Bed structure and bedload transport: Sediment grain reorientation in response to high and low flows in an experimental flume

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Abstract

Bedload is a regime of sediment transport that occurs when particles roll, hop, or bounce downstream. The formation of gravel clusters, imbrication of riverbed particles, as well as grains armoring the bed, all tend to stabilize gravel channels and decrease bed mobility. We examine how individual sediment grains reorient themselves during low flow conditions, in the absence of sediment transport, and during high flow conditions, as bedload transport occurs. We then perform flume experiments where we expose a gravel bed to varying durations of low flow and raise the water level, simulating a flood and transporting sediment. We also compare the long axis orientations of grains before and after each low flow period and transport.

We find that sediment grains reorient themselves differently during low and high flows. During low flow, grains appear to reorient themselves with the long-axes towards cross-stream direction, or perpendicular to the flow, with longer duration flows resulting in more pronounced cross-stream orientation. During high flow, grains orient themselves with their long-axes facing downstream or parallel to the flow. Further, when transport occurs, we find that median grain orientation is strongly correlated with bedload transport rates (R^2=0.98). This new result suggests that the low flow reorientation of grains perpendicular to downstream flow drives observed differences in bedload transport during high flows.

Introduction

Rivers transport sediment which travels downstream and is later be deposited in another environment. However, sediment transport only occurs when the water reaches a certain threshold or critical velocity during floods, which only happens less than 10% of the time.

How will low flow periods affect riverbed structure when no transport occurs?

Types of Riverbed Structure

Protrusion: Grains extended from bed surface
Armoring: size of grains on surface
Imbrication: orientation (in degrees) of grains

We hypothesize that longer low flow periods allow for more stable gravel structures to develop on the bed surface. Thus, less sediment will move during transport.

Experimental Methods

Apparatus:

- Conducted experiments at Richmond Field Station at UC Berkeley
- Used a flume with dimensions 5 x 0.3 m to stimulate water flow in a river
- Water flows from the top and a basket at the end catches all sediment that is transported.
- A pump allows us to adjust the amount of water and velocity flowing over the bed

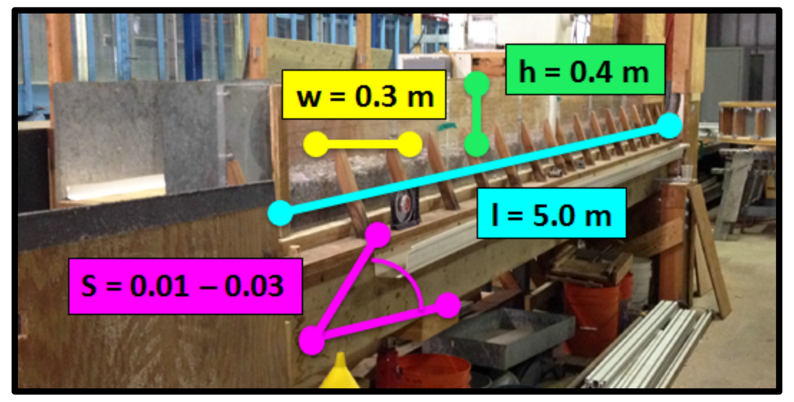
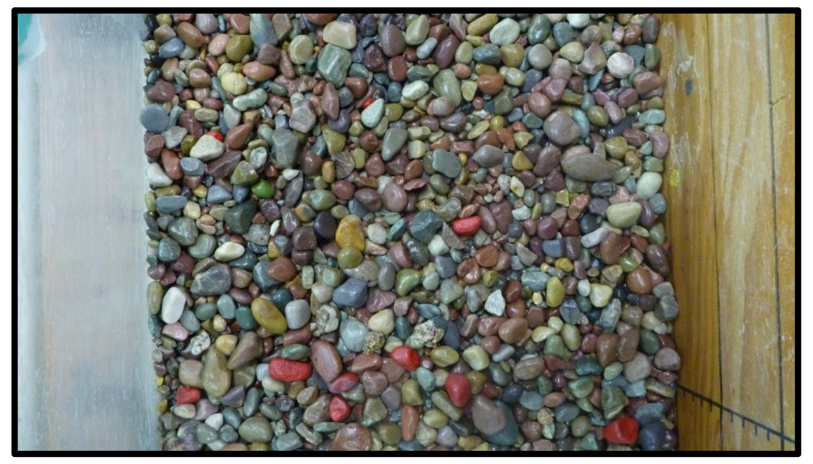


Figure 1: The flume we used to perform experiments in Richmond Field Station, UC Berkeley.

