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Interactive comment on "Multiple controls on sediment grain properties of Peruvian coastal river basins" *by* Camille Litty et al.

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Dear referee,

Thank you very much for handling our paper. We considered the comments as very constructive and have improved the paper accordingly. The major changes include the improvement of the introduction with a clear explanation of how tectonics and climate operate to potentially influence the grain size pattern. Based on this, we phrased a distinct hypothesis to be tested. We also we improved the methods part by adding additional information about the sampling strategy and the data collection. We have used the Pearson's correlation coefficient to obtain statistically robust correlation between our grain size data and the morphological characteristics of the basins including mean basin slope, denudation rate and basin size, and shear stresses exerted by

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the streams. We found distinct correlations between the grain size pattern and these variables and have framed the discussion accordingly. Therefore, we found the grouping of basins into northern and southern domains no longer as useful and have thus re-structured the paper accordingly. In summary, the major changes include: âĂć Presentation of a clear outline of how tectonics and climate could influence the grain size pattern, and based on this, a formulation of a distinct hypthothesis âĂć Presentation of more details of how we have collected and analysed the data âĂć Testing through state-of-the art statistical methods whether basin shape, sediment flux and streams' shear stresses have a measurable control on the grain size pattern. We have thus re-structured the discussion part accordingy.

Please find below a point-by-point response of how we have handled the suggestions and comments. Thank you very much for your hard work. On behalf of the co-authors

Camille Litty

Response to Referee #1

It lacks a clear explanation of how the different factors that are meant to influence grain size operate, both in the introduction and throughout the discussion. For example, it is stated that increased uplift will be expected the increase grain size, but the causal mechanism is not described.

We have addressed this point by adding a new paragraph in the introduction, which explains how tectonics and earthquake occurrence should influence the grain size pattern, and what we expect based on this. In the same sense, we have discussed how this should imprint the grain size pattern. Based on this, we were able to phrase distinct hypotheses to be tested.

There is also a difficulty in separating out the different mechanisms; for example, smaller basins seem to be correlated with lesser uplift, hence it is not obvious which of these two factors is more important.

This has been confusing, indeed. We thus have completely modified the analysis plus we have framed the discussion in a different way.

Another issue is that the paper seems to alternate between assuming that downstream fining is caused by abrasion and that it is caused by selective transport, without any explicit consideration of which process is likely to be more important, or the implications of one process being dominant. (A relevant paper for the discussion of abrasion processes is Sklar et al., 2006.)

It is true that we did not take into consideration the different processes. We have clarified this point and have been consistent in our interpretation.

Overall, I would have liked a greater sense of the underlying processes that control grain size, how they interact with each other, and the relative importance of the different factors.

This has been done. We have rephrased the discussion section, thereby addressing the interplay between the controls of the various variables more carefully.

I also have some queries about the way in which the data were collected and analysed. The authors do not state how the locations in the different river basins were selected (other than the presence of the highway).

This information has been added. In fact, we have sampled all streams where upstream basin sizes were larger than 700 km2, and we have focussed our data collection at the downstream end where these rivers cross the tip of the mountain belt. This strategy allows us to explore how the ensemble of all processes in a basin relevant for the supply of material influences the grain size patter. This has been clarified in the revised version of the paper.

My concern is that they are attempting to compare grains sizes that are collected from different relative locations within the basin, and are therefore not comparing like with like. For example, if the basins all had the same rate of downstream fining but the samples were collected from different locations within the basins, then the analysis would show differences between the basins that are not actually there. The authors need to consider this as a possible source of variation within their results.

This could indeed add a bias, however, we have selected streams where they cross the tip of the Andean mountain belt. Please see also comment above.

It would be useful to consider sample location as a function of total basin length, and also to normalise the distance to the knickpoint.

We have considered this variable (distance from edge of Western Escarpment). Please see revised version. We have not performed this normalization, but used other variables instead (e.g., shear stresses, basin-averaged denudation rates), which yield measures for flow strengths and sediment flux. Because grain size and fining trends potentially depend on these variables, we used these variables for our analysis and we have indeed found positive correlations with grain size patterns.

