Supplementary Information for: A ubiquitous ~62 Myr periodic fluctuation superimposed on general trends in fossil biodiversity: Part I, Documentation

By A.L. Melott and R.K. Bambach

In this manuscript we describe some detailed results which are only summarized in the main paper. Section I presents the results of spectral analysis of a variety of alternate reductions of the Seposki data discussed and summarized briefly in Section V. C. of the main text, and Section II looks at the data segregated into the Paleozoic and the Mesozoic/Cenozoic dominant genera noted and summarized briefly in Section VI. A. of the main text.

I. Analysis of a variety of reductions of the Sepkoski dataset

A. Sepkoski-Bambach standing diversity.— This data is a reduction of the full Sepkoski genus data as held by RKB. In this case we determined the number of genera crossing substage boundaries by subtracting the number of extinctions in each interval from the total diversity of that interval. This produces the number of genera continuing on into the next interval. This is the only measure we actually have of "standing diversity" (the actual number of genera present at just one time) because during any time interval some extinctions probably occur in the interval before all originations occur, meaning that "total diversity" levels for whole intervals probably are rarely, if ever, achieved. This record of "boundary crossers" does omit all genera confined to just one substage (all "singletons"), and so does not include all evolutionary activity. In this case, since we used entering diversity, we used the beginning date of intervals rather than the mid-point as used in most other analyses. The peak again appears at higher confidence $p<0.001$ than in analysis of data as reduced by R&M (see L&M, Cornette 2007). The peak is at 62.7 ± 2.9 Myr, as seen in Fig S1A.

B. The Sepkoski—JJS Sort.— This is the full Sepkoski data set (1996 version) sorted by Sepkoski's own sorting routine. It uses 107 intervals rather than the 155 to 166 of complete substage analyses. It is the data as Sepkoski always analyzed it himself. The peak in Figure S1B is very strong, at 62.7 ± 3 Myr. It contributes 42% of the variance of the detrended curve.

C. Peters' reduction of the Sepkoski data—"all well resolved".— This data is a reduction of the data published in Sepkoski 2002 but only includes the genera in which both end points (first and last) are known at the substage level. It differs from R&M "well-resolved" in that they interpolated end points resolved at stage level to the substage, whereas this data set omits such genera. This sorting routine does not interpolate and excludes any genus that does not have both end points resolved at the substage level. Therefore this data set is smaller than other reductions of the Sepkoski data used here. This data is publicly available on website http://strata.geology.wisc.edu/jack/. This restricted data still illustrates the periodicity, but at reduced significance (see Figure S1C). The power spectral feature is now at 61.7 Myr, with a phase consistent with its previous appearances, but now at only 95% confidence. Also, the peak at ~150 Myr is now reduced in amplitude, well below the level of interest. There are two spectral features at high formal significance at 32 and 37 Myr as well. Such features are interesting, but few survive in cross-spectra, so we do not make any claims about them.

D. Peters "multi-interval well resolved genera".— This data is a highly culled reduction of the Sepkoski (2002) data. It contains only genera that cross at least one substage boundary and have both end points resolved to substage level. It is fit by a cubic. There is no ambiguity about which function is best fit. Still, the residuals from the cubic are unusual. There are huge fluctuations associated with K-T extinction and Cenozoic recovery. They look larger than the Permian event. Due to the fact that the K-T event lies at ¼ cycle away from a minimum of the 62 Myr cycle, this large amplitude may be the reason for the existence of a peak near 90 Myr, which does not appear in any other data set. Still, the main peak appears in Figure S1D, p=0.01, 63 Myr.

