Interactive comment on "Uniform grain-size distribution in the active layer of a shallow, gravel-bed, braided river (the Urumqi River, China) and implications for paleo-hydrology" *by* L. Guerit et al.

R. Hodge (Editor)

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We have now received two thorough reviews of your paper, which are both supportive of the paper. The reviewers agree that the question of whether grain size distributions (GSD) from vertical outcrops are equivalent to those measured from horizontal surface is a useful question to ask, and has implications for interpreting paleohydrology. The reviewers do, however, also provide you with many useful comments on how you can improve aspects of this paper.

One potential weakness that is identified by both reviewers is that you could use more statistical analysis to justify your interpretations. The two reviewers both give useful suggestions as to how this could be done, and I would encourage you to take these on board. Reviewer 2 also suggests that you could consider more the entire GSD, rather than just certain percentiles of it.

Given that a justification of this work is the application to sedimentary deposits, both reviewers observe that you could say more in the discussion about the processes that can affect the GSD of sedimentary deposits post-deposition, and more broadly consider the differences between this study of modern sediments and application to paleo deposits.

Reviewer 1 also suggests that the paper would benefit from some restructuring, and consideration of how the three different grain size analyses map onto the two identified hypotheses.

Best wishes, Rebecca Hodge

First of all, we want to thank the reviewers and the associated editor for their careful work on our manuscript and their constructive comments. Following their suggestions, we have improved the manuscript and the main improvements can be summarized as follow:

- The paper is now based on samples issued from the trench only
- We add quantile-quantile plots to show that all the samples follow a lognormal distribution and we compare in more detail the grain-size distributions. In addition, we use ANOVA tests to support the similarity of the grain-size distributions of the five layers on one hand, and of the six columns on the other hand.
- The application of our study to ancient systems is discussed more thoroughly.
- We add three new figures, one table and the raw data as Supplementary Material
- The manuscript has been restructured to better separate the methodology, the results and the discussion.

We answer point-by-point to each comments of the reviewers and we provide a file highlighting the differences between the initial version of the manuscript and this revision.

ANONYMOUS REFEREE #1

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Guerit et al. present a field study from the Urumqi River, China in which they compare different methods of grain-size analysis including (i) horizontal surface counts over the whole river width, (ii) vertical surface counts on an outcropping trench wall and (iii) volumetric counts (sieving) of a 1 m deep trench excavated within the dry channel- bed. As they found no differences in sub-sample grain-size distributions in vertical nor horizontal direction within the trench, they propose that the grain-size distribution is uniform within the active layer, which might be a typical phenomenon for non-armoured gravel-bed, braided rivers. Second, they found no difference between the volumetric grain-size analysis and the vertical surface counts within the same trench. They conclude that the surface point count method, which was originally developed by Wolman for horizontal surface granulometry analyses in active rivers, can also be applied to vertical outcrops.

Temporal variations in grain-size distribution are used to reconstruct paleo environmental conditions including climate and tectonics. As such, it is important to investigate the differences between methods that are commonly applied to characterize grain-size distributions. As this study performs a very systematic comparison of three of those methods in a natural, gravel-bed, braided river, and we generally lack those systematic method validations, the study is a valuable contribution to the community. The three presented methods to measure grain-size distributions in the field are commonly applied in other studies. The methods are well explained and carefully performed in the field. The paper is clearly written and I recommend to publish the manuscript in ESurf. However, I have some comments regarding the statistical analyses, the presentation of the data, the structure of the manuscript and the extend of the discussion.

The aim of the manuscript is to compare grain-size distributions. As such, statistical tests to investigate if distributions are different from each other or indistinguishable, are mandatory. One example is on page 5 line 28, where the authors state that the grain-size distribution in the surface layer is indistinguishable from the layers below. This statement needs to be supported with a statistical test.

In the revised manuscript, we describe in more details the distributions to better support their similarities. In particular, we now present quantile-quantile plots for all the samples, showing that after being normalized by the ϕ-scale ($\log_2$ based), they all follow a normal distribution (insets in Figure 5). The means and the standard deviations of the normalized samples are presented in Figure S1 ans Table S1. The individual volumetric samples are unfortunately badly designed for statistical analysis as they correspond to a weight for a given diameter, and not to a distribution of individual measurements. Accordingly, for these samples, we propose a visual analysis of the curves together with the comparison of the characteristic diameters (D50 and D90) to discuss the differences and similarities of these samples. However, as our normalized samples follow a normal distribution, ANOVA tests are well designed to determine of the median diameters of the grain-size distributions of the five layers, or of the six columns, are similar or not. The two ANOVA tests added the revised version confirm the uniformity in grain-size at the scale of the active layer (Table 3). This approach is fully described in the Methodology section (p. 5, l. 8-22).

Another example is on page 7 line 1, where the authors report that above a threshold of 10000 kg the D50 and D90 are equivalent to the whole trench. I think that the identification of such a threshold should be based on statistical analyses. Calculating a moving mean and the according standard deviations and test when means become indistinguishable is one option.

As discussed above, the individual volumetric samples are not well-designed for statistical analysis and we choose to adapt the bootstrap method to evaluate the variation of the characteristic diameters (the D50 and the D90) with the sample weight (Figure 7). To built this figure, we randomly merge without replacement 1 to 30 of the volumetric samples and we determine the D50 and the D90 of 600 composite distributions. Then, we visually determine the weight of the distributions showing a D50 and a D90 similar to the bulk distribution issued from the trench, within the same confidence interval (i.e. +/- 5%). A statistical analysis is not required for such analysis. Accordingly, we only slightly modify the method and the figure, and explain it in more details in the revised manuscript (p. 7, l. 21-32).

In addition, the measured grain-size distributions are only presented as cumulative density functions (CDF) in fig. 6. When plotted as CDF, differences in distributions are hard to detect by eye. For better comparison of the distributions, the probability density functions (PDF) and quantile or percentile plots should be added.

Grain-size studies are generally based on some characteristic diameters that correspond to a given quantile of the grain-size distribution (i.e. the D50 is the 50th quantile of the distribution). CDF plots allow a direct read of the diameter associated to any quantile of the distribution and we therefore favor these plots instead of PDFs. Nevertheless, following the suggestion of Reviewer 2, we now present Figure 5 in logarithmic scale for the diameters, and the differences between the curves are now easier to read. In addition, we include quantile-quantile plots for the individual and bulk volumetric samples and for the vertical surface sample to illustrate that all the ϕ-normalized samples follow a normal distribution (insets Figure 5), and the mean and the standard deviation of the normalized distributions are presented on Figure S1 and Table S1. We also describe in a more systematic manner the differences and the similarities between the curves in the Results section.

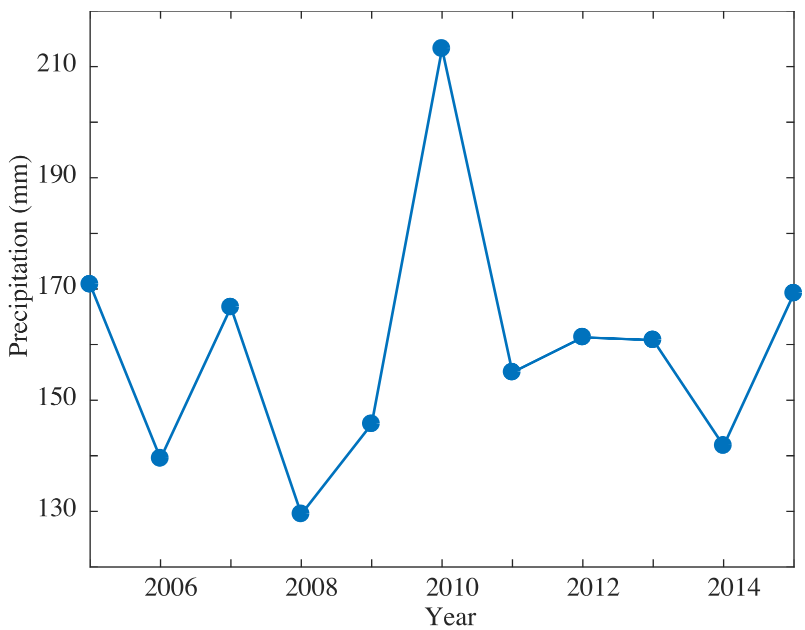
I think the structure of the manuscript is lacking a clear separation between the Methods, Results and Discussion sections. The Method section should be a clear description of the applied techniques, but should not contain any references to measured data. The Results section should be a neutral description of the data without any interpretation of it. I advise the authors to carefully check the manuscript and clearly separate method description, results description and interpretation. Below, I have listed a few points where the mixing was obvious to me:

- **p. 3 lines 11-15: To me, these sentences belong to the Results, Discussion and Conclusion section.**
- **p. 4 lines 4 – 16: This paragraph mixes the methodological descriptions and results. The description and reference to Fig. 5 is part of the results section.**
- **p. 5 line 10: Same here, the reference to Fig. 5b belongs to the Results.**
- **p. 6 line 6-8: This is more than just the description of the result, and should be moved to the discussion.**
- **p. 6 lines 16-21: From my perspective, this entire paragraph belongs to the discussion section.**
- **p. 7 lines 2-3: The last sentence of this paragraph is discussion and not a description of the results.**
- **p. 7 lines: 8 – 11: These sentences belong to the discussion.**

We reconsider the global organization of the manuscript to better separate the method from the results, and the results from the discussion. In particular, sentences related to Figure 5 have been moved to the Results section and the paragraph about armouring to the Discussion (p. 8, l. 1-7). However, we believe that the results of our analysis should be written explicitly. Therefore, we did not remove the last sentences of the Results subsections.

