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Understanding heavy mineral enrichment – Using a 3D numerical model

Gerhard Bartzke (1), Mark Schmeeckle (2), and Katrin Huhn (3)

(1) Universität Bremen, Marum, Bremen, Germany (gbartzke@marum.de), (2) School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, Arizona, USA (schmeeck@gmail.com), (3) Universität Bremen, Marum, Bremen, Germany (khuhn@marum.de)

Layered deposits of light and heavy minerals can be found in many aquatic environments. Various researchers attempted to understand the role of the enrichment process of heavy minerals in placers using flume or in situ field experiments, because of their high economic value. However, a precise quantification of the physical processes occurring at the direct vicinity and in the interior of layered deposits is often limited with such techniques. To investigate the physical processes causing heavy particle enrichment in layers at the direct vicinity and in the interior of sediment beds, a 3D numerical model as an alternative to in situ measurement was used.

The 3D model simulates particle transport in water by combining a turbulence-resolving large eddy simulation (LES) with a discrete element model (DEM) prescribing the motion of individual grains. The dimensions of model domain where X = 0.12 [m], Y = 0.06 [m], and Z = 0.04 [m]. A pressure gradient and cyclic boundaries at the side walls allowed the simulation of a recycling flow. For the generation of a granular bed 0.004 [m] in height 200,000 spherical particles (D50 = 500 μm) were generated randomly and deposited under gravity at the bottom of the domain. Seven suites of experiments were designed in which the concentration of heavy i.e. 5000 [kg/m^3] over light particles i.e. 2560 [kg/m^3] was increased ranging from 0%, 10%, 25%, 50%, 75%, 90%, to 100% heavy particle content. All beds where tested for five seconds at a predefined flow speed of 0.35 [m/s].

The model results showed that at the direct vicinity of the bed the presence of high-vorticity turbulence structures embedded within broader high speed fluid regions caused the formation of particle sweeps or high-speed wedges. The vertical extension of the sweeps decreased when a higher amount of heavy particles was mixed to the beds, which ultimately resulted in a decrease of the bed roughness. Further, the particle flux decreased when higher quantities of the heavy particles were introduced to the beds. Measurements from the interior of the beds revealed that the lighter particles segregated from the heavy particles with increasing time. The latter accumulated at the bottom of the domain forming a layer, whereas the lighter particles were transported over the layer forming sweeps. Layer thickness increased when the amount of heavy particles was increased.

Consequently, heavy particles can alter the erosion resistance of a sediment bed, and influence the bed roughness. The enrichment of heavy minerals in a layer is controlled by the segregation of a heavy mineral fraction from the light counterpart. Moreover, turbulence structures highly influence the location where segregation and layer formation occurs, which enhances the current understanding of heavy mineral placer formation.