II. Analysis of Paleozoic and Mesozoic/Cenozoic Dominants

Because it was apparent that the ~62 Myr periodicity in marine diversity was concentrated in "short-lived genera" (see section VI of the main text) and it was also clear that the periodicity was well expressed through the Paleozoic but seemed to fade in the later Mesozoic and Cenozoic (also see section VI of the main text) we wondered if the periodicity was either more dominant or possibly biologically confined to groups that had been diversity dominants in the Paleozoic. To test for this possibility we compiled two data sets (Paleozoic dominants and Mesozoic-Cenozoic dominants) which are subsets of Sepkoski's total data base as held by RKB and sorted by RKB in 1999 using Sepkoski's sorting routine and thus are interpolated to the 107 intervals (some substages, some stages) that Sepkoski used for his finest-scale analyses, and analyzed them for periodicity.

A. Paleozoic Dominants.— We define Paleozoic dominants as follows: all genera in the Paleozoic dominant group are in classes or orders that had maximum diversity sometime in the Paleozoic, no matter when particular genera occur. The taxa grouped as Paleozoic diversity dominants are: Stromatoporoidea, Anthozoa, Cricoconarida, Inarticulata, Articulata, Stenolaemata, Hyolitha, Tergomya, Mollusca Incertae Sedis, Rostroconchia, Cepahlopoda, Polychaeta, Problematica, Trilobita, Merostomata, Ostracoda, Eocrinoidea, Stylophora, Diploporita, Rhombifera, Fissiculata, Spiraculata, Isorophida, Edrioastroidea, Crinoidea, Graptolithina, Conodontophorida, Agnatha, Placodermi.

After detrending the Paleozoic dominant data over the Phanerozoic, we find a strong spectral peak at 61 +7 -4 Myr (asymmetric because of the shape of the peak) shown in Figure S2A. This is a highly significant peak, as expected. Sectioning of the series produces ambiguous results. When the Paleozoic dominants are examined only for the interval 0-250 Mya (not shown), the peak moves to 75 ± 10 Myr, at p=0.01. When the interval is restricted to 0-150 Mya, it moves to p~0.1, 67 ± 14 Myr. These changes are entirely consistent with our visual impressions of the data and with the increased uncertainty associated with a shortened time interval. We have hints that the pattern persists in the Paleozoic fauna, but nothing firm.

H. Mesozoic and Cenozoic dominants.— The Mesozoic-Cenozoic dominants are in classes and orders for which the largest number of genera occurred in the Mesozoic or Cenozoic. The Mesozoic-Cenozoic dominant groups are: Demospongia, Calcarea, Hexactinellida, Hydrozoa, Scyphozoa, Gymnolaemata, Polyplacophora, Bivalvia, Gastropoda, Malacostraca, Cirripedia, Asteroidea, Ophiuroidea, Echinoidea, Dendrochirotida, Apodida, Chondrichthyes, Osteichthyes, Reptilia, Mammalia. These are the taxa that participate most heavily in the nearly continuous and nearly exponential post-Paleozoic radiation.

This suite of taxa diversified rapidly during the Mesozoic and Cenozoic, so the best fit is an exponential. This is strongly preferred by the F-statistic, so that is what we use for detrending in the results presented here. We also truncated this data set at 450 Mya because the numbers in the Cambrian are very small. If either of these natural choices are violated, we do not have a significant peak. With these choices, this group (see Figure S2b) shows a spectral peak at 62.5 +6 -4 Myr, at $p<0.01$. When we only examine the time period 0-250 Mya, there is still a spectral bump in this region, with a phase angle consistent with previous results, but barely better than 50% confidence level. Truncation at 150 Mya produces an even lower peak. Notice that the reduction in this peak for recent times is much stronger than with the Paleozoic fauna, even though the numbers are strong.

Because there is a reasonably significant peak for the Mesozoic-Cenozoic dominant groups when the portion of the Paleozoic in which they are initiating buildup in diversity is included it is clear that the 62 Myr periodicity in total fossil diversity is not limited exclusively to Paleozoic dominant taxa. Because the buildup of total diversity through the Phanerozoic is from the accumulation of long-lived genera, and the number of short-lived genera shows no secular increase in the last 150 Myr it is inescapable that a majority of the genera of Mesozoic-Cenozoic dominants in the last 150 Myr are long-lived genera, which do not show the periodicity in any significant way. Therefore, we can conclude that the periodicity, while somewhat more obvious in the Paleozoic dominant groups, is not confined to them but is, instead, primarily displayed by short-lived genera drawn from all taxa, regardless of whether they are Paleozoic or Mesozoic-Cenozoic diversity dominants.

