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Automated Composite Depth Scale Construction and Estimates of Sediment Core Extension

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Appendix A: Detailed Methodology

A1. Hole Alignment

An automated alignment algorithm is especially well suited to composite depth construction because the records to be matched are long and fairly similar. *Lisiecki and Lisiecki* [2002] (LL02) developed an automated technique for graphic correlation using dynamic programming. The LL02 algorithm differs from previously published automated correlation techniques [*Martinson et al.,* 1982; *Brüggemann,* 1992; *Yu and Ding,* 1998] in that it finds a globally optimal alignment. Parameterized penalty functions instill geologic realism in the solution by quantifying desired alignment criteria, such as sedimentation rate variability. Stratigraphic alignments can also be constrained by user-defined tie points to include magnetic or biostratigraphic age control points or to correct errors in the automated alignment. Additionally, a user-friendly graphical interface aids in algorithm configuration, tie point creation, the identification of voids or hiatuses, and the visualization of alignment results.

The greatest challenge in the construction of composite sections is determining the length of stratigraphy missing between cores. We update the LL02 algorithm to allow for the realistic treatment of the gaps between cores, eliminating the need for interpolation. The new algorithm specifically identifies core breaks in both records and calculates the optimal size of each stratigraphic gap, including the possibility of coring overlaps. Gap sizes are optimized based on core alignments and an adjustable "gap size" penalty, which prevents physically unrealistic changes in depth across core breaks. Appendix B provides a technical description of modifications to the LL02 algorithm. The sensitivity of interhole alignments to different penalty weightings is presented in Section 4.6. The typical run-time to align two 300-m holes is approximately 2–3 minutes on a personal computer.

The modified LL02 algorithm is used to align the color reflectance, GRAPE, and/or magnetic suspitibility of each hole at a site to a single target hole. By considering the fit of several properties simultaneously, the algorithm can better constrain these alignments. Results are not sensitive to the choice of alignment target because the each hole contributes equally to the composite section and to the depth correction from mcd to cmcd. However, the target should span the entire depth range of overlap between holes without any core gaps longer than approximately 5 m. If no single hole is sufficiently continuous, two different target holes can be selected for different depth ranges to produce two composite sections that can be spliced together.

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A2. Composite Section

After all holes have been aligned to the target hole, a compositing algorithm is used to select segments from the aligned holes to splice together into a continuous composite section. The size of these segments is an adjustable parameter, which we set to 1 m. Wherever possible, the compositing algorithm avoids segments which include gaps or core material that is likely to be highly deformed. Based on shipboard visual core descriptions and our alignment results, we find that the top 2 m and bottom 1 m of each core are most susceptible to drilling disturbance and therefore attempt to exclude this core material from the composite section. However, core tops and ends are included if no sediment from the middle of a core is available for a given segment. If a core gap cannot be avoided, we select the segment (i.e., gap length) from the target hole. When two holes provide acceptable stratigraphy (containing no gaps or core ends) for a given segment, we select the segment which begins closest to the center of a core because it should be least susceptible to drilling disturbance or alignment errors. In the rare event that three or more holes provide acceptable stratigraphy, we narrow the selection to two holes by first eliminating any cores segments which are stretched or compressed by more than 50% relative to the other holes and then finding the pair of core segments whose physical properties best correlate with one another (to avoid cores with data errors or atypical stratigraphic features). From this pair of holes, we again choose the hole in which the segment is closest to the middle of a core.

The segments selected for inclusion in the composite section are spliced end-to-end by assigning offsets to their original mbsf depths. A composite depth scale is constructed by adding together the mbsf length of each segment in the composite (Figure 2, step 3) in a procedure identical to that used for traditional mcd depth scales. We use each segment's original mbsf length to create the composite because it is the only depth scale available within target gaps and because it minimizes the use of depth scales near core ends, which are more susceptible to distortion.

A3. Corrected Meters Composite Depth

The mcd scale should minimize the effects of drilling distortion by avoiding core ends where possible, but it is still subject to elastic rebound and other possible sources of core deformation. We create a corrected composite depth scale (cmcd) by adjusting the mcd based on core top mbsf measurements. This prevents any significant drift between the cmcd and mbsf depth scales. If alignment with downhole log data is desired, the mcd composite section could alternately be aligned to downhole log data using our graphic correlation algorithm.

