Anatomy of morphological evolution: Old data reconsidered

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1. Abstract

A method is shown to better illustrate morphological variation of microfossil shells through time. Bivariate measurements from series of discrete time-slices are transformed into a continuous volumetric density distribution of specimens through time in that morphospace. The method is useful for the investigation and illustration of morphological speciation of fossils.

2. Introduction

Detection of speciation in the sedimentary archive is of general interest, a task that is usually tackled by statistical analysis of shell shape or size. However, simple means or standard deviations of shell parameters do often not sufficiently document morphological speciation and an analysis of the internal structure of the morphospace is desired in order to recognize the phylogeny of morphotypes.

A major difficulty is the comprehensive communication of such complex and multidimensional data sets. Here, a method is presented to illustrate morphological evolution in two examples, the coccolithophorid *Calcidiscus leptoporus*, and the planktonic foraminifer *Globorotalia menardii*.
In both cases published bivariate data sets were applied: In *C. leptoporus* the diameter versus elements of the distal coccolith shields from Knappertsbusch (2000) were taken. In *G. menardii* the spiral height (δx) versus the length of the shell (δy) in side view from Knappertsbusch (2007) were used.

From each set of data bivariate relative frequency distributions per sample were derived. The frequency distributions for *C. leptoporus* or for *G. menardii* were fed into Voxler software from Golden Software, Inc. By „gridding" relative frequencies of specimens were interpolated between samples. In this way regularly spaced volume elements (voxels) were generated, which represent the interpolated volumetric density of specimens in the morphospace spanned by diameter versus elements or δx versus δy and time. These 3D- density distributions are then rendered and plotted as iso-surfaces. Low frequency trends occur as „outer" surfaces, high frequency trends show up as „inner" surfaces.

Voxler allows tilting and rotating frequency surfaces on the computer monitor and "erosion" of the densities making this method extremely helpful to visualize complex evolutionary structures that never would be seen with classical statistical treatment.

3. Materials

For methods and measurements of coccolith diameter and number of distal shield elements of *C. leptoporus* please refer to Knappertsbusch (2000). The production of graphs illustrated in the presenmt contribution includes Early Miocene through Pleistocene samples from several DSDP sites, e.g. Sites 223, 224 (Arabian Sea), 251 (Southern Indian Ocean), 236 (tropical Indian Ocean), 366A and 608 (Atlantic Ocean), 572A (Eastern Pacific), Vema core V16-205 and Meteor core ME-69-106 (Atlantic).

Materials, methods and data for the production of *G. menardii* graphs are described in Knappertsbusch (2007). Cores illustrated here include Late Miocene through Pleistocene samples from DSDP Sites 502 (Caribbean Sea) and 503 (Eastern Equatorial Pacific).

4. Construction of volume density diagrams

For brevity reasons only the construction of the diagram for shells of *G. menardii* (core DSDP 502) are described in the scheme below.

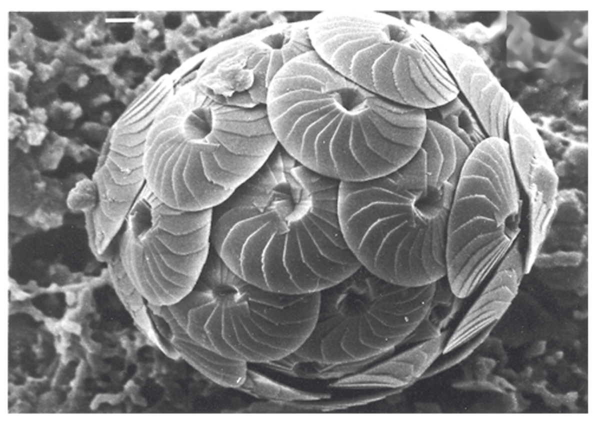
1.) Measure spiral height (δx) versus the length of the shell (δy) in keel view in downcore samples.

2.) Generate bivariate frequency distributions for each sample, with grid-cell sizes of Δδx=50μm and Δδy=100μm (use program Grid2.out from Knappertsbusch, 2004).

