Dimensionless argument: a narrow grain size range near 2 mm plays a special role in river sediment transport and morphodynamics

Response to Referees (October 9, 2023)
(Responses are in italics.)

We thank both referees for their positive and helpful comments. They have helped make our arguments clearer and stronger. We now acknowledge them at the end of the paper.

Reviewer 1

I only have very minor comments and suggestions that are indicated in the edited manuscript. Working on an edited pdf file may not be the most efficient way to prepare a revised manuscript, I thus report two comments that are not related to text clarity or figure formatting below.

Lines 255-256: is the presence of a massive, basal unit (see Figure 17 in Carling, 2013) also indicative of the thick grain flow? Carling, P.A. (2013). Freshwater megaflood sedimentation: What can we learn about generic processes? Earth-Science Reviews 125, 87-113.
We have added the reference and modified the text as follows. "This is consistent not only with suspension, but also with the formation of a thick grain flow that can be considered transitional to a debris flow (e. g. Hernandez-Moreira et al., 2019). Such a grain flow might be indicated in sedimentary deposits in terms of a massive basal unit (Carling, 2013).

Lines 354-356: is the formation of a diffuse (not abrupt) gravel-sand transition a possible consequence of the longitudinal sorting described for the mixture of 1/3 gravel, 1/3 pea gravel and 1/3 sand?
Not exactly. We have rewritten the text as follows to be clearer. "…transition may be rather disperse and elongated, with interleaving of sand and coarse gravel patches for some distance downstream of the main transition (e.g. Venditti et al., 2015; Dong et al., 2016)."

Responses to comments of Referee 1 directly on the manuscript.

Around line 25: "This part is rather obscure…"
We have split up one of the sentences for clarity. It now reads as follows. "The use of viscosity allows delineation of a generalized dimensionless bed grain size discriminator between "sand-like" and "gravel-like" rivers. This discriminator is applicable to sediment transport on Titan (ice clasts in flowing methane/ethane liquid at reduced gravity) and Mars (mafic clasts in flowing water at reduced gravity) as well as Earth.

Line 160, “why brackets?”
We retain the parentheses, as we do not want to digress into a long discussion of the merits of $\boldsymbol{Re}_p$ *versus D*. We have not changed the text.*

Figure 3d, “I cannot see the modified equation line for 0.25 mm…”
This is because the original and modified lines are on top of each other. We now note this in the caption. We have redone this figure, and indeed all the figures for clarity.

Line 226. “This seems unnecessary to me. Why is this reference important? Why mention it after the extension to sediment with non-uniform grain size?
We have deleted the material related to the extension of modified Garcia-Parker for mixtures, because it is not used later in the paper. We include the comparison including de Leeuw et al. for two reasons: a) to show that the difficulty to suspend gravel is not unique to the modified Garcia-Parker relation, and b) because we are preparing a successor paper on the evolution of bimodality that specifically refers to the de Leeuw et al. relation. This latter equation is described as applicable to “sand-gravel suspensions”. We cannot quote the successor paper yet because it is not quite submitted.

Line 282: change “more” to “most”
Done.

Line 290. Remove brackets
Done.

Referee 2

L34-38. Adding another reference or two would strengthen the case that the 2-mm grain size is a standard dividing line for classifying clast vs. matrix support.
Reply
We have added two references, listed below.
Li, Shunli, Li, Shenli, Shan Xin, Gong, Chenlin, and Yu, Xinghe.: Classification, formation, and transport mechanisms of mud clasts, International Geology Review, 59(12), pp.1609-1620: 2017.
Jutzeler, M., McPhie, J., Allen S. R., and Proussevitch, A. A.: Grain-size distribution of volcaniclastic rocks 2: Characterizing grain size and hydraulic sorting, Journal of Volcanology and Geothermal Research, 301(15), pp 191-203, 2015
Volume 301, 15 August 2015, pp. 191-203.

L70-71: “repetition, convergence and rearticulation” – the basic idea comes across, but I am curious about how each of these social phenomena are distinct from one another. As this phrase also appears in the abstract, and the Butler reference is not well known in this field, a bit more explanation of the social science would be helpful.

We have removed the phrase from the abstract. In the text, we now say "(as viewed from the perspective of social science, e.g. Butler 1997)".

