CHILD: Variable Sediment Texture and Alluvial Stratigraphy

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Introduction

Entrainment of sediment in alluvial channels greatly varies depending on the textural composition of the channel bed (e.g. Komar 1987, Kuhnle 1993). Because sediment transport rates are a non-linear function of the critical shear stress for entrainment of sediment, simulation of texture changes becomes an essential part of modeling sediment transport in a natural, heterogeneous alluvial channel. The key is to incorporate a method which links changes in critical shear stress to the textural composition of the bed. In homogeneous sediment, the relationship developed by Shields (1936) in which critical shear stress increases with grain size is quite robust. However, a similar relationship does not exist for heterogeneous sediment. The interactions between grain sizes have made a simple, blanket description of critical shear stress for all sediment mixtures unattainable. For this study, a simple two grain-size mixture of sand and gravel is modeled. Changes in the critical shear stress for entrainment in such systems has been well described by Wilcock (1998).

As a channel erodes, material below the surface becomes exposed for entrainment. The material may have been previously deposited by the channel, or it may be material produced through weathering of the source rock underlying the system. In either case, entrainment of this material depends on its texture. A layering algorithm to track the composition of material which is buried below the surface layer was developed for this study. Tracking the texture of alluvial deposits gives insight into the depositional response in a basin to perturbations such as climate change or variable uplift rates.

Greater detail on the sediment transport dynamics and the layering algorithm can be found in Section III B. (The results shown in Section III B use GOLEM, an earlier landscape evolution model similar in spirit to CHILD. The layering methodology and sediment transport equations are identical between the two models, and both models produce similar results.)

Downstream Fining in Equilibrium Erosional Drainage Basins

In order to understand the effects of sediment texture on drainage basin evolution, five experiments were performed in which all parameters were identical except the texture of the substrate material. The substrate material texture in these examples is comparable to the texture of material produced through weathering of bedrock. The substrate material is effectively infinitely deep in these simulations, representing a system in which the rate of weathering of bedrock is always greater than the rate of erosion.

The drainage basins are evolved to equilibrium conditions. In these examples two conditions must be satisfied in order to reach equilibrium: (1) The erosion rate at every node must equal the uplift rate (the uplift rate is uniform across the drainage basin); (2) The texture of material eroded at every node must be the same as the texture of the substrate material which is supplying the system (the texture of the substrate material does not vary spatially). Two equilibrium drainage basins with different substrate textures are illustrated in Figure 1; the basins are shaded according to the texture of material in the surface layer. Although the texture of material eroded everywhere in the basin is the same, the surface texture varies spatially. In an equilibrium, transport-limited system, the sediment transport rates must increase downstream in order to carry the increasing sediment load. The mutual adjustment of both the local slope and the texture of the channel bed produce the correct downstream increase in sediment transport rates. This result holds in all of the modeled basins with different substrate textures (Figure 2).

