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Solid Earth Discussions

Interactive comment on "Subsurface structures of a quick-clay sliding prone area revealed using land-river reflection seismic data and hydrogeological modelling" *by* Silvia Salas-Romero et al.

Silvia Salas-Romero et al.

silvia.salas_romero@geo.uu.se

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We thank the anonymous reviewer for the critical and useful comments. We have addressed all the specific comments in our revised manuscript, as detailed below.

(Anonymous Referee #1) The paper attempts the challenging task of integrating a large collection of geological and geophysical data to derive new insights on landslide formation in quick clays for a specific study area. Primarily using seismic reflection data, the study results in the mapping of the bedrock surface, and an overburden aquifer

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that may be associated with quick clay formation and landslide activity. However, the paper is poorly organized to the point that the results and their importance are obfuscated. In particular, the authors do not clearly distinguish between established data and interpretation, and the links between the observed data and the process-based conclusions are not effectively demonstrated. The paper would be more impactful if, for example, the authors succinctly identified previously-published data and interpretations, and then demonstrated how new data and insights build on past knowledge to support their objectives. In this fashion, more focus could be placed on the novel aspects of the paper including the hydrogeological modelling, and testing the hypotheses (or supporting the interpretations) of aquifer-driven leaching and sliding mechanism.

(Authors) We thank the reviewer for the comments, which have been useful for improving our manuscript. We have followed the advice and put more emphasis on distinguishing the previous data and our new/current contributions, and relate the last ones to the conclusions.

(Anonymous Referee #1)

Some editing for English is required throughout the paper.

(Authors) A native speaker has gone through the revised version and we hope this problem is fixed. We have taken additional steps to improve the readability and flow of the text.

(Anonymous Referee #1) p2, L2: Revise sentence.

(Authors) The sentence has been modified.

The new sentence is: 'The presence of quick clays can only be confirmed using geotechnical site and laboratory investigations enabling estimation of the sensitivity (Rankka et al., 2004). The sensitivity is defined as the ratio of undrained undisturbed to remoulded shear strength.'

(Anonymous Referee #1) p2, L4: Reference required.

(Authors) A new reference has been added now. âĂć Karlsson, R. and Hansbo, S. (1989). Soil classification and identification. Byggforskningsrådet Document D8:1989. Stockholm.

(Anonymous Referee #1) p2: Consider revising/restructuring the introduction to improve focus and logical flow of ideas. Focus switches from geophysics to hydrogeology to site specific conditions all in the same paragraph without any transitions or linking of ideas.

(Authors) We have followed this advice and have restructured the Introduction and ordered the objectives around this, creating a new subsection that clarifies the introductory materials.

(Anonymous Referee #1) p3: Consider reorganization of material into separate "Intro" and a "Study Area" sections. Geological maps, shot locations, and LiDAR data are not really introductory material. Clearly differentiate between legacy data, and new data. It is not apparent what the new contributions are.

(Authors) As mentioned, we have modified the Introduction and created a new section called Study Area. This new section includes the data that do not belong to the Introduction, such as the geological and topographical data. We also have reworked the text to better describe what legacy data are and what new contributions are.

(Anonymous Referee #1) p3, L13: The slide is of interest because it is in the middle of the study area?!

(Authors) We have modified the sentence that makes reference to the landslide scar in the study area.

(Anonymous Referee #1) p.3, L27: Is this the hypothesis being presented? The objective of the paper is not yet clear at this point.

(Authors) No, this is not the hypothesis being presented in this paper. A reference has been added to clarify this. The objectives were listed on p. 3, starting in line 32.

(Anonymous Referee #1) p.4: If all of these data sets are legacy data sets, they should be well described in the cited references. Much of this information does not seem necessary to support the objectives.

(Authors) All these data are being used within this study for achieving the objectives. We think it is reasonable to reproduce this information so that the article is as complete and as "stand alone" as possible, avoiding too much cross-referencing.

(Anonymous Referee #1) p.7: Velocity analysis was the "most important step" but receives less discussion than routine operations. How does the time-depth conversion velocity compare to the results of the velocity analysis?

(Authors) Velocity analysis was an important step in the cabled part of line 5–5b, but not the only processing step that improved the quality of the final seismic section (the text has been modified accordingly). The time-depth conversion velocity (1500 m/s) is within the range of velocities picked during the velocity analysis (1100-1600 m/s) and is also consistent with fully saturated clay, which has velocity similar to water. Velocity analysis had to take care of the dip component (dip-velocity dependent stacking velocity) but this is not required for time-to-depth conversion.