Figure 2a: The reason for flagging "granite" particles is clear in the text, but at first glance it is mildly confusing why "granite" is included as a category as the other two are grain sizes (gravel or sand). Recommend Tweaking the legend entry to indicate a grain size (e.g., "granitic pea gravel") or briefly explaining in the caption.
Text has been added to the caption:
"a) Bed surface size D60 versus bed slope for Japanese streams (adapted from Fujita et al., 1998; "granite" is shorthand for "rivers that have weathered granitic rock in their catchments"):…"

Figure 2a: missing units for D60.
Added, thank you.

L75-96. The discussion of Figure 2a and 2b is in reverse order compared to the figure itself. Suggest swapping the order of the subfigures and adding specific references to Figure 2a and 2b.
Actually they are not in reverse order. The text reads, "Both Fujita et al. (1996) and Lamb and Venditti (2016) use large data sets to illustrate that a substantial number of river reaches have coarse gravel beds (bed surface D50 or D60 > 5 mm) and sand beds (bed surface D50 or D60 < 1 mm), but very few reaches have a characteristic size in the pea gravel range (Figure 2). But we have modified "Figure 2" to "Figure 2a,b".

L98. Missing word around "may"
The original sentence read "transition may rather disperse and elongated…" Now modified to "transition may be rather disperse and elongated, with interleaving of sand and coarse gravel patches for some distance downstream of the main transition (e.g. Venditti et al., 2015; Dong et al., 2016)".

L99. Didn't follow how "patchiness" is related to the abruptness/non-abruptness of the gravel-sand transition.
See comment immediately above.

L101: Anthropogenic effects such as?
Frings (2011) quotes "river training". We have modified the text to: "anthropogenic effects such as river training."

L101: "show this" – show what? The sentence is drawing a contrast for a pristine vs. a human-modified river described in the previous sentence, so it's hard to follow what is consistent between the two rivers.
"*…this…" changed to "…this elongation…".*

L109-110: Brief rationale for the role of viscosity would be helpful.
Text changed to "…role for viscosity in regard to the grain size gap. This effect is explained in more detail below." We have added new text in this regard where we discuss Novak and Nalluri (1975); see below.

L117: What is this parameter with dimensions?
Modified to "parameter with dimensions; namely the 2 mm cutoff between sand and gravel."

L140-142: If it's the exposure of grains that makes them easier to move, why not refer to this as the exposure effect (rather than the hiding effect)? That would seem to draw a clearer contrast between the two effects: one effect that makes particles easier to move vs. one effect that makes them harder to move.
Exposure and hiding are two sides of the same coin. The larger particles are exposed compared to the smaller particles, and the smaller particles hide among the larger particles. The term "hiding effect" was introduced by H. Albert Einstein (1950). We have modified this to "hiding-exposure" in several places.

L158-160. Very helpful explanation.
Thanks for noting this!

L167. "little difference" still looks like a factor of a few. Perhaps clarify that the difference is smaller than one would expect given the ratio of the two grain sizes.
"It can be seen therein that there is little difference for the predictions for near-bed concentration c_b" has been changed as follows. "It can be seen therein that the predictions for near-bed concentration c_b for 4 mm are about half that of the corresponding predictions for 0.25 mm material. This seems unlikely, however…"

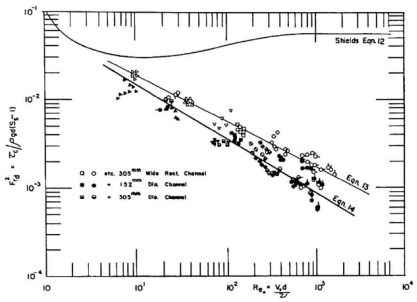
L204. It's a bit ambiguous what "just as well" means here, as what's being compared are two theoretical predictions (rather than predictions vs. observations). Suggest condensing this with the following sentence to cut straight to the finding that the predicted behavior is unchanged for D = 0.25 mm but drastically different for D = 4 mm.
The text has been modified as follows. "Figure 4 shows that when applied over the range of the original data of Garcia and Parker (1991), the predictive power of the modified formulation of Eqs. (4a,b) is as good as the original formulation of Equations (1a,b,c)."

L212-213. "predicts the data as well as the original form." I'm confused, doesn't Figure 4 compare two theoretical predictions? What are the data?
We have omitted this text in accordance with the modification immediately above.

