https://doi.org/10.1130/G47578C.1

Why do large, deep rivers have low-angle dune beds?

Jim Best[1,2], Julia Cisneros[1], Renato Paes de Almeida[3,4], Cristiano Galeazzi[3], Marco Ianniruberto[5] Hongbo Ma[6], Christopher Unsworth[7], and Thaiënne van Dijk[1,8]

[1]Department of Geology, University of Illinois at Urbana Champaign, Illinois, USA
[2]Departments of Geography & GIS, Mechanical Science and Engineering and Ven Te Chow Hydrosystems Laboratory, University of Illinois at Urbana Champaign, Illinois, USA
[3]Instituto de Geociências, Universidade de São Paulo, São Paulo, Brazil
[4]Instituto de Energia e Ambiente, Universidade de São Paulo, São Paulo, Brazil
[5]Instituto de Geociências, Universidade de Brasília, Brasília, Brazil
[6]Department of Earth, Environmental and Planetary Sciences, Rice University, Houston, Texas, USA
[7]National Oceanography Centre, Liverpool, UK
[8]Department of Applied Geology and Geophysics, Deltares, Utrecht, Netherlands

Kostaschuk and Venditti (2019, 2020) present a thought-provoking contribution to the question of why big rivers are characterized by low-angle dune beds. The authors compile a flume and field dataset that suggests high-angle dunes (HADs; leeside >24°) characterize shallow flows (<2.5 m deep), with low-angle dunes (LADs) dominant in deeper flows. Data are also reported from three large rivers (their figure 1B), most of which was drawn from our preliminary work (see reference in Kostaschuk and Venditti, 2020). Our full dataset, containing over 265,000 measurements (Cisneros et al., 2020), supports the finding that large rivers are indeed dominated by LADs. However, the key question that arises is why this should be so? Kostaschuk and Venditti (2019) contend that on LADs in deeper flows, excess pore pressures cause the failure of loosely-packed wedges of sediment on the leeside, and that these liquefied avalanches flow further, thus producing lower angle slopes. Whilst attractive, we argue this hypothesis suffers several shortcomings, as well as demanding validation and testing with real-world data. We highlight four principal issues and illustrate our discussion with respect to the Amazon River, although all rivers in our dataset (Cisneros et al., 2020) show these characteristics.

First, the authors do not explain convincingly why such a process should be restricted to flows deeper than 2.5 m. At any water depth, spontaneous liquefaction can only occur when an excess pore water pressure gradient is induced by an external mechanism, regardless of absolute hydrostatic pressure (Mason and Yeh, 2016). As such, the proposed process of post-failure liquefaction bears no direct relation to water depth. The authors argue that larger, looser wedges of sediment are required to favor a liquefied flow, and that these wedges will be (1) thicker on LADS because the dunes are larger, and (2) less compact because they form from suspension fallout. However, our data (Fig. 1A; Cisneros et al., 2020) clearly show LADs encompass a wide range of small and large dunes (heights of 0.9–8.4 m) and thus dune height cannot be a controlling factor. It is also worthy of note that the minimum leeside angle appears to increase with dune height (Fig. 1A), as well as the fact that the smaller superimposed dunes are also predominantly low-angle (Galeazzi et al., 2018; Cisneros et al., 2020; Fig. 1C). In addition, although mean leeside angle for all dunes is 10.2°, leeside angles of up to 35° occur in flow depths of ~67 m (Figs. 1B and 1C). Hence, flows >2.5m deep clearly possess LADs and some HADs. These data thus demonstrate that the liquefied flow mechanism cannot be universally applicable.

Second, the majority of LADs possess superimposed dunes on their stoss sides (~85%; Cisneros et al., 2020), suggesting the formation of leeside sediment wedges will be controlled by these bedforms (Reesink and Bridge, 2009), as highlighted by the authors as being important on HADs. Galeazzi et al. (2018) also documented superimposed dunes on up to ~94% of the leesides of lower-angle compound dunes (Fig. 1C). Quantification of dune leeside angles (Galeazzi et al., 2018; Fig. 1C) revealed simple, higher-angle leeside dunes without leeside superimposition in 10–20-m-deep flows, and lower-angle compound dunes with leeside superimposition in deeper flows. The presence of superimposed dunes and ripples on the leeside of LADs also suggests the lack of liquefied avalanches that would destroy such bedforms.

