-0.13
Ketleri	0.79	-0.05	-0.21	-0.09
Tafilalt	-0.04	-0.25	-0.70	-0.37
Andreyevka-2	0.73	-0.33	0.02	-0.02
Cleveland	0.04	-0.05	-0.96	-0.12
Chaffee	0.56	-0.02	-0.63	-0.09
Witpoort	0.38	-0.22	-0.74	-0.19
Horton	0.13	-0.93	0.00	-0.09
Izkchul	0.02	-0.95	-0.07	-0.09

Mansfield	0.12	-0.74	-0.21	-0.39
Foulden	0.15	-0.91	0.00	-0.16
Herbesskaya	-0.04	-0.73	-0.19	-0.37
Waaipoort	0.02	-0.96	-0.04	0.00
Glencartholm	0.01	-0.98	-0.04	0.00
Burdiehouse	0.07	-0.85	-0.17	-0.45
Ducabrook	0.01	-0.52	-0.26	-0.71
Wardie	0.04	-0.95	-0.10	-0.19
Cheesebay	0.07	-0.96	0.01	0.00
EastKirkton	0.12	-0.74	0.00	-0.51
Gilmerton	0.39	-0.52	0.04	-0.52
Ardross	0.04	-0.91	-0.08	0.05
Abden	0.06	-0.97	-0.07	-0.06
Inchkeith	0.15	-0.71	-0.15	-0.63
Bearsden	0.02	-0.98	-0.07	-0.03
Chokier	0.02	-0.87	-0.04	0.13
Loanhead	0.15	-0.65	-0.10	-0.72
Niddrie	0.26	-0.05	0.08	-0.73
Millstone	0.04	-0.96	-0.12	-0.15
Dora	0.10	-0.18	-0.03	-0.87
BearGulch	0.00	-0.90	-0.07	0.02

Table S11. ANOSIM R statistics for raw diversity: extinction intervals. Values generated after 1000000 permutations. Values closer to 0 indicate greater similarity between faunas, while values closer to 1 indicate high dissimilarity.

Comparison	***Overall Mean***	***Abundance Mean***	***Pres.-Abs. Mean***	**Bray-Curtis**	**Kulczynski**	**Dice**	**Simpson**	**Chord**	**Morisita**	**Raup-Crick**
Frasnian-Famennian	0.09	0.12	0.07	0.10	0.07	0.06	0.08	0.13	0.13	0.08
F-F Marine	0.25	0.22	0.27	0.24	0.40	0.53	0.05	0.24	0.18	0.11
F-F Non-Marine	-0.08	-0.01	-0.13	-0.07	-0.11	-0.12	-0.05	0.02	0.01	-0.22
Late Fra.-Early Fam.	0.19	0.31	0.10	0.18	0.09	0.09	0.13	0.39	0.35	0.10
Famennian-Tournaisian	0.76	0.77	0.76	0.73	0.77	0.76	0.74	0.80	0.79	0.75
Fam-Miss. Marine	0.90	0.96	0.85	0.91	0.85	0.84	0.88	0.98	0.98	0.84
Fam-Miss. Non-marine	0.91	0.97	0.86	0.96	0.89	0.90	0.80	0.98	0.98	0.85
Late Fam-Tour	0.71	0.76	0.68	0.71	0.70	0.70	0.65	0.79	0.79	0.65
End-Fam-Tour	0.64	0.70	0.59	0.65	0.63	0.61	0.59	0.73	0.73	0.51

Table S12. ANOSIM p-values for raw diversity: extinction intervals. Values generated from 1000000 permutations. Significant values are marked with an asterisk (α=0.05).

Comparison	***Overall Mean***	***Abundance Mean***	***Pres.-Abs. Mean***	**Bray-Curtis**	**Kulczynski**	**Dice**	**Simpson**	**Chord**	**Morisita**	**Raup-Crick**
Frasnian-Famennian	0.06	0.03*	0.08	0.04*	0.07	0.1	0.07	0.02*	0.02*	0.06
F-F Marine	0.1	0.08	0.1	0.05	0.02*	0.003*	0.4	0.07	0.1	0.2
F-F Non-Marine	0.7	0.5	0.8	0.7	0.8	0.8	0.6	0.4	0.4	0.9
Late Fra.-Early Fam.	0.1	0.04*	0.2	0.08	0.2	0.2	0.1	0.02*	0.02*	0.2
Famennian-Tournaisian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Fam.-Miss. Marine	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
Fam.-Miss. Non-marine	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
Late Fam-Tour	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
End-Fam-Tour	0.002*	0.001*	0.003*	0.001*	0.001*	0.003*	0.001*	0.001*	0.001*	0.008*

Table S13. ANOSIM R statistics for raw diversity: other intervals. Values generated from 1000000 permutations. Values closer to 0 indicate greater similarity between faunas, while values closer to 1 indicate high dissimilarity.

