Growth of Heterostegina depressa under natural and laboratory conditions

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It has been identified quite recently that shell form and size of larger benthic foraminifera (LBF) reflect environmental changes. Each growth step of these cells is represented by the addition of a single chamber, or a set of chamberlets. Volume, size and shape of these growth steps are influenced by the environmental scenario the cell is living in.
Therefore recent LBF can be used to reconstruct controlling factors that operate as underlying principles to chamber formation. Patterns oscillating around a fixed growth function can be established, which may reflect periodically recurring ecological signals in nature, such as tides, moon cycles or seasonality.

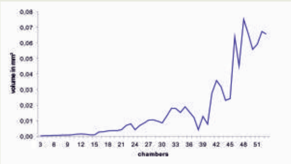

Fig.1 chamber volume sequence in *H. depressa*.

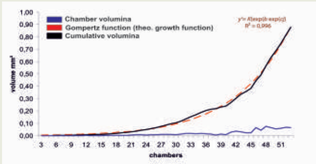

Fig.2 cumulative volumina and the theoretical growth function (Gompertz function), *j* = chamber number

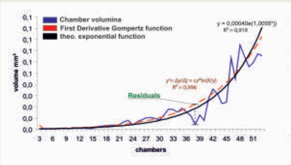

Fig.3 the chamber volume sequence oscillates around the Gompertz functions. The residuals are its deviation from the Gompertz function.

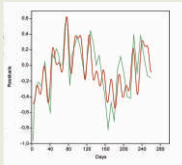

Fig.4. Residuals are plotted against the day of chamber formation and scanned for periodic cyclicities by using a sinusoidal regression model.

An additional task of this work has been the comparison of growth styles of naturally grown specimens and those cultivated under laboratory conditions, by Röttger and Krüger in 1991.
These cyclicities have been calculated and plotted (see Fig.1-4) in the larger benthic foraminifer, *Heterostegina depressa* using MicroCT technology for volumetry (see Fig.5-7). Therefore it was a firsthand opportunity to look not only into naturally grown individuals but also cultured specimens of *H. depressa* (see Tab.1).

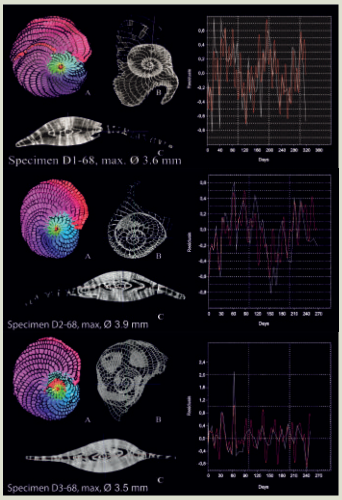

Fig.5 rendered 3D segmentation (A), equatorial (B) and axial slices (C), as well as sinusoidal function of hawaiian gamonts.

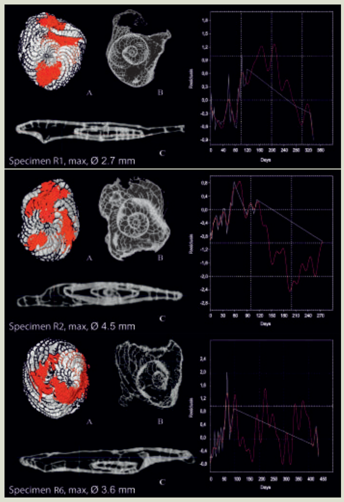

Fig.6 rendered 3D segmentation (A), equatorial (B) and axial slices (C), as well as sinusoidal function of cultured gamonts. The septal alteration is clearly visible on the radiographs.

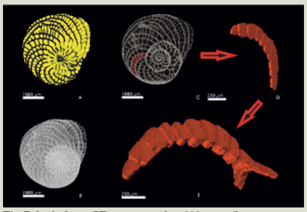

Fig.7 depicting a 3D segmentation (A), a surface reconstruction (B), a radiographic slice (C). By summing up 2D materials (D) 3D models are gained (E).

