Morphodynamics of downstream fining in rivers with a unimodal sand-gravel feed

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Over sufficiently long distances, the bed sediment of rivers most commonly becomes finer in the downstream direction. There appears to be no single driver for this. The chief drivers are often thought to be abrasion and selective deposition of coarser material. Downstream fining may be accompanied by a transition point, or transition reach from a gravel-bed to a sand-bed configuration. In some cases such transitions may be relatively sharp, but in other cases they may be more diffuse. The transition itself has been attributed to a) breakdown of clasts into constituent crystals b) depletion of the gravel through deposition, c) damped collisional abrasion of finer grains, and d) rainout of sand from suspension. Here we explore downstream fining using an input sediment that is purely unimodal. Any gravel-sand transition should be produced purely by the internal interactions in the model. The model focuses on the interaction of grains of different sizes, ranging from fine sand to cobbles. The following assumptions are used. 1. The input sediment is taken to be an undifferentiated mixture of sand and gravel with no bi- or multi-modality. 2. Abrasion and other kinds of grain breakdown are neglected. 3. The long profile of the river is assumed to consist of a channel and a floodplain, and is assumed to be undergoing slow subsidence. 4. Sediment conservation is specifically accounted for in all grain size ranges. 5. Relations for bedload transport and sediment suspension are to be grain size-specific, with exactly the same relations used for sand and gravel The goals of the modelling exercise are a) to develop a model of downstream fining of sand and gravel in which both are treated in exactly the same way, and b) to see if the interplay between sand and gravel can spontaneously give rise to a relatively sharp transition from gravel to sand.

Keywords: rivers, sand, gravel, downstream fining

Laboratory experiments to predict evolution of sediment size distributions by abrasion and fragmentation in transport

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Sediment particles carry information about the hillslope settings where they are created and the fluvial environments they traverse on their journey through the channel network to depositional zones. Information about upstream tectonic, climatic, geologic, and geomorphic conditions are encoded in the distributions of particle sizes, shapes, and rock types, and in the degree of chemical weathering. However, some information is lost due to abrasion and fragmentation of particles in transport. These processes reduce the size and alter the shape of individual particles, and thus transform the distributions of particle attributes. Despite the importance of particle wear in modulating the signals of upstream conditions contained in sedimentary deposits, many fundamental knowledge gaps remain. Here I report the results of a suite of laboratory experiments designed to enable prediction of particle wear rates, and shape evolution, in specific field settings, based on knowledge of rock strength, rates of energy expenditure in transport, and the initial particle size distribution. Facilities and methods include a set of 4 rotating drums, ranging in size from 0.2 to 4.0 meter diameter, vertically-oriented abrasion mills, and free-fall particle drops. Rock strength was measured by the Brazilian tensile splitting test, and particle shape and angularity were quantified from photographs. Particle size distributions were measured by weighing individual clasts and by sieving. Experiments reveal that abrasion rates scale with the inverse square of rock tensile strength, where strength varies with rock type and with degree of chemical weathering within a single rock type. Wear rates are not substantially influenced by the presence of particles of differing strength, contrary to a commonly-held assumption. Production rate of fine particles (<2 mm) in the drum experiments scales as a power function of the rate of energy expenditure, a result that can be used to extrapolate to field settings where intensity of particle motion can be estimated. Wear rates decline as particles become less angular, at rates that correlate with cumulative travel distance and mass loss. This result enables estimation of both initial particle size and distance from source using measurements of particle angularity and rock strength, but only for particles that have not yet reached a stable surface morphology. Fragmentation during high energy collisions can reset particle angularity, and by creating new coarse particles (>2mm), can transform particle size distributions. Particle drop experiments quantify how fragmentation probability varies with impact energy for a given rock type. Fragment sizes collapse to a single non-dimensional particle size distribution. I illustrate how these experimental results can be used in field settings to distinguish the effects of particle wear from size-selective transport in downstream fining of river bed material, and to infer the initial size of sediments supplied to channels by upstream hillslopes.