Comparison	***Overall Mean***	***Abundance Mean***	***Pres.-Abs. Mean***	**Bray-Curtis**	**Kulczynski**	**Dice**	**Simpson**	**Chord**	**Morisita**	**Raup-Crick**
Givetian-Frasnian	-0.02	0.06	-0.09	0.02	-0.09	-0.07	-0.10	0.09	0.08	-0.10
Givetian-Famennian	0.11	0.12	0.11	0.14	0.11	0.09	0.14	0.11	0.10	0.10
Givetian-Tournaisian	0.79	0.87	0.72	0.88	0.74	0.71	0.72	0.87	0.87	0.72
Frasnian-Tournaisian	0.75	0.81	0.71	0.67	0.74	0.73	0.71	0.88	0.88	0.67
Frasnian-Viséan	0.79	0.86	0.74	0.76	0.76	0.78	0.70	0.91	0.91	0.72
Frasnian-Serpukhovian	0.75	0.80	0.71	0.71	0.72	0.72	0.69	0.84	0.84	0.72
Famennian-Viséan	0.77	0.81	0.74	0.78	0.76	0.77	0.71	0.83	0.83	0.73
Famennian-Serpukhovian	0.74	0.76	0.73	0.75	0.74	0.74	0.71	0.77	0.77	0.73
Tournaisian-Viséan	-0.10	-0.04	-0.10	-0.18	-0.12	-0.13	-0.11	-0.04	-0.05	-0.06
Tournaisian-Serpukhovian	-0.06	-0.05	-0.06	-0.04	-0.06	-0.10	0.01	-0.05	-0.07	-0.10
Serpukhovian-Viséan	0.05	0.09	0.03	0.12	0.02	0.04	-0.04	0.07	0.07	0.09

Table S14. ANOSIM p-values for raw diversity: other intervals. Value generated after 1000000 permutations. Significant values are marked with an asterisk (α=0.05)

Comparison	*Overall Mean*	*Abundance Mean*	*Pres.-Abs. Mean*	Bray-Curtis	Kulczynski	Dice	Simpson	Chord	Morisita	Raup-Crick
Givetian-Frasnian	0.6	0.2	1.0	0.3	1.0	0.9	1.0	0.08	0.1	1.0
Givetian-Famennian	0.06	0.05	0.06	0.03*	0.05	0.08	0.03*	0.06	0.07	0.07
Givetian-Tournaisian	<0.001*	<0.001*	<0,001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Frasnian-Tournaisian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Frasnian-Viséan	<0.001*	<0.001*	<0.001*	<0.001*	0*	0*	<0.001*	<0.001*	0*	<0.001*
Frasnian-Serpukhovian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Famennian-Viséan	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
Famennian-Serpukhovian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Tournaisian-Viséan	0.8	0.7	0.8	0.9	0.9	0.9	0.9	0.5	0.6	0.7
Tournaisian-Serpukhovian	0.6	0.6	0.6	0.6	0.6	0.8	0.4	0.6	0.7	0.7
Serpukhovian-Viséan	0.3	0.2	0.4	0.1	0.3	0.3	0.7	0.2	0.2	0.1

Table S15. ANOSIM R statistics for relative diversity: extinction intervals. Values generated from 1000000 permutations. Values closer to 0 indicate greater similarity between faunas.

Comparison	***Overall Mean***	***Abundance Mean***	***Pres.-Abs. Mean***	**Bray-Curtis**	**Kulczynski**	**Dice**	**Simpson**	**Chord**	**Morisita**	**Raup-Crick**
Frasnian-Famennian	0.10	0.13	0.10	0.11	0.07	0.06	0.08	0.14	0.13	0.08
F-F Marine	0.25	0.23	0.27	0.28	0.40	0.53	0.05	0.24	0.18	0.10
F-F Non-marine	-0.07	-0.01	-0.12	-0.05	-0.11	-0.12	-0.05	0.02	0.01	-0.20
Late Fra.-Early Fam.	0.20	0.33	0.10	0.25	0.09	0.09	0.13	0.39	0.35	0.11
Famennian-Tournaisian	0.77	0.79	0.76	0.76	0.77	0.76	0.74	0.81	0.80	0.75
Fam.-Miss. Marine	0.91	0.98	0.86	0.99	0.85	0.84	0.88	0.98	0.98	0.84
Fam.-Miss. Non-marine	0.91	0.97	0.86	0.96	0.89	0.90	0.80	0.98	0.98	0.84
Late Fam-Tour	0.72	0.78	0.67	0.77	0.70	0.70	0.65	0.79	0.79	0.64
End Fam-Tour	0.65	0.74	0.59	0.75	0.63	0.61	0.59	0.73	0.73	0.51

Table S16. ANOSIM p-values from relative diversity: extinction intervals. Values generated from 1000000 permutations. Significant values are marked with an asterisk (α=0.05).

Comparison	*Overall Mean*	*Abundance Mean*	*Pres.-Abs. Mean*	Bray-Curtis	Kulczynski	Dice	Simpson	Chord	Morisita	Raup-Crick
Frasnian-Famennian	0.05	0.03*	0.08	0.03*	0.07	0.1	0.07	0.02*	0.02*	0.06
F-F Marine	0.1	0.07	0.2	0.04*	0.02*	0.003*	0.4	0.07	0.1	0.2
F-F Non-Marine	0.7	0.5	0.8	0.6	0.8	0.8	0.6	0.4	0.4	0.9
Late Fra.-Early Fam.	0.1	0.03*	0.2	0.06	0.2	0.2	0.1	0.02*	0.02*	0.2
Famennian-Tournaisian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
F-M Marine	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*	0.03*
F-M Non-marine	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
Late Fam-Tour	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
End-Fam-Tour	0.002*	0.001*	0.003*	0.001*	0.001*	0.003*	0.001*	0.001*	0.001*	0.008*

Table S17. ANOSIM R statistics for relative diversity: other intervals. Values generated after 1000000 permutations. Values closer to 0 indicate greater similarity between faunas.

