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Does fluid infiltration affect the motion of sediment grains? – A 3-D numerical modelling approach using SPH

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The processes that cause the creation of a variety of sediment morphological features, e.g. laminated beds, ripples, or dunes, are based on the initial motion of individual sediment grains. However, with experimental techniques it is difficult to measure the flow characteristics, i.e. the velocity of the pore water flow in sediments, at a sufficient resolution and in a non-intrusive way. As a result, the role of fluid infiltration at the surface and in the interior affecting the initiation of motion of a sediment bed is not yet fully understood. Consequently, there is a strong need for numerical models, since these are capable of quantifying fluid driven sediment transport processes of complex sediment beds composed of irregular shapes.

The numerical method Smoothed Particle Hydrodynamics (SPH) satisfies this need. As a meshless and Lagrangian technique, SPH is ideally suited to simulating flows in sediment beds composed of various grain shapes, but also flow around single grains at a high temporal and spatial resolution. The solver chosen is DualSPHysics (www.dual.sphysics.org) since this is validated for a range of flow conditions.
For the present investigation a 3-D numerical flume model was generated using SPH with a length of 4.0 cm, a width of 0.05 cm and a height of 0.2 cm where mobile sediment particles were deposited in a recess. An experimental setup was designed to test sediment configurations composed of irregular grain shapes (grain diameter, D50=1000 μm). Each bed consisted of 3500 mobile objects. After the bed generation process, the entire domain was flooded with 18 million fluid particles. To drive the flow, an oscillating motion perpendicular to the bed was applied to the fluid, reaching a peak value of 0.3 cm/s, simulating 4 seconds of real time.

The model results showed that flow speeds decreased logarithmically from the top of the domain towards the surface of the beds, indicating a fully developed boundary layer. Analysis of the fluid surrounding the sediment particles revealed critical threshold velocities at the vicinity of the beds, subsequently resulting in the initiation of motion due to drag. Moreover, it was identified that a larger quantity of sediment particles was transported at the direct vicinity of the bed, whereas the amount of transported particles along with decreasing flow speed values, within the pore spaces, decreased with depth. With increasing simulation time the uppermost portion of the bed was in motion, and porosity values at the surface increased. As a result higher quantities of fluid particles infiltrated through the larger interstices between the sediment particles, which successively increased the potential for the initiation of motion of sediment particles located in the deeper horizons.

Consequently, the opening of new pore spaces affects fluid infiltration allowing the flow to infiltrate and trigger the initiation of motion of sediment grains located in the bed interior. This effect has been underestimated in prior studies and highlights the importance of fluid infiltration as an important characteristic that can eventually help to better understand the development of various sediment morphological features.