The role of saltwater in constructing continental shelves with seaward-migrating clinoforms

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Continental shelves have been generally interpreted as drowned ancient coastal plains developed at low stand. This implies that subaqueous hydrodynamics, sediment transport, and associated morphodynamic process do not contribute the formation and development of currently observed continental shelves. However, recent measurements of submarine sediment processes and sequence stratigraphy of continental shelves have indicated that even at the present Holocene sea level high stand, some shelves or protoshelves with seaward-migrating clinoforms have been developing by the result of long-term fluvial input of suspended sediment/mud and subsequent subaqueous morphodynamic process. Here, we show a description of this physical process of continental shelf formation using a numerical model. More specifically, we demonstrate 1) the role of saltwater in the formation of continental shelves, and 2) long-term development of shelf morphology with seaward-migrating clinoforms associated with interactions among fluvial suspended sediment supply, sediment deposition from hypopycnal plumes, and wave-induced sediment re-distribution on the shelf.

Fluvially derived suspended sediment/mud input is the main source of material for constructing continental shelves. However, in general, we do not see similar bench-like morphologies in old terrestrial lakes which are known to have been influenced by large amounts of fluvial sediment supply. An important factor which differentiates these two environments is dissolved salt in ambient water. In oceans, ambient salt water is generally much heavier than the input sediment-laden water, causing surface plumes (hypopycnal flows). In contrast, ambient fresh water in lakes allows the inflow sediment-laden water plunge directly into the bottom, forming hyperpycnal flows. We numerically model these physical processes to see the differences in the morphodynamic processes between hyper- and hypopycnal flows. The model presented herein is a vertical 2D Reynolds-averaged Navier-Stokes model with the Boussinesq approximation for density-driven flows. It described the effects of both dissolved salt and suspended sediment. The numerical results clearly show that hyperpycnal flows cause less proximal deposition of sediment on the shelf, transporting the sediment into deep water. Conversely, hypopycnal flows greatly contribute to proximal sediment deposition on the shelf. This result indicates that the dissolved salt plays an important role in controlling sediment dispersal, and in particular suppressing direct delivery to deep water.

Another important mechanism for subaqueous morphodynamic process considered here is wave effects for resuspension of sediment deposited on shelves. Long-term sediment supply from hypopycnal flows constructs a large shelf-like morphology, and the height of the shelf eventually builds to wave base. The wave-induced bottom shear stress can then contribute to the resuspension of deposited sediment on the shelf, redistributing the sediment from the shelf to continental slope. We incorporate a simple model to add the effect of bottom shear stress generated by waves into the numerical model. We then consider a scenario which is likely in the natural environment, namely, repeated cycles of short-term fluvial sediment input due to major flood events and the long-term effect of waves due to repeated storm events. The numerical results show that the sediment deposited on the shelf derives from sediment supply from hypopycnal plumes. This sediment is re-suspended by the wave effect, and then wave-supported turbidity currents transports the sediment onto the continental slope. These processes maintain a specific depth on the shelf and generate a seaward-migrating clinoform characterizing the seaward extension of the continental shelf by subaqueous processes.

Keywords: continental shelves, clinoforms, dissolved salt, wave base, density current