The authors clearly state in the Introduction that they test two hypotheses, namely the investigation of granulometric uniformity within the active layer and the application of surface point counts developed for horizontal layers on vertical layers. And both of these hypotheses are discussed later. However, the authors perform three different grain-size analyses. Currently, to verify or falsify their hypotheses, they only discuss two of them in detail, which are the volumetric analysis and the surface analysis on a vertical section in the trench. I think the paper would benefit from expanding the discussion about the reach-scale surface counts. As the authors state in their manuscript, vertical surface analyses are applied in paleo-studies. But these measurements are often compared to modern channel measurements, in which case a vertical surface count is compared to a horizontal surface count. In their study, the authors show that horizontal reach-scale surface count results in a coarser distribution than the vertical surface count from within the trench (Fig. 6d). Why is that? And what implication does this observation have for field studies that compare vertical with horizontal (or paleo and modern) grain-size distributions? I think it would be a missed opportunity to not extend the discussion (and maybe add a third hypothesis accordingly). However, if the authors decide to not include it, the third method (horizontal clast counts) can be removed from the paper.

The equivalence between the horizontal surface count and the volumetric methods has been studied by previous workers and the two approaches lead to similar and directly comparable grain-size distributions (as mentioned in the Introduction (p. 3, l. 3-4), Church et al, 1987; Bunte and Abt, 2001). Therefore, in the revised version, we focus on the equivalency between the vertical count and the volumetric method only. This is also motivated by an issue with the data acquisition: the granulometric study of the trench was performed in 2008 whereas the surface sample was acquired during another field campaign, in 2010. Unfortunately, these two years appear to be the driest (2008) and the wettest (2010) years of the decade. We therefore suspect that the difference between the distributions arises from this change in water flux. However, we don't have data to support (or to reject) this idea and thus, following the suggestion of the reviewer, we decide to remove the horizontal surface count from the revised version as it is not required for the main purpose of our work.



Average precipitation in Xinjiang between 2005 and 2015 (data from Yao et al, 2018)

An important point of the paper is that the investigated gravel-bed river has no armour layer and thus, any conclusion drawn from the findings are restricted to non-armoured channels. This restriction is mentioned in some parts of the paper, but not consistently throughout. From my point of view, this restriction needs to be mentioned in the abstract and potentially even in the title of the manuscript. Further clarifications of this restriction needs to be added to the sentence page 6 lines 9 – 11 and in the Conclusion (page 8 lines 27 - 31), which are currently phrased too generalized.

We now explicitly write that the methods are equivalent on the Urumqi River bed (p. 7, l. 6) and mention in the discussion section that it might be the case for any non-armoured rivers(p. 8, l. 13) . We also add «in non-armoured, gravel-bed rivers» in the Conclusions (p. 9, l. 11).

The abstract is currently fairly short. As an abstract serves as a stand-alone summary of a paper, the abstract could be extended by clearly listing the two hypotheses, the results and the according conclusions.

In the revised abstract, we now present the two ideas tested in this work and write explicitly that vertical counts can be used to accurately sample grain-size distributions of paleo-braided rivers (p. 1, l.3-4 and 10-13).

An important difference between this method-testing study and an applied study is that the analyses in this study are performed on a modern and active channel-bed. In paleo-studies, the vertical grain size measurements are applied to deposits that are thousands, sometimes millions of years old. I think it would be useful to mention within section 5.2 (page 8 lines 1 - 19), that the grain-size distributions in sedimentary deposits can also be altered after their deposition/ abandonment. Desert pavements, for example, can form in arid or semi-arid environments. Aeolian processes form a coarse gravel layer of interlocked clasts at the surface, underlain by a layer of very fine material [e.g. McFadden et al., 1998]. Processes like this should be taken into account when applying the vertical sampling strategy to paleo-deposits. Other examples of post-depositional alterations include soil-production or bioturbation.

McFadden, L. D., E. V McDonald, S. G. Wells, K. Anderson, J. Quade, and S. L. For- man (1998), The vesicular layer and carbonate collars of desert soils and pavements: formation, age and relation to climate change, Geomorphology, 24, 101–145.

We ass a paragraph dedicated to the evolution of gravel sediments after deposition in the revised version. We now discuss that deposits can be affected by several processes such as wind deposits, soil development, or chemical alteration and we propose some methodological considerations to face these secondary processes (p. 8, l. 21-30).

As this study compares different approaches and analyses, and aims to improve the reliability of characterizing grain-size distributions in the field, it would benefit from including the raw data of the field measurements as a supplementary file. That allows the re-analysis of the data for future studies.

The dataset is now available as a Supplement.

The following points are minor comments only:

p. 2 line 8: ". . .at a reach scale. . ." I think this sentence needs some further explanation, maybe include rough dimensions or explain the term 'reach'.

We clarify the term reach by the addition of «(i.e. at the scale of the whole river bed, from several dozens to several hundreds of meters)» (p. 2, l. 12-13).

p. 2 line 20: Please clarify in the second part of the sentence that the thickness of the active layer corresponds to the maximum elevation difference within a cross section and not in the downstream direction.

corrected (p. 2, l. 24-25).

p. 3 line 6: D'Arcy et al. did not sample a vertical section, but the grain size distribution on the surface of an alluvial fan. Same accounts for p. 8 line 7.

This reference has been removed.

p. 4 lines 26-27: List all sieve sizes used for the analysis, not only the minimum and maximum, since the size step can potentially affect the resolution of the datasets.

We now write «We sieve the sediments using mesh sizes ranging from 63 μm up to 25.6 cm256 mm. Each mesh size is twice the previous one and we add three sieves (24, 48 and 96 mm) to obtain a more detail description in the gravel range.» (p. 4, l. 16-18).

p. 5 line 27: Remove the extra comma and space after 0.2 m.

corrected (p. 6, l. 10).

p. 6 line 9: Maybe clarify in the title that you compare the volumetric analysis to the horizontal surface counting and not the vertical surface counting.

This subsection has been removed from the revised version.

p. 7 line 6: The vertical counts are not only shown in fig. 6d, but in all four graphs of fig. 6.

corrected (p. 7, l. 3-4).

p. 8 line 22: For clarification the authors could add 'horizontal and vertical' surface counts and volumetric samplings.

The horizontal surface sample has been removed from the revised version.

p. 8 lines 20: As it is written now, the following paragraph is more a summary than a conclusion, so I suggest to adjust the title of this paragraph.

This final paragraph proposes a summary of our work together with the conclusions drawn from our results. We therefore believe that the title (which corresponds to the journal's format) is appropriate.

Fig. 4. It would help the reader to add length information to the pictures a, c and d.

This figure has been modified and picture a has been removed. For pictures c and d (b and c in the revised version), the perspective of the pictures prevents to propose a relevant scale so we now indicate the dimensions of the trench in the caption.

Fig 5. Although stated in the figure caption, the figure does not really show uncertainties, but rather variability. How is the inherent variability defined? It would help to explain this at

least in the figure caption. The combination of red and green colors (fig. 5b) is invisible for everybody suffering from red-green blindness.

Indeed, this figure did not show uncertainties, but a range of variability around a mean value derived from a bootstrap analysis. This variability corresponds to the confidence interval (previously named the inherent variability) of the analyzed parameters (namely, the D50 and D90) for a given sample size. We modify the figure, the caption and the related text to explicite this approach (p. 5, l. 6-7 and p. 7, l. 21-25). The color issue was corrected.

Fig. 7 (caption). 'dashed' line instead of 'dotted'. .

corrected.

ANONYMOUS REFEREE #2

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This paper presents a field study in which the authors sample the surface and sub- surface sediment in an active braided gravel-bed river in a variety of ways, and com- pare the resulting grain size distributions. The overall intent of the work is to assess whether grain-size distributions collected from vertical exposures are representative of the overall grain-size distribution of the river bed, as this has important implications when interpreting data from outcrops in paleohydrology studies.

Overall this is a clear paper that presents useful data that should be of interest to the readers of Earth Surface Dynamics. There are, however, a few areas in which the manuscript may be improved.

Much of the analysis relies on comparison of grain size distributions – either individual volumetric samples compared against each other, horizontally or vertically aggregated volumetric samples compared with each other, volumetric samples compared to Wolman-style point counts, surface transects compared to trench samples, and so on. . . – but the presentation limits the comparison to the D50 and D90, with some estimate of the uncertainty in each parameter, and visual comparison of cumulative grain- size distributions. Some sort of more rigorous statistical testing would greatly improve the main thrust of the paper. Some possible options could be the Mann-Whitney test to compare medians, or the Kolmogorov-Smirnov test to compare entire distributions.

The volumetric samples are unfortunately badly designed for statistical analysis as they correspond to a weight for a given diameter, and not to a distribution of individual measurements. Accordingly, for these samples, a visual analysis of the curves together with the comparison of the characteristic diameters (such as the D50 and D90) appear as the best approach to discuss the differences and similarities of these samples. To support the visual comparison of the curves, we add QQ plots to the revised version showing that after being normalized by the ϕ-scale ($\log_2$ based), all the samples follow a lognormal distribution (insets Figure 5). However, it is possible to use a statistical approach to compare the grain-size distributions of the five layers, or of the six columns, as the layers or columns form different groups described by several samples. As our normalized samples follow a normal distribution, we can use parametric tests and ANOVA tests appear as the best approach to determine whether the median diameters of the grain-size distributions of the five layers, or of the six columns, are similar or not. The two ANOVA tests added the revised version confirm the uniformity in grain-size at the scale of the active layer (Table 3). This approach is fully described in the Methodology section (p. 5, l. 8-22).