Stages of High-Resolution Photo Collection:

Initial: before water runs over riverbed



Conditioning: subthreshold flow velocity, no sediment is transported, grains wiggle

Transport: over threshold flow velocity, sediment is transported

Imbrication Measurements:

Measured long axis orientation of grains in GS photos to measure imbrication using ImageJ, Matlab, and Adobe Photoshop.

1) ImageJ: converted photos to 8-bit images
2) Matlab: wrote script to choose 100 grains at random to measure
3) Photoshop: long axis measurements for 100 grains
4) ImageJ: used to measure grain orientations using "OrientationJ" plug-in

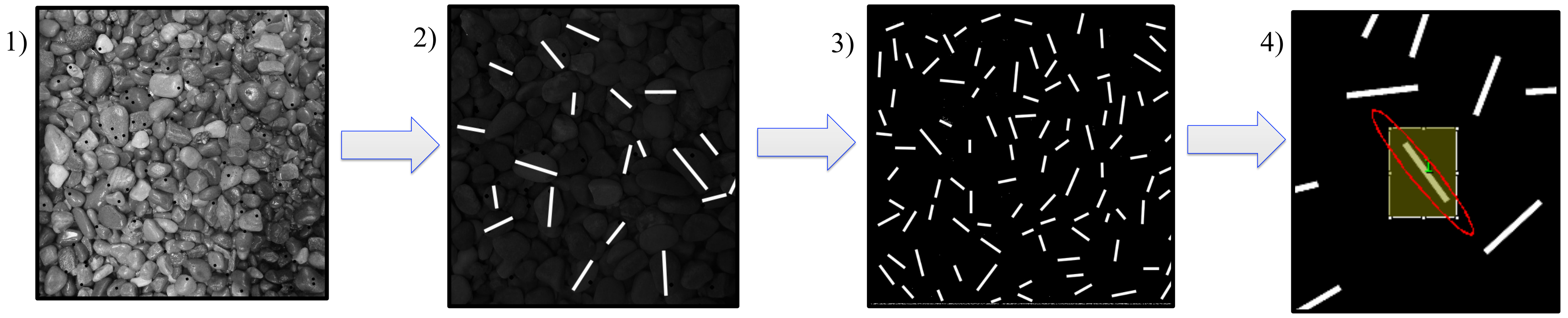
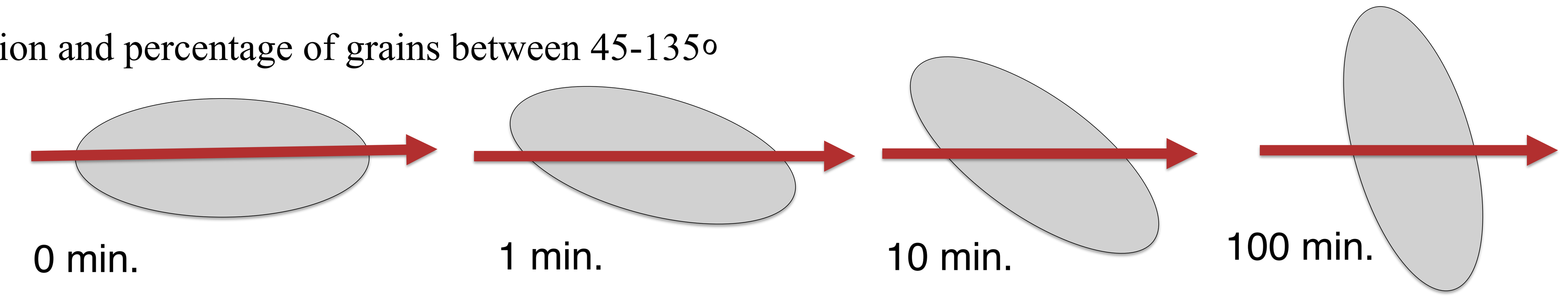


Figure 3: High-resolution photographs depicting the imbrication measurement process.