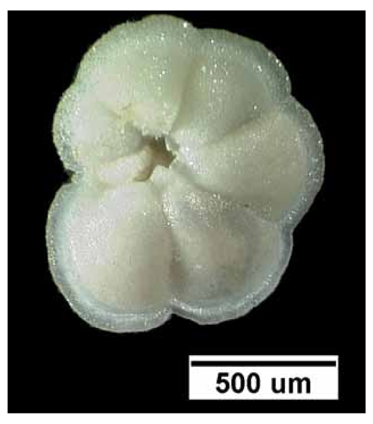
3.) Calculate relative frequency distributions for each sample, combine them into a single file together with numerical sample ages, and re-format columns (use program Grid_to_Vox.out from Knappertsbusch for the preparation for input into Voxler).

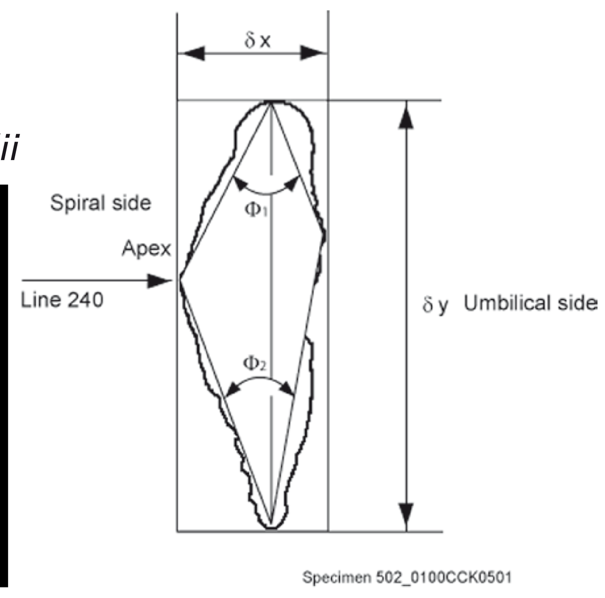
4.) Input of re-formatted data to Voxler. Apply nearest neighbor interpolation for gridding. Plot density surfaces for selected iso-values. See example volume density plots at upper right corner to see the effect of „erosion" at increasing iso-values.

