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

## Empirical Analysis

**Table DR1.** n is the number of dunes used to average H, L and $\alpha$. H is dune height, L is dune length, $\alpha$ is slipface angle, U is mean velocity, h is flow depth, $d_{50}$ is median particle size, $d_{90}$ is the 90th coarsest percentile particle size, $q_s$ is suspended load, $q_b$ is bed load.

**Figure DR1.** Scatterplots of selected data from Table DR1. $\alpha$ is slipface angle, L is dune length, H is dune height, U is mean velocity, $q_s$ is suspended load, $q_b$ is bed load, $r_s$ is the Spearman correlation coefficient and p is the probability that the results occurred by chance (p-value).

## Wallis-Lowe Model

The model assumes that, at the instant of liquefaction in a deposit, the particles are supported by excess pore pressure and the fractional particle concentration (volume of sediment/total volume) of the dispersion is constant with a concentration $C_0$. As pore pressures dissipate, the particles settle to the bed in a simple two-layer resedimentation process where the interface between the dispersed grains at $C_0$ and the resedimentated grains, at a higher concentration $C_1$, rises at a uniform velocity. Resedimentation is complete when the interface between the overlying clear water and the liquefied dispersion coincides with the surface of the resedimented grains. Complete resedimentation of the dispersion occurs over a time $t$:

$$t = \frac{\Lambda(C_1 - C_0)}{C_1 w_d \cos\alpha} \quad . \tag{1}$$

where $\Lambda$ is the initial thickness of the deposit, $\alpha$ is slipface angle, $w_d = w_f(1 - C_0)^n$, is the aggregate fall velocity of the dispersion, $w_f$ is the fall velocity of a single particle, and $n$ is an empirically derived coefficient. For the simplest case of laminar flow and no interaction between the liquefied grains, the maximum distance travelled by the flow $\Gamma$ is:

$$\Gamma = t\,u_h \ . \tag{2}$$

where $u_h = 0.7\sqrt{(\Delta\rho_{l-f} / \rho_l) g \Upsilon}$, is the slope-parallel velocity of the head of the flow, $\Delta\rho_{l-f}$ is the density difference between the liquefied avalanche $\rho_l$ and the overlying fluid $\rho_f$, and $\Upsilon$ is the thickness of the head. In our calculations we assume characteristic values of $C_0 = 0.54$, $= C_1 = 0.6$, $\rho_l$ = 1900 kg/m$^3$, $\rho_{l-f}$ = 900 kg/m$^3$, $g$ = 9.81 m/s$^2$ (Lowe, 1976) and particle size of 0.3 mm with $w_f \approx$ 4 cm/s (Soulsby, 1997).

## Bedload Model

The shear stress $\tau_0$ exerted by downslope currents is given by the quadratic stress equation:

$$\tau_0 = \rho_f C_D u^2 \ . \tag{3}$$

where $C_D$ is a drag coefficient that is related mainly to bed particle size (Soulsby, 1997) for a flat surface such as a slipface, and $u$ is the mean velocity of the current. Volumetric bedload transport $q_b$ is expressed in the recent reformulation of the classic Meyer-Peter & Müller bedload equation (Huang, 2010) as:

$$q_b = c_b(\tau_0 - \tau_c)^{5/3} \ . \tag{4}$$

where $c_b$ is a coefficient related to the characteristics of bed sediments and $\tau_c$ is the critical shear stress for the incipient movement of bed material. Assuming constant water temperature and particle size, then $\rho_f$, $C_D$, $c_b$ and $\tau_c$ are constant. Thus bedload transport is proportional to velocity as $q_b \propto u^{10/3}$.

## Supplementary Information References

Bennett, S.J., and Best, J.L., 1995, Mean flow and turbulence structure over fixed, two-dimensional dunes - implications for sediment transport and bedform stability: Sedimentology, v. 42, p. 491–514.