Keywords: Sediment, Abrasion, Fragmentation, Experiment, Particle Size Distribution

Simulations of Lateral Erosion in a Mixed Bedrock-Alluvial Meander

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1. Introduction

Most of the previous bedrock channel evolution models use shear stress or stream power of water flow as the deciding factor for lateral erosion. These models use shear stress/stream power erosion rule, and compose all relevant erosional processes into a single hydraulic parameter. These models ignored the effects of sediment transport in the channel. Some recent experiments and field studies have proposed sediment particle impact wear as an overriding factor for bedrock bank erosion (e.g., Fuller et al., 2016). Here, we implemented erosion model of bedrock bank into 2D physics-based morphodynamics model and reproduced the laboratory experiment results.

2. Methodology

2.1 Flume experiment

A laboratory scale experiment was carried out to inspect the interaction between sediment and banks of a bedrock channel. We used a Sine Generated Curve Shaped flume. The flume majorly consisted of weak erodible mortar. The length of the flume was 3 meters and width was 5 cm. The banks of flume were 10 cm high. The bed was covered initially with sediment. The initial alluvial thickness for bed was 0.5 cm. The grain size is 0.75 mm. The sediment used as an alluvial cover for bed was the same size as the sediment supplied as load. Flow discharge, channel slope, sediment feed rate, and grain size were kept constant throughout the experiment. The experiment was conducted for 4 hours.

2.2 Model

The governing equations for flow field and bed deformation in a mixed alluvial-bedrock channel are based on the numerical model proposed by Inoue et al (2016). In this study, we assumed that the lateral erosion rate in bedrock depends on a product of abrasion coefficient of bank with lateral bedload transport rate. We implemented the equations for bedrock bank erosion in the numerical model.

3. Results and Conclusions

In our experiment, the bank erosion occurred predominantly due to bed load abrasion. This shows that sediment supply can be one of the dominant factors causing lateral erosion in bedrock meander. In our experiment, the outer bank was eroded, but the inner bank was not eroded even if the sediment moved near the inner bank.

We compared the bank erosion width in left and right banks of simulation results with laboratory results. We found that our model could quantitatively reproduce the results. Our model could trace the bank erosion, and mimic the behavior of erosion in left and right banks.

References

Fuller, T. K., Gran K. B., Sklar L. S., and Paola C. (2016), Lateral erosion in an experimental bedrock channel: The influence of bed roughness on erosion by bed load impacts, *J. Geophys.Res. Earth Surf.*

Inoue, T., Parker, G., and Stark,C.P., (2016), Morphodynamics of a Bedrock-Alluvial Meander Bend that Incises as it Migrates Outward: Approximate Solution of Permanent Form, *Earth Surface Processes and Landforms.*

Keywords: bedrock river, meander, laboratory experiment, numerical simulation

Experimental study of upper regime bedforms and the associated modes of bedload transport.

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Upper regime bedforms are important to the interpretation of the stratigraphic record and the study of river floods, coastal storms and turbidity currents but how they form remains poorly defined. Two different upper plane bed configurations are described in the literature, one with long wavelength, small amplitude downstream migrating bedforms, the other with nearly flat beds under a transport layer of colliding grains few tens of grain diameters thick –the sheet flow layer. We performed laboratory experiments to study the interactions between flow hydrodynamics, mode of bedload transport and bedform geometry of the emplaced deposit in these upper regime plane bed configurations. The experiments showed that in the absence of suspended load two upper plane bed configurations exist for increasing values of the bed material transport capacity. The upper plane bed with long wavelength and small amplitude bedforms occurs for a relatively small bed material transport capacity. As the bed material transport capacity increases, downstream migrating antidunes form as a stable bed configuration. Further increasing the bed material transport capacity, the bed flattens out and the sheet flow layer forms. This change in bed configuration is associated with a change in the mode of bedload transport, from *standard bedload transport* with a two-three grain diameter thick bedload layer to *bedload transport in sheet flow mode*, and flow resistances.