Along these same lines, the grain size distributions are shown in Figure 6 with an arithmetic horizontal (grain size) axis. In some circumstances this may be okay, but in general with a wide range of grain sizes, as is the case here, it is preferable to use a logarithmic horizontal axis as it does not overly compress the finer range of grain sizes. Replotting the distributions with a logarithmic axis will also probably better represent how the D50 differs from one distribution to the next.

We agree that differences between distributions are easier to read from logarithmic plots and we modified Figure 5 accordingly.

In addition to the D50 and D90, it would be instructive to see how the variability (perhaps quantified by the geometric standard deviation) of the grain size distributions varies as a function of the individual volumetric samples, and as samples are aggregated. I suspect the standard deviation of the individual samples is smaller than the aggregated samples, supporting the idea that individual morphologic features within the active layer are better sorted patches of sediment than the distribution of the active layer as a whole.

As discussed above, the volumetric samples are not designed for statistical analysis and accordingly, on Figure 7, we propose a visual estimation of the variation of two characteristic diameters (the D50 and the D90) with the sample weight. This figure is built by artificially and randomly merging without replacement the 30 volumetric samples issued from the trench, and we observe that light samples show a greater variability around the mean values than larger samples. This illustrates that the variability in grain-size distributions observed at small scale (i.e. at the size of our volumetric samples) is a local feature that vanishes at the scale of the whole river bed. This point is discussed more carefully in the revised manuscript (p. 7, l. 21-32).

The results from the transects (the surface samples) are not really presented in the Results section of the paper. Currently they are mentioned only in passing in Section 4.3 and shown in Figure 6d. It would help to provide more information on these samples in the Results, and perhaps to add a table or amend a current table to include the relevant grain size statistics from this dataset. Looking at Figures 5 and 6, it is not clear to me that the D50 of the surface transects and the D50 of the trench sediment are the same.

As discussed in the answer to the first reviewer, the horizontal surface sample has been removed from the revised version and we now focus on the similarity between the samples issued from the trench only, i.e. the volumetric samples and the vertical surface count.

The Discussion section 5.2 on vertical sampling could be expanded to provide some more context to relate the present work to the stratigraphic record. An important out- come of the sampling strategy employed in the present study is that only the active layer (defined as ~10*D90 thick) was sampled, and the authors conclude that if the sample size is large enough the grain size distribution does not vary in space throughout the active layer. In the rock record, deposits from different time periods are likely to have different active layer thicknesses, and these may be further changed after emplacement by erosion events, which may reduce the thickness of or even completely destroy an active layer. Some further discussion about how the findings in this paper may apply to paleo studies would be welcome.

This section has been extended in the revised version. In particular, we now explicitly write that the absolute thickness of the active layer may vary in time and that deposits can be eroded (p. 8, l. 32-35).

Some other comments, by line number:

P. 4, line 27, and elsewhere: the word "weight" appears in several places in the manuscript, when it should be a different form of the word (i.e., here, it should be "We then weigh the grains. . ." .

This has been corrected throughout the manuscript.

P. 7, line 3: "excesses" should be "exceeds". Also, what is the "typical size of the morpho-sedimentary elements of the bed"? Those data were not presented, and no mention of how to estimate them is given.

These sentences have been changed in the revised version but the spatial scale of the morpho-sedimentary elements is now explicitly mentioned (p. 7, l. 19)

Figure 3: This figure could use a legend. And the vertical axis has no units? My interpretation of the plot is that the vertical axis is the deviation from the mean bed elevation at each cross section, which should still have units of (probably) meters.

We add units to the vertical axis (indeed, it is in meter) and add to the caption «Elevation is given as the deviation from the mean bed elevation at each cross section.»

Figure 5: How is "inherent variability" determined here? Fit by eye, or some statistical method?

Following this comment and the one from Reviewer 1, we modify the figure, the caption and the text to better explain the boostrap approach used here. The confidence interval (previously named inherent variability) is defined as the variability around the mean values, for a given sample size (p. 5, l. 6-7 and p. 7, l. 21-25).

Figure 8: Caption should say "Photographs", not "Photographies" .

corrected (this figure has been moved to Supplementary material)

References

Yao, J., Zhao, Y., & Yu, X. (2018). Spatial-temporal variation and impacts of drought in Xinjiang (Northwest China) during 1961–2015. PeerJ, 6, e4926.

Uniform grain-size distribution in the active layer of a shallow, gravel-bed, braided river (the Urumqi River, China) and implications for paleo-hydrology

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Abstract. The grain-size distribution of ancient alluvial systems is commonly determined from surface samples of vertically exposed sections of gravel deposits. This method relies on the hypothesis that the grain-size distribution obtained from a vertical cross-section is equivalent to that of the river bed. ~~We~~ Such hypothesis implies first, that the sediments are uniform in size in the river bed, and second, that the sampling method implemented on a vertical section leads to a grain-size distribution equivalent to the bulk one. Here, we report a field test of this hypothesis on granulometric samples collected on an active, gravel-bed, braided stream: the Urumqi River in China. We compare data from volumetric samples of a trench excavated in an active thread and from surface counts performed on the trench vertical faces. ~~We~~ Based on this data set, we show that the grain-size distributions obtained from all the samples are similar and that the deposit is uniform at the scale of the river active layer, a layer extending from the surface to a depth of approximately ten times the size of the largest clasts. As a consequence, the grid-by-number method implemented vertically leads to a grain-size distribution equivalent to the one obtained by a bulk volumetric sampling. This study thus brings support to the hypothesis that vertical surface counts provide an accurate characterization of the grain-size distribution of paleo-braided rivers.

1 Introduction

The size of the river-bed ~~sediments~~ sediment and its spatial distribution result from transport and deposition mechanisms in alluvial systems. These mechanisms have been intensively studied to model fluvial behavior and landscape evolution (Wilcock and McArdell, 1993; Paola and Seal, 1995; Vericat et al., 2008; Piedra et al., 2012; Sun et al., 2015), and the temporal variations in grain-size distributions can be used to reconstruct paleo-environments or changes in tectonic and climatic conditions (Duller et al., 2010; Whittaker et al., 2011; Michael et al., 2014; Schlunegger and Norton, 2015; D'Arcy and Whittaker, 2016; Chen et al., Acc.). For this, the granulometry in ancient systems is often characterized on the basis of a single grain-size distribution sampled along vertical conglomeratic outcrops with a limited extension (Duller et al., 2010; Whittaker et al., 2011; Chen et al., Acc.). This simplification can be relevant to derive quantitative information about a stream from its deposits, but it is based on two assumptions. First, the sampled deposits must be equivalent to the ones that were in direct contact with the flow, and thus actively involved in the transport and deposition processes. Second, the grain-size distribution obtained from vertical outcrops must be equivalent to the reach-scale distribution (i.e. to the granulometry of the whole river bed).

In alluvial gravel systems, sediments can experience strong spatial variations in size. Downstream fining, which results from abrasion and preferential deposition of coarse particles, dominates the large-scale evolution of granulometry along a river path (Parker, 1991; Paola and Seal, 1995; Singer, 2008; Rice and Church, 2010). This preferential deposition of the coarse grains, together with the removal of fine grains by winnowing during low flows, can be responsible for the formation of a coarse layer, or armour, at the surface of the bed (Parker and Klingeman, 1982; Church et al., 1987; Wilcock and McArdell, 1993; Mao et al., 2011). This layer generally forms at reach scale (i.e. at the scale of the whole river bed, from several dozens to several hundreds of meters), although it is not always observed (Laronne et al., 1994; Laronne and Shlomi, 2007; Storz-Peretz and Laronne, 2013b, 2018). In addition, local (from a meter to a few tens of meters) trends in grain size are observed at the scale of the morpho-sedimentary elements (e.g., the bars, anabranches, and chutes for the braided rivers) that built the river bed with coarser or finer grained patches (Fig. 1)(Bluck, 1971; Smith, 1974; Milne, 1982; Lisle and Madej, 1992; Ashworth et al., 1992; Laronne et al., 1994; Laronne and Shlomi, 2007; Guerit et al., 2014; Storz-Peretz et al., 2016). As a consequence, two different features of granulometric sorting can occur at a given location along a stream: ~~first,~~ (1) a vertical evolution at reach scale with a surface layer (the first centimeters of the bed deposits, often scaled with the larger grains) coarser than what is below (the subsurface layer), and ~~second,~~ (2) local lateral variations associated with the morpho-sedimentary elements.

However, recent experimental findings suggest that the granulometry of gravel-bed braided streams might be uniform above a given scale. Indeed, over a hydrological season, grains actively involved in transport and deposition are contained within the active layer of a river bed. Using a physical model of braided streams, Leduc et al. (2015) show that this layer extends laterally over the whole river bed and that its thickness corresponds to the maximum difference in bed elevation measured in cross-section on the surveyed reach. They also observe that the active layer scales with the largest clast of the bed ~~,~~ and extends over a thickness closed to 10 D_{90} (the 90^{th} percentile of the ~~grain size~~ grain-size distribution). Based on the spatial organization of deposits with different calibers, a few experimental studies show that the sediments are well-mixed in ~~this active layer~~the active layer, and thus suggest that the grain-size distribution of gravel-bed braided rivers is uniform at the scale of the active layer (Gardner and Ashmore, 2011; Leduc et al., 2015; Gardner et al., 2018) . However, such an analysis has not yet been performed on natural rivers. The first aim of this study is therefore to investigate the granulometric uniformity of ~~the~~ this active layer of a gravel-bed braided river, which is a prerequisite for a relevant paleo-grain size sampling.

