Insights from the study of morphological evolution of menardiform globorotalids at Western Pacific Warm Pool ODP Hole 806C (Ontong-Java Plateau)

Michael Knappertsbusch
Naturhistorisches Museum Basel, Augustinergasse 2, 4001-Basel, Switzerland
Email: michael.knappertsbusch@unibas.ch

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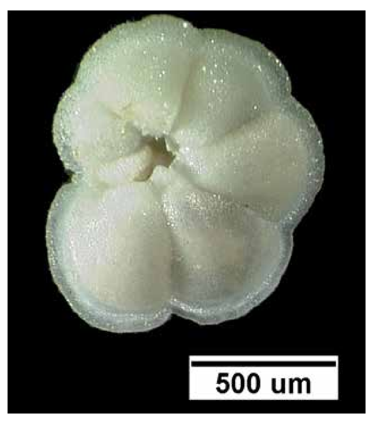
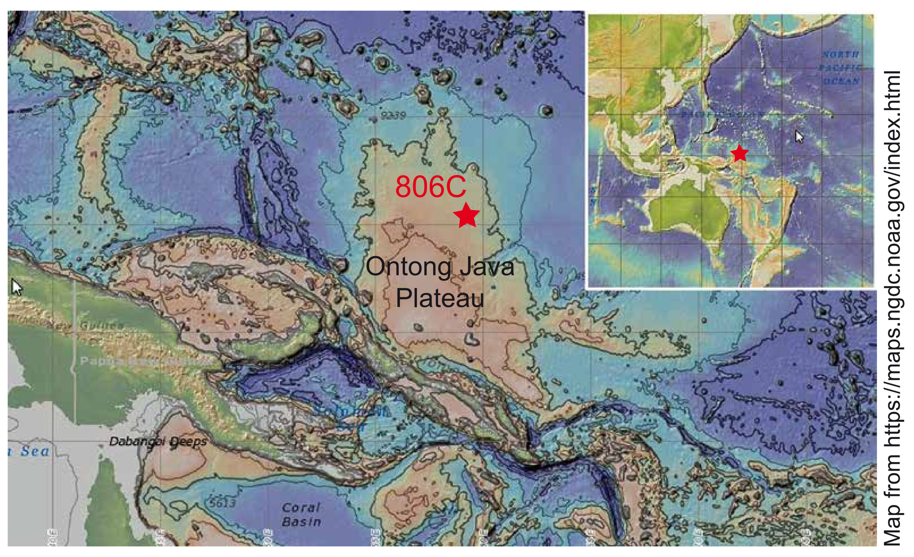
1. Introduction - Speciation patterns in planktonic foraminifera

In the framework of studying evolution and speciation in calcareous marine plankton the morphological variation of shells (tests) of the Neogene planktonic foraminifer *Globorotalia menardii* during the past 8 million years was measured at ODP Hole 806C (Ontong-Java Plateau).

Globorotalia menardii



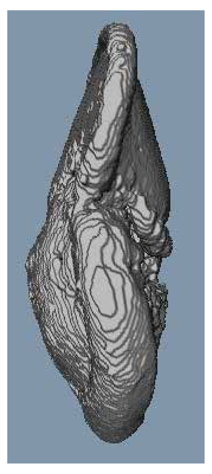
Umbilical view



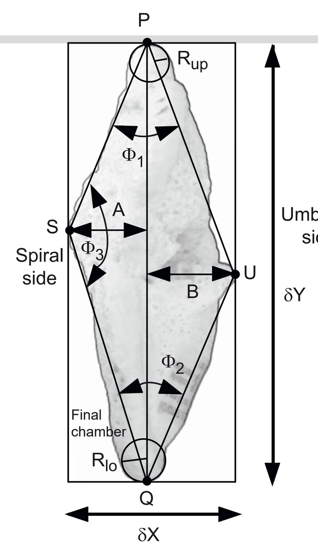
Position of ODP Hole 806C (0° 19.1'N / 159° 21.7'E, waterdepth 2521m).