Comparison	***Overall Mean***	***Abundance Mean***	***Pres.-Abs. Mean***	**Bray-Curtis**	**Kulczynski**	**Dice**	**Simpson**	**Chord**	**Morisita**	**Raup-Crick**
Givetian-Frasnian	-0.03	0.06	-0.09	0.01	-0.09	-0.07	-0.10	0.09	0.08	-0.10
Givetian-Famennian	0.10	0.10	0.11	0.08	0.11	0.09	0.14	0.11	0.10	0.10
Givetian-Tournaisian	0.79	0.88	0.72	0.90	0.74	0.71	0.72	0.87	0.87	0.72
Frasnian-Tournaisian	0.78	0.86	0.71	0.85	0.74	0.73	0.71	0.88	0.88	0.67
Frasnian-Viséan	0.81	0.90	0.74	0.88	0.76	0.77	0.70	0.91	0.91	0.72
Frasnian-Serpukhovian	0.76	0.83	0.71	0.81	0.72	0.72	0.69	0.84	0.84	0.72
Famennian-Viséan	0.77	0.82	0.74	0.80	0.76	0.77	0.71	0.83	0.83	0.73
Famennian-Serpukhovian	0.75	0.77	0.73	0.76	0.74	0.75	0.71	0.77	0.78	0.73
Tournaisian-Viséan	-0.09	-0.07	-0.11	-0.11	-0.12	-0.13	-0.11	-0.04	-0.05	-0.06
Tournaisian-Serpukhovian	-0.06	-0.04	-0.08	-0.02	-0.06	-0.10	0.01	-0.05	-0.07	-0.10
Serpukhovian-Viséan	0.05	0.07	0.03	0.08	0.02	0.04	-0.04	0.07	0.07	0.09

Table S18. ANOSIM p-values from relative diversity: other intervals. Values generated after 1000000 permutations. Significant values are marked with an asterisk (α=0.05)

Comparison	*Overall Mean*	*Abundance Mean*	*Pres.-Abs. Mean*	Bray-Curtis	Kulczynski	Dice	Simpson	Chord	Morisita	Raup-Crick
Givetian-Frasnian	0.6	0.2	1.0	0.4	1.0	0.9	1.0	0.08	0.1	1.0
Givetian-Famennian	0.07	0.08	0.06	0.1	0.05	0.08	0.03*	0.06	0.07	0.07
Givetian-Tournaisian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Frasnian-Tournaisian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Frasnian-Viséan	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0*	0*	0*	<0.001*	<0.001*
Frasnian-Serpukhovian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Famennian-Viséan	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
Famennian-Serpukhovian	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Tournaisian-Viséan	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.5	0.6	0.7
Tournaisian-Serpukhovian	0.6	0.6	0.6	0.5	0.6	0.8	0.4	0.6	0.7	0.7
Serpukhovian-Viséan	0.3	0.2	0.4	0.2	0.3	0.3	0.7	0.2	0.2	0.1

Table S19. SIMPER average dissimilarities. Results based on relative diversity data.

Boundary	**Givetian.-Frasnian**	**Frasnian-Famennian**	**Famennian-Tournaisian**	**Tournaisian-Viséan**	**Viséan-Serpukhovian**	***Average.***
Average Dissimilarity	58.65	60.80	83.19	40.74	50.52	*58.78*

Table S20. SIMPER for all Frasnian and Famennian sites. Results based on relative diversity data. Average dissimilarity: 60.80.

Taxon	**Contribution**	**Cumulative %**	**Mean abund. Frasnian**	**Mean abund. Famennian**
Arthrodira	10.61	17.45	29.40	15.10
Antiarcha	6.43	28.02	8.63	17.00
Elasmobranchii	4.92	36.12	5.93	8.29
Porolepiformes	4.46	43.46	7.59	6.39
Dipnoi	4.14	50.27	11.4	12.90
Tristichopteridae	3.87	56.63	3.06	7.80
Osteolepididae	3.09	61.71	2.61	5.91
Tetrapoda	2.78	66.28	2.84	4.78
Ptyctodontida	2.72	70.75	5.29	1.32
Acanthodida	2.71	75.21	3.19	3.97
Actinopterygii	2.06	78.60	4.48	2.20
Ischnacanthida	1.87	81.68	3.23	1.50
Rhizodontida	1.84	84.70	2.21	2.05
Onychodontida	1.74	87.55	2.73	1.75
Phyllolepida	1.46	89.94	0.00	2.91
Actinistia	1.34	92.14	1.74	1.48
Climatiida	1.32	94.31	2.40	0.40
Symmoriiformes	1.00	95.96	0.71	1.54
Holocephali	0.77	97.23	0.92	0.82
OtherPlacoderms	0.74	98.44	1.22	0.40
Gyracanthida	0.50	99.27	0.45	0.64
Megalichthyidae	0.45	100.00	0.00	0.89

Table S21. SIMPER for all Famennian and Tournaisian sites. Results based on relative diversity data. Average dissimilarity: 83.19.