(Anonymous Referee #1) p.7, L32: What is the nature of S1? In particular, does it have finite thickness relative to the wavelength? You refer to it as a layer, an interface and a horizon. How are you picking it? Because it could be interpreted as a compacted top of a reflection package, which seems to be supported by the mag. suc. that increases below S1 and stays high. More discussion of the interpretation logic and reflection facies is necessary. Core?

(Authors) The text has been modified to clarify that S1 represents the top of the coarse-grained layer, i.e. an interface. Our earlier publication in the journal of Landslides and a previous study by Malehmir et al. (2013) already identified S1 and discuss the nature of this layer, using core samples and other evidence.

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(Anonymous Referee #1) p.8, L19: If there is core, how come lithological logs are not part of the analysis?

(Authors) In the previous paper published in Landslides by Salas-Romero et al. (2015) ('Identifying landslide preconditions in Swedish quick clays–insights from integration of surface geophysical, core sample- and downhole property measurements'), grain size distributions are shown for the core samples of the three boreholes (also soil textures are estimated with the natural gamma radiation data). We believe that these results are good enough for describing the core material as they are soils and their appearance is difficult to quantify in a visual inspection (the cores collected in the three boreholes drilled in the study area were visually inspected when samples were collected for the different laboratory measurements). We use some of the core information from our previous work for supporting the new data, but we prefer not to repeat too much in this manuscript.

(Anonymous Referee #1) p.9, L32: It looks like a decrease in penetration resistance.

(Authors) We have removed borehole 7073 as the increase in penetration resistance is unclear, but we keep borehole 7075 because it does show an increase in penetration resistance at the interface S1. It may not be visible at the figure's size but the reference can be checked online.

(Anonymous Referee #1) p11, L6: The landslide scar is not apparent in Fig.11.

(Authors) We did not mean that the landslide scar is visible in Fig. 11, but that the landslide scar is located in that position and that the deposits located in the river may be related to it. We have rephrased the sentence and made it clearer to the reader.

(Anonymous Referee #1) p.11, L11: The paper seems to have been comparing previous studies the whole time.

(Authors) We have reworked this subsection to include only new contributions when comparing with previous studies.

(Anonymous Referee #1) p.11, L15: It is unclear how this proposed mechanism works with infiltration "through outcrops and fracture zones" and how this is related to the coarse-grained layer. Consider more development of the hydrogeological conceptual model, and then provide supporting evidence.

(Authors) The hydrological model has been improved and we hope that it now provides sufficient information about the infiltration mechanism.

(Anonymous Referee #1) p.11, L25: This is well below your quoted resolution. You have not show any frequency spectra, but it is likely well below quarter-wavelength as well.

(Authors) We are aware that our data resolution cannot distinguish such a thin layer. Our intention was to mention that we have checked other borehole data to the north and south of the study area and that the coarse-grained layer can be found in many of them but in some places can be thinner than in our study area.

(Anonymous Referee #1) p.12, L13: Where are the total sounding data with top and bottom of S1? The nature of S1 and the coarse layer (deposition, thickness, etc.) has not been discussed up to this point.

(Authors) The total sounding data are not included in this manuscript as a lot of information is already present in it. Nevertheless, we provide references about where to find this material, available for any person providing the area information and borehole id. We discussed largely about the nature of the coarse-grained layer in our paper published in Landslides (reference included in the text). Thus, we do not think it is necessary to discuss it again.

(Anonymous Referee #1) p.12, L13: Where are the data that go into this most important interpolation? How are you handling the multiple interpreted faults?

(Authors) The boreholes used in the interpolation are now included in a new figure that shows the surface contours. The LiDAR data are shown partially in Fig. 2b. The interpreted faults have not been used for the interpolation of the elevation surfaces.

(Anonymous Referee #1) p.13, L13: There are more boreholes in Fig.2b than in Fig.14. Need to distinguish water wells from other holes.

(Authors) We have improved the maps and clarified this information distinguishing between the wells used in the hydrological modelling and the others in Fig. 2 and in the new figure showing the surface contours, as mentioned before.

(Anonymous Referee #1) p.13, L14: It is hard to tell from the figure, but it appears that 3 of 7 boreholes in the model domain (excluding the southern holes) are not fit by the model. This is a lot, and is attributed to "only one measurement" but these holes have not been distinguished from any of the other holes (do they have two measurements?) and the possibility of the model simply being wrong needs to be addressed. Consider presenting and discussing water well data.

(Authors) We provide a table with information about the pore pressure and well data and sort them by depths near the estimated coarse-grained layer (lower aquifer) versus shallower measurements in the fissured near surface clay (upper aquifer). With this distinction in place our simple model manages to approach the former type of values with an RMSE of 0.5 m.

