Interactive comment on "Controls on the distribution of the soil organic matter in mountain permafrost regions on the north Qinghai-Tibet Plateau" by C. Mu et al.

Anonymous Referee #1

1. *Manuscript General comments*

This manuscript is about the controls of SOM distribution in a mountain permafrost region of the QZP. The authors over simplified the factors controlling the carbon stores/density and distribution of SOC in deep strata in a permafrost environment. The discussion and conclusion (as in lines 21-23 and lines 160-169). The conclusions may well apply to the active layer or 0-2 m as described in many other papers. The near surface SOM is biogenic, resulting from the biomass accumulation form the vegetation community. However, the SOC accumulated in the deep strata may, and often the result of the geomorphic processes such as erosion and sedimentation. Therefore, the SOC stores in deep layers may not be controlled by vegetation as what is currently on the surface. Since the parent materials of these soils or cores studied are of Quaternary age, the past climate, vegetation, and especially the mode of deposition are important to the SOC stores; as we consider the syngenetic nature of the soil development.

Response: Thanks for your comments. All the comments and reviews were explained as below:

(1) The effects on SOC in the active layer or upper 0-2m layer have been described in many other papers. We also hypothesized that the deep SOC may be affected by many other factors. However, these factors, such as erosion and sedimentation, were difficult to describe quantitatively and thus could not be performed a statistical analyses. In this study, we investigated the SOC in deep soils and found that the SOC was also "affected" by vegetation and

soil textures. However, as you pointed out, this opinion should not be the mechanisms of SOC accumulation. Instead, this could be a result that vegetation types and soil textures were also the result of pedogenesis and geomorphology. Thus, we added a schematic diagram and corresponding discussion to describe the relationship in the revised version (Figure 7).

Since the vegetation and soil texture data were easier available than sedimentation progress, and also could be upscaled to a regional scale, this study would be of interest to the future study in mountain permafrost regions. Therefore, in the revised version, we changed the "controls" into "close relationships" in the Conclusions and Title.

(2) To promote the conclusion in Lines 21-23:

The original version (Lines 14-17) was revised as: "To examine the pools and properties of deep SOC and their possible relationships to environmental factors, ten boreholes to the depth of about 20 m depth were drilled under alpine swamp meadow (ASM), alpine meadow (AM) and alpine steppe (AS) in the permafrost regions over Heihe River basin, Qilian Mountains."

We changed the original version (L17) "The results showed that…." was changed into "The results from these deep boreholes showed that……". We hope this revision would be helpful to potential readers for the contribution of this study.

The L21-22 was changed into "Meanwhile, the C/N ratios and carbon isotopes suggested that the SOC, which extent to tens of meters, accompanied with fine-fractions soils under swamp meadow are more decomposable than those of coarse soils at all depths. The results suggest that both the SOC stocks and chemical nature of organic matter in the upper and deep soils have close relationships with soil texture and vegetation types, which could be explained as a complex effect of geomorphology and pedogenesis."

(3) For L160-169, the original version was revised as:

“The SOC densities at AM sites (PT4, PT5, PT6, PT7) were higher than those at AS sites (PT10, PT11 and PT12), while lower than those at ASM sites (PT9, EB1, and EB2). For the upper ~3 m layers, it has been well known that vegetation types affect the SOC contents (Jobbágy and Jackson, 2000; Wu et al., 2012). This study confirmed that this pattern was not only limited to the upper layers (which were usually studied in previous reports) but also extended to deeper permafrost layers, which could reach to 5 meters (PT6, PT9, EB1, EB2) and even about 20 m depth (PT4, PT5, PT7). This study shows that the vegetation types have closely relationships with SOC distribution in deep layers in mountain permafrost areas on the north QTP.”

(4) For the schematic diagram and the relationship between geomorphology, paleoclimatic conditions and SOC, we added the figure 7 in the revised version.