Correcting mcd depth inflation based on direct measurements of depth (mbsf) at the top of each core has the advantages of real-time measurement during drilling and availability for all stratigraphic depths and holes. "Replicate" depth measurements from the core tops of different holes are also useful due to inherent uncertainty in measured drill depths, which produces scatter in the mcd-mbsf coretop offsets from different holes (Figure S1). (Leg 202 introduced a new technique to relate precalculated tidal movements to depth offsets between holes [*Shipboard Scientific Party,* 2003], which may reduce scatter in core top depths at newer ODP sites.) To account for uncertainty in the mbsf scale, we define a best-fit polynomial function (up to order 10) for core top offsets and subtract that polynomial from the mcd depths of the composite section to create the cmcd scale which is consistent with measured drill depths (Figure 2, step 4).

We avoid introducing excessive structure to the polynomial fit by evaluating the percent improvement in the standard deviation, σ, of the residuals for each increase in polynomial order. We select the polynomial with the highest order $n \leq 10$ for which $\sigma(n)$ is at least 1% less than $\sigma(n-1)$. The rate of change of the polynomial is not allowed to exceed 0.5 m of offset per meter (mbsf), and the offset between mcd and mbsf is held constant for all values after the last non-target core top. If necessary, corrections are made to the top and bottom of the fit to compensate for the tendency of polynomials to change rapidly near the ends of the constraining data. In the top 20 m of the composite, we eliminate short-term negative offsets because these either produce negative composite depths at the top of the record or create more structure in the offset correction than can be confidently resolved given the scatter in core top depths. In the last 15% of hole overlap, the offset is held constant if the polynomial fit generates a negative trend in offset. A graphical user interface also allows for the development of custom offset functions.

The final composite section is the record of spliced segments converted to cmcd by subtracting the best-fit polynomial from the mcd scale. For maximum accuracy the conversion from the mbsf of each hole to cmcd should be accomplished by aligning each hole to the composite section. However, tie points for these final alignments can be estimated based on the interhole alignments, making the labor investment for this step minimal. This final step also serves as an opportunity to check for errors in the composite section.

References

Brüggeman, W. (1992), A minimal cost function method for optimizing the age-depth relation of deep-sea sediment cores, *Paleoceanography, 7,* 467–487.

Lisiecki, L. E., and P. A. Lisiecki (2002), Application of dynamic programming to the correlation of paleoclimate records, *Paleoceanography, 17,* doi:10.1029/2001PA000733.

Martinson, D. G., W. Menke, and P. Stoffa (1982), An inverse approach to signal correlation, *Journal of Geophys. Res., 87 B6,* 4807–4818.

Shipboard Scientific Party (2003), *Proc. ODP, Init. Repts., 202,* College Station, TX (Ocean Drilling Program).

Yu, Z. W., and Z. L. Ding (1998), An automatic orbital tuning method for paleoclimate records, *Geophys. Res. Letters, 25,* 4525–4528.

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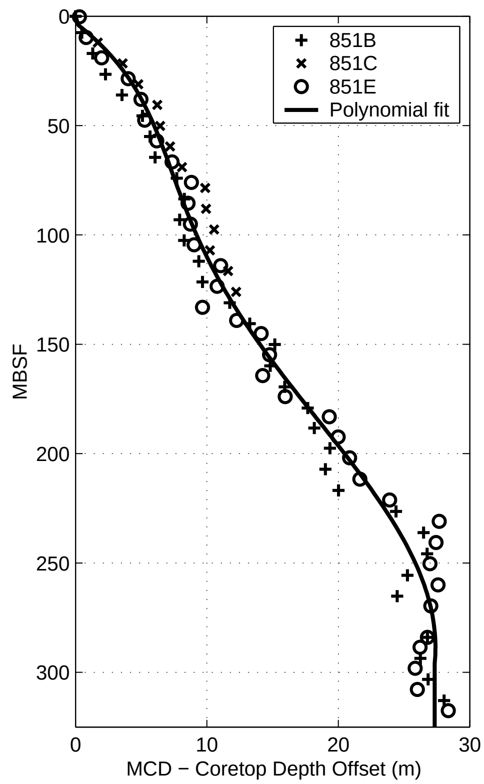

Figure 1. Offset between core top mbsf and mcd for Site 851 and the fifth-order polynomial used to convert mcd to cmcd.