Figure 1

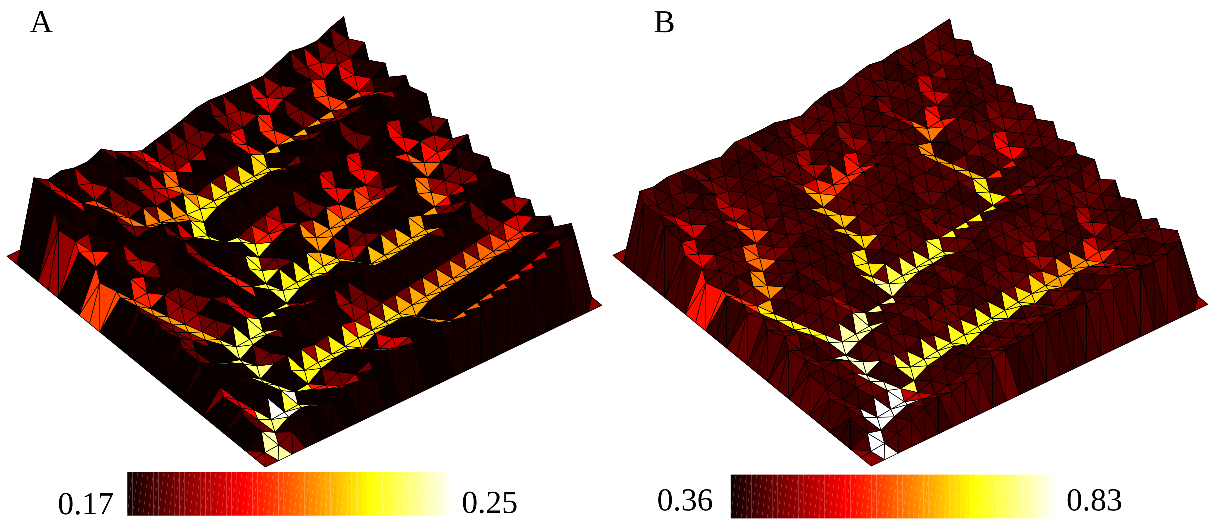

FIGURE 1. Two drainage basins in equilibrium shaded according to the proportion of sand (versus gravel) in the surface layer. Basin A has 10% sand in its substrate, basin B has 90% sand in its substrate. The color bars illustrate the range of surface texture values in each basin.

Figure 2

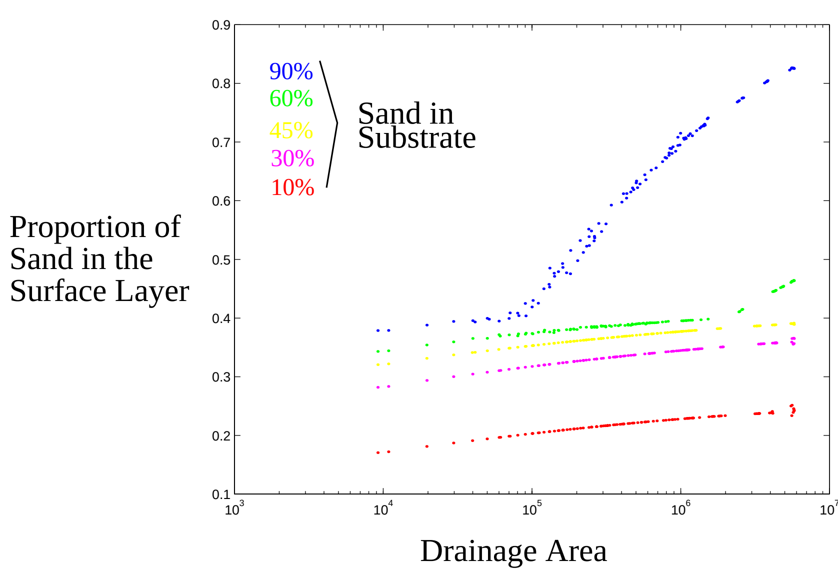

FIGURE 2. Surface texture changes in five equilibrium drainage basins with different substrate textures.

Alluvial Stratigraphy in a Depositional Basin

The previous section illustrates drainage basins which are only experiencing erosion, therefore no alluvial layers are developed. This section highlights the model's capability to produce alluvial layers using a simple example of an uplifting fault block. Steady uplift occurs in the mountainous region of the domain. Sediment is eroded from the mountainous region and deposited in the valley below, which experiences no uplift. The boundary across from the mountainous region (on the other side of the valley) is a free boundary in which sediment and water can leave the system (Figure 3). The substrate texture is uniform across the entire model domain. This simulation is a simple example of the development of alluvial fans, the free boundary representing a river which carries sediment out of the valley.