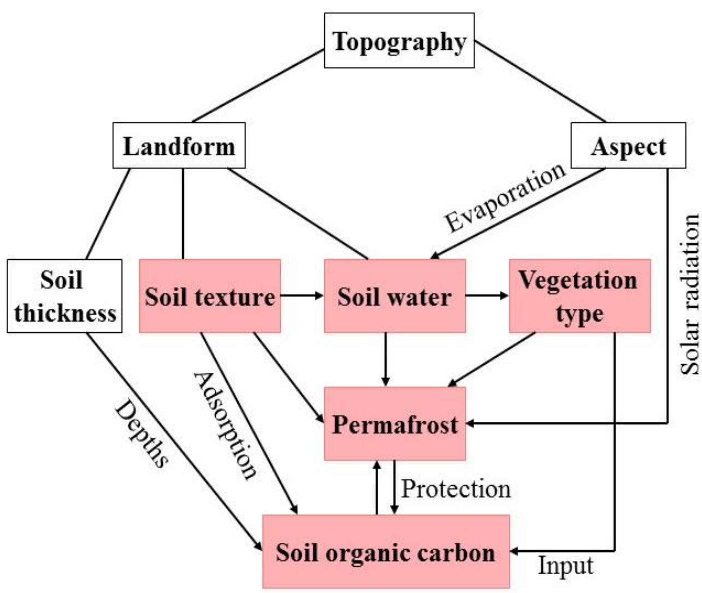

Figure 7 A schematic diagram for the relationship between environmental factors and soil organic carbon (SOC) in mountain permafrost area. The solid lines show the components of environmental conditions, arrows

show the direct effect of one factor on the other. There is also another possible effect of soil water content on the soil organic carbon via affecting the microbial growth and oxygen availability (Mu et al., 2016).

Meanwhile, the corresponding discussion was shown as follows:

"From the basic theory of SOC in permafrost carbon and results from this study, a conceptual framework was proposed as Figure 7. Topography has been long recognized as an important factor in the distribution of permafrost and soil water content (Noetzli et al., 2007), and consequently has important effects on the vegetation types (Wang et al., 2006). The landform determined sediment processes and even soil textures during pedogenesis (Yoo and Mudd, 2008). In this study, the PT9, EB1 and EB2 sites have north facing aspects with poor drainage conditions, and thus belong to swamp meadow types. The distribution of PT sites follows a pattern from mountain hills to mountain foot along with elevation gradients: (PT9, PT6) > PT7 > PT4 > PT5 > (PT10, PT11, PT12). It could be seen that drainage conditions, which usually were greatly affected by microrelief conditions (Schoeneberger, 2002), are extremely important to vegetation types (Tab 1). In QTP, previous studies showed that soil texture, vegetation, and soil water content are of great importance for the existence of permafrost (Wang et al., 2012; Wu et al., 2015). This framework was consistent with the basic theory of SOC accumulation and preservation (Genxu et al., 2012; Wu et al., 2015). It has been also known that the fine particles can protect the SOM from decomposition by the adsorption effects (Jardine et al., 1989), and soil water could be a controlling factor in microbial decomposition through limit the microbial growth and oxygen availability (Mu et al., 2016). In addition, soil water content interacts with texture and vegetation (Mohanty and Skaggs, 2001). This study showed close relationships between soil texture, water content, vegetation and SOC. Therefore, the effects of these factors on the SOC could be both direct and indirect, which via the permafrost (Fig. 7). From this schematic diagram, it is obvious that geomorphology is the fundamental factors in the determination of SOC by the mechanisms of pedogenesis."