Blom, A., Ribberink, J.S., and de Vriend, H. J., 2003, Vertical sorting in bed forms - flume experiments with a natural and a trimodal sediment mixture: Water Resources Research, v. 39(2), 1025, https:doi:10.1029/2001WR001088.

Bradley, R.W., Venditti, J.G., Kostaschuk, R.A., Church, M.A., Hendershot, M.L., and Allison, M.A., 2013, Flow and sediment suspension events over low-angle dunes - Fraser Estuary, Canada: Journal of Geophysical Research Earth Surface, v. 118, p. 1693–1709, https://doi:10.1002/jgrf.20118.

Carling, P.A., Golz, E., Orr, H.G., and Radecki-Pawlik, A., 2000, The morphodynamics of fluvial sand dunes in the River Rhine, near Mainz, Germany - I. Sedimentology and morphology: Sedimentology, v. 47, p. 227-252.

Gabel , S.L.,1993, Geometry and kinematics of dunes during steady and unsteady flows in the Calamus River, Nebraska, USA: Sedimentology, v. 40, p. 237-269.

Holmes, R.R., and Garcia, M.H., 2008, Flow over bedforms in a large sand-bed river - A field investigation: Journal of Hydraulic Research, v. 46, p. 322–333.

Huang, H.Q., 2010, Reformulation of the bed load equation of Meyer-Peter and Müller in light of the linearity theory for alluvial channel flow: Water Resources Research, v. 46, W09533, https://doi:10.1029/2009WR008974.

Kostaschuk, R.A., and Ilersich, S.A., 1995, Dune geometry and sediment transport, *in* Hickin, E.J., ed., River Geomorphology: Chichester: John Wiley & Sons, p. 19-36.

Prent, M.T.H., and Hickin, E.J., 2001, Annual regime of bedforms, roughness and flow resistance, Lillooet River, British Columbia: Geomorphology, v. 41, p. 369-390.

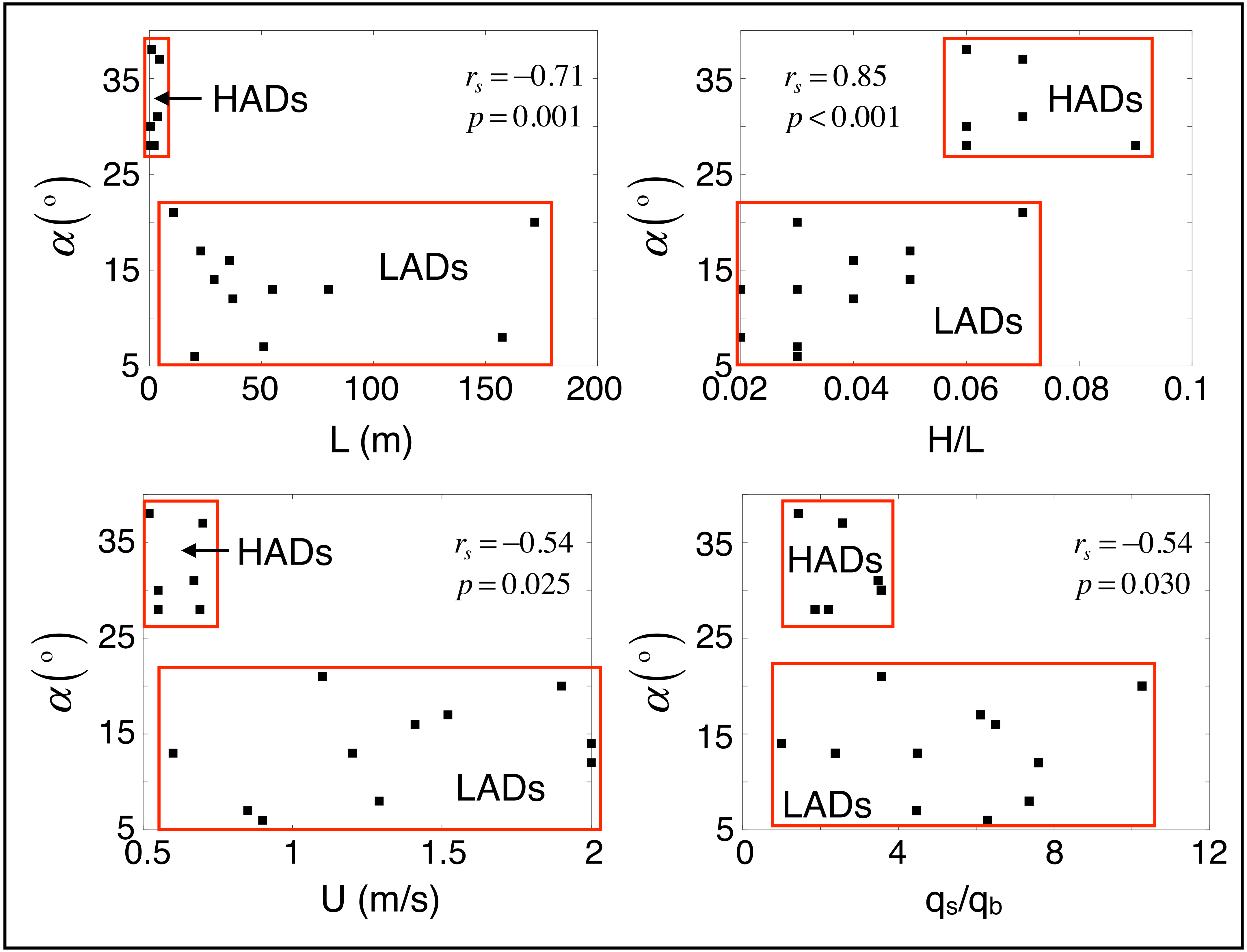
Robert, A., and Uhlman, W., 2001, An experimental study on the ripple-dune transition: Earth Surface Processes and Landforms, v. 26, p. 615-629.