The simulated topography colored by surface texture at an early time in the evolution is illustrated in Figure 3A. Channels are cutting into the uplifting mountain block, but have not yet reached their boundary. Sediment carried out of the mountainous region is deposited in the valley below, forming small alluvial fans. A cross-section through one of the fans shaded according to deposit texture is illustrated in Figure 3B. The light green color of the bottom layers represents the substrate texture and the initial surface texture. The blue material deposited on top of the substrate material and at the bottom of the fan is finer than the substrate material. This indicates that the mountainous region first supplied material finer than the substrate to the fans. The red color of the mountainous area in Figure 3A indicates that this region has been stripped of its fine material and is now coarser, supporting the pattern shown in the fan deposits. Further erosion of the mountainous area produced some coarse material, as indicated by the yellow and orange deposits at the top of the fan in Figure 3B.

The fan topography and cross-section at a later time are illustrated in Figure 4. As the fan continues to evolve, the coarse material which is carried out of the mountainous area is deposited farther and farther down the fan as the fan slope builds up. The finer material which can be transported farther down the fan is deposited at the toe of the fan on the gentler slopes. Eventually, as the fan slope builds up, the fine material which was deposited earlier becomes completely buried by coarse material (Figure 5). At this stage of the evolution, fine material eroded out of the mountainous region get transported out of the system.

Figure 3

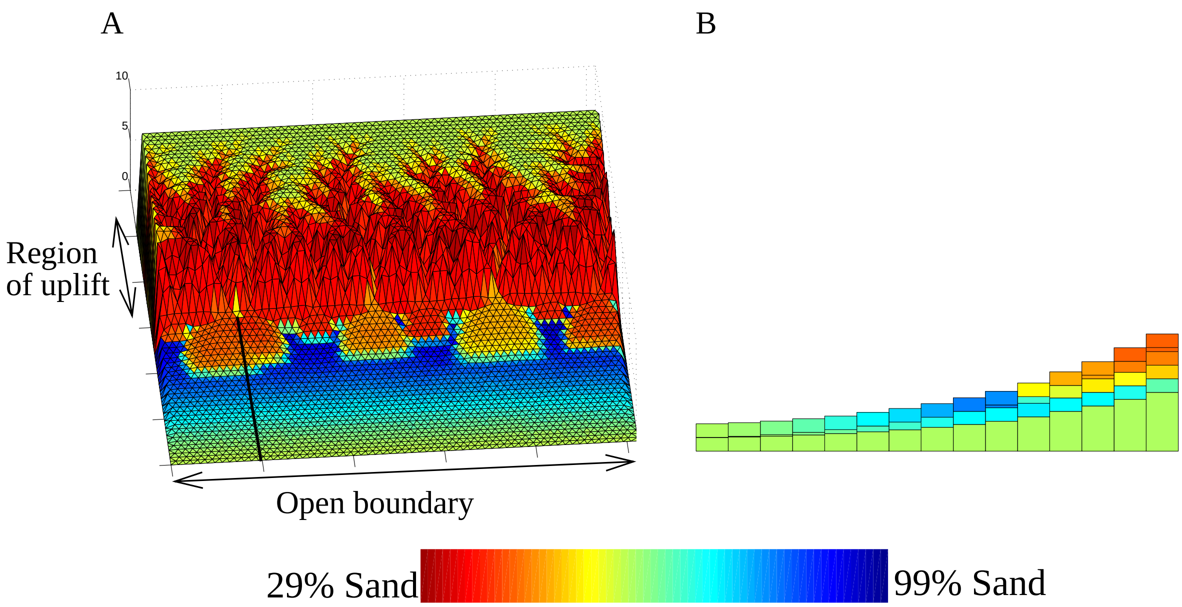

FIGURE 3. Figure A show the topography of the uplifting fault block and deposition valley at an early time in the evolution. The topography is shaded according to surface texture, as defined by the color bar (the percent of sand versus gravel). The black line on the fan illustrates the location of the cross-section shown in Figure B.