(Anonymous Referee #1) p.13, L32: This needs to be explained.

(Authors) We have intensively reworked and extended that paragraph to make it clearer to the reader.

(Anonymous Referee #1) p.14, L5: Explain this. You have "calibrated" the recharge area and the recharge transmissivity which will have a direct trade-off with the required recharge. The modelling requires some sensitivity analysis.

(Authors) A new automated calibration procedure gave better estimates of the optimal values and a better understanding of the model near that minimum (an updated figure was prepared). As can be understood, the two parameters can partially compensate for each other, which leaves some uncertainty in their estimate. Hydraulic tests and/or tracer tests would be required to improve the estimates of the model parameters or to elaborate on the model structure. This single layer hydrogeological model was built almost as a back-of-the-envelope scoping calculation and will not bring positive proof of the validity of the leaching assumption as the cause of quick-clay formation. The intention was to provide a quick plausibility check for this area.

(Anonymous Referee #1) p.14, L8: What data?

(Authors) We rephrased this sentence to make it clearer. The statement is about the pore pressure data.

(Anonymous Referee #1) p.14, L17: Groundwater velocity of 0.00015m/s or âĹij13m/day is very fast.

(Authors) We agree with the reviewer. This velocity obviously shows some limitations of the simple hydrogeological model that isolate the coarse-grained layer.

(Anonymous Referee #1) p.14: Consider showing and analyzing the mag data with the rest of the data in the data section as opposed to in the discussion section.

(Authors) We have considered it and we still believe that the magnetic data are better discussed in the Discussion, subsection about the morphology of the Göta River valley. The data in the Results section are subsurface data describing the subsurface structures, whereas the magnetic data are superficial data.

(Anonymous Referee #1) p15, L21: Should be easy enough to test with a multivariate regression of mag, T and depth - or some combined variable of T and depth.

(Authors) We thank the reviewer for this useful advice. This test helped interpreting the results.

(Anonymous Referee #1) p.17: In my opinion, many of the conclusions from L16 down (and in the abstract) remain conjecture. The catchment area is prescribed without validation, it is not clearly demonstrated that there is aquifer-driven leaching, or that the coarse layer is a sliding surface, and the nature of the mag. anomaly is an interpretation.

(Authors) The conclusions have been modified in order to add the new information obtained after this revision.

(Anonymous Referee #1) Fig.1: Demonstrate value of this figure.

(Authors) We believe that it is interesting to show the potential for destruction of this type of landslides near the same river in an area very close to the south of our study area. The current risk of landslides is medium-high in the study area, so we think that the picture is illustrative of a possible scenario.

(Anonymous Referee #1) Fig.2: Shorten caption. Do not repeat what is stated in the text or what is evident from the figure (such as the legend). Improve figure clarity. Much of the text and symbols on the map are not easily legible.

(Authors) We followed this advice, and shortened the caption and improved the figure clarity.

(Anonymous Referee #1) Figs.3&4: Remove repetitive material from captions.

(Authors) The captions have been shortened.

(Anonymous Referee #1) Figs.5&6: The captions are far too long and complicated. The borehole logs require scales and labels (other figures also).

(Authors) The captions have been shortened. We do not think that we require scales or labels for the borehole logs. Precisely, we included close-ups for each borehole in every figure for helping to visualize them. The maximum and minimum values for every log are included in the caption of the figure. We believe that adding scales to these figures will worsen their clarity. The same information and more details can be found in our previous work published in Landslides and in the SGI website.

(Anonymous Referee #1) Fig.12: While visually impressive, perspective images are not good for evaluating interpolated surfaces, particular with respect to potential bias introduced by spatially non-uniform data such as sparse boreholes combined with dense points along seismic lines. Contour plots should be used for analysis. What about coarse layer thickness?

(Authors) We followed this advice and added a new figure that shows the contour plots for the elevation surfaces. The perspective images are now included in the supplementary material for not increasing the manuscript length. We prefer to keep the perspective images because they give a good perspective of the relationship between the surfaces, the river, and possible fault zones. The coarse-grained layer thickness is an estimation that may include more uncertainties than the delineation of the top of the layer. Figure 14b (transmissivity) shows essentially the layer thickness as T=K*thickness, K=const.

(Anonymous Referee #1) Fig.13: b and c add nothing.

(Authors) These figures have been removed.

(Anonymous Referee #1) Table 2: For all but the LiDAR perhaps, these values are nominal resolutions, and the spatial sampling interval is not indicative of the resolution.

(Authors) We agree with the reviewer and added more information to the table for clarifying these terms.

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