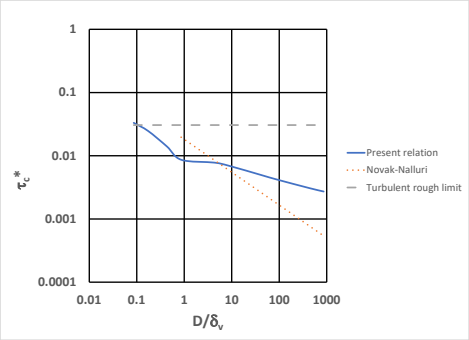
L215-216. Concordance issue. Should be "relations…encompass"
Thank you: change made.

L279-281. I don't know if anyone who isn't familiar with the Shields number will be reading, but just in case, it may be helpful to go back to basics here and state that the particles are easier to move relative to their weight. Also, while the "lubrication" metaphor is evocative I left this paragraph confused as the physical mechanism by which viscosity makes smaller grains easier to move. I get that it comes out of the equations but can you help the reader build some physical intuition?
We have added a reference which explains the viscous effect: Ikeda, S., Lateral bed load transport on side slopes, J. Hydraul. Engrg. 128(HY1), 1982. 128(HY1), 1982. We do not discuss this in detail here, as we have added a more detailed explanation in a new Appendix, in response to one of the referee's comments below. For the sake of the referee, we note that the critical Shields number τ_c varies inversely with the ratio u_f/u_*, where u_f is the effective mean flow velocity acting on a grain and u_* is shear velocity. This ratio increases with increasing ratio of nominal thickness of the viscous sublayer to grain size.*

L299: This looks like a key point but seems like you'd need to dig into Novak and Nalluri (1975) to fully understand how the change in near-bed flow affects the Shields number. Slightly more explanation here would be helpful.



Novak and Nallluri (1975) show the following diagram to the left, but do not discuss the reason as to why viscous effects reduce the critical Shields stress on a particle placed on a bed under turbulent smooth flow. They simply say: "Because of the mechanics of incipient motion, it is, of course, to be expected that in a conveyance with a fixed smooth bed the critical mean velocity of flow is substantially lower for any particle size for alluvial beds. We modified the text here to state as follows. "Novak and Nalluri (1975) offer no explanation for their result that a grain in a turbulent smooth flow has a lower critical Shields number than the same grain in turbulent rough flow, other than remarking that the result is "to be expected". We have added an Appendix, where we outline a broad-brush theory as to why this should be true. The key parameter is the ratio u_f/u_*, where u_f is the flow velocity averaged over turbulence acting on the grain. This ratio takes an asymptotic value for the limit of turbulent rough flow, but increases monotonically with increasing grain size for turbulent smooth flow, causing the critical Shields number to correspondingly decline monotonically. See our new figure immediately below and in the new Appendix.



L330-331. “now…applicable” – good place to restate what this study has added in order to make this application possible.
Thank you. We now state: “The formulation is now directly applicable to rivers on Mars and Titan as well as Earth, in so far as it can be applied to a heavenly body with arbitrary gravitational acceleration g, a fluid with arbitrary kinematic viscosity ν, and a sediment particle of arbitrary submerged specific gravity R.

L348. “pea gravel tends to become diluted over a long reach.” Reasoning is not fully clear until the thought experiment in the next paragraph – a phrase like “as described in the following though experiment” would help reader stay in the flow.
Done, thanks. Now reads “diluted over a long reach, as described in the following thought experiment.”

L356. I like the thought experiment, but the allusion to preferential mobility is somewhat unsatisfying because the thought experiment has only described a static condition (distributions of grain size in upstream and downstream reach). Perhaps this would be more effective if it considered two time steps: an initial condition before transport, and then final condition after transport. Might consider adding a sketch figure also.
We have not modified the text, as we do not want to make the thought experiment overly complicated. But please note that in the main text there is a reference to An et al. (2020), where the relevant effect is explained in more detail.

L378-379: I find the latter description of pea gravel not being able to concentrate in a location where it can “dominate the deposit” to be more clear and informative than the “dilution” metaphor that is used elsewhere in the manuscript. Whereas dilution implies that the pea gravel is getting lost by addition of another grain size, the mechanisms that are the focus have more to do with the mobility of pea gravel relative to other grain sizes.
We have re-read the text and decided not to change it, again so as to avoid making the text overly complicated.

Figure 3b. In legend, indicate that blue line is the Dietrich relation.
Done, thank you.

L385. This table is very helpful. It did take a moment to figure out that the “[1]” indicates dimensionless variables. Perhaps this is a standard notation but I haven’t seen it before. A brief note to indicate that [1] indicates dimensionless would clarify.
Done, thank you.