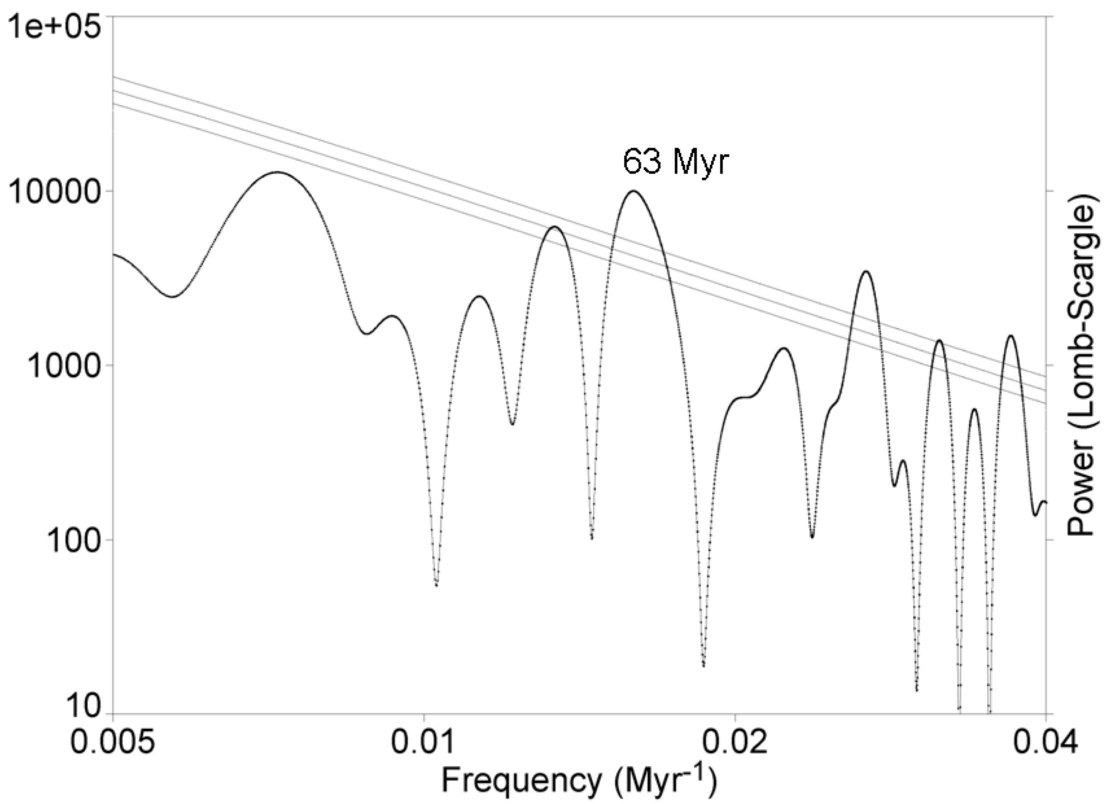

Figure S1A. The power spectrum of the RKB (entering) standing diversity reduction of the Sepkoski data. Again, a peak at 62.7 ± 3 Myr is more significant than in original R&M analysis.

