shell-change through time

\[ \Delta \delta Y \text{ versus } Y \text{ through time (Knappertsbusch & Mary, 2012; Knappertsbusch 2016)} \text{ using Voxler from Golden Software.} \]

The shown surface includes in the lowermost contour-line include very large rareforms. Frequencies were obtained by gridding during the past 8 million years was measured at ODP Hole 806C (Ontong-Java Plateau).

**3. Bivariate frequency distributions of IX versus \( \delta Y \) for \( G. \text{menardii} \) from ODP Hole 806C.**

**4. Volume Density Diagnostics (VDD’s) visualize morphological shell-change through time**

Volume-density diagrams (VDD’s) are iso-surfaces of stacked bivariate frequency distributions of \( \Delta X \text{ versus } \Delta Y \text{ through time (Knappertsbusch & Mary, 2012; Knappertsbusch 2016)} \text{ or Voxler from Golden Software.} \]

The shown surface (XY2D) at isoline=1.1 encloses all specimens inside of the lowermost contour-line including very large rare forms. Frequencies were obtained by gridding at a grid-cell size of \( \Delta X = 50 \mu \text{m} \) and \( \Delta Y = 100 \mu \text{m} \) 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 isoline was then visually estimated by best match with the contour lines reproduced in Voxler.

**5. Internal structure of VDD’s helps to detect morphological speciation patterns**

Above: Vertical slice through the VDD for \( G. \text{menardii} \) from section 4 in the 45° plane (offset=0). Blue contours show volume divergence in \( X \) vs \( Y \) through time (contour intervals at 4 specimens/grid-cell). Note dichotomy into smaller and larger \( G. \text{menardii} \) in samples 2.4 Ma (Z=0.33) and 7.1 Ma. The outer are VDD’s for \( G. \text{limbata} \) (orange) and \( G. \text{multicamerata} \) (red). Line diagrams are mean \( X \text{ versus } Y \) of \( G. \text{menardii} \) (black), \( G. \text{limbata} \) (orange), and \( G. \text{multicamerata} \) (red). Increased divergence of \( G. \text{limbata} \) since 5.7 Ma (Z=0.72). ID81 isotopic record (G. sacculiferid from ODP Hole 806B are data from Banger et al. (1993) and from Jasans et al. (1993). Right: Slices for \( G. \text{menardii} \) parallel to the 45° plane at offsets from \( X \text{ versus } Y \) away from reader) to 0.15 (towards reader).

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

Next to \( X \text{ and } Y \) trends of other shell parameters were studied, such as the keel view area, radii of osculating circles in keel regions, and spiral convexity.

**7. Conclusions**

In contrast to the tropical Atlantic, where VDD’s show a sudden east-west time-transgressive size-increase of \( G. \text{menardii} \), western Pacific ODP Site 806C \( G. \text{menardii} \) show a more gradual evolution. This manifests a strong asymmetry in shell evolution of menardiforms between the two oceans. \( G. \text{limbata} \) split-off from \( G. \text{menardii} \) at an age >7.96 Ma and morphologically diverged from it since 5.7 Ma. Combining observations from this work and data from Chaisson & Leckie (1993) \( G. \text{multicamerata} \) evolved from \( G. \text{limbata} \) at Site 806B between 9.31 Ma-7.96 Ma and began to diverge morphologically from 4.35 Ma onwards.

**8. Acknowledgements**

This research is supported by the Swiss National Science Foundation Grant: 200011 L08648 1, project ‘Testing the Agulhas Dispersal Hypothesis for Neogene planktonic foraminiferal evolution in Indian Ocean or Pacific Hne versus Central American passages’. Remaining sampling from ODP and support from the Natural History Museum Basel are acknowledged.

**References cited, see also https://micropalaeo-basel.unibas.ch/**


