Fourier shape analysis of *Elphidium crispum* (LINNAEUS) from the Gulf of Piran (Northern Adriatic) : preliminary results

Adrijan KOSIR

Institute of Paleontology, ZRC SAZU, LJUBLJANA **(Slovenija)**

There is an abundance of information on the relationships between environmental parameters and intraspecific morphologic variability in benthic foraminifera. Modern quantitative image analysis allows rapid, accurate and objective analysis of numerous specimens and makes possible to examine subtle changes in foraminiferal test morphology along the environmental gradient. In the past two decades Fourier morphometric techniques have been successfully applied to numerous studies of various organisms, especially foraminifera (e.g. GARY & HEALY-WILLIAMS, 1988).

In the present study we used five samples from the Gulf of Piran (Fig.1) from the collection of the Institute for Paleontology ZRC SAZU, Ljubljana. Samples were taken from sites, ranging from the Mouth of Dragonja river to the open Adriatic. They were chosen according to sedimentological and chemical data of RANKE (1976), so that they exhibit maximal differences in environmental conditions. From each sample we selected 24 specimens of *Elphidium crispum* with 22 to 28 chambers in the last whorl. Specimens were correctly mounted on glass slides, and the outline of the side view of each specimen was quantified using a computerized image analysis system of the Institute of Biophysics, University of Ljubljana. The system consist of a video camera mounted onto a microscope, a video recorder and a digitizer, all interfaced with a computer. The analog signal from the camera is digitized, and the edge-finding algorithm of the computer locates the foraminiferal test boundary. The shape analysis program transforms the digitized outline to Fourier series.

Fourier analysis develops a mathematical expression for the radius of the shape outline measured from an origin in the terms of the polar angle. The radius is given by :

$$r(\theta) = a_0 + \sum_{n=1}^{N} [(a_n \sin(n\theta) + b_n \cos(n\theta)] \quad \text{or} \quad r(\theta) = c_0 + \sum_{n=1}^{N} c_n \cos(n\theta - \phi n)$$

noting that

$$c_n^2 = a_n^2 + b_n^2 \quad \text{and} \quad \phi_n = \arctan(b_n/a_n)$$

where a_n and b_n are Fourier coefficients, c_n is the harmonic amplitude, and $\varnothing_n$ is the phase angle. The subscript $_n$ is the harmonic number or simply the harmonic.

Each harmonic amplitude represents the relative contribution of the specific shape component to the total test shape. The "zeroth" term (a_0 or c_0) represents the mean radius of the outline. The first harmonic amplitude describes a centering error. The second harmonic amplitude measures the contribution of a figure eight, and the third harmonic amplitude measures the contribution of a trefoil to the total shape. In general, the "*n*th" harmonic amplitude represents the shape contribution of a "*n*-leaved clover". The associated phase angle orients each shape component relative to the other shape components. Each harmonic amplitude can be used as amorphologic variable, and the test shape can be described as precisely as desired, depending on the number of harmonics calculated.

In the present study only the first ten pairs of Fourier coefficients were computed from 64 peripheral points spaced at equal angles subtended from the center of gravity of the outline. Visually, these 10 terms sufficiently reproduce relative smooth outlines of E. *crispum.*

The set of harmonic amplitudes constitutes the harmonic amplitude spectrum. Each sample thus consist of 24 spectra of nine harmonic amplitudes (the first harmonic amplitude is an error measurement and was not used for further analysis). Amplitude values are normalized (divided by the a_0), so that the differences in size do not affect shape comparisons. By the relative entropy method (FULL*et al.*, 1984)(Fig.2) we determined that harmonic amplitudes 3 and 4 contain the most information concerning intersample shape variability of E. *crispum* from the Gulf of Piran.

Figure 3 shows a comparison of sample amplitude means for harmonics 3 and 4 of E. *crispum* and environmental parameters (median grain size, total carbonate content, organic carbon and Eh values) in the surface sediments of the Gulf of Piran. The grain size and the carbonate content increase from the Mouth of Dragonja towards the Gulf entrance. The content of C_{org} in the surficial sediments has an inverse gradient. Eh values are positive for all surface sediments, however the depth of the Eh(0)-layer, ranging between 1 and 10 cm, increase seawards (RANKE, 1976). Mean harmonic amplitudes 3 (triangularity) and 4 (lobateness) both decrease from the Dragonja mouth (sample SEC) toward the open Adriatic (sample PI42).

We can see (Fig. 3) that there is a correlation (positive or negative) between test morphology of *E. crispum* and environmental properties taken into account. However, we cannot define any causal relationships from these preliminary data. Furthermore, we think that morphologic variability of *E. crispum* from the Gulf of Piran is not so much the result of environmental gradients mentioned, but more the response to the temporal (seasonal) changes in ecological parameters, which affect the growth of E. *crispum* and make its peripheral margin uneven.

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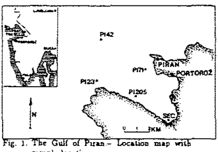

Fig. 1. The Gulf of Piran - Location map with sample locations.

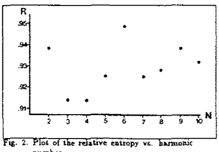

Fig. 2. Plot of the relative entropy vs. harmonic number.

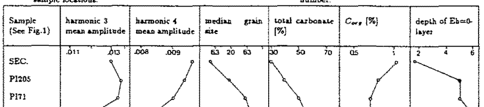

Fig. 3. Comparison of sample amplitude means for harmonic 3 and 4 and environmental parameters [sedimentological and chemical data estimated from Ranke, 1976]

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