Taxon	Contribution	Cumulative %	Mean abund. Famennian	Mean abund. Tournaisian
Actinopterygii	19.08	22.94	2.20	40.40
Antiarcha	8.48	33.13	17.00	0.00
Arthrodira	7.55	42.21	15.10	0.00
Elasmobranchii	7.07	50.71	8.29	13.00
Dipnoi	4.68	56.34	12.90	4.69
Gyracanthida	4.59	61.85	0.64	9.55
Acanthodida	4.14	66.82	3.97	9.11
Tristichopteridae	3.90	71.51	7.80	0.00
Rhizodontida	3.74	76.00	2.05	8.63
Porolepiformes	3.19	79.84	6.39	0.00
Osteolepididae	2.96	83.39	5.91	0.00
Holocephali	2.53	86.44	0.82	4.86
Tetrapoda	2.53	89.47	4.78	2.87
Megalichthyidae	2.12	92.02	0.89	4.03
Phyllolepida	1.46	93.77	2.91	0.00
Symmoriiformes	1.32	95.35	1.54	1.54
Actinistia	1.18	96.78	1.48	1.33
Onychodontida	0.87	97.83	1.75	0.00
Ischnacanthida	0.75	98.73	1.50	0.00
Ptyctodontida	0.66	99.52	1.32	0.00
OtherPlacoderms	0.20	99.76	0.40	0.00
Climatiida	0.20	100.00	0.40	0.00

Table S22. Factor analysis of Frasnian-Famennian sites: taxon loadings. See Fig. S11*A* for plot of factors 1 and 2.

Taxon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Actinopterygii	-0.39	0.36	-0.62	-0.88
Onychodontida	-0.46	-0.07	-0.68	-1.17
Porolepiformes	2.21	-0.06	0.39	0.44
Dipnoi	0.89	0.21	-0.71	-2.61
Osteolepididae	0.21	0.05	0.13	-1.54
Tristichopteridae	1.74	-0.07	-0.05	0.49
Megalichthyidae	0.04	-0.02	-0.01	-0.17
Rhizodontida	1.21	-0.05	-0.05	1.05
Actinistia	-0.12	0.14	-0.59	-0.15
Arthrodira	0.65	4.49	-0.15	0.40
Antiarcha	3.06	-0.65	-0.38	-0.97
Phyllolepida	0.70	-0.18	-0.33	0.35
Ptyctodontida	-0.41	0.91	0.34	-0.65
OtherPlacoderms	-0.11	0.20	-0.11	-0.12
Elasmobranchii	-0.25	0.00	-4.19	0.29
Symmoriiformes	-0.04	-0.17	-1.04	0.11
Holocephali	-0.23	0.14	0.05	-0.51
Ischnacanthida	-0.23	0.45	0.25	-0.76
Climatiida	-0.05	-0.14	-0.68	-0.31
Gyracanthida	0.04	0.13	-0.08	0.08
Acanthodida	-0.46	0.16	0.69	-2.44
Tetrapoda	0.76	-0.02	0.20	-0.66
Variance Explained	*54.95%*	*16.82%*	*6.06%*	*4.56%*

Table S23. Factor analysis of Frasnian-Famennian relative diversity: site scores. See Fig. S11*A* for plot of factors 1 and 2

Site	Factor 1	Factor 2	Factor 3	Factor 4
Tafilalt	0.06	0.45	-0.82	0.08
Cleveland	0.11	0.88	-0.40	0.07
Cheiloceras	0.12	0.52	-0.79	0.01
Chaffee	0.38	0.56	-0.29	-0.48
Miguasha	0.59	0.17	-0.11	-0.54
Stolbovo	0.60	0.61	-0.07	-0.42
ScaatCraig	0.78	0.28	-0.02	-0.14
Rodebjerg	0.71	0.48	-0.06	-0.34
Boghole	0.83	0.27	0.01	0.14
NorthEvans	0.04	0.91	-0.12	-0.05
Gogo	0.21	0.91	-0.15	-0.18
Chemung	0.18	0.60	-0.44	-0.46
Wietrznia	0.22	0.94	-0.16	-0.06
Rhinestreet	0.15	0.88	-0.12	-0.24
Kerman	0.36	0.62	-0.46	-0.43
Chahriseh	0.11	0.15	-0.87	-0.32
Gladbach	0.17	0.63	-0.24	-0.55
Wildungen	0.15	0.97	-0.11	0.03
Witpoort	0.34	0.69	-0.35	-0.20
Andreyevka	0.34	0.01	0.01	-0.78
Evieux	0.66	0.63	-0.20	-0.15
Portishead	0.84	0.18	-0.06	-0.20
Grenfell	0.73	0.16	-0.09	-0.33
BrittaDal	0.70	0.36	-0.21	-0.43
AinaDal	0.79	0.05	-0.07	-0.42
Hyner	0.57	0.21	-0.36	-0.14
Ketleri	0.46	0.22	-0.02	-0.74
Oryol	0.46	0.15	-0.37	-0.71
Tervete	0.64	0.23	-0.02	-0.59
Canowindra	0.77	0.20	-0.10	-0.23
DuraDen	0.88	-0.10	-0.09	-0.29
Rosebrae	0.75	-0.06	-0.13	-0.53

Table S24. Factor Analysis of Famennian-Mississippian sites: taxon loadings. See Fig. S11*C* for plot of factors 1 and 2.

Taxon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Actinopterygii	4.50	0.04	0.16	0.82
Onychodontida	-0.05	-0.33	0.09	-0.39
Porolepiformes	-0.07	-1.18	0.19	0.01
Dipnoi	0.07	-2.24	0.02	-1.35
Osteolepididae	-0.06	-1.07	0.01	0.14
Tristichopteridae	0.05	-1.28	-0.33	1.40
Megalichthyidae	0.22	-0.14	0.04	-0.25
Rhizodontida	0.63	-0.32	-0.07	-0.63
Actinistia	0.33	0.05	-0.51	0.52
Arthrodira	-0.27	-1.01	-3.21	1.64
Antiarcha	-0.10	-3.07	0.38	0.77
Phyllolepida	-0.08	-0.49	-0.09	-0.33
Ptyctodontida	-0.03	-0.23	-0.08	-0.10
OtherPlacoderms	0.01	-0.03	-0.15	0.15
Elasmobranchii	0.53	0.41	-3.19	-2.27
Symmoriiformes	0.00	0.04	-0.46	-0.03
Holocephali	0.50	-0.09	0.03	-0.01
Ischnacanthida	0.03	-0.29	0.04	0.18
Climatiida	0.01	-0.03	-0.15	0.15
Gyracanthida	0.42	0.05	-0.31	-0.62
Acanthodida	0.53	-0.83	0.66	-1.30
Tetrapoda	0.32	-0.94	0.40	-2.44
Variance Explained	*42.92%*	*25.88%*	*9.85%*	*4.05%*

Table S25. Factor Analysis of Famennian-Mississippian sites: site scores. See Fig. S11*C* for plot of factors 1 and 2.