Two methods are commonly used to characterize the granulometry of gravel deposits (grains larger than 4 mm, Wentworth, 1922): the surface count (grid-by-number) and the volumetric (sieve-by-weight) methods. The first one consists in measuring the intermediate axis (b-axis) of the grains lying on the top of a river bed and located at the nodes of a predefined grid. It is classically used to determine the surface granulometry of present-day stream beds (Wolman, 1954; Church et al., 1987; Bunte and

Abt, 2001). The second one consists in sieving a volume of sediments excavated from a river bed. It is generally used to sample the subsurface or bulk granulometry. The grain-size distribution obtained by this method is generally considered as representative of the whole river bed (Church et al., 1987; Bunte and Abt, 2001). The two methods lead to grain-size distributions that can be directly compared (Kellerhalls and Bray, 1971; Church et al., 1987; Bunte and Abt, 2001). In ancient alluvial systems, sediments are often cemented and it is not always possible to remove grains from outcrops. Photographic approaches, that do not require grain extraction, can be implemented for such outcrops but these methods suffer from the 2D exposure of 3D grains, which biases the measurement of their diameter (Kellerhalls and Bray, 1971; Church et al., 1987; Diplas and Fripp, 1992; Bunte and Abt, 2001; Storz-Peretz and Laronne, 2013a; Buscombe, 2013). Consequently, ~~Wolman's~~ the surface count methodology adapted on vertical sections is preferably used (Duller et al., 2010; Whittaker et al., 2011; Michael et al., 2014; Chen et al., Acc.). However, this method has been developed to characterize the surface granulometry of active rivers where grains can be easily picked up and measured at the surface of the bed. To date, its validity on vertical sections has not been demonstrated. This is the second aim of this study.

~~In this article~~Accordingly, we present a granulometric study on the Urumqi River, an active braided river in China. First, we describe the methodology implemented to sample the grain-size distributions by ~~horizontal or~~ volumetric sieving and vertical surface counts~~and volumetric sieving~~. Then, based on a large data set, we show that despite local heterogeneities probably associated with the morpho-sedimentary elements of the river bed, the grain-size distribution of the sediments is uniform at the scale of the active layer. In addition, we observe that the distribution obtained by vertical surface counts is similar to the bulk granulometry of the river bed. This study thus shows that quantitative information about the granulometry of paleo-rivers can be accurately derived from surface counts along vertical conglomeratic outcrops.

2 Sampling site

The Urumqi River is a shallow (<1 m-deep), gravel-bed, braided river draining the northern side of the Tian Shan Range in China (Figs. 1 and 2a-b). ~~The~~ This river initiates at the front of a glacier in the high range at 3600 m and runs northwards to the Junggar Basin where it dies out into the desert at an elevation of 1100 m. The sediments sampled in this study are located about 10 km downstream of the mountain topographic front. There, the Urumqi River braids within an alluvial valley cut into the deposits of a Pleistocene alluvial fan (Zhou et al., 2002; Guerit et al., 2016) (Fig. 2a-b). At this location, the catchment area of the river is close to 1000 km^2, its average slope is 0.02, and its runoff is mainly due to summer rains and snow or ice melt. As a consequence, the river mostly flows from May to September with a mean annual discharge of about 7.5 m^3 s^{-1} (Zhou et al., 1999) (Fig. 2b-c) and a total sediment load of 1-2 10^8 kg yr^{-1} (Liu et al., 2008, 2011). The river is almost dry outside of the high flow season and we can thus measure the granulometry of its bed (Fig. 1). The sediments found at the surface of the river bed are mostly gravels (Guerit et al., 2014).

To estimate the thickness of the active layer of the Urumqi River, we acquired 5 transverse topographic profiles across the river bed with a Timble S6 DR300+ total station with a point every meter on average~~(Fig. 3).~~. Differences in elevation between the highs and the lows of the river bed are in the order of 1 meter (Fig. 3). We thus estimate the active layer of the Urumqi River to be ∼1 meter. This morphological estimate is in good agreement with the one based on the D_{90} of the grain-size distribution at the same location. Indeed, the D_{90} is ∼ 10 cm at the sampling site (Guerit et al., 2014) and according to this value, the active layer should also extend from the surface down to 1 meter (i.e. 10 D_{90}) (Leduc et al., 2015).

3 Methodology

We combine two methods to characterize the grain-size distribution of the Urumqi River ~~: the surface count and the volumetric methods.~~

~~To characterize the surface granulometry of the river bed at reach scale, we perform an horizontal surface count over the whole river width (Fig. 4a). The grid is positioned perpendicular to the main water flow direction, with nodes every 10 m. We choose the spacing of~~ at the ~~grid larger than the size of the granulometric patchiness related to the river morpho-sedimentary elements (Guerit et al., 2014). We extract the grains located directly under each node and measure their *b*-axis. However, grains smaller than 4 mm (36% of the total sample) are not considered in the analysis in order to reduce the measurement uncertainties (Kellerhalls and Bray, 1971; Church et al., 1987; Bunte and Abt, 2001). The resulting sample is composed of 351 grains with $D \geq$ 4 mm. The uncertainties associated with the grain-size distribution obtained by this methodology are mainly due to the limited number of measurements. It is generally considered that 100 grains must be measured in order to accurately characterize the D_{50} of a distribution with a surface count , while 400 grains are required for the coarse quantile D_{90} (Wolman, 1954; Church et al., 1987; Rice and Church, 1996). In this study, we evaluate the uncertainties on these characteristic diameters by a bootstrapping method (Bunte and Abt, 2001). We estimate the quantiles of 10530 distributions built by randomly sampling with replacement 1 to 351 grains from our surface sample. We find the D_{50} and D_{90} to be defined within a range of ±15% (Fig. 6a).~~ scale of its active layer: the volumetric and the surface count methods.

To characterize the surface-layer and subsurface granulometries of the river bed, we dig into its deposits a 7.2×1.2×1 m trench perpendicular to the flow direction of one thread (Fig. 4b-c). The sediments are excavated step by step from this trench as individual volumetric samples. We set the thickness of these samples to 2 D_{90} to insure that the largest grains are contained within one sample, and we determine the volume to be large enough to accurately characterize the grain-size distribution. Indeed, the accuracy of the volumetric method depends upon the sample weight with respect to the weight of its largest clast (Church et al., 1987; Haschenburger et al., 2007). Ideally, the largest grain of a volumetric sample should not contribute to more than 0.1% of the total weight ~~. In this case, the grain-size fractions are determined with a 0.1% precision. However, this~~ but this criterion is difficult to achieve on the field and ~~in~~ a relaxed criteria of 5% is acceptable when the large particules are > 128 mm, as for the Urumqi River. In this study, ~~the fractions are defined~~ each grain-size fraction is thus determined within ± 5%. The corresponding individual volumetric samples are 1.2×1.2×0.2 m, resulting in 30 samples labelled from 1 to 5 with respect to their depth, and from A to F with respect to their lateral position (Fig. 4c). We sieve the sediments using mesh sizes ranging from ~~25.6 cm down to~~ 63 μm ~~. We then weight~~ up to 256 mm. Each mesh size is twice the previous one and we add three sieves (24, 48 and 96 mm) to obtain a more detail description in the gravel range. We then weigh the grains retained in each mesh to obtain a mass for a given diameter~~, which~~ . The diameter of the grains retained in each sieve corresponds to the geometric mean of the sieve size and the following larger sieve, and it is considered to be the b-axis of the clasts (Church et al., 1987; Bunte and Abt, 2001; Guerit et al., 2014). To be consistent with the surface counts, for which only the grains larger than 4 mm are considered, we remove all the grains smaller than 4 mm (24% of the volumetric samples on average) from the analysis. These individual volumetric samples ~~are~~ can be combined in different ways. (i) They ~~are~~ can be used individually to characterize the grain-size distribution at local scale. (ii) They ~~are~~ can be merged according to their depth (layers 1 to 5) or to their lateral position (columns A to F) to document potential granulometric variability associated with the location of a sample within the river bed. (iii) These individual volumetric samples ~~are also~~ can also be merged altogether to characterize the bulk granulometry of the Urumqi river bed at the scale of the active layer. (iv) Finally, they ~~are~~ can be merged randomly and analyzed to document the granulometric evolution with respect to the weight of a sample.

