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A model to quantify sediment mixing across alluvial piedmonts with cycles of aggradation and incision

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The accurate interpretation of clastic sedimentary records hinges on a good understanding of the timescale and mode of sediment transport from source to sink. An environmental signal can be accurately recorded in the stratigraphy if it is transported quickly without being mixed with older sediments, or it can be entirely shredded by a slow transport and significant mixing along the way. Both transformations can happen in alluvial piedmonts by successive episodes of aggradation and incision. For example, in the Tian Shan the sediment flux reaching the foreland basin is mixed with sediments of up to 0.5 Ma age, mixing and blurring the environmental signals it carries.

We present here a numerical model that reproduces cycles of aggradation and incision on an alluvial fan and keeps track of the age composition in the sediment outflow. The model is based on three fundamental time- and length-scales: the period of aggradation-incision cycles, the depth of incision with respect to net aggradation, and the pattern of lateral migration. All three parameters can be reasonably easily surveyed in the field and with remote sensing. For simple geometries, we replace the numerical model with a probabilistic light analytical model. The output of both models quantifies sediment mixing in terms of the probability of finding a given minimum proportion of sediments of age T or older in the output flux.

We apply and test the analytical and numerical models to the Eastern Tian Shan where we can rely on independent measurements of mixing and buffering. There, rivers repeatedly aggraded and incised 100's of meters every 20 to 30 kyr with two main effects: 1) the delivery of coarse sediments to the basin is delayed by at least 7 to 14 kyrs between being first evacuated from the mountain and later re-eroded and transported basinward; 2) the outflux of coarse sediments from the piedmont contains a significant amount of recycled material that was deposited on the piedmont as early as the Middle Pleistocene. These initial field constrains are matched and completed with a probabilistic model. It is possible to identify which system is likeliest to preserve environmental signals and to which degree the environmental is modified based on the three model parameters that we can estimate in the field (incision frequency, incision depth, and lateral migration). The model can be used to inform future sampling strategies in foreland basins and also to revisit existing sediment records.