There is also the question as to whether these basins are in a form of equilibrium or whether the grain size might actually reflect transient processes such as a coarse sediment slug progressing through the basin. I think that you need more discussion of the literature on controls on downstream grain size; at present the relevant papers are only referred to in passing at the start of the introduction.

This might work for individual basins, such as exemplified for Majes, where the grain size decreases downstream. However, this does not work if all basins along the western Peruvian margin of the Andes are considered, because the D50, as an example, increases with downstream distance from the uppermost edge of the Western Escarpment. In fact, we would have expected the opposite where grain sizes decrease with increasing transport distance. However, we found positive correlations with grain size and mean basin slope, mean basin denudation rates and shear stresses of the streams. This suggests that supply of material (higher denudation rates) and water flow strengths have a large influence on the downstream fining trends within each basin. We have thus framed the discussion in this direction.

What were the channel morphologies

The channels have a braided pattern, and the morphology of the longitudinal stream profiles is characterized by two segments separated by a distinct knickzone. Please see revised version.

how large were the individual images ?

This has been clarified: Individual images are about 1 m2.

how were grains selected within the images ?

Every pebble, which was entirely visible on the digital images, has been measured.

how representative are the selected bars ?

For these basins, sampling sites were situated in the trunk streams of these valleys where the streams cross the tip of the mountain belt, which is located near the Pacific Coast in most cases. We selected the downstream end of these streams because the grain size pattern at these sites is likely to record the ensemble of the main conditions and forces controlling the supply of material to the trunk stream in the upstream basin and thus the grain size caliber of these streams where they leave the Andes. In these streams, we randomly selected c. 5 longitudinal bars where we collected our grain size dataset. As such, we consider the selected bars as representative for the ensemble of supply and transport processes in the streams' basins.

how were grain outlines identified (automated or manual analysis) ?

From those photos, the intermediate b-axes and the long a-axes of around 500 pebbles were manually measured. We have added this information in the revised version.

was any attempt made to verify the grain size data produced,

No attempt has been made to verify the grain size data produced for this paper.

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Nonetheless, all the pebbles have been measured by the same operator. This yields the same bias for every sampling site, if there is any.

why were 500 extra grains used for grain shape

We have clarified this in the method part

and what are the error bars on D50/D84/D95 (and hence are the identified differences significant)?

Uncertainties on the grain size percentiles are also about 3 mm. This value corresponds to the precision limits of the measurements with the software ImageJ and of the digital pictures' resolution. For the significance of the difference, correlations or trends have all been estimated through the Pearson correlation coefficient (p-value) and not anymore on a visual estimation as we have don before.

The lack of a clear hypothesis early on means that some of the analysis comes across as a bit of a fishing expedition, with lots of correlations on different data groupings being undertaken, and only the significant ones being presented. I think that you need to be more thorough about this analysis, for example through multiple or stepwise regression.

This has been done, and a hypothesis has been phrased. Please see also comment above.

Comments by line: 10: Overall the abstract could be more specific and provide some more evidence for the various claims.

We have addressed this point

53: To what extent are these different factors interrelated?

We have addressed this point by adding a new paragraph in the introduction

55: Make it clearer how this information about the general setting is related to the overall aim of understanding grain size.

Done

78: Be more explicit about why uplift produces larger clasts.

This has been specified

79: You describe both N-S and E-W variations; which are most important for your study?

N-S are more relevant; we have rephrased the introduction and clarified this point.

97: I'm surprised that erosion is nearly zero (line 89) given this high precipitation.

Abbühl et al. (2011, ESPL) have shown that the low denudation rates are due to the flat landscapes on the Altiplano.

122: Be more specific about uplift rates.

This has been changed accordingly

125: Is five sites enough to identify trends?

We have changed our data interpretation as there was no real reason to separate the basins into 2 groups (i.e. northern and southern domains). We have worked with all our dataset.

196: Calculate sorting parameters to quantify these trends.

No trend actually exists as there is no real change in the grain size from north to south, so we also did not introduce the sorting parameter.

176: Suggests that you are downstream of the gravel-sand transition? Does the transition occur in other basins?

This transition seems to not occur in the other basins. We have addressed this point in the discussion part.