In order to test whether the bulk granulometry of the river bed can be characterized from the sampling of a cross-section, we ~~eventually~~ determine the grain-size distribution of the sediments outcropping on the walls of the trench by a vertical surface count. We implement the ~~Wolman~~ surface count methodology on the vertical sections of the river deposits (Fig. 4d), using a square grid of 20 cm ($\sim 2\ D_{90}$ in order to avoid sampling twice the same grain). We extract ~~and measure the b-axis of the grains~~ the grains located directly under each node ~~. As for the horizontal surface count, the smallest grains~~ and measure their b-axis (Wolman, 1954). However, grains smaller than 4 mm (19% of the total sample) are not considered ~~and the~~ in the analysis in order to reduce the measurement uncertainties (Kellerhalls and Bray, 1971; Church et al., 1987; Bunte and Abt, 2001). The resulting sample is thus composed of 298 grains with $D > 4$mm. ~~To evaluate the uncertainties~~ We evaluate the confidence interval by a bootstrap method (Rice and Church, 1996; Bunte and Abt, 2001) for two characteristic diameters: the D_{50} (the diameter associated with the ~~main diameters, we estimate the quantiles of 8940~~ 50^{th} percentile of the distribution) and the D_{90}. We estimate the D_{50} and the D_{90} of 10000 distributions built by randomly sampling with replacement 1 to 298 grains from ~~our vertical count sample(Bunte and Abt, 2001). We find the~~ the vertical surface sample. For both diameters, the range of values decreases with increasing bootstrap resample size. Above a given bootstrap sample size, values stabilize around the D_{50} (or D_{90}) of the initial sample and the confidence intervals correspond to the observed scatter.

Grain-size distributions often follow a lognormal distribution. We thus normalize our samples using the ϕ-scale ($\log_2$ based) and fit the distributions by a normal law. The simplest way to assess the accuracy of this fit is to compare the quantiles of our normalized samples to the quantiles of a normal distribution with the same mean and standard deviation (Q-Q plots) to test whether or not our samples follow such a distribution. For the volumetric samples, in order to avoid interpolation between the measurements, the quantiles correspond to those defined by the points issued from the discrete CDF, whereas for the vertical surface sample, we compare the Q_{10} to Q_{90} quantiles. If the distributions are similar, points align on the x = y line. Regardless of the nature of the grain-size distributions, the individual volumetric samples are not designed for statistical analysis as the volumetric method only provides the frequency distribution of the grain sizes. Accordingly, the similarities and differences between the 30 volumetric samples are discussed based on the visual comparison of the distributions together with the comparison of the characteristic diameters, D_{50} and D_{90}~~to be defined within a range of $\pm 15\%$ and ± 20~~. However, ANOVA tests can be performed to compare the median values of the normalized distributions of the five layers (1 to 5) and of the six columns (A to F) issued from the trench. ANOVA tests determine whether at least two groups of samples come from the same population, based on the analysis of their variance. The ratio F of the variability within and between the different groups is calculated and compared to theoretical F-values. The tests are based on the null hypothesis that all the samples come from the same population of grains. This hypothesis is rejected if F is higher than the acceptable values F_{95} and F_{99} at a level of significance of 95% and 99%, respectively~~(Fig. 6b).~~ .

4 Results

4.1 Granulometry of the river bed at different spatial scales

4.1.1 ~~Grain-size~~ Local variability in grain-size distribution~~of volumetric samples~~

First, we analyze the grain-size distributions of the individual volumes excavated from the trench (Fig. 5a, Table 1). These 30 volumetric samples have an average weight of 440 kg and they are composed by more than 85% of pebbles (i.e. grains with $D \in$ 4-64 mm). ~~Their median diameter D_{50} ranges between 17±1 mm and 32±2 mm, while their D_{90} is comprised between 52±3 and 126±6 mm. Although the 30 distributions are similar in shape,~~ The Q-Q plots indicate that all the normalized samples follow a normal distribution, although we observe some ~~scatter between them (~~deviation for the coarser quantiles (inset Fig. 5a~~, Table 1). In particular, the D_{50} and the D_{90}~~). In addition, the means and the standard deviations of the fitted curves are very similar (Fig. S1, Table S1). Accordingly, all the distributions show a similar shape and as they describe a similar range of values, the 30 curves plot close to each other (Fig. 5a). However, we observe some scatter between them and for any quantile, diameters can vary within a range of ±~~25% and~~ 25-30% around the mean value. For example, the D_{50} vary between 17±~~30% around the means of the samples (~~1 mm and 32±2 mm for an average value of 23 ~~and~~ mm, while their D_{90} are comprised between 52±3 and 126±6 mm for an average of 73 mm ~~, respectively~~(Table 1).

4.1.2 Vertical sorting

Second, we merge the individual volumetric samples according to their depth (layers 1 to 5) and analyze the ~~grain size~~ grain-size sorting with respect to depth (Fig. 5b, Table 2). On average, the different layers ~~weight~~ weigh 2600 kg and they are composed by 93% of pebbles. ~~Their~~ The five distributions are similar in shape and for any quantile, diameters vary within a limited range of ±10% around the mean value (Fig. 5b). This is illustrated by the limited variability of the characteristic diameters: their D_{50} ~~ranges~~ range between 21±1 and 25±1 mm, while their D_{90} ~~is~~ are comprised between 65±1 and 76±2 mm~~. Accordingly, the granulometries of these five layers show a limited scattering, with the D_{50} and D_{90} varying within a range of ±9% around the means of the samples (~~, for mean values of 23 and 70 mm, respectively (Table 2). The grain-size distributions of these larger samples is thus less scattered than the individual ones. In addition, ~~the ratio between the D_{50}~~ we observe that the grain-size distribution of the surface layer (between 0 and 0.2 m, i.e. layer 1~~between 0 and~~) is similar to the grain-size distribution of the subsurface layer (between 0.2 ~~m,) and the sub-surface ones (~~and 1 m, i.e. merged layers 2 to 5~~between 0.2 and 1 m)~~) (Fig. S2), and in particular, that the ratio between the D_{50} of the two layers is of 1.07. ~~The surface layer of the deposits is thus indistinguishable from the subsurface. Therefore,~~ Moreover, the ANOVA tests confirm that the five layers are statistically indistinguishable (Table 4). Our data set thus indicates that at the scale of the active layer, there is no vertical sorting in the Urumqi river bed.

4.1.3 Horizontal sorting

Third, we ~~analyze the grain-size distributions of the individual volumes merged~~ merge the individual volumes according to their lateral position (columns A to F) and analyze the horizontal grain-size sorting (Fig. 5c, Table 3). On average, the different columns ~~weight~~ weigh 2200 kg and they are composed by 92% of pebbles. ~~Their~~ Here again, we observe that the samples exhibit a similar grain-size distribution and for all the quantiles, the scatter between these 6 samples is quite limited (Fig. 5c). For example, the D_{50} ~~ranges~~ range between 21±1 and 26±1 mm, while their D_{90} ~~varies~~ vary between 64±1 and 76±2 mm ~~. Here again, the granulometric distributions exhibit limited scattering as the D_{50} and D_{90} vary within~~ (Table 3). This corresponds to a range of ±13% and ±10% around the means of the samples (23 and 71 mm, respectively). Here again, the ANOVA tests confirm that the six columns are indistinguishable in terms of grain size (Table 4). Thus, at the scale of the active layer, the Urumqi river bed has no horizontal ~~grain-size sortingeither~~granulometric sorting. In consequence, grain-size distributions issued from vertical pits are equivalent to distributions issued from horizontal layers.

4.1.4 ~~Volumetric versus surface grain-size distributions~~

4.2 Granulometry of the river bed according to sampling methods

Finally, we merge all the volumetric samples together to determine the bulk granulometry of the river bed ~~.~~ (Fig. 5d, Table 5). Based on 13150 kg of sediments, this ~~bulk~~ large volumetric distribution is composed of 92% of pebbles~~. It has~~ , and the Q-Q plot indicates that the normalized sample also follows a normal distribution (inset Fig. 5d). It is characterized by a D_{50} of 23±1 mm and a D_{90} of 73±1 (Fig. 5d, Table 5). ~~This is in agreement with the reach-scale grain-size distribution characterized by surface counts . Indeed, based on 351 grains ($D \geq 4$ mm), the surface distribution is made up of 78% of pebbles. Its median diameter D_{50} is 30±5 mm, while the D_{90} is 100±15 mm~~

We compare this distribution to the one obtained by vertical counts along the walls of the trench (Fig. 5d~~, Table 5). The surface granulometry is thus slightly coarser than the bulk one, but no major shift, depletion or enrichment in the fine or coarse fractions is observed between the two distributions.~~

4.2.1 ~~Armouring versus uniformity~~

~~The uniformity in the grain-size distributions of the various samples we analyzed (individual volumes, layer and column samples), and their similarity with the bulk one, suggest that the Urumqi river bed is not armoured at reach scale. In addition, the absence of vertical or lateral sorting in grain size within the active layer implies that at any depth or location of this layer, the deposits are representative of the sediments transported as bedload in direct contact with the flow. Our results therefore accord with the experimental findings of Gardner and Ashmore (2011), Leduc et al. (2015) and Gardner et al. (2018).~~

4.3 ~~Granulometric uniformity of the active layer~~

~~Although the grain-size distributions of the different samples resemble the bulk one, we observe some scatter that seems to be dependent on the sample size. Indeed, the grain-size distributions of the 30 individual volumetric samples are more scattered than the distributions of the layer and column samples. To assess the minimum weight required for the grain-size distributions to converge toward a sample equivalent to the bulk one, we randomly merge with replacement the individual samples to determine the~~). Based on 298 grains ($D \geq 4$ mm), this sample is made up of 85% of pebbles. From the bootstrap approach, we find the D_{50} and D_{90} ~~as a function of the sample weight (Fig. 7). By authorizing replacement, we maximize the variability of the virtual samples. We observe that variability around the mean decreases with increasing weight, and at first order, sample weight must be multiplied by a factor 2 to decrease the variability by 5%. Accordingly, the bulk grain-size distribution can be determined~~ to be respectively defined within a range of ±~~10% from a sample composed of 4000 kgs of sediments (∼2 m^3) larger than 4 mm (Fig. 7), but we observe that > 10000 kg of sediments are required to compose a sample equivalent to the whole trench one. In fact, above this weight, both the D_{50} and the D_{90} are equivalent to the ones of the whole trench (23±1~~ 15% and ~~73~~±~~4 mm, respectively). At the scale of the active layer, the grain-size distribution of the Urumqi River deposits can thus be considered as uniform, providing that the sample size excesses the typical size of the morpho-sedimentary elements of the river bed.~~