Roden, J. E., 1998, The sedimentology and dynamics of mega-dunes, Jamuna River, Bangladesh: Leeds, U. K., University of Leeds, Doctoral Dissertation.

Soulsby, R., 1997, Dynamics of Marine Sands. London: Thomas Telford.

Venditti, J.G., and Bauer, B.O., 2005, Turbulent flow over a dune: Green River, Colorado: Earth Surface Processes and Landforms, v. 30, p. 289-304.

Wilbers, A. W. E., 2004, The development and hydraulic roughness of subaqueous dunes [PhD thesis]: Utrecht, the Netherlands, University of Utrecht, 227p.



HADs
LADs
$r_s = -0.71$
$p = 0.001$
$\alpha(^\circ)$
L (m)
$r_s = 0.85$
$p < 0.001$
H/L
$r_s = -0.54$
$p = 0.025$
U (m/s)
$r_s = -0.54$
$p = 0.030$
$q_s/q_b$


Fig. DR1

**Table DR1.** n is the number of dunes used to average H, L and α. H is dune height, L is dune length, α is slipface angle, U is mean velocity, h is flow depth, $Fr = U\sqrt{g/h}$ is Froude number, $g = 9.81$ m/s$^2$ is acceleration due to gravity, $d_{50}$ is median particle size, $d_{90}$ is the 90th coarsest percentile particle size, $q_s$ is suspended load, $q_b$ is bed load.