Code	Origin	Sample No.	A/B	Depth in m	Gompertz parameter	Amplitude	Phase	Period	p	R²
D1-68	Maui, Kekaa Point	#68	A	40	k = 723,23 b = 12,036 c = -0,0305 R² = 0,996	a1 = 0,239 a2 = 0,245 a3 = 0,213	φ1 = 3,02 φ2 = -1,6 φ3 = -0,822	τ1 = 192,8 τ2 = 12,28 τ3 = 28,16	0,00000099	0,55
D2-68	Maui, Kekaa Point	#68	A	40	k = 70184,89 b = -17,133 c = -0,008 R² = 0,996	a1 = 0,252 a2 = 0,188 a3 = 0,158	φ1 = 3,18 φ2 = -2,81 φ3 = 2,83	τ1 = 158,38 τ2 = 24,58 τ3 = 15,79	0,00000006	0,60
D3-68	Maui, Kekaa Point	#69	A	40	k = 2,596 b = -8,546 c = -0,033 R² = 0,999	a1 = 0,281 a2 = 0,331 a3 = 0,23	φ1 = 0,269 φ2 = 3,03 φ3 = 1,33	τ1 = 32,33 τ2 = 14,27 τ3 = 10,29	0,00000087	0,57
B44	Maui, Kekaa Point	P.1.10.91	B	n.a	k = 562,684 b = -16,118 c = -0,011 R² = 0,998	a1 = 0,253 a2 = 0,241 a3 = 0,217 a4	φ1 = -2,47 φ2 = -3,11 φ3 = 1,22 φ4 = -2,4	τ1 = 36,02 τ2 = 178,3 τ3 = 26,19 τ4 = 13,48	0,00000080	0,57
B13	Maui, Kekaa Point	P.1.10.91	B	n.a	k = 335,223 b = -13,765 c = -0,0935 R² = 0,998	a1 = 0,318 a2 = 0,166 a3 = 0,128 a4	φ1 = -1,89 φ2 = -2,12 φ3 = 0,135 φ4 = -1,96	τ1 = 136,5 τ2 = 54,96 τ3 = 22,8 τ4 = 25,93	0,00000291	0,51
B69	Maui, Kekaa Point	P.1.10.91	B	n.a	k = 42060,4 b = -20,7 c = -0,07 R² = 0,999	a1 = 0,222 a2 = 0,252 a3 = 0,223 a4	φ1 = 3,13 φ2 = -2,12 φ3 = -1,82 φ4 = -2,96	τ1 = 13,84 τ2 = 56,98 τ3 = 14,39 τ4 = 13,74	0,00011760	0,46
B80	Maui, Kekaa Point	P.1.10.91	B	n.a	k = 23707,446 b = -17,630 c = -0,06 R² = 0,999	a1 = 0,272 a2 = 0,150 a3 = 0,175 a4	φ1 = -1,55 φ2 = 2,2 φ3 = -1,78 φ4 = 1,73	τ1 = 181 τ2 = 17,79 τ3 = 59,27 τ4 = 35,64	0,00001040	0,43
A1	Sesoko-Jima	Transect A	A	20	k = 164,52 b = -13,271 c = -0,012 R² = 0,999	a1 = 0,282 a2 = 0,202 a3 = 0,198 a4	φ1 = 2,74 φ2 = 2,71 φ3 = 0,402 φ4 = 3,13	τ1 = 62,24 τ2 = 34,6 τ3 = 26,75 τ4 = 12,28	0,00000001	0,76
A2	Sesoko-Jima	Transect A	A	20	k = 2,192 b = -10,794 c = -0,031 R² = 0,999	a1 = 0,318 a2 = 0,135 a3 = 0,145 a4	φ1 = -1,44 φ2 = 0,097 φ3 = -1,7 φ4 = -1,32	τ1 = 84,48 τ2 = 18,08 τ3 = 34,24 τ4 = 29,08	0,000000083	0,75
A3	Sesoko-Jima	Transect A	A	20	k = 8,693 b = -12,602 c = -0,0075 R² = 0,995	a1 = 0,27 a2 = 0,23 a3 = 0,161 a4 =	φ1 = -1,29 φ2 = 0,503 φ3 = 2,11 φ4 = 2,68	τ1 = 74,32 τ2 = 22,68 τ3 = 10,12 τ4 = 35,92	0,00785930	0,51
B1	Sesoko-Jima	Transect A	B	20	k = 146482,1 b = -25,3 c = -0,009	a1 = 0,309 a2 = 0,288 a3 = 0,263 a4	φ1 = -0,948 φ2 = -1,08 φ3 = -2,43 φ4 = 3,01	τ1 = 28,96 τ2 = 13,74 τ3 = 43,6 τ4 = 213,63	0,00000080	0,79
R1	Universität Kiel	F1.27.1.91	A	n.n.	k = 8,573 b = -4,844 c = -0,03 R² = 0,887	a1 = 0,741 a2 = 0,246 a3 = 0,18	φ1 = -2,45 φ2 = 0,218 φ3 = -2,11	τ1 = 280,1 τ2 = 52 τ3 = 37	0,00000080	0,87
R2	Universität Kiel	F1.27.1.92	A	n.n.	k = 7,269 b = -7,990 c = -0,015 R² = 0,976	a1 = 1,15 a2 = 0,3 a3 = 0,115	φ1 = 1,75 φ2 = 1,23 φ3 = -2,56	τ1 = 275,3,1 τ2 = 35,85 τ3 = 21,32	0,00000080	0,98
R3	Universität Kiel	F1.27.1.93	A	n.n.	k = 8,548 b = -6,842 c = -0,046 R² = 0,988	a1 = 1,22 a2 = 0,76 a3 = 0,695	φ1 = -2,15 φ2 = -2,55 φ3 = 1,22	τ1 = 336,3,1 τ2 = 47,35 τ3 = 43,79	0,00000080	0,96
R6	Universität Kiel	F1.27.1.94	A	n.n.	k = 1119288,97 b = -20,39 c = -0,085 R² = 0,996	a1 = 0,674 a2 = 0,315 a3 = 0,34	φ1 = -2,73 φ2 = 1,75 φ3 = -2,82	τ1 = 146,4,1 τ2 = 30,43 τ3 = 40,41	0,00000080	0,84

