Unit bars formed by dune stacking in a recirculating flume

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ABSTRACT: The flume experiment described in this presentation was designed to study the initiation and development of unit bars. The flume runs started with an initially flat bed within a 10 m long observation channel. Initial unit bar formation resulted from dune amalgamation. Subsequent growth was from bedforms superimposed on the incipient bar amalgamating with it. Bars accreted vertically, upstream and downstream and the lee face prograded downstream. Unit bar internal structure was initially dominated by trough cross-stratification.

1. INTRODUCTION

Smith (1974) defined unit bars as relatively unmodified bars with morphologies determined mainly by depositional processes. Unit bars form in most river types over most climatic regimes. Previous flume research on unit bars (e.g. Jopling, 1965; Reesink & Bridge, 2007, 2009) focused on angle-of-repose lee face development and the resulting high angle cross-stratification, which Cant and Walker (1978) suggested to be the dominant feature of unit-bar deposits. However, Sambrook Smith *et al*. (2006), Lunt *et al.* (2013) and Parker *et al.* (2013), examining ground penetrating radar data from American perennial rivers, suggest that dune cross-sets can make up a significant, or dominant, proportion of preserved unit bar deposits. Lunt and Bridge (2004) and Parker *et al.* (2013) suggest that this may result from scour in the lee of dunes migrating over the bar, cutting deeply into the bar top, replacing the original bar forests with dune cross-strata. Conversely, Sambrook Smith *et al.* (2006) suggest it may result from dune stacking.

Bar formation has been linked to local hydraulic changes such as a downstream change in flow or sediment conditions (Smith, 1974; Cant & Walker, 1978). In published flume research the bar initiation point has been the entry to the experimental channel, a sediment input point (at or upstream of the entry to the channel; e.g. Reesink & Bridge, 2007, 2009), or a constructed bed step mimicking an angle of repose lee-face (e.g. Jopling, 1965). Consequently these publications concentrate on unit bar migration but not bar formation, either because they started with a pre-formed bar-shape bed feature, or because the bars formed at the upstream end of the flume where they could not be fully observed. The flume runs described here were designed so that bars formed spontaneously within the glass-wall section of a flume channel allowing bar initiation to be observed.

2. METHODS

Three flume runs, each of 7200 s duration, are described here. These used a 10 × 1 × 1 m glass-sided channel with 1.95° bed slope, with water and sediment circulated continuously in a closed loop, via pipes and pumps with no holding or settling tanks. Pumping started 1200 s before each run to establish steady conditions. In all 3 runs, the mean flow velocity decreased and water depth increased down the length of channel. Velocity was measured at fixed points using two acoustic Doppler velocimeters and an ultrasonic Doppler velocity profiler array. Observations were made throughout each run via the glass side walls and the bed was cored and sampled after each run.

Run 1 started with a clean steel floor and involved steady addition of 1000 kg of well sorted sand (D_{50} = 725 μm, standard deviation = 1.3). Before Run 2 the bed was mixed and flattened. During Run 2, 2000 kg of sand was added steadily. Before Run 3 the bed was again mixed and flattened. During Run 3, 1000 kg of sand was added steadily. The flow conditions in all runs were as similar as possible, however as the bed aggraded the water surface rose and in Run 3 the water level had to be controlled to avoid water overtopping the channel. In this case, the discharge (controlled by the pumping rate) was reduced to keep the mean velocity at the upstream end of the channel similar to the previous runs.

3. RESULTS

Unit bars formed in all three runs. In Runs 1 and 3 unit bars initiated c. 1 m down the flume (Figure 1). The higher sediment input rate in Run 2 led to unit bar formation nearer the upstream end of the channel where the initiation processes could not be fully observed.

In Runs 1 and 3, flow conditions at the upstream end of the flume caused rapid dune migration. Dune migration slowed downstream and amalgamation was induced by the changes in flow conditions along the channel, creating an incipient unit bar. Following the amalgamation of dunes, the incipient bar accreted vertically, downstream and upstream (Figure 1B). This was achieved by superimposed bedforms stacking on the stoss side of the bar. With small superimposed bedforms, their lee face amalgamated with the bar lee face, but larger superimposed bedforms resulted in major modification of the bar lee face (cf. Reesink & Bridge, 2009).

As dune amalgamation and stacking was key to the formation of unit bars in Runs 1 and 3, and because of the repeated modification of the bar lee face in the lee of larger superimposed bedforms, unit bar internal structure was dominated by small scale cross-stratification formed by the superimposed bedforms (Figure 1A). In both Runs 1 and 3 an avalanche face began to form by the end of the run.