2. Methods

Morphometric parameters Distances δX, δy, angles Φ_1, Φ_2, Φ_3, radii R_{up}, R_{lo}, sections A, B, and the keel view area were measured on isolated, oriented tests in profile view, and using digital image analysis (see Knappertsbusch, 2016).

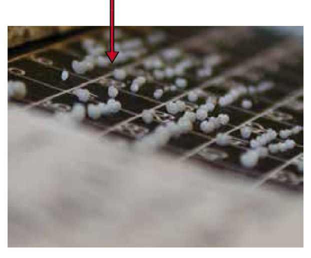


Keel-view (CT-scan)

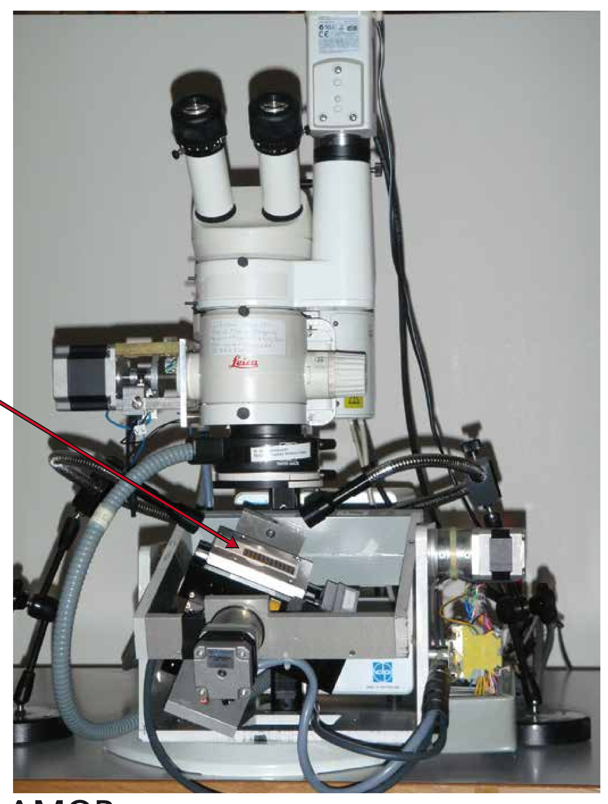


Parameters for studying shell evolution (Knappertsbusch, 2016)

Standard Plummer-cell with 36 or 60 fields containing menardiform shells



Enlarged view showing specimens in keel-position

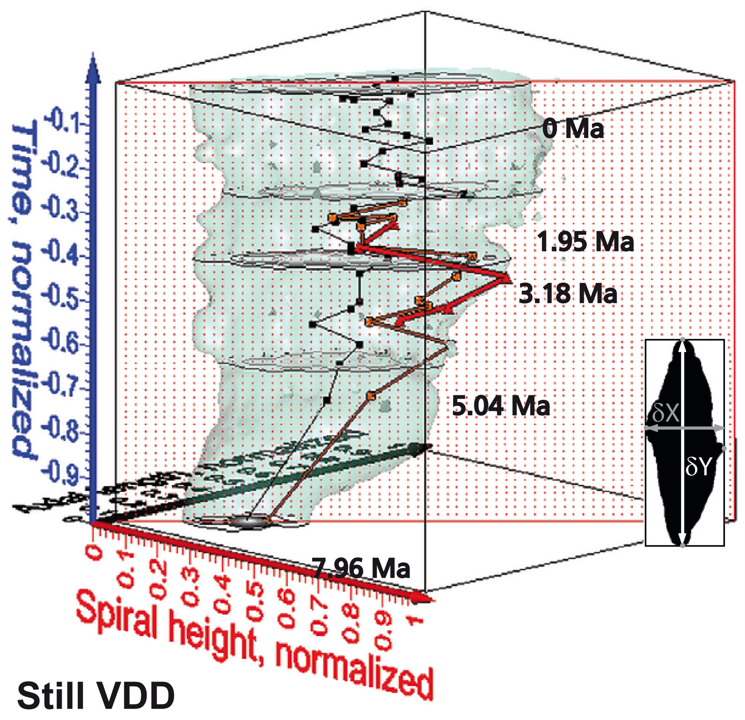


AMOR

For orientation and imaging of specimens under the binocular microscope a special robot called **AMOR**, (**A**utomated **M**easurement system for shell m**OR**phology) was used (see Knappertsbusch et al., 2009). An improved version - **System AMOR2** - was completed in 2019, see
https://micropal-basel.unibas.ch/Research/POSTERS/SGM_2019s.pdf