"The QTP is a young plateau that was uplifted since Palaeogene epoch, and the parent materials for soils distributed in the vast areas on the plateau were mainly alluvium associated mountain processes (Zheng and Yao, 2004). Therefore, the sampling area could be potentially considered as an example for the study of SOC distribution in the other areas on the QTP. Since the sampling area for PT sites is less than 100 km^2, and has similar meteorological conditions, thus the great differences for SOC among these sites could be attributed to the difference of topography, which affects the SOC via the pedogenesis (Fig.7). For the deep SOC stocks, the paleoclimatic conditions may also play important roles during the SOC accumulation (Schuur et al., 2009). However, this data is largely unavailable, which limited the further study of deep SOC in mountain permafrost. This study showed that the SOC both in upper layers and deep layers, which could be down to tens of meters, has close relationship with vegetation and soil texture. Although the accumulation process of SOC is difficult to be interpreted in this study due to the lack of chronological sequences of the soil layers, the results demonstrated that vegetation types and soil textures are useful proxies for the predictions of SOC in both upper and deep layers. Since these data are more accessible in regional scale (Li et al., 2015; Wang et al., 2016), it would be possible to upscale the SOC pools in the regional scale using vegetation types and soil texture data in the future."

We hope these revisions are helpful to the potential readers to understand the importance of this work and can get a clear framework of the SOC in deep permafrost-affected soils.

2. The major problem for me to review this manuscript is the lack of original data. There is no tabulated data for each analyzed soil horizon or layer. Thus there is no way to tell if the values of pH, soil texture, conductivity, C-density, C/N ratio presented are from one particular section/horizon or the average of the whole sampling depth. The authors are responsible should provide the original data as supplement that should include all the analyses as indicated in the Method section, and present the analytical data of each sampled layers of sections.

Response: Sorry for the confusion. We are pleased provide the original data during the submission. We also submitted it as supplementary file. Unfortunately, it could not be found in the TCD. Therefore, in the revised version, we explained it clearly and gave the link of the data, thus potential authors can realize we also submit this regional data.

In the revised version, this had been explained as:

"All the original data were available on the website of The Cryosphere Discussions (http://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=25&_lcm=oc73lcm74a&_acm=get_supplement_file&_ms=50278&id=704538&salt=1523858444357408567)."

3. The soils are likely syngenetic if the particle size distribution is more relatively uniform, or fluvial/erosion or sedimentation modification if there are contrasting soil textures. The %SOC correlates well with %clay because of physical protection, a function of surface area. But the fine soil particles are not limited to clay. There are several papers dealing with SOC contents in both the clay and silt fractions. Will there be any difference if the %silt is considered in the correlation?

Response: Thanks for the review. From the parent materials, the soils are likely syngenetic. We also hoped that there would be a statistically significant correlation between the silt content and

SOC, but the silt was excluded from the stepwise linear regression, and the *Pearson* correlation was not significant. The non-significant relationship between the silt content and SOC could be due to the methods for size distribution, because the laser diffraction instrument only showed the proportions of silt, while without the detailed information about very fine silt, fine silt, medium silt and coarse silt. This was discussed in the revised version as below:

"In this study, the clay content was significantly correlated with the SOC content. This finding is in agreement with the reports for the upper 2 m layers (Wu et al., 2015) and can be explained by the presence of fine particles, which tend to stabilize and retain more organic matter than coarser particles (Gregorich et al., 1994). In addition, fine particles have a higher water holding capacity (Gómez-Plaza et al., 2001). The fine particles are not confined with clay, other proportions such as very fine silt, fine silt, may also relate to the SOC contents (Vogel et al., 2015). However, this study showed no significant relationship between SOC and silt content. The non-significant relationship between the silt content and SOC could also be due to the methods for size distribution, because the laser diffraction instrument only showed the proportions of silt, while without detailed information about very fine silt, fine silt, medium silt and coarse silt."

4. Soil drainage is mentioned in Table 1 but not discussed. The SOC content is controlled by vegetation community which is affected by drainage or soil water content due to soil texture and landform position. I recommend the manuscript be accepted upon major revision.

Response: Thanks for the suggestion. It is true that soil water content was affected by soil texture, landform position and aspect, meanwhile, soil water influences the distribution of vegetation community, which can determine SOC content. It is a closely and inseparable relationship.