Site	Factor 1	Factor 2	Factor 3	Factor 4
Glencartholm	0.99	0.00	-0.04	0.10
Ardross	0.87	-0.01	-0.09	0.05
Herbesskaya	0.71	0.01	-0.36	-0.29
Abden	0.95	-0.03	-0.11	-0.02
Waaipoort	0.97	0.00	-0.03	0.08
Foulden	0.94	-0.13	0.03	-0.06
Ducabrook	0.55	-0.07	-0.54	-0.54
Gilmerton	0.58	-0.40	0.09	-0.47
Cheesebay	0.98	-0.03	0.04	0.09
EastKirkton	0.80	-0.13	-0.06	-0.35
Inchkeith	0.76	-0.19	-0.29	-0.45
Burdiehouse	0.87	-0.09	-0.31	-0.32
Mansfield	0.74	-0.12	-0.35	-0.41
Izkchul	0.96	-0.01	-0.11	-0.01
Horton	0.96	-0.11	0.04	-0.02
Wardie	0.96	-0.04	-0.16	-0.09
Tafilalt	0.22	-0.07	-0.90	-0.12
Chaffee	0.00	-0.66	-0.50	-0.03
Cleveland	0.05	-0.18	-0.89	0.13
Cheiloceras	0.07	-0.17	-0.93	-0.17
Andreyevka-2	0.31	-0.68	0.17	-0.26
Portishead	0.00	-0.81	-0.13	0.06
Ketleri	0.05	-0.81	-0.06	-0.20
Evieux	0.14	-0.72	-0.54	0.19
Oryol	0.15	-0.80	-0.19	-0.24
DuraDen	-0.01	-0.87	0.05	0.13
Hyner	0.20	-0.58	-0.35	-0.25
Grenfell	-0.02	-0.85	-0.14	0.29
Tervete	0.05	-0.87	-0.05	-0.18
Witpoort	0.25	-0.49	-0.64	0.09
BrittaDal	0.03	-0.86	-0.30	-0.17
AinaDal	0.02	-0.89	0.01	-0.15
Rosebrae	-0.01	-0.91	0.05	-0.01
Canowindra	0.02	-0.82	-0.20	0.25

Table S26. SIMPER for Frasnian-Famennian marine sites. Results based on relative diversity data. Average dissimilarity: 54.53

Taxon	Contribution	Cumulative %	Mean abund. Frasnian marine	Mean abund. Famennian marine
Elasmobranchii	10.57	19.45	9.22	28.60
Arthrodira	10.51	38.78	36.00	34.80
Dipnoi	5.00	47.99	11.20	7.81
Ptyctodontida	4.12	55.57	8.24	0.00
Symmoriiformes	2.85	60.81	1.10	5.88
Actinistia	2.48	65.38	1.97	4.86
Osteolepididae	2.42	69.83	1.98	3.85
Actinopterygii	2.30	74.05	6.22	3.06
Onychodontida	2.21	78.11	4.25	1.92
Ischnacanthida	2.16	82.09	4.32	0.00
Antiarcha	2.15	86.04	4.34	3.39
Acanthodida	1.39	88.60	2.78	0.00
Holocephali	1.32	91.03	1.44	1.92
Porolepiformes	1.30	93.42	1.36	1.92
Tristichopteridae	1.16	95.55	0.78	1.92
Climatiida	1.13	97.62	2.25	0.00
OtherPlacoderms	0.95	99.36	1.90	0.00
Gyracanthida	0.35	100.00	0.69	0.00
Megalichthyidae	0.00	100.00	0.00	0.00
Phyllolepida	0.00	100.00	0.00	0.00
Tetrapoda	0.00	100.00	0.00	0.00
Rhizodontida	0.00	100.00	0.00	0.00

Table S27. SIMPER for Frasnian-Famennian non-marine sites. Results based on relative diversity data. Average dissimilarity: 49.15.

Taxon	Contribution	Cumulative %	Mean abund. Frasnian Non-marine	Mean abund. Famennian Non-marine
Porolepiformes	6.65	13.52	18.80	7.66
Arthrodira	5.35	24.40	17.50	9.48
Antiarcha	5.02	34.61	16.40	20.80
Tristichopteridae	4.21	43.19	7.17	9.48
Dipnoi	3.56	50.44	11.80	14.40
Rhizodontida	3.36	57.27	6.19	2.63
Tetrapoda	3.35	64.10	7.94	6.14
Acanthodida	3.20	70.61	3.92	5.11
Osteolepididae	3.13	76.98	3.75	6.50
Phyllolepida	1.87	80.79	0.00	3.74
Climatiida	1.49	83.81	2.67	0.51
Ischnacanthida	1.29	86.43	1.25	1.93
Actinopterygii	1.27	89.00	1.33	1.95
Elasmobranchii	1.24	91.52	0.00	2.47
Ptyctodontida	0.85	93.25	0.00	1.70
Onychodontida	0.85	94.98	0.00	1.70
Actinistia	0.83	96.66	1.33	0.51
Megalichthyidae	0.57	97.82	0.00	1.15
Gyracanthida	0.41	98.66	0.00	0.82
OtherPlacoderms	0.26	99.18	0.00	0.51
Holocephali	0.26	99.70	0.00	0.51
Symmoriiformes	0.15	100.00	0.00	0.30

Table S28. SIMPER for Famennian-Mississippian marine sites. Results based on relative diversity data. Average dissimilarity: 80.74.