4. Volume Density Diagrams (VDD's) visualize morphological shell-change through time

Volume-density diagrams (**VDD's**) are iso-surfaces of stacked bivariate frequency distributions of δX vs δY through time (Knappertsbusch & Mary, 2012;Knappertsbusch 2016) using Voxler from Golden Software. The shown surface (XYZFs) at isovalue=1.1 encloses all specimens inside of the lowermost contour-line includeing very large rare forms. Frequencies were obtained by gridding at a grid-cell size of δX =50μm versus δY=100μm in every sample. Contours were constructed from the gridded frequency matrix using Surface III 2.6 plus from Kansas Geological Survey without weighting of grid values. The above isovalue was then visually estimated by best match with the contour lines reproduced in Voxler.



Still VDD

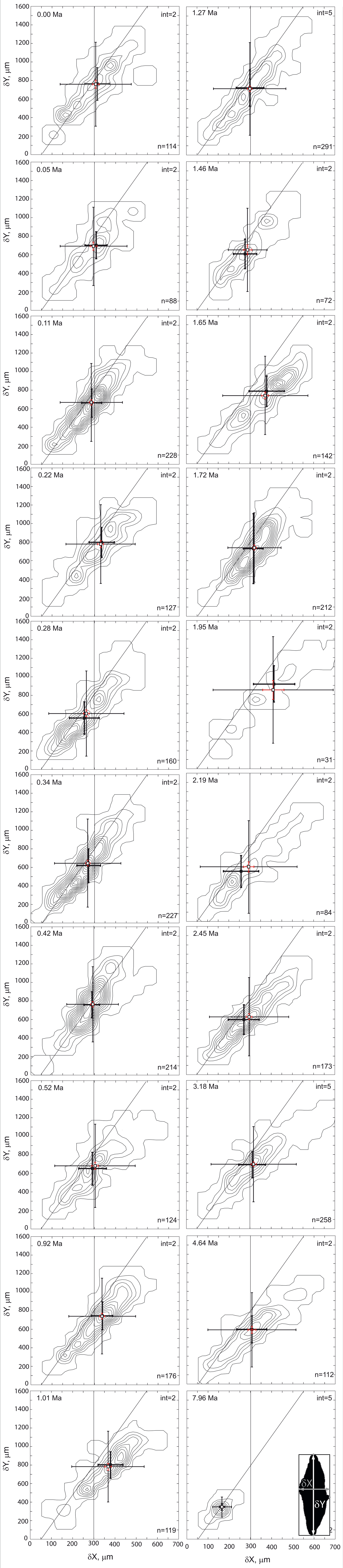
Interactive VDD (please save poster pdf to your PC for full functionality)

Left - VDD for *G. menardii* at ODP Site 806C. ***Right*** - Interactive VDD. Mouseclick to tilt, rotate or zoom VDD. Vertical axis = normalized time from 8 Ma to Recent (-1 corresponds to 8 Ma, 0 corresponds to Recent). Red axis = spiral height (δX) from 0-675μm, normalized to 0-1. Black axis = axial length (δY) from 0-1550μm, normalized to 0-1. Isosurface represents frequencies at an isovalue of 1.1.
Contours: Level method=Min,Max,Count; Min level=0, Max level=36, Number of levels=30. Selected time slices are shown at 0 Ma, 1.95 Ma, 3.18 Ma, 5.04 Ma, and 7.96 Ma. Maximal variation in the δX vs δY space occurs parallel to the diagonal (45°) plane. Variation of specimen frequencies of *G. menardii* along the 45° plane helps for better recognition of cladogenetic speciation, see diagram in section 5.
Interactive VDD was created using PDF3D ReportGen from Visual Technology Services Ltd.