195: It would be useful to calculate stream power, as this would enable you to look at the combined impact of slope, width and discharge.

Yes, indeed, but we have calculated shear stresses instead. We have done so and we do see correlation in between the grain size and the shear stress.

201: Is the relationship significant?

Indeed, we are not considering anymore the grouping (northern and southern domains) of basins.

209: Overall there are many competing ideas in the discussion, and it's not clear which are most important.

This has been confusing, indeed. We thus have completely modified this part of the analysis plus have framed the discussion in a different way.

216: This is the first mention of sediment sources; this needs to go earlier in the paper.

We now mention it earlier in the text. 'The upstream edges of this knickzone called the Western Escarpment also delineate the upper boundaries of the major sediment sources'

225: Note that rivers can also adjust to changes in uplift by changing other factors such as width, morphology and the amount of sediment cover.

Yes we have changed the part on the tectonic control on grain size

244: What is the mechanism that relates different flood characteristics to different grain sizes?

We have rephrased the entire discussion and have likewise changed this section.

257: What is your evidence?

Because we have only found a correlation between the D50 and the basins scale properties (basin area, denudation rates, mean slope, we infer that the mean grain size reflects the ensemble of a complex pattern of erosional processes operating in the

Peruvian basins

273: How does the size of this fracture network compare to the grain sizes?

We had no indication of the size of the fabric network. We have removed this part of the discussion as we found more compelling evidence for correlations with other variables.

287: This argument would be stronger if you presented the lithological characteristics of your grains, which you could identify from the photos. Or state that they are all identical within each basin. 300: Is this consistent with the geological variations?

A test of the inferred positive correlation between mean basin slope, bedrock lithology and particularly the occurrence of plutonic rocks, and the pebbles' sphericity would require a higher resolution topographic and geologic data, which are currently not available, we thus decided to remove this part, which also does not fit anymore in the discussion, as the grouping of basins into southern and northern domains is not considered anymore.

288: Note that you only have information on 2D grain shape not 3D.

Yes indeed, these are the a- and b-axis. So we are indeed missing the information about the third dimension to talk about the shape of the clasts. In this sense, the reviewer is correct. Nevertheless, we are still convinced that the 2D info contains valuable information about the shape of the clasts in the sense that preferential abrasion due to an inherited fabric (fractions, bedding, schistosity) returns elliptical rather than spherical clasts. We have thus kept this part of our analysis.

296: Which idea do you think is more correct?

This point has been addressed in the revised version of the text.

321: I'm still not entirely clear what you mean by a 'geomorphic' control.

It was indeed unclear, we have rephrased that. But what we wanted to say is that the geomorphic parameters (basin slopes, size, denudation) were controlling the grain size distribution

323: But much of the earlier discussion has referred to abrasion.

We have indeed been contradictory. However, we have substantially changed the paper and thus also the conclusions.

Table 1: Add an indication of where the site is relative to the knickpoint and within the basin.

This has been done in the method part

It would help to also present distances normalise by total basin length.

We did not normalize by the basin length because this is one of the parameters that we wanted to test as control on the grain size

Table 3: Give sorting values.

We have deleted table 3 as we do not group the basins into northern and southern basins

Figure 1: Add basin outlines to maps B and C.

This has been made

Figure 2: Add the channel.

This has been made

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Fig. 1.

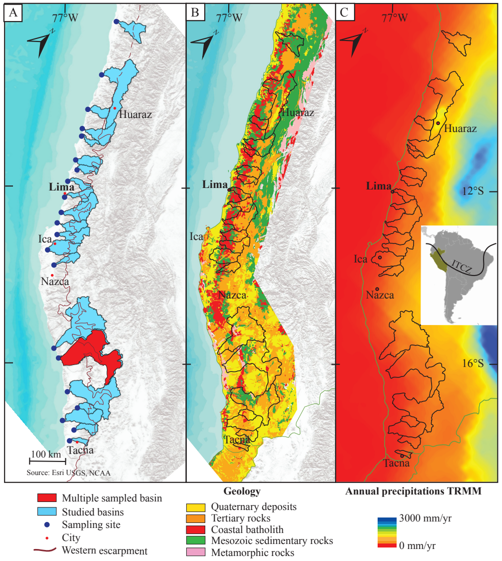


Figure 1: A: Map of the studied basins showing the sampling sites and the western escarpment (western escarpment modified after Trauerstein et al., 2013). **B:** Geological map of the western Peruvian Andes. **C:** Map of the precipitation rates showing the spatial extend of the ITCZ, modified after Huffman et al., 2007.)

