Upscaling Sedimentary Processes: From Bed to Basin

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Understanding sedimentary processes is key to unraveling stratigraphic complexity and predicting subsurface architecture. Uniformitarianism, the principle that evolution over geologic time is governed by the processes we see acting today, has guided sedimentary research since first proposed by Hutton in the 18th century. However, while much progress has been made characterizing modern sedimentary processes, the problem of upscaling to large-scale stratigraphy is as challenging as ever. Process-based numerical modeling provides a powerful tool to bridge scales. Here I use examples of surface and stratigraphic evolution in coastal systems to demonstrate the issues and propose solutions for numerical modeling on timescales of years to Ma.

Well constrained physics makes reductionist models attractive, but naïve upscaling of event-based models is fraught with danger. It is easy to focus on the daunting computational demands of detailed fluid flow simulations, but if this were the prime issue then current weather models would reliably forecast centuries into the future. Weather models solve the problem of sensitivity to initial-boundary conditions by data assimilation, a solution unavailable to paleo-sedimentary process models, as data quality and availability degrades sharply as we move back in time.
I argue that successful models must be targeted models. No universal sedimentary model can work. I use examples of several coastal evolution models to demonstrate the power of targeted scale-appropriate models.

I suggest three fundamental scales of stratigraphic modeling—micro, meso, and macro—based on the morphologic unit of evolution (bed, landform, shoreline trajectory), forcing style (stochastic, autogenic, allogenic), and model target (event bed, reservoir, basin). I close with a simplified delta model, formulated at the event scale, which gives insights into the transitions in dynamics and forcing that occur across scales. Model simulations show how morphodynamic feedbacks drive self-organization of channels and lobes at the meso-scale, and lobe switching and compensational stacking at the macro-scale. These results suggest that naïve upscaling can only work to bridge nearby scales. Robust sedimentary process models must aim to faithfully reproduce the dominant morphodynamic feedbacks at scales smaller than, but comparable to, the scale of interest.