In the revised version, this was discussed via the schematic as below:

"In this study, the PT9, EB1 and EB2 sites have north facing aspects with poor drainage conditions, and thus belong to swamp meadow types. The distribution of PT sites follows a pattern from mountain hills to mountain foot along with elevation gradients: (PT9, PT6) > PT7 > PT4 > PT5 > (PT10, PT11, PT12). It could be seen that drainage conditions, which usually were greatly affected by microrelief conditions (Schoeneberger, 2002), are extremely important to vegetation types (Tab 1)."

The soil water content was also discussed (Response to Question 1).

5. Specific comments

L. 18. "silt loam over ASM" change "over" to "in". L. 19-20. "higher fine-fractions" change to "higher finer textured fractions"; "coarse soils" change to "coarser-textured soils".

Response: Thanks. Changed.

6. L. 21. "more decomposable" or "more decomposed"?

Response: Thanks. It should be "more decomposed".

7. L. 29. Insert "more" after "become". Insert "due to climate warming" after "decomposition".

Response: Thanks. Changed.

8. L. 34. Delete "permafrost".

Response: Deleted.

9. L. 38. Citation "(Bockheim and Hinkel, 2007)" is not the proper reference. In their paper, the deepest soil horizon was sampled at 161 cm. This can hardly be called "deep carbon". For the vulnerability of deep carbon, refer to the papers by Schuur et al. and Zimov et al.

Response: Thanks very much. The references were changed.

10. L. 46-48. "consequently resulting in easily decomposable substances". It is because the original substrate was easily decomposable thus resulting in less negative delta ^{12}C values. So consequently resulting in highly decomposed substances as indicated by lower C/N values.

Response: Thanks. It was changed as below:

"^{12}C is preferentially used by decomposers, which may lead to ^{13}C enrichment in the remaining SOC (Natelhoffer and Fry, 1988), because the original substrate was easily decomposable thus resulting in less negative delta $\delta^{12}C$ values, consequently resulting in highly decomposed substances as indicated by lower C/N values. Therefore, the C/N ratios and $\delta^{13}C$ values of organic matter can be used to reveal the potential for microbial decomposition of organic matter in permafrost regions."

11. L. 60. "soil texture also relates to vegetation types". Soil texture is one of the several factors affecting vegetation types.

Response: Thanks. Changed into "Moreover, soil texture is one of the several factors affecting vegetation types, soil moisture and even the thickness of the active layer of permafrost"

12. L.64. Insert "carbon" between "the" and "contents".

Response: Thanks, inserted. The first hypothesis was changed into "(1) the distribution of SOC in the soils, including surface and deep layers, has close relationships to vegetation types and soil texture on the QTP; (2) there are significant differences in the characteristics of SOC under different vegetation types and different soil texture classes."

13. L. 70. Change "area" to "region".Last word "westerlies"?

Response: Thanks. Changed into "region"

It should be "Prevailing Westerlies". Because it has nothing to do with the topic, we deleted this in the revised version.

14. L. 71. Insert "mean" before "annual".

Response: Thanks. Inserted.

15. L. 74. Change "main"to "major".

Response: Thanks. Changed.

16. L. 76. Capitalize "Quaternary"/

Response: Thanks. Capitalized.

17. L. 80. Change "gradually" to "gradual".

Response: Thanks. Changed.

18. L. 86. Last word "largely" change to "strongly". Are the pH values and electric conductivity measured for only the surface soil (topsoils) or average values for the whole profile (down to the bottom of sampling? For definition for saline and alkaline soils, see http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052523.pdf Reaction of EB1 is neutral and EB2 is slightly alkaline.