Grain Orientation:

- Calculated median, standard deviation and percentage of grains between 45-135o
  - 90o are downstream
  - 0 or 180o are cross-stream



Results

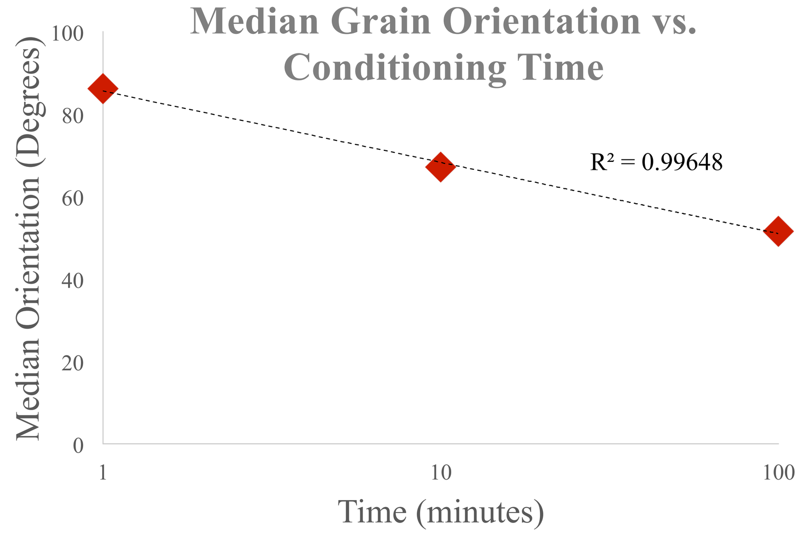


Figure 5: A graph plotting median grain orientation during the conditioning phase.

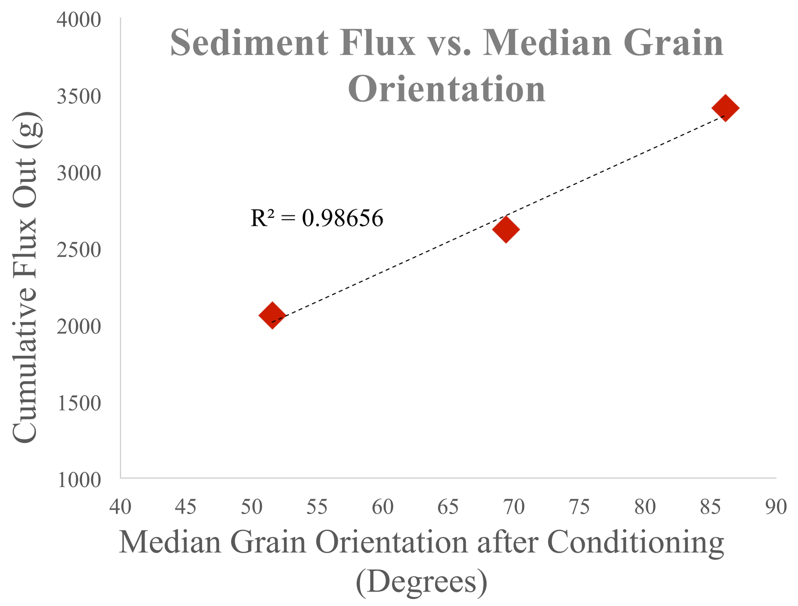


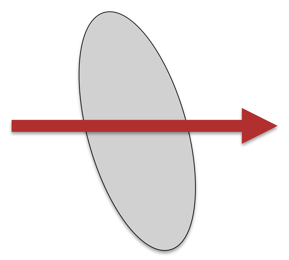
Figure 6: A graph displaying sediment flux vs. median grain orientation. As the orientation of the grain increased more sediment is transported

After transport: Grains return to downstream orientation (~90°)

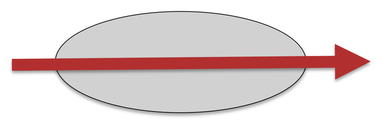
Conclusions

Grains reorient themselves differently in high and low flow periods

Low flow: grain long axes reorient to face perpendicular to the flow (cross-stream)



High flow: grain long axes face parallel to the flow (downstream)



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