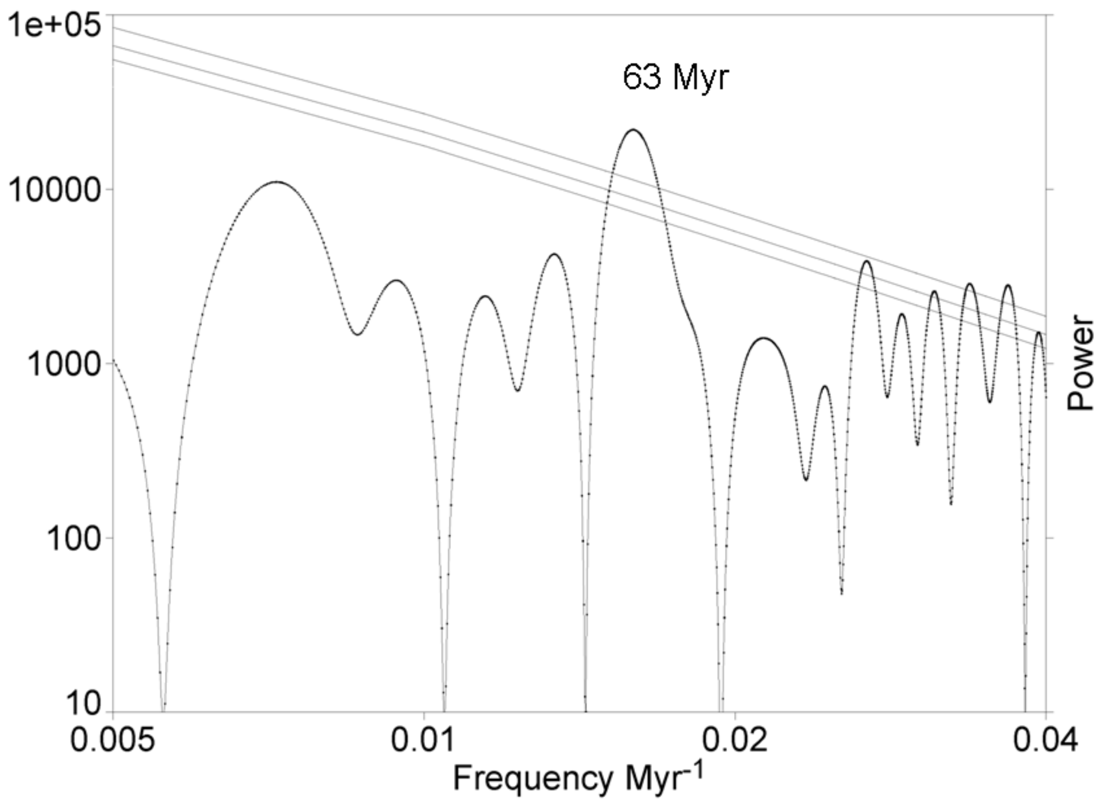

Figure S1B: Power spectrum of the raw Sepkoski sort data, with no cuts. The peak is now at 62.7 Myr.