Response: Thanks. The "largely" was changed into "strongly". The pH and EC values were for the active layers, and this was clarified in the revised version. Thanks for the references, and the soils for EB1 and EB2 were corrected into neutral and slightly alkaline in the revised version. This sentence was revised as below:

"The soils in the study area were strongly alkaline, with pH values of 8.53-8.84, with the exception of EB1 (neutral) and EB2 (slightly alkaline). The conductivities of the soil suspensions ranged from 0.95 to 1.33 ms cm^{-1} (Table 2, data for the active layers, and the upper 2 m for the PT11)."

19. L. 99. Delete "values" and change "conductivities" to singular.

Response: Thanks, changed into "pH and conductivity".

20. L. 100-103. Where is the data for soil texture and rock fragment content?

Response: Thanks for the review. For the soil texture analysis, we firstly removed the gravels (rocks) and calculated the ratios by weight methods, then these samples were used for laser diffraction instrument. In the revised version, we changed the rock into gravel. These data were presented as supplementary materials in the revised version as below:

“All the original data were available on the website of The Cryosphere Discussions (http://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=25&_lcm=oc73lcm74a&_acm= get_supplement_file&_ms=50278&id=704538&salt=1523858444357408567).”

21. L. 103. Insert “contents” after “(TN)”.

Response: Inserted.

22. L. 120. The variation of vegetation type is limited to 2 Kobresia species.

Response: Thanks, the “different” was removed in the revised version.

23. L. 122. The SOC density ranged from 0.4 to 22.4 kg m^{-3}. Is the density of different soil horizon or this is the average of the whole soil profile? If so, then what is the carbon stores (kg m^{-2}) of the active layer or 0-2 m and the whole profile?

Response: Thanks. This is for the soil layers at different depths. In this paper, the main goal is to discuss the relationship between carbon densities and the textures, especially for the deep layers. Since the SOC stores for the 0-2 m and the whole profile are of interesting for potential readers, we calculated these values in the results section.

“As shown in Table 2, the SOC stocks for the upper 2 m were highest for ASM sites (varied from 38.39 to 58.20 kg m^{-2}), followed by AM sites (varied from 8.62 to 21.73 kg m^{-2}). The lowest values appeared in AS sites (lower than 5.0 kg m^{-2}). For all the sites, the most SOC was distributed in the upper 6 m. The upper 6 m SOC stocks showed similar trends with those of upper 2 m. The highest SOC was recorded at EB1 site, while the PT9 had higher SOC stocks than that of EB2 since the later had a shallower soil thickness. The SOC stocks for the upper 6 m layers at AM sites varied from 29.7 to 48.5 kg m^{-2}. The SOC stocks were lowest at AS sites."

Table 2 SOC stocks (SOCC, kg m^{-2}) for different layers for the sampling sites

Site	0-1 m	0-2 m	0-3 m	0-6 m	Active layer
PT4	9.74 ±0.62	10.81 ±1.35	18.17 ±1.67	38.04 ±2.09	3.63 ±0.44
PT5	8.94 ±0.65	16.05 ±1.21	20.37 ±1.87	29.72 ±3.01	3.42 ±0.38
PT6	11.84 ±0.88	21.73 ±2.04	29.47 ±3.08	48.51 ±4.33	2.40 ±0.14
PT7	5.20 ±0.48	8.62 ±0.75	13.20 ±1.43	29.89 ±3.05	2.41 ±0.17
PT9	22.76 ±2.14	38.39 ±3.66	57.46 ±6.35	104.17 ±7.76	1.63 ±0.09
EB1	39.62 ±3.17	58.20 ±4.43	81.88 ±7.77	134.46 ±9.94	1.20 ±0.05
EB2	34.49 ±2.43	52.89 ±3.20	64.24 ±4.31	69.47 ±5.66	1.30 ±0.04
PT10	3.85 ±0.11	3.91 ±0.18	4.07 ±0.32	4.66 ±0.38	4.85 ±0.31
PT11	3.91 ±0.22	4.70 ±0.27	5.24 ±0.37	7.25 ±0.67	6.00 ±0.60
PT12	0.55 ±0.04	1.10 ±0.08	2.36 ±0.14	7.59 ±0.51	5.75 ±0.43

Data were presented as Mean ±SD from measurements of three triplicate samples.

