Dear Dr Sofia,

Herewith we enclose our response to the referees' comments made on our manuscript titled "A photogrammetry-based approach for soil bulk density measurements with an emphasis on applications to cosmogenic nuclide analysis".

We would like to thank the referees for their valuable comments made on our manuscript. Our responses are given below – first, the replies to the comments of *Anonymous Referee #1*, followed by the replies to the comments of *Dr Ángel Rodés*. During the course of this evaluation process, we noted that the simple error propagation that was applied to the calculations made in this study is not regularly used in scientific publications. Thus, we re-calculated all error propagation by adding the sums of the uncertainties in quadrature, which led to a reduction of most errors reported. As a result, parts of the text needed to be slightly modified; these modifications are listed below the replies to the comments of Dr Ángel Rodés. We did not include corrections on spelling errors in our reply.

1 Reply to the review of *Anonymous Referee #1*

#1.1 Line 28: implications?

We added:

"*This implies that the method tested in this study may also being applied in other fields of research and work, such as soil science, agriculture, or in the construction sector*."

#1.2 Line 32: add references

We added two references: *Rodés and Evans (2020)* and *Rodés et al (2011)* exemplary show the importance of soil densities to determine process rates and surface ages, respectively.

#1.3 Line 39: add reference

We added two references.

#1.4 Line 65: are they invasive?

The cited references give an overview about how SfM-MVS is used in geosciences. This does not include the derivation of soil densities, since this is a relatively recent field of research. SfM-MVS is mainly used to reconstruct surfaces to generate 3D models of topographic features or landscapes, so they are non-invasive. To clarify this we changed the sentence to:

"*Both studies found good agreements between soil densities/excavation volumes derived from traditional methods and those obtained using photogrammetry (basic concepts of photogrammetry, structure-from-*

motion multi-view stereo (SfM-MVS) photogrammetry, and their general application in combination with non-invasive methods in geosciences are explained e.g. in Eltner et al., 2016; James and Robson, 2012; Westoby et al., 2012)."

#1.5 Line 84: it is not simple and you need a good equipment, at least, a strong pc

We acknowledge that the simplest method would be to upload pictures into a program, click a button and receive the pit volume or even the density immediately. Such a program has – to our knowledge – not been written yet. Further, we acknowledge that the workflows we tested here have been run in a Windows 10 environment, which might cause some problems for users of different OS. However, the Windows OS is the most regularly used in the world and the workflows we present here do not require any special knowledge of programming etc.; final soil densities can routinely be derived by just following a single, simple recipe. Given these arguments, we think that the application of the method tested here can be described as being simple.

In our study, we further successfully test the SfM-MVS reconstruction using an ordinary smartphone (five years old) and a computing machine that is more than six years old (sec. 2.4). However, using a lowest-grade laptop or a computer with insufficient working memory will likely result in strongly increased computing times or even computing failure. As a response to this comment, we tested the freeware/smartphone workflow for the test pit BD17-01 using a Toshiba Satellite C50-A-19T Laptop (1.90 GHz processor, 6 Gb RAM, Intel HD Graphics 630, more than six years old). By using exactly the same input parameters as in our study, the processing time increased significantly to about 4:30 h and the amount of keypoints generated was less, resulting in less dense point clouds and the abundance of holes in the mesh, which had to be interpolated automatically by Microsoft's 3D Builder. However, the bulk of time expenditure was spent on automated processing in Regard3D (4:10 h), while the manual processing took in total 22 min in CloudCompare, Netfabb and the 3D Builder. Most importantly, the volume derived was 7874 ± 281 cm^3, which represents a deviation of about +2% from the reference volume. All in all we think that it is reasonable to conclude that, considering presently available state-of-the-art computing hardware, the method can be used also with outdated computers.

We did not change the text here.

#1.6 Line 99: be more clear with the goals of this research

We changed the text to:

"*Finally, we applied the method during a TCN sampling campaign in the Coastal Cordillera of northern central Chile, where we investigate the impact of aspect-related differences in microclimate and vegetation on Earth-shaping processes and the formation of topography along narrow transects (cf. Bernhard et al.,* *2018; Gutiérrez-Jurado and Vivoni, 2013a, b; Oeser et al., 2018). Therefore, soil densities were derived, initially to scale soil production rates inferred from saprolite TCN concentrations (e.g. Heimsath and Burke, 2013) across contrasting slope aspects. However, due to the simple and time-efficient application of the method, we extended our dataset of regolith densities along the respective slopes in order to study aspect-related differences in this particular soil property*."

#1.7 Line 207: add version

We added the versions.

#1.8 Line 340: this is methods

We changed the text to:

"*The reference PU foam-based method (Section 2.2) yields consistent field-state bulk densities for BD17-P01 and -P06 (~2.12 g cm*$^{-3}$*)*."

#1.9 Line 538: add other research with similar findings

We added some references.

#1.10 Line 538: implications?

We added:

"*If no reliable estimation of* ρ_{BR} *can be made, a possible workaround could be to sample a certain amount of the > 2 mm fraction and measure its volume in the laboratory. Vincent and Chadwick (1994) have shown that a representative sample mass to reflect the particle size distribution of a gravelly soil is on the order of ~10 kg, which would then have to be sieved in the field to retain the > 2 mm fraction. However, this implies that at least one additional sieve and the aliquot material would have to be carried along (e.g. 3 kg of gravel from a soil containing 30% gravel by mass)*."

#1.11 Comment: I miss in the discussion some mentions to sensors, traditional methods, etc. to compare their results to other ones.