Keywords: upper regime plane bed , bedload transport , donwstrem migrating antidunes, sheet flow

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

Formation of Ilsands on Deltas from Radially Symmetric Flow Expansion

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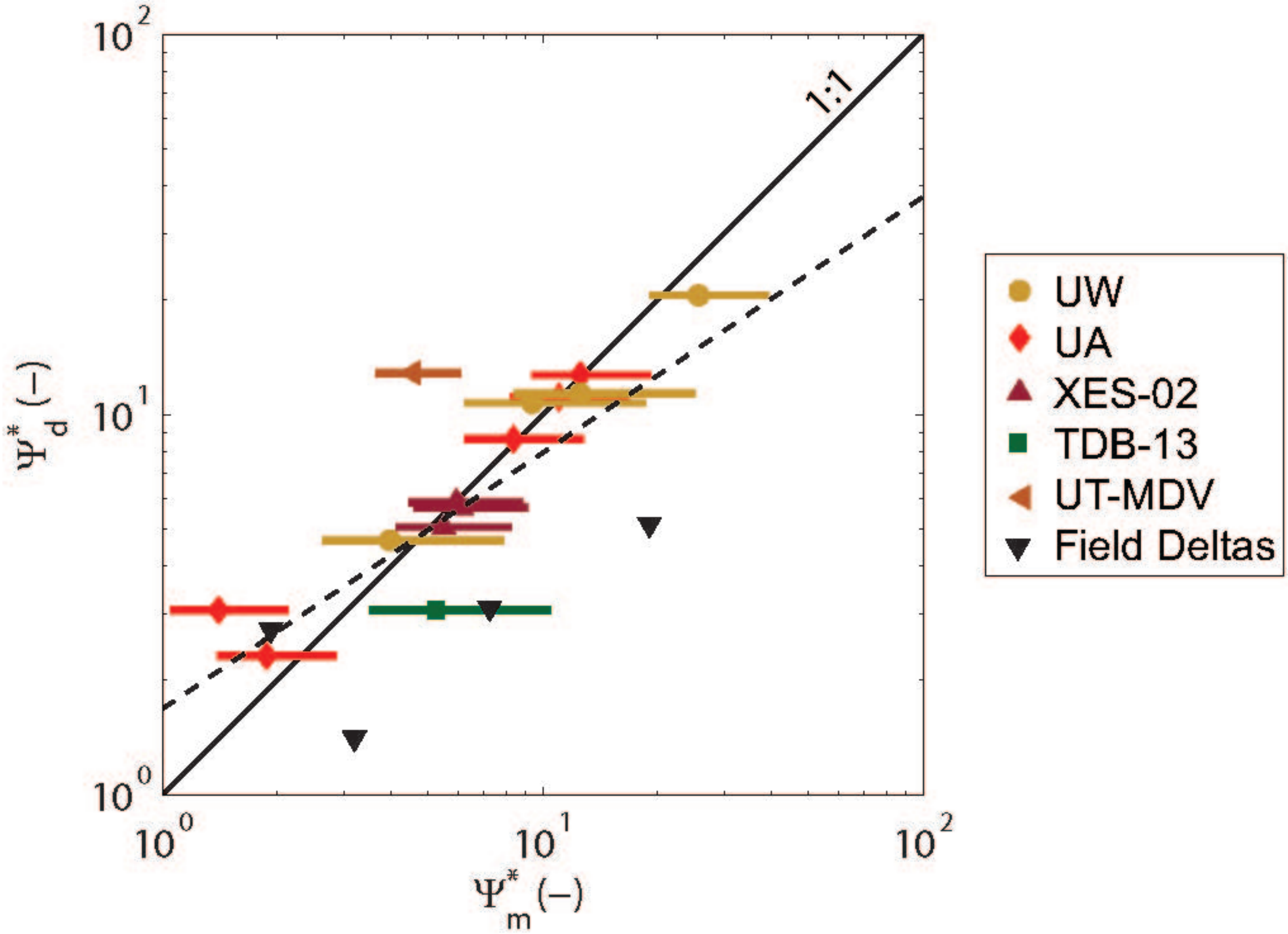
The creation of islands on delta tops is a primary means of coastal land generation and a critical process for interpreting the stratigraphy of ancient deltas. To-date, models of island creation have been largely based in sediment laden jet-theory and its application to river mouths. Inspired by a suite of laboratory experiments and collection of planform data from modern deltas, we propose another model for island formation that is based on topographic flow expansion. Consistent behaviour was observed in 9 new and 5 previously published delta experiments that began as wall-bounded, planar turbulent jets. Initial deposition occurred as predicted by jet theory produced elongate deposits followed by lunate bars. The lunate bars did not immediately evolve into islands. Instead the lunate bars first transitioned into topographic flow expansions that were stable to topographic perturbations. These deposits prograded and maintained a uniform, characteristic flow depth until island formation and channel bifurcation occurred. The islands appeared to form at a consistent distance from the center of the spreading flow. The experimental deltas all developed radially symmetric deposits and flow patterns (i.e. where flow width increases uniformly with radius). We hypothesize that the islands on these deltas form at the distance from the center of spreading, Ψ_m, where flow per unit width drops below that which provides critical stress to move the median grain size. To test this hypothesis, we analyzed channelization and island formation for the 14 experiment and 4 field scale deltas gathered from the literature. Distances to the position of channelization, Ψ_d, were measured and compared to predictions of distance, Ψ_m. Experimental and field data are predicted with a root-mean-square error of 17%, and the best-fit model offers only a modest improvement in explanatory power over a 1:1 line model (i.e. $\Psi_d = \Psi_m$). This new model predicts island formation on delta tops where radially symmetric flow patterns develop from sediment-laden jets before prograding until flow conditions drop below the threshold of motion through radial expansion. This model explains well a set of experimental and natural deltas. The model predicts that the distance to the first channel bifurcation scales with water discharge, scales inversely with flow depth over the apron, and scales with the inverse square-root of median grain diameter.