Calcidiscus leptoporus

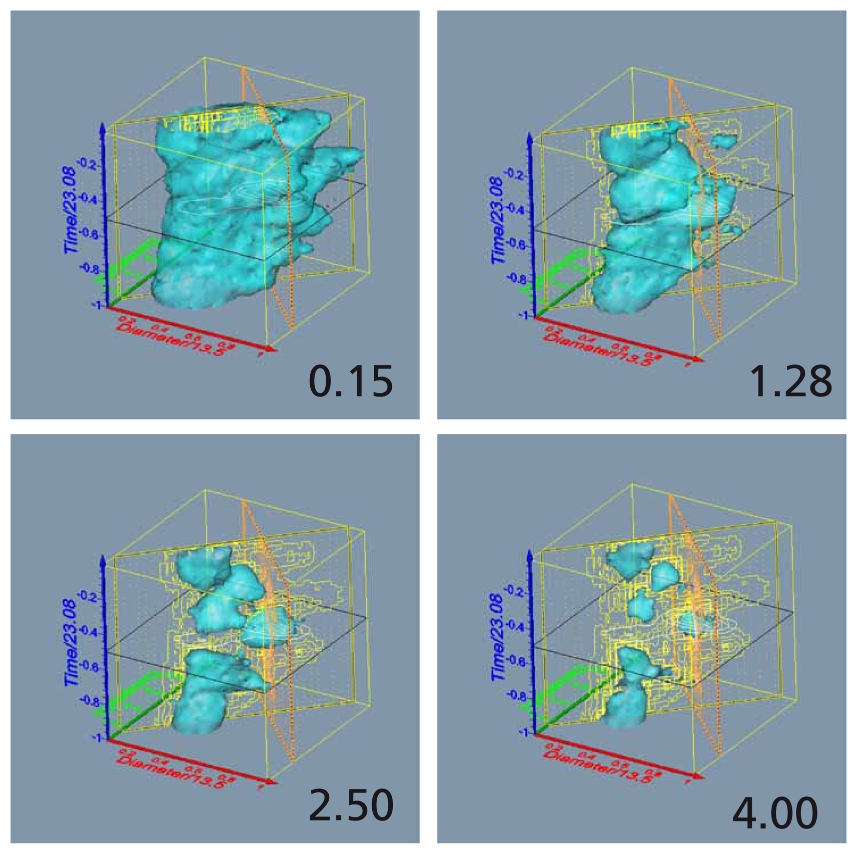


Globorotalia menardii



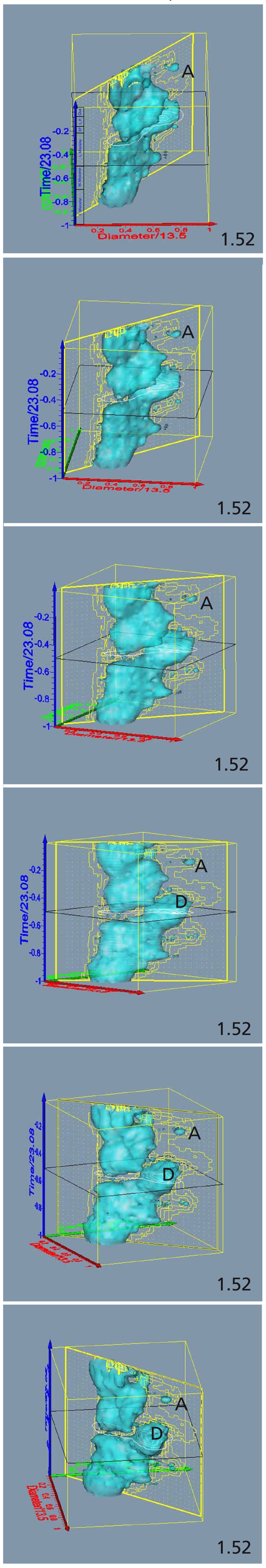


Morphological parameters in side view of *G. menardii*.

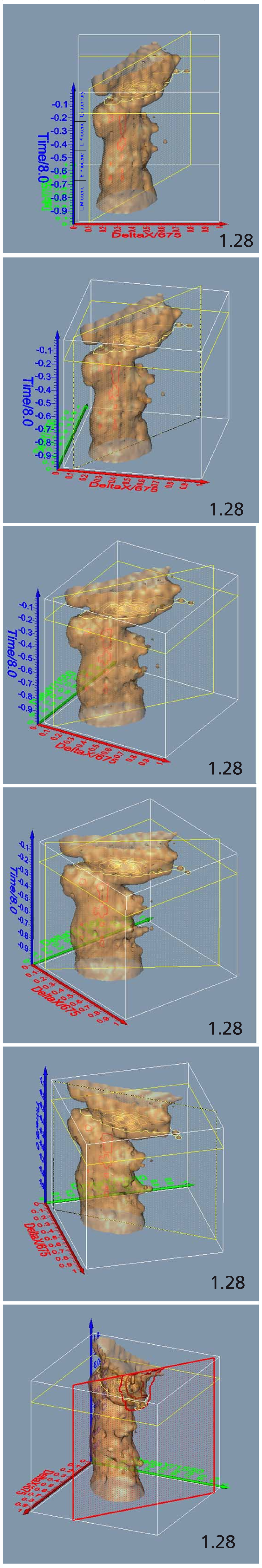


Example volume density diagrams for *C. leptoporus* at iso-values of 0.15, 1.28, 2.50 and 4.0.

Evolution of *C. leptoporus* (combined data, from Atlantic, Pacific and Indian Ocean*)*



Evolution of *G. menardii* (DSDP Site 502, Caribbean Sea)