Tab.1. List of the used specimens, showing Gompertz parameter, amplitudes, phases as well as p and R² values.

Results

Periods around ~ 14 and 29 days are the most frequent with very high significance possibly proving the effects tides and lunar month (see Fig.8).
Besides these short-term cycles, naturally grown specimens show also intermediate term periods of ~ 60 to 85 days (Gamonts Sesoko) and long-term period of 213.6 days (Agamont Kekaa Point).
As expected, the laboratory-cultured gamonts show different cyclicity patterns, as those seen in naturally grown foraminifera. Therefore they can be used to validate that these short-term cycles of natural grown specimens are enviornmentally induced.

Conclusion

Larger benthic foraminifera record short to long-term oscillation during their chamber formation expressed as chamber size variation, which are affected by lunar oscillations. The approach of simulating complex environmental factors of natural marine habitats should be closely revised. Serendipity of very acute developed teratologies support this view and create severe complications for further analysis using cultured specimens. Therefore, the validity of many geochemical analyses and environmental proxies applied on cultivated foraminifera may be badly affected.

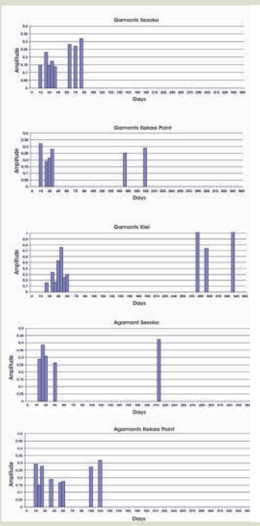

Fig.8 Histograms of the most significant periods of the naturally grown gamonts and agamonts of Kekaa Point and Sesoko-Jima and of laboratory cultured gamonts from University of Kiel.

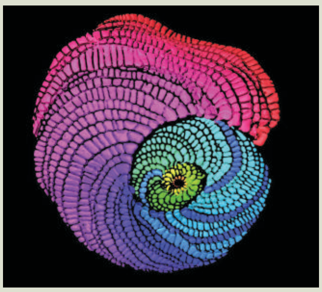

Fig.9 complete 3D segmentation of a *Heterostegina depressa* agamont (B33) from Kekaa Point, Hawaii.

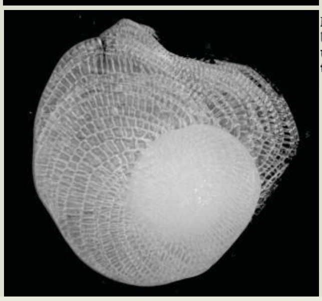

Fig.10 the radiograph slices obtained by MicroCT analysis can also be used to reconstruct the foraminfer's test surface.

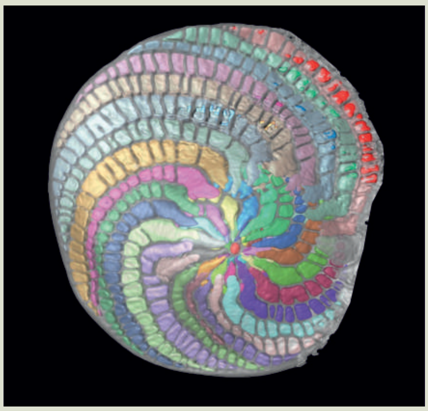

Fig.11 the test surface is transparent to allow a closer look at the 3D reconstruction of the chamber volume sequence.

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