Keywords: delta, bifurcation, island, jet, flow expansion


10^2
10^1
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1:1
Ψ*d (–)
Ψ*m (–)
UW
UA
XES-02
TDB-13
UT-MDV
Field Deltas

Two mathematical approaches to delta evolution

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For many morphodynamic problems, the Exner equation can be applied in two different ways. In the first approach, a transport law is prescribed, from which the morphology freely evolves. In the simplest case, if the transport rate is assumed proportional to slope, the long profile becomes governed by a diffusion equation. In the second approach, the morphology is constrained, and it is the transport rate that must accommodate the constrained surface evolution. In the simplest case, avalanching at the angle of repose, the constant slope morphology becomes governed by the eikonal equation. Using either approach or a combination of both, it will be shown that various interesting solutions can be derived to problems of delta evolution. These include the infill of finite reservoirs by hyperpycnal inflows, and the progradation of three-dimensional Gilbert deltas. Laboratory and field examples from Taiwan will be used to compare predicted and observed behaviors.

Keywords: delta morphodynamics, diffusion equation, eikonal equation

Facies Relationships in a Simulated Fan-delta System

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Intrinsic relationships between associated sedimentary facies have been proven to be existed during the depositional process, such as channel-mouth bar systems in deltaic settings. However, little attention has been paid to the developmental patterns of such associated sand bodies, i.e., channel, mouth bar, and slide-slump deposit, which are favorable for the development of high quality hydrocarbon reservoirs if preserved. Therefore, we conducted a flume experiment to simulate a fan-delta under controlled boundary conditions and hope to explain the genesis of these associated sand bodies.

The delta was simulated in a flume. Volume of sediments and flowrate were variables and were strictly controlled. Sediments mixed with the water supply at the sand pool outflowed from the feeder outlet. Meanwhile, the water volume and tectonic setting were kept constant, without tidal or wave interactions.

