Bedform development below transient turbulent, partly cohesive open-channel flows

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ABSTRACT:

1 INTRODUCTION

Flume experiments in the Sorby Environmental Fluid Dynamics Laboratory show that small-scale bedforms developing below partly cohesive, open-channel flows have unique geometry and kinematic behaviour. These flows carried a mixture of cohesive clay particles (kaolin) and non-cohesive silt and sand grains at a range of concentrations (0 to 18.3 % by volume) within the turbulent, transitional and laminar flow regimes.

In each experimental run, vertically well-mixed flows were converted into supersaturated flows by imposing instantaneous deceleration from depth-averaged flow velocities of >1 ms^{-1} to ~0.4 ms^{-1}. Supersaturation then forced deposition of suspended sediment, and small-scale bedforms subsequently developed in most experiments.

At low suspended sediment concentrations, the flows were fully turbulent and “classic” current ripples developed. As clay concentration was increased, these ripples first became progressively more elongate (with ripple length increasing faster than ripple height; Figs 1a and 1b) before being replaced by an entirely different bedform type within the transitional flow regime, where cohesive forces dominated turbulent forces (Fig. 2). These bedforms were almost twice as long as the current ripples in the equivalent turbulent flows and they were significantly flatter (Figs 1a and 1b). Cross-lamination in the form of alternating sand-rich and mud-rich laminae was observed, but more pronounced was a thick core of cohesive mud, draped by a thinner surface layer of sand (Fig. 2: mud is light grey, sand is dark grey). A prominent sand layer below the bedforms, which formed by rapid deposition of non-cohesive sediment immediately after flow deceleration, was one of the sources for the sand within the surface layer. The other source were sand particles slowly settling out of suspension.

All bedforms migrated in a downstream direction, but the bed sediment flux was dependent on suspended sediment concentration, near-bed turbulence intensity and bed shear strength (Fig. 1c). At suspended sediment concentrations up to 3%, the bed sediment flux decreased with increasing concentration, possibly due to admixture of cohesive clay into the bed. From 3% to 7%, the bed sediment flux was found to increase. This trend was paralleled by an increase in near-bed turbulence intensity. Bed sediment flux decreased rapidly as suspended sediment concentration increased from 7 % to 9%, presumably as a result of a combination of rapidly declining near-bed turbulence intensity and further increasing bed shear strength.

In the experiments with the highest clay concentrations, in which turbulence was rare to absent, the basal sand layer still formed, but no bedforms developed on top of this sand layer.

The physical processes responsible for the observed changes in bedform development will be discussed. In particular the changing role of cohesive and turbulent forces within the transitional flow regime and the role of yield strength within the transitional flow-type bedforms will be considered.

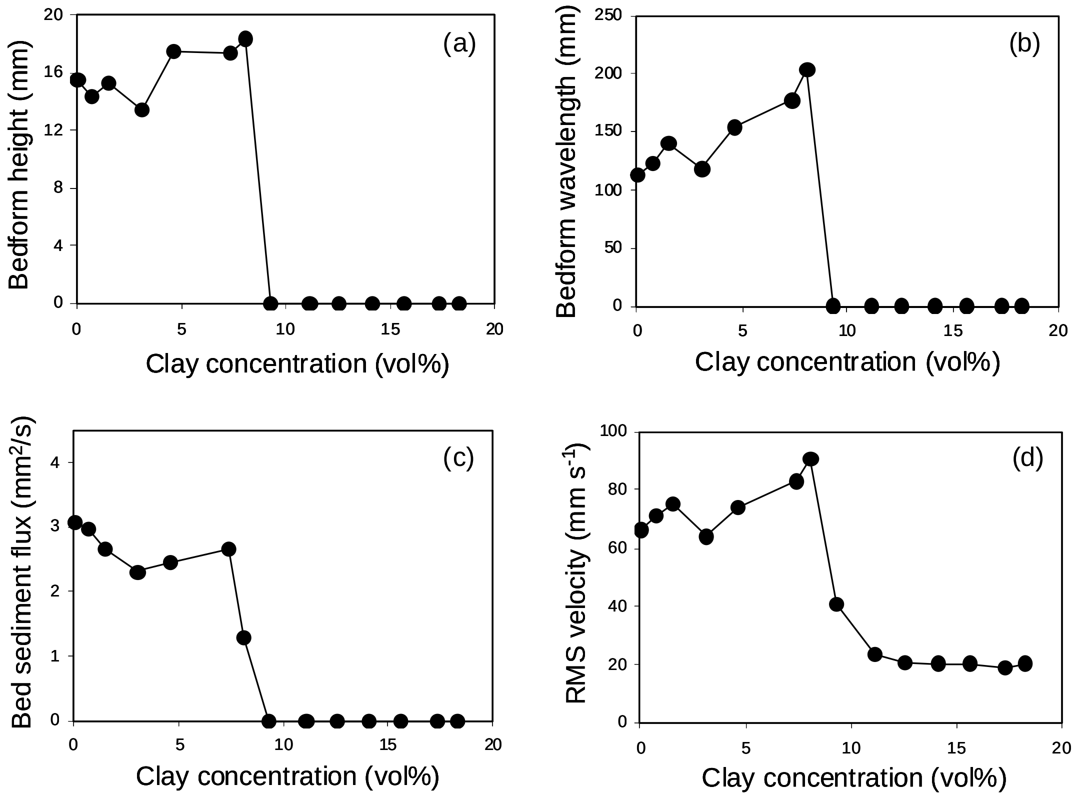

Fig. 1 - Equilibrium bedform height (a), equilibrium bedform wavelength (b), bed sediment flux (c) and near-bed turbulence intensity (d) as a function of suspended clay concentration. Turbulence intensity is approximated by the root-mean-square (RMS) of downstream velocity. Note the close correspondence between trends in bedform height and turbulence intensity, and between trends in bedform wavelength and turbulence intensity, which suggests that near-bed flow dynamics, and associated bed erosion, are a primary control on bedform size.

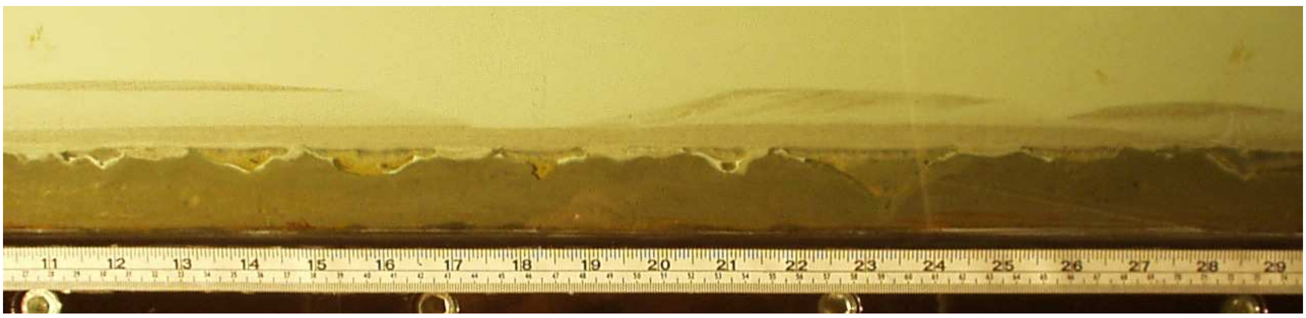

Fig. 2 – Characteristic bedforms of the transient turbulent flow regime. Scale is in inches (top of ruler) and cm (base of ruler). Flow is from right to left.