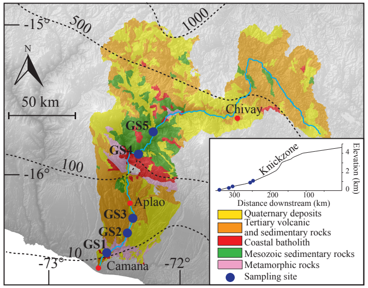
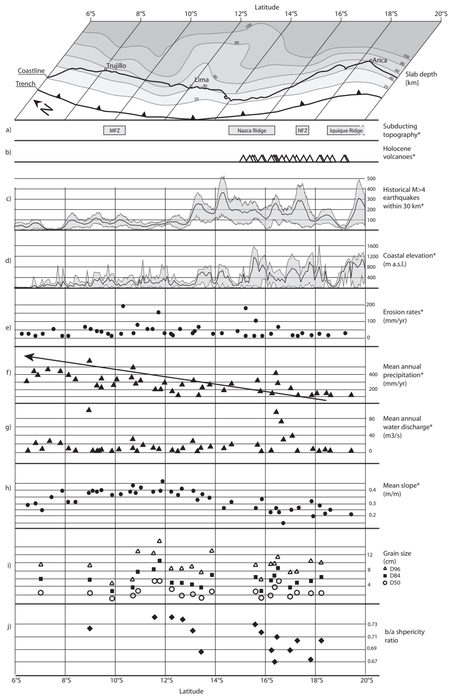


Figure 2: Geological map of the Majes basin overlain by the precipitation pattern (Precipitation data from Steffen et al., 2010., where the black dashed lines show precipitation rates (mm/yr). GS1 to GS5 represent sites where grain size data has been collected. The right corner shows the Majes river long profile.

Fig. 2.



* Data from Reber et al., in review

Figure 3: Topography of subducting Nazca plate, where slab depth data has been extracted from earthquake.usgs.gov/data/slab/. This N-S projection also illustrates: a) tectonic lineaments such as submarine ridges and MFZ: Mendaña Fracture Zone; NFZ: Nazca Fracture Zone; b) Holocene Volcanoes; c) Earthquake data, taken from earthquake.usgs.gov/earthquakes/search/; number of earthquakes M>4 within 30 km radius window; d) Coastal elevation. The data has been extracted from a 20 km-wide swath profile along the coast. The three lines represent maximum, mean and minimum elevations within the selected swath; e) Catchment averaged denudation rates have been corrected for quartz contents; f) Mean annual precipitation rates;
g) Mean annual water discharge; h) Mean basin slope i)Grain size results for the intermediate (b)-axis of the pebbles in the streams from north to south at the sampling sites presented in Figure 1; j) Ratio between the intermediate axis and the long (a)-axis (modified after Reber et al., in review).

Fig. 3.

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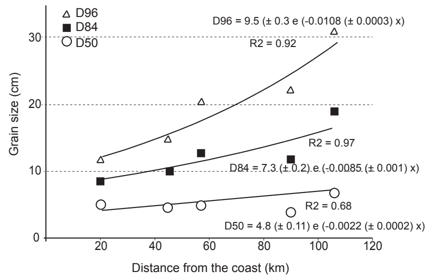

Figure 4: Grain size results along the Majes River.

Fig. 4.