23. L. 128. Add "respectively" at the end of sentence.

Response: Thanks, added.

24. L. 141. Insert "class" after "texture".

Response: Inserted.

25. L. 151. "moisture" is not the proper word; water! The equation is poorly constructed. Use symbols; in line 150, add (D) after depth, add (W) after water content, add (Db) after bulk density, and "Cy" or other choice after clay content.

Response: Thanks, it was changed as below:

According to the relationship between the SOC contents and depth (D), total water content (W), Gravel (G), and clay content (Cy), the best regression models were as follows:

$SOC(\%)=0.092W-0.214D-0.20lG+0.672Cy$; $r^2=0.566$, $p<0.001$ (n=158).

26. L. 155. See general comments.

Response: Thanks, see the responses to Question 1-4.

27. Tables Need footnote for the Drainage class in Table 1. Why are there 2 columns of conductivity? Tables 1 and 2 should be combined and titled "Physiographic environment of the study sites in the Heihe River basin, Qinghai_Tibetan Plateau". Soil properties should be in another table. Besides pH, conductivity, the methods section also include SOC and water contents, C/N ratio, bulk density, particle size distribution, rock fragment content.

Response: Sorry for the mistakes for the conductivity. The tables were reformed and revised according to your suggestions. The combined table was presented at Table 1 as below:

For the soil properties, the table is too large, and could not be presented in the paper, therefore, we submitted it as supplementary file. See response to Question 20.

Table 1 Physiographic environment of the study sites over Heihe River basin, Qilian Mountains

Site	Longitude (°)	Latitude (°)	Altitude (m)	ALT (m)	Aspect	Slope (°)	Topography	Drainage class	BD (m)	SLT (m)	Vegetation types	Vegetation cover%	Dominant species	pH	Conductivity (ms cm^{-1})
PT4	98.946	38.833	3770	3.63	southeast	flat	PP	P	90	32.5	AM	94	*Kobresia pygmaea* C. B. Clarke	8.53	1.11
PT5	99.026	38.806	3692	3.42	southeast	flat	PP	P	20	>20*	AM	90		8.84	0.95
PT6	98.963	38.955	4159	2.40	southeast	2	PS	P	50	9	AM	80	*Ajania tibetica*	8.64	1.05
PT7	98.963	38.903	3970	2.41	southeast	1.5	PP	P	36	25.5	AM	85	*Rhodiola subopposita*	8.70	1.09
PT9	98.950	38.627	4138	1.63	northeast	2	PS	VP	160	7	ASM	96	*K.tibetica Maxim*	8.65	1.12
PT10	99.068	38.789	3681	4.85	flat	flat	PP	SE	20	>20	AS	87	*K. humilis* (C.A.Mey.) Serg	8.76	1.14
PT11	99.068	38.789	3680	SFG	flat	flat	PP	SE	20	>20	AS	78		8.61	1.03
PT12	99.068	38.788	3680	5.75	flat	flat	PP	SE	20	>20	AS	75		8.80	1.83
EB1	100.916	37.998	3700	1.2	northwest	1.2	PS	VP	20	8**	ASM	95	*K.tibetica Maxim*	6.58	1.02
EB2	100.907	38.003	3615	1.3	northwest	2.5	PS	VP	11.7	8***	ASM	95	*K.tibetica Maxim*	7.44	1.33

ALT: Active layer thickness; BD: Borehole depth; SLT: Soil layer thickness; MAGT: Mean annual ground temperature; ASM: Alpine swamp meadow; AM: Alpine meadow; AS: Alpine steppe. SFG: Seasonal frozen ground.

PP: Piedmont plain; PS: Piedmont slope;

*Clay for the soils below; 16 m; ** High ice contents for 6-8 m; *** high gravel contents for 5-8 m