The experiment showed developmental relationships between different facies. Subaqueous channels are the underwater extension of subaerial braided channels. As water and sediment were fed into the flume, the subaqueous channel was eventually replaced by a mouth bar. During this evolution process, the mouth bar first prograded, followed by accretion, backstepping and widening, with an increasing to decreasing depositional rate, influenced by backwater effect. After the mouth bar emerged, it caused the flow to bifurcate. The two branches would be bifurcated again by subsidiary mouth bars. Nevertheless, several bars might almost simultaneously develop basinward of the outlet if the channel was wide and shallow. Progressive deposition around the bar increased the angle of bifurcation and the original mouth environment evolved into fan-delta plain. It is worth mentioning that sediment failures would form in front of torrential and highly loaded channels.

The conclusions are: 1) the mouth bar first develops progradationally, then aggradationally, retrogradationally and transversely from the initial formation of the subaqueous channel; 2) there are two modes of channel bifurcation, i.e., multi-stage bifurcation by sequentially formed mouth bars and simultaneous bifurcation by arrays mouth bars; 3) slide-slump deposits are more easily formed in flood periods; 4) in the process of fan-delta development, sedimentary slope break is formed, which is favorable for the development of high quality reservoirs.

Keywords: facies relationships, flume experiment, fan-delta system, channel-mouth bar system

The roles of hydrodynamic backwater and relative sea-level rise in setting deltaic avulsion frequency

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Many of the world’s deltas are built through periods of construction of depositional lobes punctuated by lobe-scale avulsions. Deltaic rivers avulse when backwater effects create a locus of deposition in the river that reaches a critical thickness that scales with the channel flow depth. Recent work suggests that relative sea-level rise can play an important role in setting the pace of aggradation and frequency of avulsions within the backwater zone, but the fundamental relationship between avulsion frequency and sea-level change remains unexplored. We address this knowledge gap using an analytical model and a quasi-2D morphodynamic model. In our preliminary simulations, avulsion frequency increases under faster rates of normalized relative sea-level rise, because more sediment is deposited on the topset relative to the foreset and thus less time is required before the channel avulses. This behavior is well-predicted by our analytical solution, at least for low rates of relative sea level rise. At higher rates of relative sea level rise, avulsion frequency becomes more variable because lobes partially drown between avulsions. Results have implications for the sustainable management of modern deltas undergoing relative sea-level rise and for interpreting avulsions in stratigraphic sequences.

Keywords: Deltas, Avulsions, Sea-level rise

The Kinematics and Sedimentary Record of a Self-evolving Continental Slope Fed by a Prograding Shelf Delta

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A key issue with elucidating terrestrial environmental signals from the deep-sea stratigraphic record is the lack of quantitative theory that facilitates: 1) the separation of signals associated with local autogenics and autogenics of the upstream feeder system, and 2) the separation of autogenic signals from tectonic, climate and sea-level signals. We take the first steps towards understanding the kinematics of sedimentation and the resulting stratigraphic record associated with the coevolution of a prograding shelf delta and the down-dip continental slope fed by turbidity currents, using physical experiments. In a 26 hour experiment, we prograded a delta across a flat shelf, under conditions of constant sea-level rise to mimic pseudo subsidence. We analyze patterns of flow and sedimentation from overhead photographs and topographic scans to characterize the kinematic evolution of the slope during the delta’ s approach to the shelf-edge. In this experiment, the shoreline marked the transition between a transport-limited regime and an advection-settling regime in this experiment. The continental slope experienced a gradual roughening of the surface tied to a growth of depositional topography. As the delta migrated towards the shelf-edge, the proximal slope initially exhibited the vertical growth of topography through persistent, laterally discontinuous sedimentation associated with pathways of higher flow velocity (and likely higher sediment concentrations), followed by compensational lateral stacking of lobes characterized by high sedimentation rates downstream of active delta channels. As the upstream feeder channel migrated laterally, or subaqueous flow on the slope was steered around growing topography, sediment rapidly filled in topographic lows, smoothing away topographic roughness through compensational stacking of sediment bodies. Locations farther down-dip of sediment lobes, characterized by low sedimentation rates, continued to exhibit the vertical growth of topography through persistent, laterally discontinuous sedimentation. The paths of higher velocity flow (likely carrying higher sediment concentrations) in these distal locations remained relatively unchanged for the duration of the experiment.