Taxon	**Contribution**	**Cumulative %**	**Mean abund. Famennian marine**	**Mean abund. Mississippian marine**
Actinopterygii	20.86	25.83	3.06	44.80
Arthrodira	17.40	47.39	34.80	0.00
Elasmobranchii	9.20	58.78	28.60	12.80
Holocephali	6.80	67.20	1.92	15.50
Dipnoi	3.90	72.04	7.81	0.00
Actinistia	3.51	76.39	4.86	7.64
Acanthodida	3.51	80.74	0.00	7.02
Symmoriiformes	2.94	84.38	5.88	0.00
Rhizodontida	2.82	87.87	0.00	5.64
Gyracanthida	2.21	90.60	0.00	4.41
Osteolepididae	1.92	92.99	3.85	0.00
Antiarcha	1.70	95.09	3.39	0.00
Megalichthyidae	1.08	96.43	0.00	2.17
Porolepiformes	0.96	97.62	1.92	0.00
Tristichopteridae	0.96	98.81	1.92	0.00
Onychodontida	0.96	100.00	1.92	0.00
OtherPlacoderms	0.00	100.00	0.00	0.00
Ptyctodontida	0.00	100.00	0.00	0.00
Phyllolepida	0.00	100.00	0.00	0.00
Tetrapoda	0.00	100.00	0.00	0.00
Climatiida	0.00	100.00	0.00	0.00
Ischnacanthida	0.00	100.00	0.00	0.00

Table S29. SIMPER for Famenian-Mississippian non-marine sites. Results based on relative diversity data. Average dissimilarity: 81.73.

Taxon	Contribution	Cumulative %	Mean abund. Famennian Non-marine	Mean abund. Mississippian Non-marine
Actinopterygii	20.90	25.58	1.95	43.80
Antiarcha	10.42	38.32	20.80	0.00
Elasmobranchii	6.48	46.25	2.47	13.7
Arthrodira	4.74	52.05	9.48	0.00
Tristichopteridae	4.74	57.85	9.48	0.00
Dipnoi	4.66	63.55	14.40	6.74
Tetrapoda	4.46	69.00	6.14	9.91
Porolepiformes	3.83	73.69	7.66	0.00
Rhizodontida	3.58	78.07	2.63	8.39
Acanthodida	3.41	82.24	5.11	6.22
Osteolepididae	3.25	86.22	6.50	0.00
Gyracanthida	2.82	89.67	0.82	5.86
Phyllolepida	1.87	91.96	3.74	0.00
Megalichthyidae	1.47	93.76	1.15	2.49
Ischnacanthida	0.96	94.94	1.93	0.00
Ptyctodontida	0.85	95.98	1.70	0.00
Onychodontida	0.85	97.02	1.70	0.00
Actinistia	0.75	97.94	0.51	1.15
Holocephali	0.73	98.83	0.51	1.11
Symmoriiformes	0.44	99.38	0.30	0.64
OtherPlacoderms	0.26	99.69	0.51	0.00
Climatiida	0.26	100.00	0.51	0.00

Table S30. Factor analysis of late Frasnian-early Famennian sites: taxon loadings. See Fig. S11*B* for plot of factors 1 and 2.

Taxon	Factor 1	Factor 2	Factor 3	Factor 4
Actinopterygii	-0.04	0.09	-0.68	0.06
Onychodontida	0.05	-0.29	-1.05	0.09
Porolepiformes	-0.13	-0.44	-0.05	-3.79
Dipnoi	2.03	-0.27	-1.93	-0.71
Osteolepididae	1.17	-0.20	-0.38	0.25
Tristichopteridae	2.41	0.75	1.23	1.32
Megalichthyidae	0.00	0.00	0.00	0.00
Rhizodontida	0.03	0.22	0.73	-1.44
Actinistia	-0.12	0.02	-0.58	0.12
Arthrodira	-0.11	4.49	-0.39	-0.63
Antiarcha	3.18	-0.28	-0.02	-0.78
Phyllolepida	0.03	-0.03	0.13	-0.76
Ptyctodontida	0.30	0.09	-0.50	0.15
OtherPlacoderms	-0.13	0.08	-0.38	-0.06
Elasmobranchii	-0.47	-0.10	-3.54	0.50
Symmoriiformes	0.03	-0.17	-0.63	0.14
Holocephali	-0.12	-0.03	-0.44	-0.06
Ischnacanthida	0.09	0.67	-0.48	0.23
Climatiida	0.00	0.00	0.00	0.00
Gyracanthida	0.00	0.00	0.00	0.00
Acanthodida	0.41	0.54	-0.50	0.10
Tetrapoda	-0.06	0.03	-0.03	-1.15
Variance Explained	56.84%	19.86%	6.04%	5.44%

Table S31. Factor analysis of late Frasnian-early Famennian sites: site scores. See Fig. S11*B* for plot of factors 1 and 2.