In comparison to Site **502A**, **925B** and other sites studied earlier in the tropical Atlantic there is no sudden size-jump during the Late Pliocene (approximately at -0.25 on the vertical axis) suggesting a different - rather gradual and non-disturbed shell-size evolution of *G. menardii* in the western tropical Pacific.

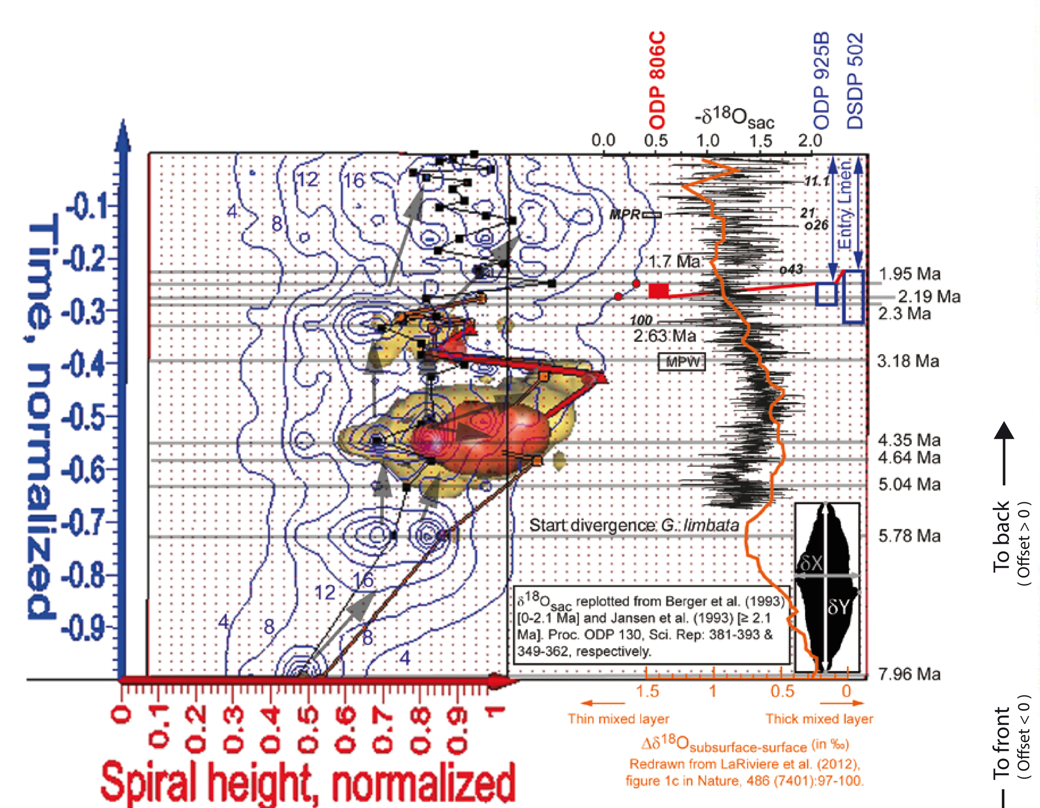
3. Bivariate frequency distributions of δX versus δY for *G. menardii* from ODP Hole 806C.

