Markov-chains and graphs for linking facies with environments and biology in space and time (Recent Arabian Gulf, Miocene Paratethys) and an ODE-based model of biotically-driven facies dynamics

Bernhard Riegl and Samuel Purkis
National Coral Reef Institute, Nova Southeastern University

If, as comparative sedimentology maintains, knowledge of the Recent can sometimes be helpful to explain the past (and vice-versa), common quantitative denominators might exist between Recent and fossil systems. It may also be possible to describe dynamics and find linkages between space and time with a unique set of quantitative tools. To explore such conceptual links, spatial facies patterns mapped using satellite imagery were compared with temporal patterns in analogous ancient outcropping facies using Markov chains and graphs. Then, an ODE-based model is developed to examine potential population dynamics within the facies. Landsat and Ikonos satellite imagery was used to map benthic facies in Arabian Gulf carbonate ramps and were compared to aMiocene (Badenian) Paratethys ramp. Facies adjacencies (i.e. Moore neighborhood of color-coded image pixels of satellite image or outcrop map) were expressed by transition probability matrices which suggested horizontal (spatial) facies sequences and vertical (temporal) outcrop sequences had the Markov property and that equivalent facies were comparable in frequency. We expressed the transition probability matrices as weighted digraphs and calculated fixed probability vectors which encapsulate information on both the spatial and temporal components (size of and time spent in each facies). Models of temporal functioning were obtained by modifying matrices (digraphs) of spatial adjacency to matrices (digraphs) of temporal adjacency by using the same vertices (facies) but adjusting transitions without changing paths. With this combined spatio-temporal model, we investigated changes in facies composition in falling and rising sea level scenarios by adjusting transition likelihoods preferentially into shallower (falling sea level) or deeper (rising sea level) facies. Our model can also be used as a numerical analogue to a Ginsburg-type autocyclic model. The fixed probability vector was used as a proxy for final facies distribution. Using Markov chains it is possible to use vertical outcrop data to evaluate the relative contribution of each facies in any timeslice which can aid, for example, in estimation of reservoir sizes and to gain insight into temporal functioning as derived from spatial pattern. The validity of the approach was examined by building a dynamic Lotka-Volterra type model of facies interactions which allowed facies transitions to be explained by biological dynamics.