5. Results: Volume density diagrams for *C. leptoporus* and *G. menardii*

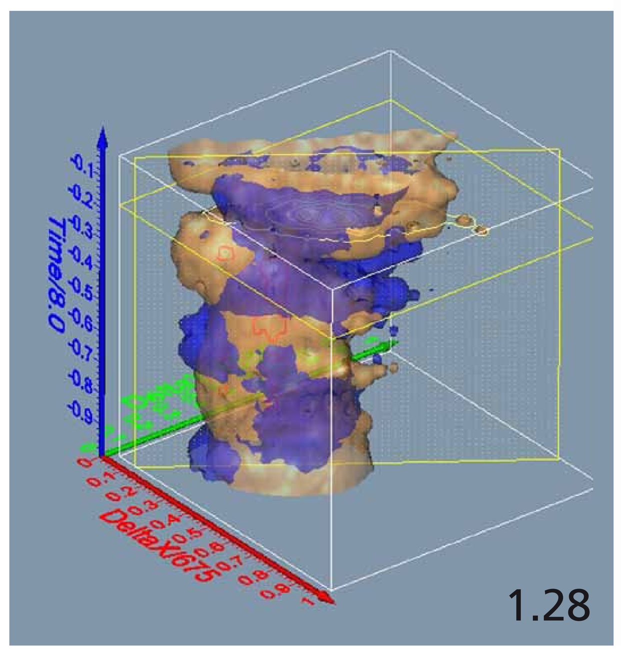
Volume density distributions of *C. leptoporus* (left column) and *G. menardii* (right column) in the morphospaces of diameter versus elements and δx versus δy, respectively at 7 successive angles of view.

The Iso-surfaces represent relative frequencies of specimens per volume element. Iso-values of 1.52 are shown for *C. leptoporus* and of 1.28 for *G. menardii*.

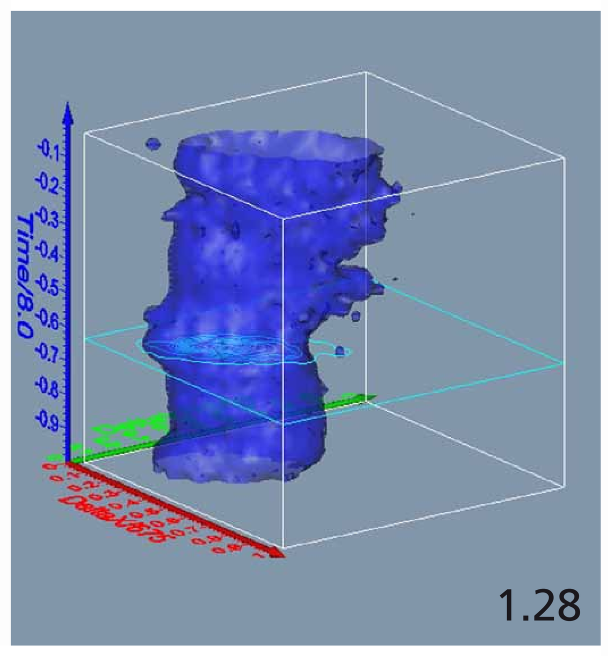
In *C. leptoporus* the prominent cladogenetic separation of large morphotype (D) of Knappertsbusch (2000) appears clearly. The extinction of Pliocene morphotype A (=*C. macintyrei*) appears as a small cloud.

In the evolution of *G. menardii* in the Caribbean Sea Site 502 a major shell-size increase coincides with shoaling and paleoceanographic reorganisation in the course of the closure of the Isthmus of Panama. In in the Eastern Equatorial Pacific a constantly gradual pattern is seen.

X-, Y-, and Z-axes are scaled for better illustration of morphological trends: For *C. leptoporus* the values on each axis were divided by 13.5μm (diameter), 52 (elements), 23.08 (million years).
For *G. menardii* X values were divided by 675μm (δx), Y values by 1550μm (δy), and the time axis by 8 million years.



G. menardii, from DSDP Sites 502 & 503 plotted together. Isovalue =1.28



G. menardii, DSDP Site 503 only (Eastern equatorial Pacific) Isovalue=1.28

6. Conclusions

Volume density plots are a useful method to visualize complex patterns of morphological evolution in microfossils.

Using an iso-value of 1.52 in *C. leptoporus* the prominent Late Miocene cladogenetic event leading to super-large coccoliths of morphotype D of Knappertsbusch (2000) could be better visualized with this method. Terminal morphotype A of Knappertsbusch (2000) [=*C. macintyrei*] appears as a small, isolate coud.

In *G. menardii* volume density diagrams suggest strong ecophenotypy along the major axis of the bivariate morphospace of δx versus δy. The minor axis, however, shows mainly stasis over long periods of time except in the Late Pleistocene, where morphotype differentiation occurred in a subrecent cladogenetic event around 0.23 Ma (not resolved here).

7. Acknowledgements

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8. References cited

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