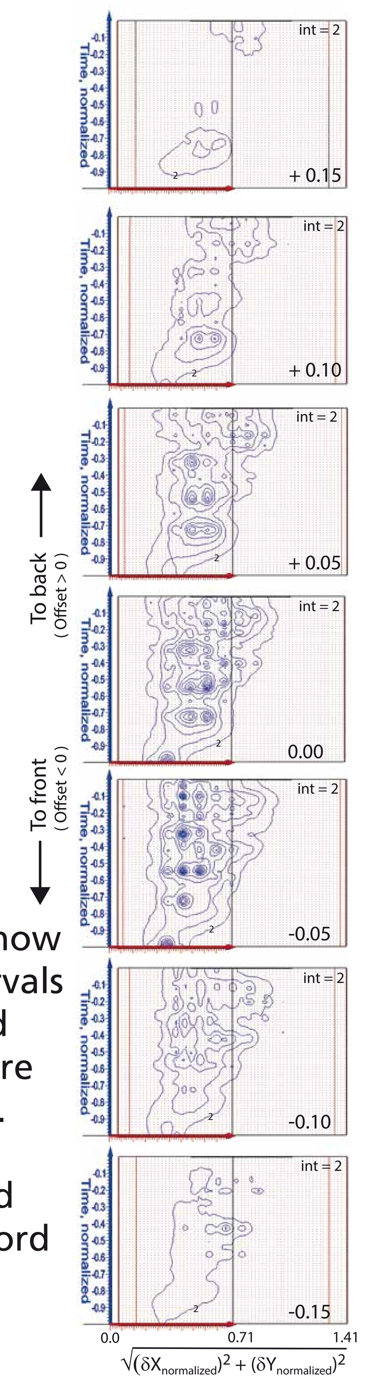
Legend - Open squares: Mean δX and δY, ±95% confidence intervals about the mean (small red bars), and 95% prediction intervals for observation (thin black bars).
Closed squares: Medians, and quartile ranges about the median from 25%-75% (thick black bars).



Left: **Selected contour diagrams of *G. menardii*** from 0 Ma to 8 Ma. Gridding of δX versus δY measurements with a grid-cell size of ΔδX=100μm x ΔδY=50 μm. int=contour intervals in specimens per grid-cell. n=number of specimens. Numbers in upper left corner indicate the age in Ma. Lines are for comparison between samples.