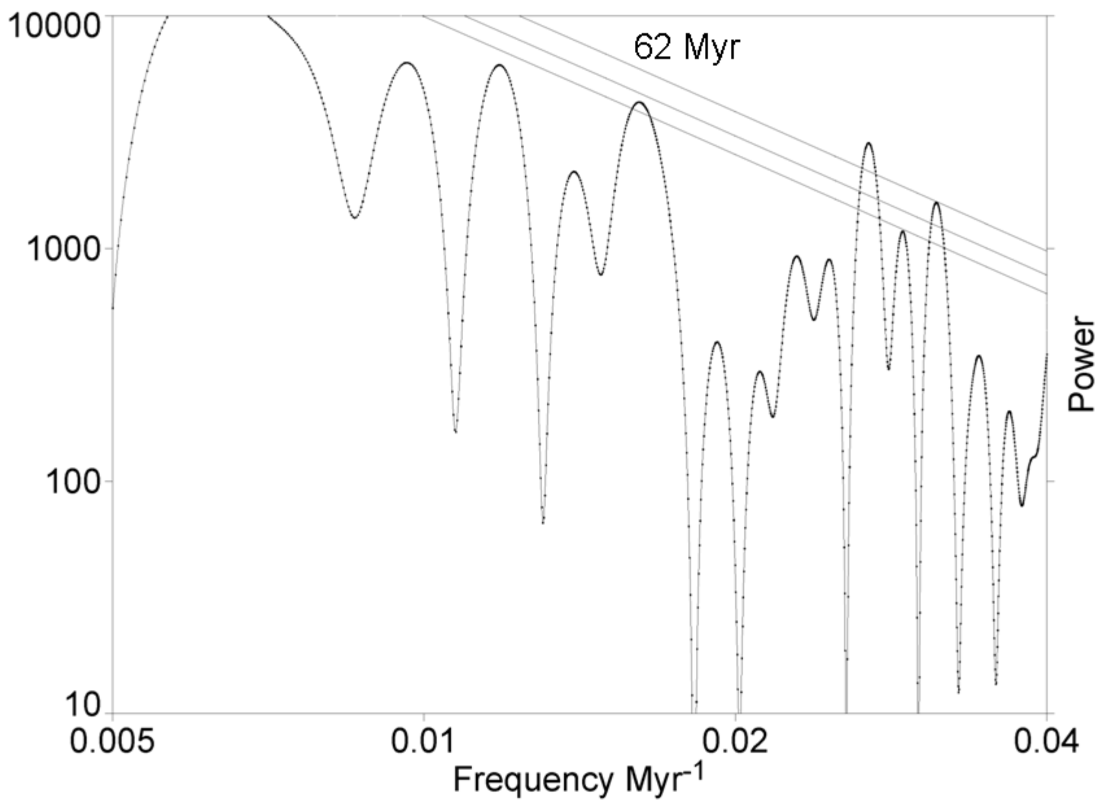

Figure S1C: Power spectrum of the Peters sort of “all well resolved genera”. The power spectral feature is now at 61.7 Myr, with a phase consistent with its previous appearances, but now at only ~95% confidence. There are two spectral features at high formal significance at 32 and 37 Myr as well, but we cannot independently confirm them. The former peak ~150 Myr has dropped far below the level of significance.