4.3 ~~Equivalence of sampling methods~~

~~Finally, we analyze the grain-size distribution obtained by vertical counts along the surface of the walls of the trench~~ (20% (Fig. 6b), and here again, the Q-Q plot indicates that the normalized sample follows a normal distribution (inset Fig. 5d~~, Table 5). Based on 298 grains ($D \geq 4$ mm), this sample is made up of 85% of pebbles. Its~~). The median diameter D_{50} of this vertical surface count is 20±4 mm, while its D_{90} is 82±16 mm ~~. This~~ (Table 5). Accordingly, the shape of the vertical surface grain-size distribution compares well with the ~~reach-scale surface count and the~~ bulk volumetric distribution of the trench, but also with the 30 individual volumetric samples as well as with the 5 layers and the 6 columns (Fig. 5~~d).~~). Except for the smallest grain sizes, the diameters associated to each quantile are very similar (Fig. 5). A Q-Q plot also confirms that the distribution obtained by the vertical surface count is similar to the bulk volumetric one (Fig. S3). This comparison indicates that the characterization in cross-section of the Urumqi active layer is equivalent to the more traditional ~~horizontal surface count and volumetric methods. The similarity between the distributions documented by these different sampling methods~~ volumetric method, and thus shows for the first time that surface counts implemented on vertical outcrops can be used as proxies for a bulk volumetric sampling.

5 Discussion

5.1 Grain-size ~~sorting~~uniformity in an active, gravel-bed, braided river

At local scale (< meter to 10s of meters), features of grain-size sorting are commonly observed and documented on the bed of braided gravel-bed streams (Leopold et al., 1964; Bluck, 1971, 1976; Smith, 1974; Ashworth, 1996; Ashmore, 2013; Guerit et al., 2014). In these rivers, this surface sorting is associated with the morpho-sedimentary elements (bars, anabranches and chutes) that shape the river bed. In the Urumqi River, we also observe local variations in grain sizes ~~are also visible~~ in the vertical section of the active layer with small areas enriched in fine or ~~in~~ coarse grains (Fig. ~~??) . This~~ S4) and this variability could be the expression in cross-section of the small-scale sorting associated with the morpho-sedimentary elements observed on the bed (Guerit et al., 2014). ~~This~~ We propose that this sorting may be responsible for the scatter observed between the granulometric distributions of the 30 individual volumetric samples (Fig. 5a)~~that scale~~ , as they scale in size with the morpho-sedimentary elements ~~. This~~ corresponding to meters-large and centimeters-to-decimeters-deep grain-size patches. This suggestion is supported by the ~~decreasing scatter between the grain-size distributions with increasing~~ fact that scatter around the mean values seems to be dependent on the sample size (~~Figs. 5and 7). In particular, at the sampling site, a grain-size uniformity is observed above a given amount of sediments. Based on the virtual distribution built by random merging~~ Fig. 5).

To assess the minimum weight required for a sample to go over the local variability and to be equivalent to the bulk one, we randomly merge without replacement the individual volumetric samples to obtain 600 composite volumetric samples of 241 to 13150 kg. We then determine the D_{50} and D_{90} as a function of the sample ~~, 4000 kgs (corresponding to ~~~weight (Fig. 7). Variability around the mean decreases with increasing weight and at first order, the sample weight must increase by a factor 2 ~~m^3) seems to be required~~ for the variability around the mean value to decrease by 5% (Fig. 7). We observe that ~5000 kg of sediments larger than 4 mm (about 11 individual volumetric samples) are required to estimate a D_{50} and a D_{90} within a range of ±10% around the mean values (Fig. 7)~~, but the granulometric similarity between the layers, or between the columns, suggests that uniformity may arise for a smaller amount of sediments (Fig. 5b and c).~~ . To reach a level of accuracy equivalent to the bulk sample (±5%), we observe that 9000 kg (about 20 individual volumetric samples) are necessary (Fig. 7). This analysis confirms that small-scale grain-size sorting exists in the active layer of the Urumqi River, but this sorting becomes negligible as the sample size increases. The active layer of the Urumqi River thus appears as the superposition of small-scale structures (the morpho-sedimentary elements), whose variability vanishes above a given scale. Accordingly, at the scale of the active layer, the ~~deposits~~ grain-size distribution of the Urumqi River ~~are uniformin space in terms of~~ deposits can be considered as uniform.

The uniformity in the grain-size ~~distribution. In particular, no trend of lateral or vertical sorting is observed within~~ distributions of the various samples we analyze (individual volumes, layer and column samples), and their similarity with the bulk one, indicates that the Urumqi river bed is not armoured at reach scale. In consequence, at any depth or location of the active layer of the ~~river bed(Fig. 5) in agreement with previous experimental works~~ bed, the deposits are representative of the sediments transported as bedload in direct contact with the flow, providing that the sample is large enough to integrate at least a dozen of morpho-sedimentary elements. Our results therefore accord with the experimental findings of Gardner and Ashmore (2011), Leduc et al. (2015) and Gardner et al. (2018). The agreement between field and physical experiments ~~lead~~ leads us to propose that the absence of vertical and lateral sorting may be typical of non-armoured, gravel-bed, braided rivers.

5.2 ~~Vertical~~ Grain-size sampling in ancient systems

~~Finally, the granulometric uniformity at the scale of the active layer implies that the grain-size distribution of paleo-rivers can be adequately determined from conglomeratic outcrops. In fact, the calibers of the river deposits are similar to the ones of the grains directly in contact with the flow.~~

We show that the broadly used Wolman grid-by-number method can be implemented on vertical sections to characterize grain-size distributions with a good level of confidence. In addition, the granulometric uniformity at the scale of the Urumqi active layer implies that the grain-size distribution of paleo-rivers can be adequately determined from conglomeratic outcrops. Our study thus legitimates this ~~acquisition, for braided rivers at least~~kind of sampling (Duller et al., 2010; Whittaker et al., 2011) (Michael et al., 2014; Chen et al., Acc.), at least for unarmoured braided rivers, for stratigraphical or paleo-hydrological reconstructions ~~. However, two~~ However, three limitations must be considered to generalize our results to any field work in ancient systems. First, this study is based on ~~the~~ grains removed from ~~the~~ trench walls so that it is possible to measure their actual b-axis. In ancient systems, deposits are often cemented and it is not always possible to remove grains from ~~the outcrop~~outcrops. In that case, outcropping diameters should be identified before implementing measurements. Indeed, in a section perpendicular to the main flow, the b- (intermediate) and c- (small) axis are expected to be visible. In such situation, the b-axis will appear to be the longest one. On the contrary, in a section parallel to the main flow, the a- (long) and b- (intermediate) axis are expected to be visible, and the b-axis will then appear to be the shortest one (e.g., Bunte and Abt, 2001). Indications of paleo-flows can ~~help to recognize~~ thus help to identify the actual b-axis. ~~The second~~

Second, the grain-size distribution of the deposits can be altered after deposition or after surface abandonment by several factors. Aeolian processes can either bring fine material that can infiltrate the gravels and decrease the global granulometry of the deposits, or lead to the formation of desert pavements (McFadden et al., 1987, 1998). Soils development on the top of a surface can also induce the formation of secondary particules that will contaminate the initial gravel deposits (e.g., Pimentel, 2002). However, the gravel fraction should not be affected by such secondary processes that generally affect the fine-grain content, and truncation of the grain-size distribution below a given diameter (4 mm here) should insure the removal of these secondary signals. Moreover, as these processes might mostly affect the upper part of gravel deposits (Wooster et al., 2008; Cui et al., 2008), samples should be acquired as much as possible where evidences for such modifications are not observed. With time, chemical alteration can also modify the size of the initial gravels, but this process might be difficult to quantify. Accordingly, we suggest that outcrops showing evidences of gravel alteration should not be sampled.

Finally, the third limitation is related to the limited thickness of the active layer, which extends in depth over several D_{90} only ~~(Laronne et al., 1994; Gardner and Ashmore, 2011; Leduc et al., 2015). In addition, in stratigraphic successions, deposits are stacked vertically through time~~ for an active system (Laronne et al., 1994; Gardner and Ashmore, 2011; Leduc et al., 2015). Moreover, the thickness of this layer is not fixed though time as it could evolve with potential changes of the river characteristics~~and preservation rate during the sedimentation. Consequently,~~. The sediments deposited during an hydrological season can also be remobilized afterwards if the river incises, leading to a partial or total destruction of the former active layer(s). In stratigraphic successions, deposits are stacked vertically through time and consequently, to compensate for ~~the~~ this limited extension in depth of the active layer and for ~~the potential sedimentation~~ its potential preservation changes through time, the grids used for vertical surface counts should extend laterally rather than vertically to stay as much as possible within the same sedimentary layer.