In Run 2 the rapid growth of the bar was such that the superimposed bedforms were relatively small and resulted in less modification of the lee face of the bar (cf. Reesink & Bridge, 2009). The bar had a steep lee-side avalanche face over most of the run. Consequently the deposit was dominated by bar-lee cross-stratification.

Bar development tended towards a near-horizontal bar stoss surface (Figure 1A). This leads to more uniform, higher velocity flow above the bar, which has the capacity to transport all the sediment entering the upstream end of the channel. Once this threshold of total sediment transport is reached, unit bar growth is dominated by progradation down the channel, unless the flow or sediment conditions change.

4. DISCUSSION

In Runs 1 and 3 unit bar development was controlled by the amalgamation of dunes, consistent with Sambrook Smith *et al*. (2006) proposal that dune stacking could be a mechanism of unit bar formation. This formation mechanism may account for some of the dune cross-stratification observed within unit bar deposits in some North American rivers.

Where bedform amalgamation and stacking leads to bar initiation and growth, and the growth pattern is mostly vertical accretion, the deposits will tend to be dominated by small cross-stratified sets. In contrast, where progradation dominates bar growth, the deposit may be dominated by a larger scale high-angle cross-stratified set.

The formation of an avalanche face is influenced by the relative size of superimposed bedforms. Early in Runs 1 and 3 the superimposed dunes were often a similar height to the unit bar avalanche face (e.g. Figure 1B, 2280 s). As the unit bar grew the relative height of superimposed bedforms reduced, limiting modification of the bar avalanche face by scour in the lee of the superimposed bedforms, and so favoring the formation of a continuous high angle cross-stratified set.

5. CONCLUSIONS

The flume experiments demonstrate that unit bar growth can be initiated by dune amalgamation encouraged by downstream changes in flow and sediment transport. Initial incipient unit bar growth consisted of vertical, upstream and downstream accretion.

The internal structure of the unit bars was dominated by trough cross-stratification, with high angle planar cross-stratification occurring where progradation was the dominant unit bar growth mechanism.

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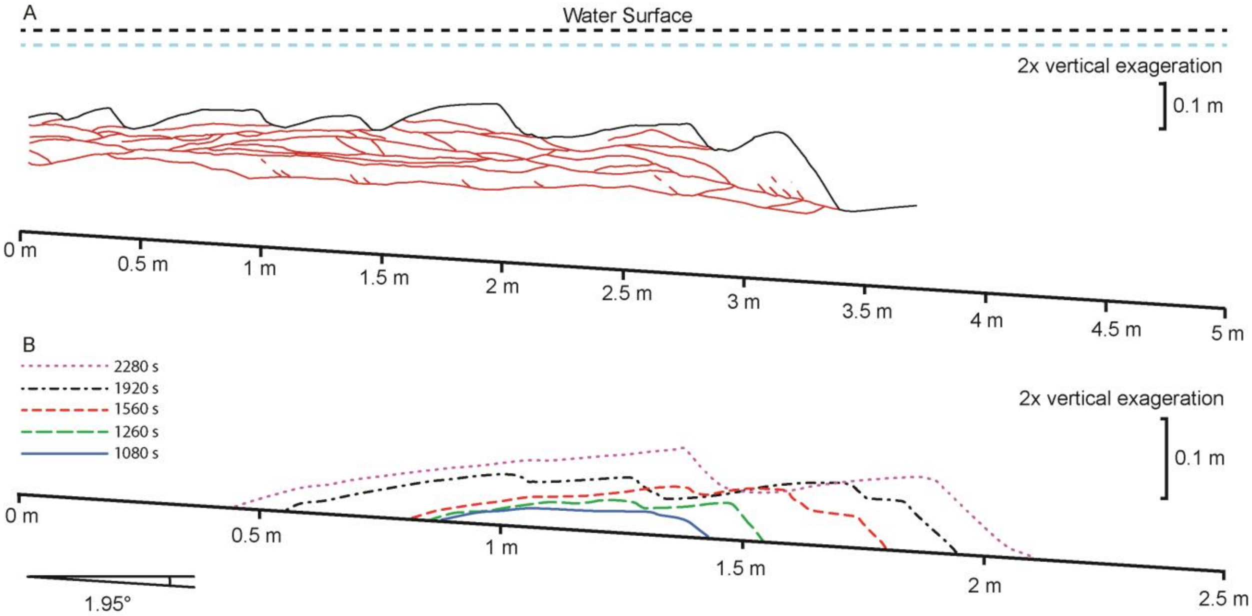

Figure 1. Schematic diagram of; A) the unit bar formed by the end of Run 3, with details of the internal erosion surfaces observed through the right side wall. The water level at the start (lower line) and end (upper line) of Run 3 are denoted with dashed lines; B) unit bar development over 20 minutes of Run 1, recorded from the right side wall.