Our results support the hypothesis that the advection length of the modal grain-size in suspension at the transition from transport-limited to advection settling-dominated, represents the length scale that separated compensational and random or persistent stacking of deposits. Compensational stacking only occurred in zones where: 1) local flow paths were influenced by close proximity to the laterally migrating deltaic feeder channel, and/or 2) rapidly growing lobes characterized by high sedimentation rates were capable of steering flow. These sediment lobes were constructed primarily from coarse silt- the modal grain-size in suspension at the shoreline, and developed at distances bracketed by the estimated advection lengths of coarse silt. Downstream of sediment lobes, temporally persistent and laterally discontinuous sedimentation of finer sediment resulted in the continuous vertical growth of topography. In natural systems, it is likely that distal locations may never enter the “sweet spot” of high sedimentation rates associated with the characteristic advection length suspended sediment, without the influence of allogenic factors.

Keywords: shelf-margins, shelf-edge deltas, stacking patterns, advection length

Stratigraphic feedbacks on free and forced alternate bar morphodynamics

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As rivers aggrade, they develop subsurface stratigraphy consisting of heterogeneous grain-size distributions in the downstream, cross-stream, and vertical directions. During subsequent periods of degradation, grain-size heterogeneity stored in stratigraphy may be exhumed and potentially feedback on the processes that drive morphodynamic evolution. Here we investigate these feedbacks by implementing the ability to store, track, and access bed stratigraphy in the two-dimensional morphodynamic model FaSTMECH. We use a modified active layer approach, in which during aggradation the active layer and bedload are released to and stored in the highest stratigraphy layer. During degradation, the active layer takes on the sediment properties stored in stratigraphy. We simulate two straight-channel scenarios: one with an obstruction at the upstream end to force formation of fixed alternate bars, and one without an upstream obstruction where freely migrating alternate bars can form. Each scenario was modeled with and without stratigraphy enabled to isolate its effect on the system's dynamics. The simulations with an obstruction showed minimal differences in sediment sorting and bed morphology between runs with and without stratigraphy enabled. However, the free bar simulation with stratigraphy enabled developed bars that were coarser, higher, and wider than the bars from the simulation without stratigraphy. The cyclical periods of aggradation and degradation associated with bar migration result in surface-subsurface interactions producing a corridor of fine bed material connecting the pools, facilitating sediment transport and allowing bars to grow and become coarser. Our results indicate that autogenic stratigraphy can have an important influence on the development and evolution of migrating alternate bars.

Keywords: stratigraphy, morphodynamics, bars

Lost in translation: Defining thresholds for the storage of environmental signals in stratigraphy

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Alluvial basins provide important records of climate and tectonic changes on Earth, as well as information about how land surfaces evolve under different boundary conditions. These deposits also contain important energy and water reserves. Consequently our ability to reliably interpret and predict stratigraphic patterns is fundamentally important both scientifically and in its bearing on broader society. While stratigraphy is our best record of paleo Earth surface dynamics, the record also contains significant gaps over a range of time and space scales. These gaps result from stasis on geomorphic surfaces and erosional events that remove previously deposited sediment. Building on earlier statistical studies, we examine the fidelity of the stratigraphic record in laboratory experiments where the topography of aggrading deltas was monitored at high temporal and spatial scales. The resulting stratigraphic architecture is influenced by both stochastic and deterministic processes. We start by quantifying the temporal scales that climatic perturbations must possess to be stored in stratigraphy via geochemical proxies. Then we investigate the temporal and spatial scales necessary for changes in forcing conditions, including sea level and/or sediment flux, to generate signals in the physical stratigraphic record. Finally, we examine how environmental stochasticity can further complicate signal identification. This work helps improve efforts at recovering meaningful data about autogenic processes from stratigraphic datasets, isolating signals of changing boundary conditions in ancient basins, and modeling and predicting stratigraphy in alluvial basins.

Keywords: Deltas, Stratigraphy, Experiments