Apart from the fact that we compare our results to two traditional methods, we added the following paragraph to give an overview on the accuracy and precision of bulk density measurements for other methods (line 544 of the updated manuscript):

"*Finally, when compared to the broad range of established methods to determine soil bulk densities, the SfM-MVS photogrammetry-based method as tested in this study regularly yields results of comparable precision and accuracy. Values for measurement precision and/or accuracy as found in the literature are* *generally about 5% to < 15% of the mean bulk density for the clod, core and non-photogrammetry excavation methods in uniform substrates (Casanova et al., 2016; Coelho, 1974; Grossman and Reinsch, 2002 and ref. therein; Muller and Hamilton, 1992; Timm et al., 2005). This holds also for some indirect measurement techniques, such as the TDR method (Liu et al., 2008) and nuclear radiation methods (Timm et al., 2005). In contrast to that, soil bulk densities of gravelly soils derived from uncalibrated pedotransfer functions have been shown to be less accurate (Casanova et al., 2016).*"

2 Reply to the review of *Dr Ángel Rodés*

#2.1 Comment: YES, if using Microsoft Windows®, which is not freeware.

We added the fact that our workflows are indeed based on a commercial OS (lines 97 and 207 of the updated manuscript):

L 97:

"As our intention is to contribute a method that can be adopted by the TCN community, our workflow either included the combined use of commercial and non-commercial software, or was solely based on non-commercial software (under the premise that Microsoft's Windows 10 is used as operating system)."

L 207:

"As such, we aimed at deriving a workflow that relies entirely (except for the operating system) on freeware computer programs ("freeware workflow"; a detailed protocol on the computing steps is provided in the supplement) as well as one that might be a more convenient to apply, but which involves commercial software ("performance workflow"; Fig. 5)."

#2.2 Comment: Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? YES

We acknowledge that the study is very detailed and comprehensive, but we believe that all tests conducted and described and all statements made are necessary to provide a full understanding of how we obtained our data and what it may indicate.

Thus, we did not change the text here, unless the reviewer may specify which passages might need further clarification or reduction.

#2.3 Comment: Is the amount and quality of supplementary material appropriate? N/A (it seems that all figs. and tables will be included in the main file)

We uploaded a supplementary file to the Journal during submission of the manuscript; it might be not accessible to all reviewers for any reason (?). If possible, we will attach the file to this comment.

#2.4 Comment: Other commonly used field techniques for assessing the bulk soil density are usually not accurate enough to allow the determination of precise maximum ages from TCN profiles in unconsolidated materials (see some examples in Rodríguez-Rodríguez et al.,2020, appendix A, table I; doi:10.1016j.gloplacha.2020.103271).

We added the reference (line 531 of the updated manuscript):

"For this kind of analysis, the derivation of sediment densities can be complex (for examples see Brye et al., 2004; Rodríguez-Rodríguez et al., 2020), but the (time-integrated) sediment density accuracy and precision can largely affect the overall results (e.g. Braucher et al., 2009; Hidy et al., 2010; Rodés et al., 2011)."

Additional changes made to the text, tables and figures.

As mentioned in the introduction of this reply, we re-calculated all errors by adding their sums in quadrature, which is the regularly used method to propagate errors in scientific publications. This led to a reduction of most uncertainties reported. As a result, the uncertainties shown in Figures 6, 7, and 8 as well as stated in Tables 2, 3, 4, 5, 6, B2, S1 and S2 were modified. We also modified the values in the main text, if stated (not reported in this reply). It is important to note that the re-calculation of the uncertainties does not affect the conclusions drawn on the data, as they predominantly rely on the mean values. In Table B2, wrong values were reported for $m_{e,d}$ and $p_{B,d}$ of site BD17-P06 (typos), which we corrected.

In the following, the changes we made on the main text are listed (except for those passages where we simply adjusted the uncertainties of measurements):

L 254 (new version)/L 245 (old version): A paragraph was accidently not included into the submitted manuscript. We added it now:

"The experience obtained during the testing phase was important in applying SfM-MVS photogrammetry for expedient soil bulk density analysis along N-S oriented TCN sampling transects spanning the slopes of three E-W running valleys (C1, C2, C5; Fig. 9) in the Altos de Talinay. Geographically, the study area is part of the Coastal Cordillera of northern central Chile (30.5°S; 71.7°W). The main aim of the TCN sampling campaign […]."

L 361 / L 346: We added how measurement errors propagate:

"We subtracted this value from the PU foam cast-derived measurements of sites P11 and P12, yielding volumes of 93789 ± 326 cm^3 and 88959 ± 326 cm^3, respectively (error propagation in this study by adding uncertainties in quadrature)."

L 370 / L 356: Based on the reduction in reported uncertainties, we changed the text.

Old version:

"Consequently, calculated densities are very similar at each site (average difference is ~0.02 g cm^{-3}). DSLM/freeware and smartphone/freeware workflow-derived densities are slightly less consistent (average difference ~0.04 g cm^{-3}) but mostly reproduce the respective reference volumes within one standard deviation."

Modified version:

"Consequently, calculated densities are very similar at each site (average difference is ~0.02 g cm^{-3}); DSLM/freeware and smartphone/freeware workflow-derived densities are slightly less consistent (average difference ~0.04 g cm^{-3})."

L 387 / L 374: Based on the reduction in reported uncertainties, we changed the text.

Old version:

"However, values mostly overlap within their errors at sites BD17-P12 and -P13."

Modified version:

"However, the obtained mean values are very similar to those derived using SfM-MVS photogrammetry, and partially overlap within their error ranges at sites BD17-P12 and -P13."