| Source | n | H (m) | L (m) | H/L | α (°) | U (m/s) | h (m) | Fr | $d_{50}$ (mm) | $d_{90}$ (mm) | $q_s$ (m$^2$/s) | $q_b$ (m$^2$/s) | $q_s/q_b$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flume (Bennett and Best, 1995) | 1 | 0.04 | 0.63 | 0.06 | 30 | 0.55 | 0.11 | 0.53 | 0.30 | 0.50 | 5.62E-05 | 1.58E-05 | 3.56 |
| Flume (Blom et al., 2003: Exp T5) | - | 0.12 | 2.18 | 0.06 | 28 | 0.69 | 0.39 | 0.35 | 0.68 | 1.00 | 2.19E-05 | 1.18E-05 | 1.86 |
| Flume (Robert and Ullman, 2001) | 4 | 0.03 | 0.32 | 0.09 | 28 | 0.55 | 0.11 | 0.53 | 0.40 | 1.00 | 2.59E-05 | 1.17E-05 | 2.20 |
| Flume (Tuijnder et al., 2009) | 9 | 0.07 | 1.11 | 0.06 | 38 | 0.52 | 0.20 | 0.37 | 0.80 | 1.08 | 3.03E-06 | 2.12E-06 | 1.43 |
| Calamus River (Gabel, 1993: April 24 1985, 1125 h) | 4 | 0.24 | 3.60 | 0.07 | 31 | 0.67 | 0.50 | 0.30 | 0.33 | 0.60 | 6.12E-05 | 1.76E-05 | 3.48 |
| Fraser River (Kostaschuk and Ilersich, 1995: low tide, June 15 1989) | 15 | 1.52 | 35.70 | 0.04 | 16 | 1.41 | 10.00 | 0.14 | 0.32 | 0.57 | 1.22E-03 | 1.88E-04 | 6.50 |
| Fraser River (Bradley et al., 2013: low tide) | 8 | 1.49 | 37.30 | 0.04 | 12 | 2.00 | 11.10 | 0.19 | 0.27 | 0.35 | 5.94E-03 | 7.82E-04 | 7.60 |
| Green River (Venditti and Bauer, 2005) | 1 | 0.32 | 4.50 | 0.07 | 37 | 0.70 | 1.20 | 0.20 | 0.60 | 1.00 | 2.23E-05 | 8.66E-06 | 2.57 |
| Jamuna River (Roden, 1998: September 14 1995) | 7 | 5.85 | 172.00 | 0.03 | 20 | 1.90 | 15.00 | 0.16 | 0.20 | 0.49 | 6.57E-03 | 6.41E-04 | 10.26 |
| Lillooet River (Prent and Hickin, 2001: August 5 1995, 1535 h) | 11 | 0.71 | 10.80 | 0.07 | 21 | 1.10 | 3.50 | 0.19 | 0.52 | 1.00 | 2.48E-04 | 6.95E-05 | 3.57 |
| Missouri River (Holmes and Garcia, 2008: dune MO-1) | 1 | 1.25 | 23.00 | 0.05 | 17 | 1.52 | 6.46 | 0.19 | 0.31 | 0.55 | 1.78E-03 | 2.92E-04 | 6.11 |
| Ob River: May 2010; (unpublished aDcp data) | 4 | 0.53 | 20.30 | 0.03 | 6 | 0.90 | 3.70 | 0.15 | 0.26 | 0.33 | 2.45E-04 | 3.90E-05 | 6.29 |
| Rhine River (Carling et al., 2000: dune 94/6) | 1 | 1.35 | 80.00 | 0.02 | 13 | 0.60 | 4.00 | 0.10 | 0.90 | 1.80 | 2.51E-06 | 1.05E-06 | 2.38 |
| Rhine River (Wilbers, 2004: Bovenrijn section 1: Feb 4 1995) | 15 | 1.53 | 28.90 | 0.05 | 14 | 2.00 | 10.30 | 0.20 | 3.34 | 11.30 | 2.15E-04 | 2.15E-04 | 1.00 |
| Rio Paraná, Paso de la Patria: May 2004 (unpublished aDcp and MBES data) | 7 | 1.69 | 55.00 | 0.03 | 13 | 1.20 | 7.70 | 0.14 | 0.48 | 1.23 | 3.95E-04 | 8.79E-05 | 4.49 |
| Rio Paraná, Paso de la Patria: March 2004 (unpublished aDcp and MBES data | 23 | 1.53 | 51.10 | 0.03 | 7 | 0.85 | 8.00 | 0.10 | 0.48 | 0.07 | 7.37E-05 | 1.65E-05 | 4.47 |