Third, our data (Cisneros et al., 2020) show that dune leeside shape is complex, with regions of maximum leeside slope that may be at the top, middle or bottom of the leeside face. In the presence of such leeside complexity, liquefied flows would have to either stop on an upper, low-angle, leeside before reaching the lower, but steeper, part of the slope, or initiate further down a higher-angle upper leeside and then move downflow to create a lower-angle bottomset. Such a differential liquefied flow behavior is difficult to reconcile with the authors conceptual model (their figure 3C) that does not portray the common complexity in shape of low-angle leesides.

Lastly, Kostaschuk and Venditti highlight past work on ancient fluvial sandstones to support their hypothesis. However, the studies they cite concerned dunes at the transition to upper-stage plane beds, a condition atypical of large deep rivers that typically possess low Froude numbers (Cisneros et al., 2020).

Thus, although Kostaschuk and Venditti contend that liquefied leeside avalanches are the mechanism that allows LADs to form in deep flows, we argue this is not supported by empirical evidence. We argue that the formation of LADs likely has several contributing processes (Cisneros et al., 2020)—such as turbulence modulation by suspended sediment, leeside fallout patterns, and bedform superimposition, as well as the influence of unsteady flows on these processes—but that enhanced liquefied avalanches are unlikely important.

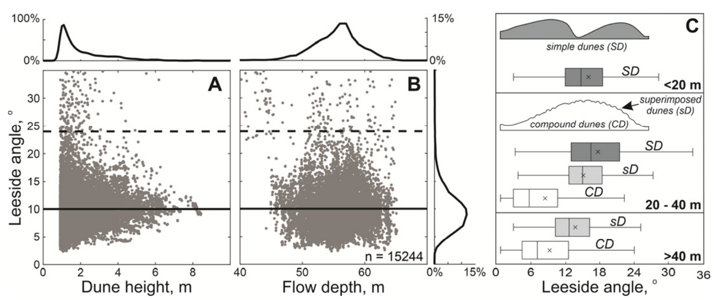

Figure 1: Plots of leeside angle, Amazon River, against (A) dune height and (B) flow depth (modified from Cisneros et al., 2020); probability distributions are also shown for dune height, flow depth, and leeside angle. (C) Leeside angles in various flow depths, for simple (*SD*), superimposed (*sD*), and compound (*CD*) dunes (modified from Galeazzi et al., 2018).

REFERENCES CITED

Cisneros, J., Best, J., van Dijk, T. et al., 2020, Dunes in the world's big rivers are characterized by low-angle lee-side slopes and a complex shape: Nature Geoscience, v. 13, p. 156–162.

Galeazzi, C.P., Almeida, R.P., Mazoca, C.E.M., Best, J.L., Freitas, B.T., Ianniruberto, M., Cisneros, J., and Tamura, L.N., 2018, The significance of superimposed dunes in the Amazon River—Implications for how large rivers are identified in the rock record: Sedimentology, v. 65, p. 2388–2403.

Kostaschuk, R.A., and Venditti, J.G., 2019, Why do large, deep rivers have low-angle dune beds?: Geology, v. 47, p. 919–922, https://doi.org/10.1130/G46460.1

Kostaschuk, R.A. and Venditti, J.G., 2020, Why do large, deep rivers have low-angle dune beds? Erratum: Geology, v. 48, p. 207, https://doi.org/10.1130/G46460E.1.

Mason, H.B., and Yeh, H. 2016, Sediment Liquefaction: A Pore-Water Pressure Gradient Viewpoint: Bulletin of the Seismological Society of America, v. 106, p. 1908–1913.

Reesink, A.J.H., and Bridge, J.S., 2009, Influence of bedform superimposition and flow unsteadiness on the formation of cross strata in dunes and unit bars—Part 2, Further experiments: Sedimentary Geology, v. 222, p. 274–300.