Morphological response of Foraminifera to environmental stress during the deposition of a Mediterranean sapropel

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Foraminifera are a highly diverse and morphologically variable group of marine protists, which show an outstanding preservation in the fossil record. This continuous fossil record, in combination with the rather complex test structure, makes them ideal candidates for studies of biotic response to past environmental changes.

Our study aims at the understanding of the morphological reaction of Foraminifera on environmental stress. For that purpose we investigated a portion of Sapropel S5 from the Eastern Mediterranean Sea, which was deposited following the Eemian Insolation Maximum *c.*125 000 BP. It was presumably triggered by an enhanced freshwater input from Africa, which caused a reduction in surface water salinity and a stagnation of the vertical circulation. As a result, the Mediterranean Sea experienced pronounced environmental change during that time interval—which led to local extinction events of several species of planktonic Foraminifera that can be correlated across the entire Eastern Mediterranean. This interval therefore offers an excellent opportunity to assess the evolutionary and ecological response of marine organisms to environmental stress leading to local extinction.

We have chosen a portion of gravity core M51-3/SL104—comprising an extraordinary thick and well preserved Sapropel S5—for that study, which allows for a temporal resolution of *c.*100 years. Specimens of three different species of planktonic Foraminifera were analysed for changes in a wide variety of morphological traits, including calcification rate, size, incidence of abnormal growth patterns, and shell shape. *Orbulina universa* shows an occurrence pattern recording one local extinction shortly after the onset of the sapropel and a second local extinction approximately 4000 years after sapropel onset. During that time a continuous decrease in calcification rate can be observed, superimposed by a strong decrease in calcification rate after onset of the sapropel. A distinct decrease in roundness of the terminal chamber can be observed with onset of the sapropel. Intervals shortly before both local extinctions show increasing proportions of abnormal morphotypes and increasing test sizes. *Globorotalia scitula* displays stable abundances until shortly before onset of the sapropel, followed by a rapid local extinction within less than 200 years. During time the species shows a continuous decrease in calcification rate, but no visible patterns in size or incidence of abnormal morphotypes. An Elliptic Fourier Analysis shows a generally variable morphology, but no clear deviations when approaching local extinction. An analysis of the spiral growth pattern, however, revealed a significant increase in both growth rate and growth-rate variance in the last sample, about 100 years prior to its extinction. Preliminary results for *Globorotalia inflata* imply that there is no effect of environmental stress on calcification rate in this species.

These results show that environmental stress influences the morphology of foraminiferal tests. Either it hinders internal control mechanisms that would normally ensure a more symmetrical growth pattern, or it represents an attempt of the species to adapt to the changing environment by relaxing the growth pattern. The fossil

record investigated here nevertheless represents a natural experiment that involved the change of several environmental parameters at once, making it difficult to determine which environmental stressor affected the growth and morphogenesis of the species. Our results, however, demonstrate that environmental stress is causing morphological reactions in foraminiferal tests, which provides a strong case for carrying out *in vitro* experiments under controlled laboratory conditions to isolate the effects and induction levels for individual potential stressors.