Site	Factor 1	Factor 2	Factor 3	Factor 4
Rhinestreet	0.14	0.89	-0.31	-0.11
Chemung	0.20	0.52	-0.70	-0.26
Wildungen	0.02	0.95	-0.17	-0.12
ScaatCraig	0.34	0.23	-0.12	-0.87
Stolbovo	0.63	0.64	-0.22	-0.27
Canowindra	0.88	0.32	0.03	-0.09
Rosebrae	0.89	-0.07	-0.24	-0.31
DuraDen	0.86	-0.04	-0.06	-0.38
Cheiloceras	0.03	0.50	-0.72	-0.02
Tervete	0.69	0.24	-0.23	-0.38
Oryol	0.67	0.05	-0.60	-0.24
Portishead	0.55	0.16	-0.12	-0.73

Table S32. Factor analysis of late Famennian-Tournaisian sites: taxon loadings. See Fig. S11*D* for plot of factors 1 and 2.

Taxon	Factor 1	Factor 2	Factor 3	Factor 4
Actinopterygii	0.38	4.13	0.24	-0.63
Onychodontida	-0.28	-0.09	-0.05	1.44
Porolepiformes	0.49	-0.10	-0.06	1.04
Dipnoi	1.34	0.14	-0.32	1.68
Osteolepididae	0.09	-0.24	-0.21	2.02
Tristichopteridae	1.50	-0.14	-0.30	-0.35
Megalichthyidae	0.12	0.44	0.04	0.28
Rhizodontida	0.38	0.94	0.05	-0.38
Actinistia	0.14	0.19	-0.34	-0.32
Arthrodira	1.39	-0.55	-3.47	-0.25
Antiarcha	3.14	-0.18	0.76	0.43
Phyllolepida	1.11	0.14	0.07	-0.83
Ptyctodontida	0.18	0.02	-0.16	-0.25
OtherPlacoderms	0.18	0.02	-0.16	-0.25
Elasmobranchii	-0.85	1.07	-2.84	0.55
Symmoriiformes	-0.15	0.15	-0.50	-0.07
Holocephali	-0.40	0.47	-0.17	0.99
Ischnacanthida	0.36	-0.01	0.16	0.33
Climatiida	0.18	0.02	-0.16	-0.25
Gyracanthida	0.09	1.04	-0.20	-0.20
Acanthodida	-0.30	0.89	0.47	2.92
Tetrapoda	1.74	0.32	0.47	0.03
Variance Explained	*43.59%*	*22.78%*	*12.45%*	*5.11%*

Table S33. Factor analysis of late Famennian-Tournaisian sites: site scores. See Fig. S11*D* for plot of factors 1 and 2.

Site	Factor 1	Factor 2	Factor 3	Factor 4
AinaDal	0.90	0.02	0.04	0.27
BrittaDal	0.83	0.02	-0.30	0.32
Grenfell	0.81	-0.08	-0.11	0.23
Hyner	0.65	0.27	-0.31	0.06
Evieux	0.72	0.10	-0.57	0.16
Ketleri	0.51	0.04	-0.14	0.79
Tafilalt	0.06	0.27	-0.86	0.01
Andreyevka-2	0.42	0.33	0.13	0.77
Cleveland	0.21	0.04	-0.92	0.01
Chaffee	0.43	-0.02	-0.58	0.52
Witpoort	0.58	0.24	-0.64	-0.01
Horton	0.16	0.93	0.05	-0.01
Izkchul	0.04	0.94	-0.08	-0.02
Mansfield	-0.01	0.83	-0.31	0.28
Foulden	0.17	0.94	0.04	0.01
Herbesskaya	-0.08	0.81	-0.33	0.14

Table S34. Factor analysis of end-Famennian- Tournaisian sites: taxon loadings. See Fig. S12*D* for plot of factors 1 and 2.

Taxon	Factor 1	Factor 2	Factor 3	Factor 4
Actinopterygii	4.40	-0.28	-0.24	-0.05
Onychodontida	-0.20	0.09	1.19	0.11
Porolepiformes	-0.12	-0.30	1.23	-0.25
Dipnoi	0.24	-0.91	1.98	-0.50
Osteolepididae	-0.32	-0.22	1.90	-0.10
Tristichopteridae	0.04	-1.01	0.37	-0.45
Megalichthyidae	0.32	0.08	0.45	0.22
Rhizodontida	0.94	-0.08	-0.02	-0.02
Actinistia	0.24	-0.47	-0.23	-0.06
Arthrodira	-0.34	-4.10	-0.13	-0.28
Antiarcha	-0.04	-0.46	1.61	-0.37
Phyllolepida	0.04	-0.20	0.02	-0.18
Ptyctodontida	0.12	-0.36	-0.12	-0.28
OtherPlacoderms	0.12	-0.36	-0.12	-0.28
Elasmobranchii	-0.13	-1.01	-0.27	4.18
Symmoriiformes	0.00	-0.25	-0.22	0.61
Holocephali	0.17	0.27	0.72	0.91
Ischnacanthida	0.00	0.01	0.52	-0.03
Climatiida	0.12	-0.36	-0.12	-0.28
Gyracanthida	0.90	-0.09	-0.07	0.56
Acanthodida	0.40	0.96	2.62	1.19
Tetrapoda	0.50	-0.39	0.82	-0.71
Variance Explained	*45.68%*	*24.04%*	*13.81%*	*5.95%*