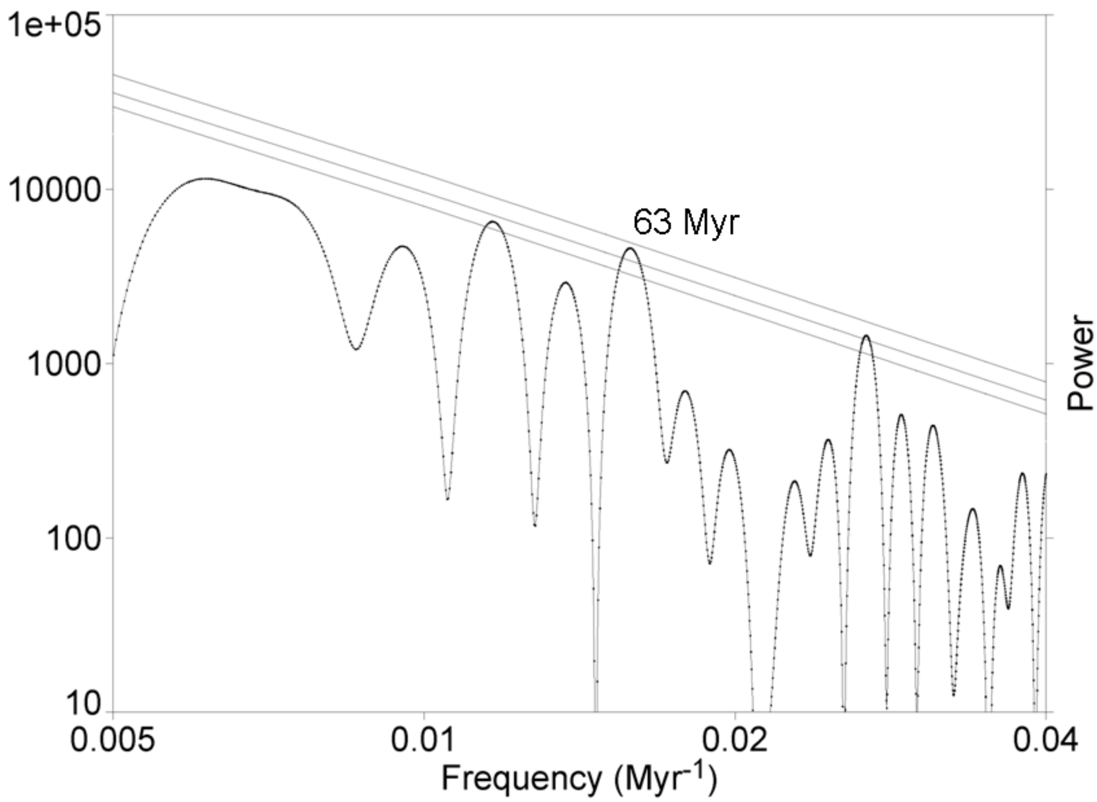

Figure S1D: Power spectrum of fluctuations in the Peters “multi-interval well-resolved” reduction of the Sepkoski data. There is a peak at 63.3 ± 2 Myr, $p<0.01$ which has a phase angle consistent with all the other appearances of this cycle. However, there is also a weak peak at 90 Myr which does not appear in any of the other reductions. Alternate analysis using Lomb-Scargle, or adding a minimal tapered-cosine window to force the ends of the series to zero (Muller and McDonald 2002) give results consistent with what is shown here.