Figure 4

A B

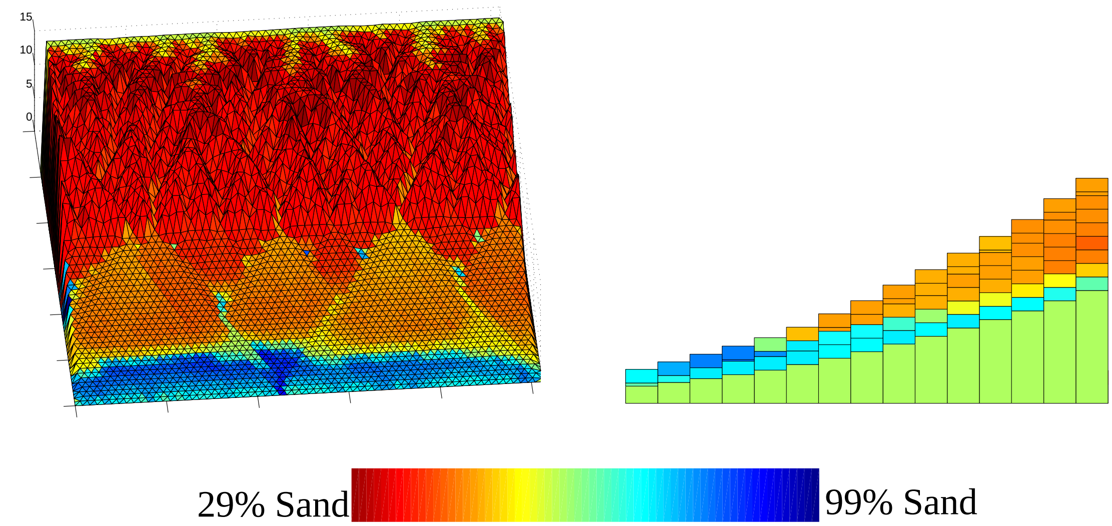

FIGURE 4. This figure shows a later time in the evolution of the same topography (A) and fan cross-section (B) shown in Figure 3.

Figure 5

A B

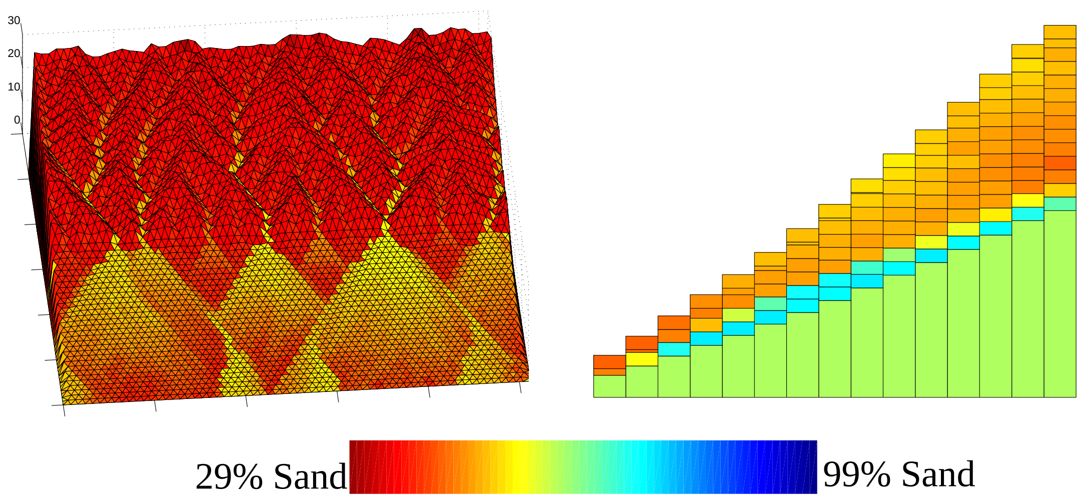

FIGURE 5. This figure shows a later time in the evolution of the same topography (A) and fan cross-section (B) shown in Figure 4. The time period elapsed between Figure 3 and Figure 4 is less than the time period elapsed between Figure 4 and Figure 5.

References

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