River name	Sample name	Altitude (m)	Latitude (DD WGS84)	Longitude (DD WGS84)	D50 (cm)	D84 (cm)	D96 (cm)	b/a	Catchment area (km2)	Mean elevation (m.a.s.l.)	Mean slope (m/m)	Slope at the sampling site (m/m)	Distance form the western escarpment (km)	Mean annual precipitation (mm/yr) (Reber et al., in review)	Mean annual water discharge (m3/s) (Reber et al., in review)	Denudation rates (mm/ka) (Reber et al., in review)	Denudation rates uncertainties (mm/ka) (Reber et al., in review)	Denudation rates corrected for Qz content in bedrock (mm/ka) (Reber et al., in review)
Tacna	PRC-ME1	231	-18.12	-70.33	2.3	6.2	10.0	0.70	899	2733	0.28	0.015	48	149.6	3.4	13.3	3.6	12.2
Rio Sama Grande	PRC-ME3	455	-17.82	-70.51	2.5	5.5	10.6	0.67	2150	3105	0.3	0.013	73	136.4	4	28.6	5.3	27.7
Ilo / Rio Osmore	PRC-ME5	1072	-17.29	-70.99	2.6	5.1	7.8	0.70	1783	3398	0.26	0.018	53	137.8	3.4	21.4	4.8	18.6
Rio Tambo	PRC-ME6	145	-17.03	-71.69	1.5	3.6	7.5	0.69	12885	3568	0.24	0.051	141	216.3	38.1	89.7	16.7	72.1
Tambillo / Rio Sihuas	PRC-ME802	117	-16.34	-72.13	2.0	6.0	10.0	0.69	1708	3285	0.15	0.019	70	170.2	30.1	34	6.4	27.7
Camana / Rio Majes	PRC-ME7	69	-16.51	-72.64	5.2	8.7	11.6	0.67	17401	3635	0.23	0.005	188	283.9	68.4	127.5	23.4	106.8
Ocona / Rio Ocona	PRC-ME9	14	-16.42	-73.12	4.8	6.8	10.0	0.71	16084	3745	0.26	0.004	192	414.7	91.1	242.1	45	184.1
Nasca / Rio Grande	PRC-ME1402	15	-15.85	-74.26	1.3	3.0	6.0	0.71	1412	2716	0.32	0.014	48	283.6	20.4	46.1	8.6	29.4
Chacaltana / Rio Ica	PRC-ME15	3	-15.63	-74.64	2.9	6.4	9.6	0.73	4677	2204	0.26	0.003	88	188.4	12.1	27	5.7	25.1
Humay District / Rio Pisco	PRC-ME16	400	-13.73	-75.89	3	6.6	13		3649	3464	0.34	0.013	62	272.6	13.6	104.1	20.4	69.1
Chinca Alta / Rio San Juan	PRC-ME17	75	-13.47	-76.14	1.3	3.8	7.6	0.69	3090	3197	0.37	0.01	78	237.8	10.1	61.2	11.7	44.1
Rio Canete	PRC-ME19	23	-13.12	-76.39	2	4.6	8.8	0.72	6029	3648	0.4	0.01	100	318.4	26.4	66.8	12.3	51.2
Rio Omas	PRC-ME20	33	-12.67	-76.65	1.6	4.8	8.8	0.73	2322	3294	0.41	0.0076	78	257.6	8.2	27.1	5.4	17.9
Rio Lurin	PRC-ME22	40	-12.25	-76.89	3	5	8.8	0.74	1572	2568	0.38	0.022	70	175.5	3.7	38.5	7.1	23.6
Lima / Rio Chillon	PRC-ME39	402	-11.79	-76.99	5.3	10.5	15.5		1755	2942	0.39	0.018	51	204.7	4.9	82.2	15.5	53.4
Rio Chancay	PRC-ME23	72	-11.61	-77.24	5.5	8.3	12.5	0.74	3059	2697	0.39	0.01	66	211.4	8.9	97.7	18.4	52.8
Rio Supe	PRC-ME25	74	-11.07	-77.59	2.8	7.7	13		4306	2365	0.38	0.012	82	275.4	3.8	41.7	7.7	25.6
Rio Pativilca	PAT-ME	10	-10.72	-77.77	1.8	3.6	6		4607	3378	0.44	0.014	74	490.6	30.9	260.1	48.8	190.9
Huarmey	PRC-ME38	24	-10.07	-78.16	1.7	3.4	5.2		2072	2337	0.37	0.004	78	340.1	9.8	19.7	4.5	10.1
Rio Santa	PRC-ME27	80	-8.97	-78.62	2	5.4	9	0.72	12313	3262	0.38	0.005	65	571.7	96.1	71.2	13.4	70.4
San Martin de Porres	PRC-ME30	67	-7.32	-79.48	2.9	6.3	10		3882	2292	0.34	0.007	126	472.8	25.4	30.5	5.9	25.8

Table 1 : Location of the sampling sites with the altitude in meters above sea level.
The table also displays grain size results together with the rivers' and basins' properties and hydrological properties.
Morphometric dataset for the sampled drainage basins. All calculations are based on the 90 m resolution DEM (NASA)
The precipitation, water discharge data and the denudation rates are from Reber et al., in review

Fig. 5.