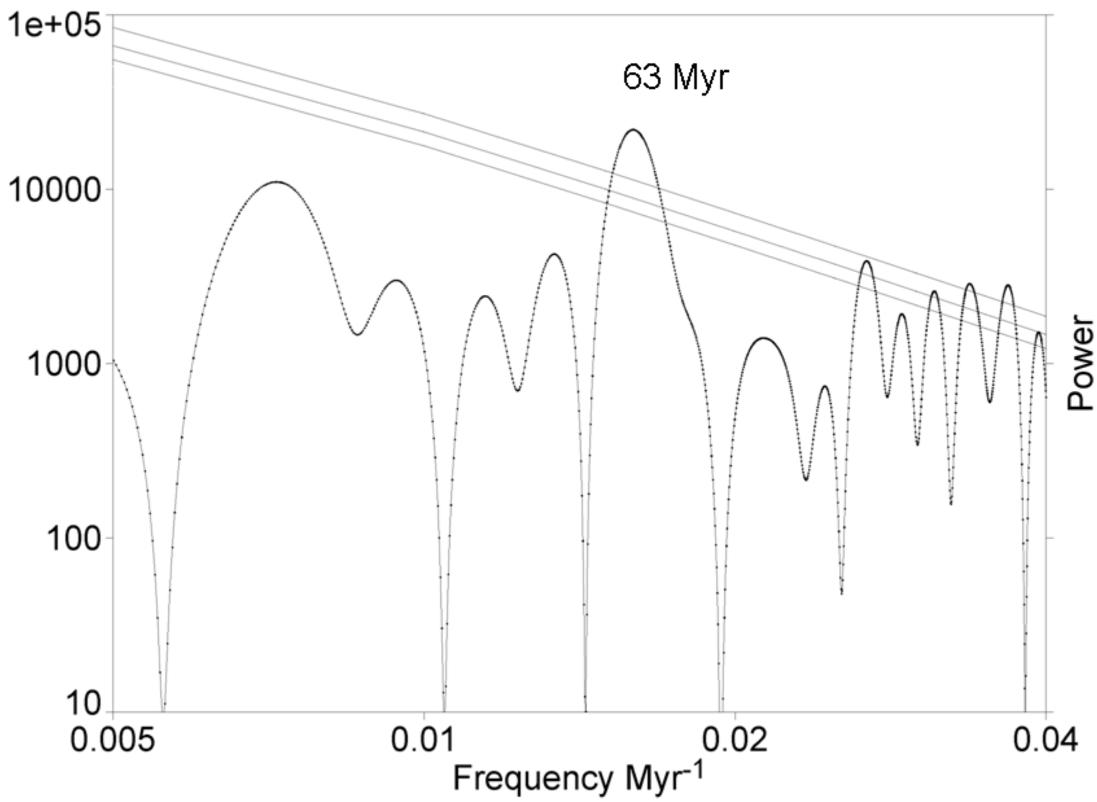

Figure S2A: Power spectrum of diversity fluctuations of the Paleozoic dominant fauna, as described in the text. There is a strong peak at a period of 63 Myr.

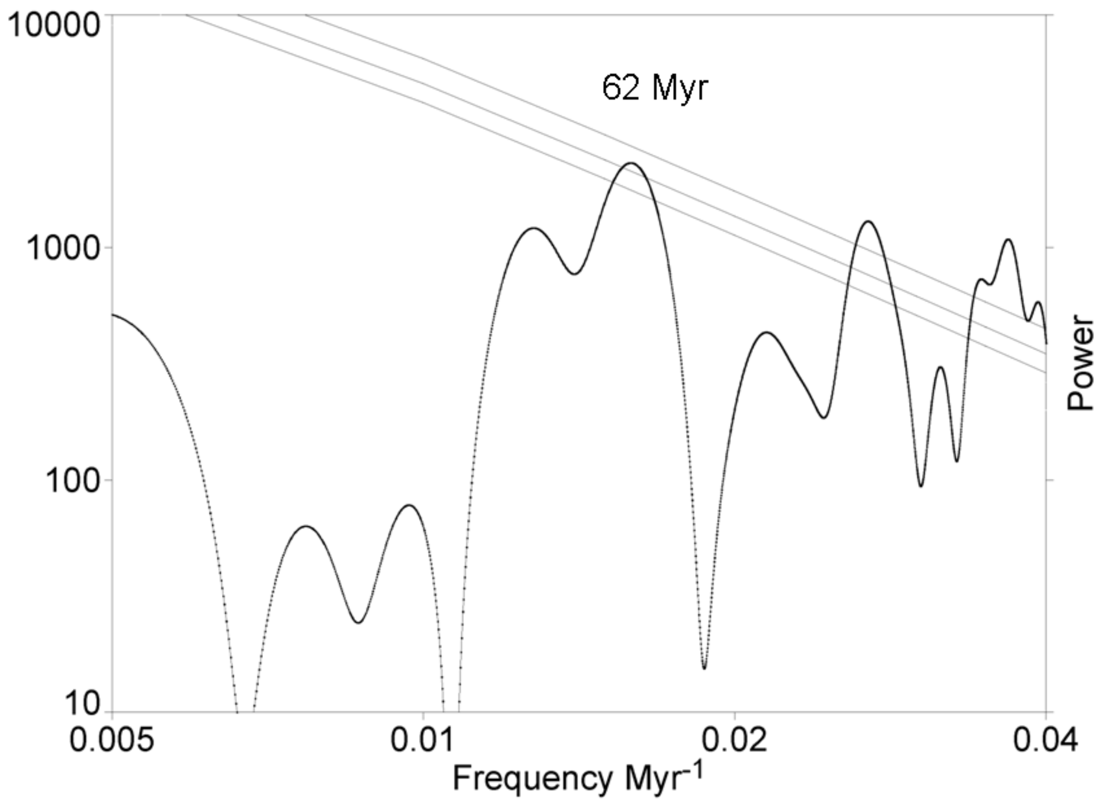

Figure S2B: Power spectrum of diversity fluctuations of the Mesozoic + Cenozoic dominant fauna. There is a strong peak at 62.5 Myr, albeit not as strong as in Figure S2B.