6 Conclusions

We perform a granulometric study on the deposits of the Urumqi River, an active, gravel-bed, braided stream in China. Based on a large data set collected by ~~surface counts and volumetric~~ volumetric and vertical surface count samplings, we show that the grain-size distribution of the river bed is uniform at the scale of its active layer. Despite some local variabilities related to small-scale grain-size features, there is no vertical or lateral granulometric trend within this layer. Because our findings confirm earlier physical models (Gardner and Ashmore, 2011; Leduc et al., 2015; Gardner et al., 2018), we propose that, beyond the Urumqi River, this uniformity be the case for all the non-armoured, gravel-bed, braided streams.

This uniformity implies that it is possible to determine the grain-size distribution of gravel-bed braided alluvial systems from vertical outcrops. We show that the grid-by-number method, initially developed and tested on the horizontal surface of river beds, can be implemented on vertical outcrops to obtain samples equivalent to a volumetric investigation in non-armoured, gravel-bed rivers. This study thus ~~brings support to~~ supports the hypothesis that vertical surface counts can be implemented on conglomeratic outcrops to provide an accurate characterization of the grain-size distribution of paleo-braided rivers.

Competing interests. The authors declare no competing interests.

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Figure 1. Example of a shallow gravel-bed braided river bed during the dry season (Urumqi River, China). Spatial variations in grain size can be observed at the surface of the river bed with finer- and coarser-grained areas.

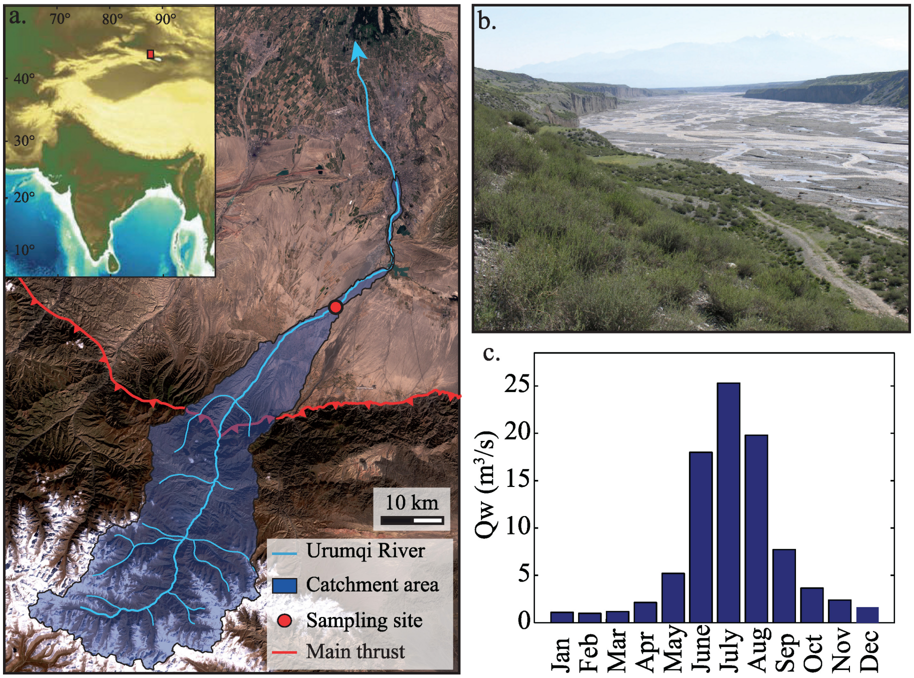

Figure 2. a) Location, drainage network and catchment area of the Urumqi River system, b) picture of the river at the sampling site during the high flow season, and c) annual hydrograph of the river (after Zhou et al., 1999).

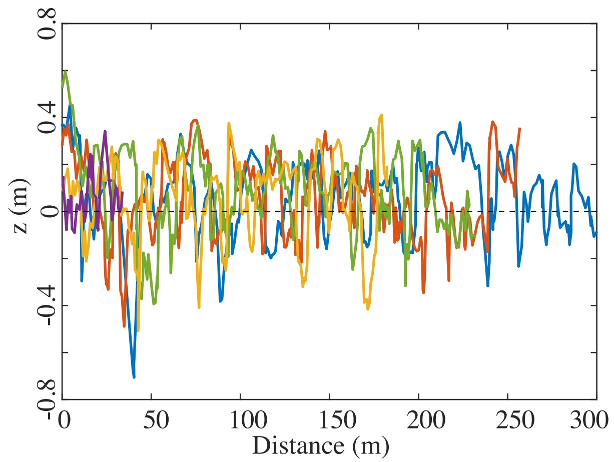

Figure 3. Transverse topographic profiles acquired along the Urumqi River bed. Elevation is given as the deviation from the mean bed elevation at each cross section.

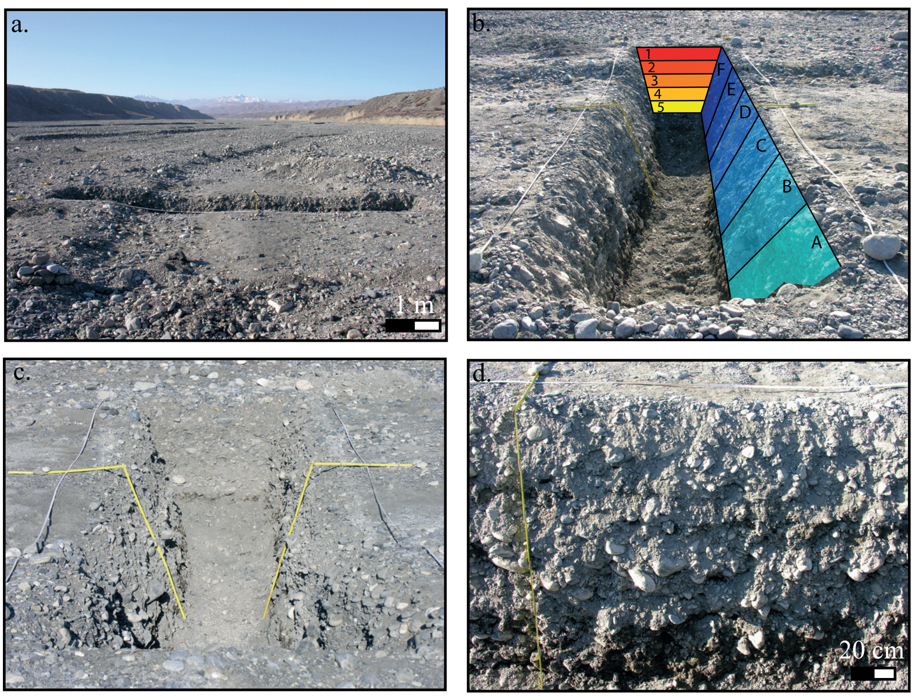

Figure 4. View a) ~~Implementation of the horizontal surface counts at reach scale with a node every 10 m. View b)~~ from the north and ~~c~~b) from the west of the 7.2-m long and 1.2-m large trench. On this second view, the sampling nomenclature is indicated. Layers are ~~labelled from 1 to 5 and~~ colored from red to yellow and labelled from 1 to 5, whereas columns are ~~labelled from A to F and~~ colored from light to dark blue and labelled from A to F. c) and d) Implementation of the vertical surface counts along the trench walls with a node every 20 cm.

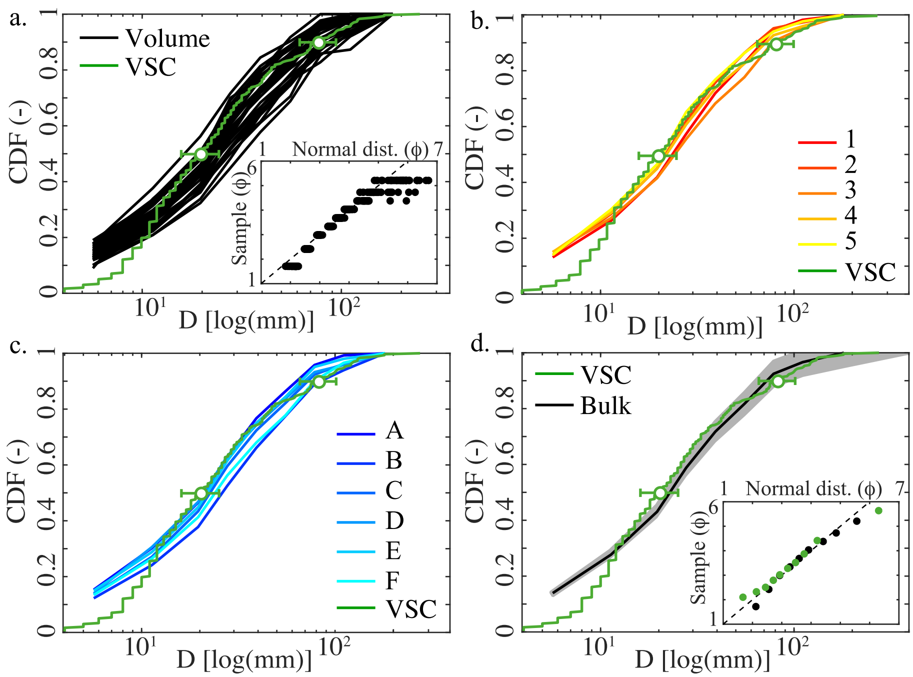

Figure 5. Grain-size distributions of a) the 30 individual volumetric samples excavated from the trench (1.2×1.2×0.2 m, black lines) with corresponding Q-Q plots in inset (ϕ-scale), b) the five 20 cm-thick layers of the trench from the surface to 1 m-deep (red to yellow), and c) the six 1.2 m-wide columns of the trench from the west to the east (dark to light blue). On each figure, the ~~granulometry~~ grain-size distribution sampled by vertical surface counts on the trench wall is indicated (VSC, green~~line~~), together with its D_{50} and D_{90} and their associated uncertainties (green dots). d) Grain-size distributions of the ~~three~~ two bulk samples obtained by ~~horizontal~~ vertical surface counts ~~at~~ on the ~~scale~~ walls of the ~~reach (gray),~~ trench and volumetric sieving of the trench (bulk, black) ~~, and vertical surface counts on~~ with corresponding Q-Q plots in inset (ϕ-scale). The gray shape corresponds to the ~~walls~~ uncertainties of the ~~trench (green)~~volumetric sample quantiles. These four ~~panels~~ graphs suggest that the sediments of the Urumqi River active layer follow a similar distribution and are thus uniform at the scale of ~~the~~ this active layer in terms of grain-size distribution.