Table S35. Factor analysis of end-Famennian-Tournaisian sites: site scores. Fig. S12*D* for plot of factors 1 and 2

Site	Factor 1	Factor 2	Factor 3	Factor 4
Evieux	0.13	-0.84	0.38	-0.05
Ketleri	0.02	-0.33	0.91	-0.04
Tafilalt	0.10	-0.65	-0.08	0.69
Andreyevka-2	0.28	0.01	0.89	0.11
Cleveland	-0.01	-0.90	-0.04	0.30
Chaffee	-0.05	-0.69	0.57	0.08
Witpoort	0.26	-0.86	0.15	0.04
Horton	0.97	-0.08	0.10	0.02
Izkchul	0.91	-0.08	0.03	0.24
Mansfield	0.67	-0.13	0.24	0.63
Foulden	0.96	-0.08	0.13	0.05
Herbesskaya	0.64	-0.11	0.09	0.65

Table S36. SIMPER for late Frasnian and early Famennian sites. Results based on relative diversity data. Average dissimilarity: 64.01.

Taxon	Contribution	Cumulative %	Mean abund. late Frasnian	Mean abund. early Famennian
Arthrodira	13.42	20.96	34.50	9.36
Antiarcha	8.39	34.07	6.90	22.80
Porolepiformes	5.26	42.28	8.30	9.40
Elasmobranchii	4.74	49.69	4.95	7.07
Tristichopteridae	4.56	56.80	2.87	9.21
Dipnoi	4.55	63.91	12.20	16.6
Osteolepididae	3.28	69.04	1.25	6.75
Ischnacanthida	3.00	73.72	6.11	0.60
Acanthodida	2.97	78.37	5.31	2.98
Rhizodontida	2.44	82.18	2.86	3.37
Tetrapoda	2.29	85.76	4.11	1.79
Ptyctodontida	1.68	88.39	2.29	2.38
Actinopterygii	1.45	90.65	2.88	0.60
Phyllolepida	1.39	92.82	0.00	2.78
Onychodontida	1.20	94.70	1.70	1.19
OtherPlacoderms	1.04	96.32	2.07	0.00
Actinistia	0.97	97.84	0.37	1.68
Symmoriiformes	0.72	98.96	0.00	1.44
Holocephali	0.67	100.00	1.33	0.00
Megalichthyidae	0.00	100.00	0.00	0.00
Gyracanthida	0.00	100.00	0.00	0.00
Climatiida	0.00	100.00	0.00	0.00

Table S37. SIMPER for late Famennian and Tournaisian sites. Results based on relative diversity data. Average dissimilarity: 80.79.

Taxon	Contribution	Cumulative %	Mean abund. late Famennian	Mean abund. Tournaisian
Actinopterygii	18.57	22.98	3.22	40.40
Arthrodira	9.38	34.60	18.80	0.00
Elasmobranchii	6.82	43.04	9.06	13.00
Antiarcha	6.61	51.22	13.20	0.00
Gyracanthida	4.46	56.75	1.04	9.55
Acanthodida	4.10	61.82	4.60	9.11
Rhizodontida	3.81	66.54	1.20	8.63
Dipnoi	3.76	71.20	10.60	4.69
Tristichopteridae	3.45	75.47	6.90	0.00
Tetrapoda	3.07	79.26	6.68	2.87
Osteolepididae	2.69	82.59	5.38	0.00
Holocephali	2.59	85.80	1.35	4.86
Porolepiformes	2.23	88.57	4.47	0.00
Megalichthyidae	2.19	91.27	1.46	4.03
Phyllolepida	1.50	93.13	3.00	0.00
Symmoriiformes	1.39	94.85	1.60	1.54
Actinistia	1.10	96.21	1.35	1.33
Onychodontida	1.05	97.51	2.11	0.00
Ischnacanthida	1.04	98.79	2.07	0.00
OtherPlacoderms	0.32	99.20	0.65	0.00
Ptyctodontida	0.32	99.60	0.65	0.00
Climatiida	0.32	100.00	0.650	0.00

Table S38. SIMPER for end-Famennian and Tournaisian sites. Results based on relative diversity data. Average dissimilarity: 79.19.

Taxon	**Contribution**	**Cumulative %**	**Mean abund. end-Famennian**	**Mean abund. Tournaisian**
Actinopterygii	17.96	22.68	4.44	40.40
Arthrodira	11.59	37.32	23.20	0.00
Elasmobranchii	7.21	46.42	12.20	13.00
Acanthodida	4.72	52.38	5.44	9.11
Gyracanthida	4.47	58.02	1.02	9.55
Rhizodontida	3.99	63.06	0.65	8.63
Dipnoi	3.61	67.62	9.34	4.69
Antiarcha	3.32	71.82	6.65	0.00
Osteolepididae	3.12	75.77	6.25	0.00
Holocephali	2.69	79.16	2.12	4.86
Tristichopteridae	2.63	82.48	5.26	0.00
Porolepiformes	2.30	85.39	4.61	0.00
Megalichthyidae	2.22	88.19	1.67	4.03
Tetrapoda	1.92	90.61	3.88	2.87
Symmoriiformes	1.75	92.81	2.52	1.54
Onychodontida	1.65	94.90	3.31	0.00
Actinistia	1.35	96.60	2.12	1.33
Ischnacanthida	0.84	97.66	1.67	0.00
OtherPlacoderms	0.51	98.30	1.02	0.00
Ptyctodontida	0.51	98.95	1.02	0.00
Climatiida	0.51	99.59	1.02	0.00
Phyllolepida	0.32	100.00	0.65	0.00

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