5. Internal structure of VDD's helps to detect

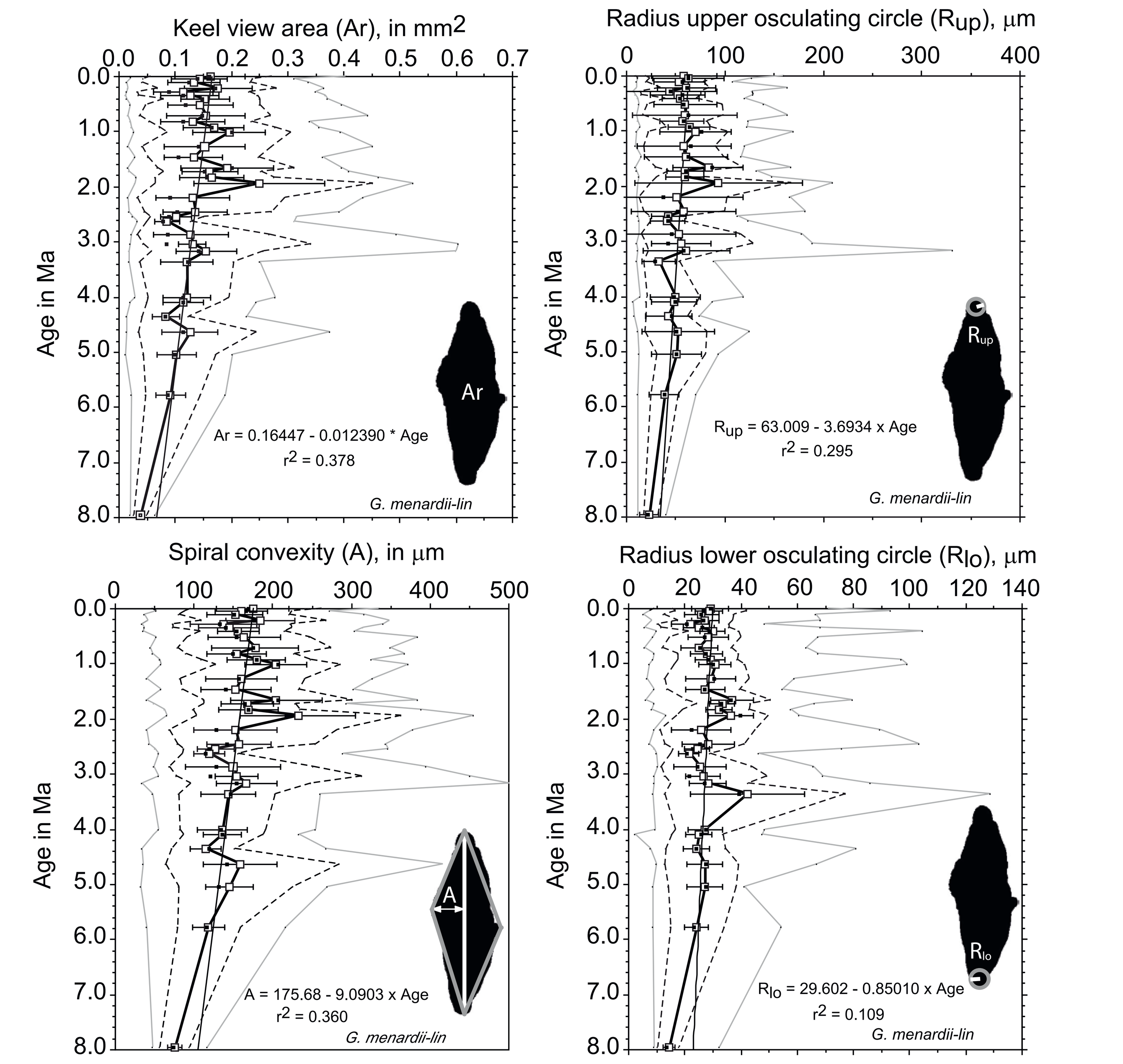




Above: Vertical slice through the VDD for *G. menardii* from section 4 in the 45°plane (offset=0). Blue contours show maximal variation in δX vs δY through time (contour intervals at 4 specimens/grid-cell). Note dichotomy into smaller and larger *G.menardii* in samples < 2.4 Ma (Z=-0.3). Overlain are VDD's for *G. limbata* (orange) and *G. multicamerata* (red). Line diagrams are mean δX vs δY of *G. menardii* (black), *G. limbata* (orange), and *G. multicamerata* (red). Increased divergence of *G. limbata* since 5.78 Ma (Z=-0.72). δO^{18} record (*G. sacculifer*) from Hole 806B from Berger et al. (1993) & from Jansen et al. (1993). $\Delta\delta^{18}O_{subsurface-surface}$ (orange) from LaRiviere et al. (2012).
Right: Slices for *G. menardii* parallel to the 45° plane at offsets from +0.15 (away from reader) to -0.15 (towards reader).

6. More results from Site 806C - Selected other shell parameters

Next to δX and δY trends of other shell parameters were studied, such as the keel view area, radii of osculating circles in keel regions, and spiral convexity.



Legend:
Open squares, horizontal bars and thick line: Means, range from lower to upper quartiles; Small solid squares: medians;
Dashed black lines: 10% and 90% percentiles; Solid grey lines: Minima and maxima. Straight line: Linear regression line through means.

7. Conclusions

In contrast to the tropical Atlantic, where **VDD's** show a sudden east-west time-transgressive size-increase of *G. menardii* , western Pacific ODP Site 806C *G. menardii* show a more gradual evolution. This manifests a strong asymmetry in shell evolution of menardiforms between the two oceans. *G. limbata* splitted off from *G. menardii* at an age >7.96 Ma and morphologicall diverged from it since 5.78 Ma. Combining observations from this work and data from Chaisson & Leckie (1993) *G. multicamerata* evolved from *G. limbata* at Site 806 between 9.31 Ma-7.96 Ma and began to diverge morphologically from 4.35 Ma onwards.

8. Acknowledgements

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9. References cited, see also https://micropal-basel.unibas.ch/

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