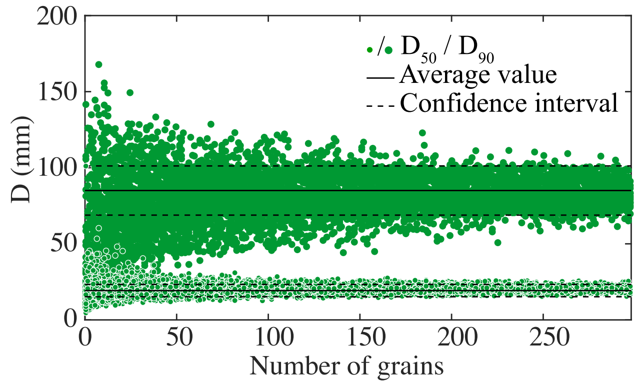

Figure 6. Estimation of the confidence interval by a bootstrap approach of the D_{50} and D_{90} of the surface counts performed along the walls of the trench (see text for details on the method). Diameters are defined within a range of $\pm$15-20%.

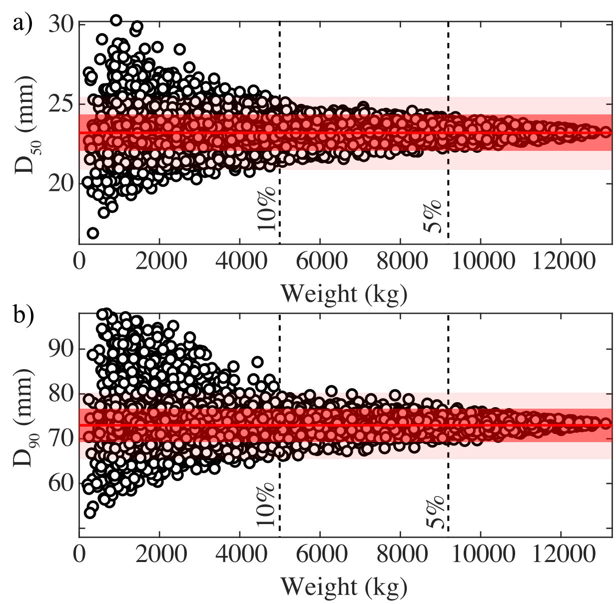

Figure 7. Evolution of a) the D_{50} and b) the D_{90} with respect to the sample weight. ~~The~~ These diameters are issued from grain-size distributions ~~corresponding to the quantiles shown on this graph are~~ built by random merging without replacement of the individual volumetric samples. Red ~~lines are~~ line is for the mean value, ~~dotted lines indicate~~ the dark red area for the mean$\pm$5%, the light red area for the mean$\pm$10%.

Table 1. Main characteristics of the local-scale samples excavated from the trench. P and C are the proportions of pebbles and cobbles within the sediments defined after Wentworth (1922). D_{50} is the mean diameter and D_{90} the 90^{th} quantile of the grain-size distributions. Confidence intervals are calculated from the Church et al. (1987)'s criteria.

Sample	Size	P (%)	C (%)	D_{50} (mm)	D_{90} (mm)	Sample	Size	P (%)	C (%)	D_{50} (mm)	D_{90} (mm)
A1	649 kg	96	4	23 ± 1	66 ± 3	D1	372 kg	97	3	17 ± 1	52 ± 3
A2	300 kg	100	0	21 ± 1	56 ± 3	D2	309 kg	92	8	22 ± 1	74 ± 4
A3	506 kg	96	4	20 ± 1	62 ± 3	D3	273 kg	95	5	23 ± 1	70 ± 4
A4	475 kg	93	7	20 ± 1	70 ± 4	D4	314 kg	86	14	26 ± 1	126 ± 6
A5	338 kg	89	11	22 ± 1	66 ± 3	D5	241 kg	97	3	20 ± 1	60 ± 3
B1	607 kg	85	15	32 ± 2	97 ± 5	E1	618 kg	97	3	25 ± 1	65 ± 3
B2	615 kg	95	5	24 ± 1	65 ± 3	E2	465 kg	97	3	21 ± 1	60 ± 3
B3	599 kg	88	12	29 ± 1	94 ± 5	E3	504 kg	88	12	25 ± 1	78 ± 4
B4	510 kg	88	12	22 ± 1	74 ± 4	E4	441 kg	97	3	21 ± 1	64 ± 3
B5	343 kg	83	17	27 ± 1	104 ± 5	E5	484 kg	96	4	20 ± 1	60 ± 3
C1	363 kg	97	3	20 ± 1	61 ± 3	F1	537 kg	88	12	24 ± 1	88 ± 4
C2	368 kg	88	12	24 ± 1	78 ± 4	F2	554 kg	91	9	27 ± 1	77 ± 4
C3	271 kg	90	10	27 ± 1	77 ± 4	F3	399 kg	91	9	23 ± 1	70 ± 4
C4	386 kg	90	10	25 ± 1	76 ± 4	F4	525 kg	87	13	25 ± 1	89 ± 4
C5	271 kg	98	2	20 ± 1	60 ± 3	F5	509 kg	91	9	23 ± 1	73 ± 4

Table 2. Main characteristics of the five layers issued from the trench. P and C are the proportions of pebbles and cobbles within the sediments defined after Wentworth (1922). D_{50} is the mean diameter and D_{90} the 90^{th} quantile of the grain-size distributions. Confidence intervals are calculated from the Church et al. (1987)'s criteria.

Sample	Size	P (%)	C (%)	D_{50} (mm)	D_{90} (mm)
Layer 1	3226 kg	95	5	24 ± 1	$69 \pm \cancel{1}\ 3$
Layer 2	2523 kg	95	5	22 ± 1	$65 \pm \cancel{1}\ 3$
Layer 3	2657 kg	91	9	25 ± 1	$76 \pm \cancel{2}\ 4$
Layer 4	2566 kg	92	8	22 ± 1	$72 \pm \cancel{1}\ 4$
Layer 5	2161 kg	93	7	21 ± 1	$66 \pm \cancel{1}\ 3$
Average	2626 kg	93	7	23 ± 1	$70 \pm \cancel{1}4$

Table 3. Main characteristics of the six columns issued from the trench. P and C are the proportions of pebbles and cobbles within the sediments defined after Wentworth (1922). D_{50} is the mean diameter and D_{90} the 90^{th} quantile of the grain-size distributions. Confidence intervals are calculated from the Church et al. (1987)'s criteria.

Sample	Size	P (%)	C (%)	D_{50} (mm)	D_{90} (mm)
Column A	2268 kg	95	5	21 ± 1	64 ± ~~1~~ 3
Column B	2674 kg	88	12	26 ± 1	77 ± ~~2~~ 4
Column C	1659 kg	92	8	23 ± 1	73 ± ~~1~~ 4
Column D	1509 kg	93	7	21 ± 1	71 ± ~~1~~ 4
Column E	2512 kg	95	5	22 ± 1	67 ± ~~1~~ 3
Column F	2524 kg	90	10	24 ± 1	76 ± ~~2~~ 4
Average	2191 kg	92	8	23 ± 1	71 ± ~~1~~ 4

Table 4. ANOVA tests on the grain-size distributions of the five layers and the six columns from the trench. df is the number of degrees of freedom, SS the sum of square, and MS the mean square. The null hypothesis is that there is no difference in the mean values of the grain-size distributions, and P is the probability to get the obtained F value from samples extracted from a single population. The five layers, as well as the six columns, are indistinguishable ($F < F_{95}$)

Group	Variation source	df	SS	MS
	Inter	4	0.03	0.01
	Intra	25	0.50	0.02
Layers 1 – 5	Total	29	0.53	0.02
	F	F_{95}	F_{99}	P
	0.42	2.76	4.18	0.80
	Inter	5	0.18	0.04
	Intra	24	0.35	0.01
Columns A – F	Total	29	0.53	0.02
	F	F_{95}	F_{99}	P
	2.39	2.62	3.90	0.07

Table 5. Main characteristics of the large-scale samples. P and C are the proportions of pebbles and cobbles within the sediments defined after Wentworth (1922). D_{50} is the mean diameter and D_{90} the 90^{th} quantile of the grain-size distributions. Confidence intervals are calculated by bootstrapping for the surface counts and from the Church et al. (1987)'s criteria for the volumetric sample.

Sample	Size	P (%)	C (%)	D_{50} (mm)	D_{90} (mm)
~~Horizontal surface count 351 grains 78 22 30 ± 5 100 ± 15~~ Total volume	13150 kg	92	8	23 ± 1	73 ± 4
Vertical surface count	298 grains	85	15	20 ± 4	82 ± 16