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	Distance from the coast (km)	Altitude (m)	Latitude (°)	Longitude (°)	D50	D84	D96	b/a
GS1	20	69	-16.51	-72.64	5.2	8.7	11.6	0.67
GS2	45	283	-16.37	-72.49	4.8	10	15	0.69
GS3	57	378	-16.28	-72.45	5.4	12.7	21	0.65
GS4	90	700	-16.00	-72.48	3.3	12	22.5	0.67
GS5	106	882	-15.86	-72.45	6.2	19	31	0.71

Table 2: Location of the sampling sites in the Majes basin and grain size results in the Majes basin.

Fig. 6.

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	Altitude (m)	*Latitude (DD WGS84)*	*Longitude (DD WGS84)*	***D50 (cm)***	***D84 (cm)***	***D96 (cm)***	***b/a***	*Catchment area (km2)*	*Mean elevation (m.a.s.l.)*	*Mean slope (m/m)*	*Distance form the western escarpment (km)*	*Mean annual precipitation (mm/yr)*	*Mean annual water discharge (m3/s)*	*Shear stress*	*Denudation rates (mm/ka)*	*Denudation rates corrected for Qz content in bedrock (mm/ka)*
Altitude (m)	1.00															
Latitude (DD WGS84)	-0.36	1.00														
Longitude (DD WGS84)	0.46	-0.97	1.00													
D50 (cm)	0.09	0.00	-0.01	1.00												
D84 (cm)	0.14	0.04	-0.03	**0.87**	1.00											
D96 (cm)	0.18	0.02	-0.02	**0.73**	**0.93**	1.00										
b/a	-0.30	0.66	-0.71	0.09	0.00	-0.02	1.00									
Catchment area (km2)	-0.25	-0.12	0.12	**0.31**	0.16	0.04	-0.25	1.00								
Mean elevation (m.a.s.l.)	0.21	-0.38	0.37	0.03	-0.07	-0.03	**-0.49**	0.53	1.00							
Mean slope (m/m)	-0.23	0.72	-0.78	-0.07	-0.10	-0.03	**0.63**	-0.28	-0.20	1.00						
Distance form the western escarpment (km)	-0.32	-0.14	0.14	**0.35**	0.16	0.03	**-0.33**	0.84	0.37	-0.35	1.00					
Mean annual precipitation (mm/yr) (Reber et al., in review)	-0.43	0.65	-0.61	-0.08	-0.16	**-0.23**	0.21	0.44	0.11	0.39	0.30	1.00				
Mean annual water discharge (m3/s) (Reber et al., in review)	-0.30	0.03	-0.01	0.18	0.05	-0.07	-0.13	0.87	0.51	-0.23	0.64	0.66	1.00			
Shear stress	0.45	-0.11	0.14	**0.23**	**0.33**	**0.39**	-0.06	-0.21	0.09	0.06	-0.23	-0.43	-0.37	1.00		
Denudation rates (mm/ka) (Reber et al., in review)	-0.23	0.04	-0.09	**0.34**	0.09	0.00	-0.09	0.56	0.53	0.12	0.48	0.50	0.56	-0.07	1.00	
Denudation rates corrected for Qz content in bedrock (mm/ka) (Reber et al., in review)	-0.22	0.01	-0.04	0.30	0.06	-0.03	-0.17	0.64	0.57	0.05	0.54	0.54	0.65	-0.11	0.99	1.00

Table 3: Results of the statistical investigations, illustrated here as correlation matrix values.
The valuess in bold show significant correlation between the grain size data and the morphometric parameters and basins characteristics

Fig. 7.