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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Field observations of soil hydrological flow path evolution over 10 Millennia" *by* Anne Hartmann et al.

Nicholas Jarvis (Referee)

nicholas.jarvis@slu.se

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This paper presents the results of dye tracing experiments showing how the mechanisms of preferential flow (PF) change with soil development in alpine moraines exposed by glacial retreat. This work culminates in a very nice schematic diagram (Figure 9) that summarizes and illustrates the main findings. The main strength of the paper is that the study of PF from this kind of pedological perspective is still really quite novel. Nevertheless, the authors are not the first researchers to have taken this kind of pedological approach and it would strengthen the paper if some of this relevant earlier work could be mentioned in the Introduction. The authors could check out Quisenberry et al. (1993), Lin (2003), Cammaraat and Kooijman (2009) and Jarvis et al. (2102).

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Discussion paper

Another interesting and rather novel aspect of the paper is the demonstration of the importance of stones and rocks for generating and maintaining preferential flow. Maybe the authors could also cite Bogner et al. (2014), who demonstrated the same thing. The paper is generally well written and presented and easy to read, although the language could be improved further by a native speaker. One minor concern is that the author's use of terminology related to PF is, at times, unnecessarily confusing. I have two other criticisms. First, the methods are not described in sufficient detail. Secondly, the authors could do a better job of discussing their results with respect to the fundamental processes causing the observed changes in flow patterns. These aspects are explained more fully in the following.

Methods: It was not clear to me what aspects of the vegetation cover were actually measured. For example, you use the term "mapped" on page 4 at line 15, but this is a rather vague. Do you have measurements of anything like above-ground biomass or was only species composition recorded? Please write this more explicitly. The description of vegetation complexity on page 5 at lines 2-4 is also not very helpful. Can you give a brief description here, maybe with an equation? The reader should not have to consult another paper (Musso et al.).

The description of the irrigation procedure on page 5 (lines 15-18) was quite difficult to follow. It seems as if the irrigation pattern was different between the plots. Why was that? Perhaps a schematic figure might help to explain this.

The method to classify the flow patterns into different groupings is described only very briefly (on pages 6/7) and it was also difficult to follow. To complement the text (e.g. at lines 28-30 on page 6), could you give an equation or perhaps include a schematic diagram (or both)? This procedure is quite central to the paper, so it is important to explain this carefully.

The description of the particle size analysis on page 7 makes no mention of the gravel/stone fraction (>2 mm). Did you measure the content of stones/gravel? I know

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this is very difficult in stony soils, so it is understandable if you didn't, but I think this should be stated.

The description of how bulk density and porosity were measured (page 7, lines 31-32) is quite vague. Can you describe more exactly (but still briefly) how you measured bulk density and (especially) porosity? It would be good to give some details, because the porosity values are extremely small in the young moraine and in the subsoils. I suppose this is because of the high stone content, but it could also be because air got trapped in the samples during saturation.

The authors do not report any measurements of soil organic matter content (SOM). This data should ideally be included in the paper, as the build-up of SOM over millennia due to the growth of vegetation seems to be a very important control on the observed changes in the flow patterns. If SOM was not measured, then I think it should be measured now and the results included in the paper (the analysis is quick and cheap).

Processes: Can you explain (e.g. on page 16, lines 9-17) why the texture becomes finer with age? Is it due to weathering or is it deposition of fine materials by wind, or maybe both (or something else)? The cause(s) might be obvious to the authors, but perhaps they will not be to all readers.

The process(es) operating to increase porosity and decrease bulk density should be explained better (e.g. on page 16, line 20, and lines 33-34). I presume that it is mostly related to a build-up of organic matter in the soil, which is supplied by the litter and roots of the increasingly dense vegetation cover and subsequently processed by soil micro-organisms and fauna, which ultimately results in a more open (aggregated) soil structure.

The authors associate the homogeneous flow patterns found in the young moraine with "gravity-driven" water flow (e.g. on page 15, line 2; page 18, line 2; page 20, line 21). This is rather misleading to my mind. Fundamentally, it must be the case that both gravity and capillarity were driving the infiltration process in all your experiments,

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because the soils were (presumably) initially quite dry. In fact, the authors do not really need to discuss whether gravity or capillarity dominated the flow patterns in the different moraines, but if they want to do so, then I think in reality, it is the opposite of what they write. Both macropore flow and finger flow are gravity-dominated processes, whereas a homogeneous flow pattern implies that capillarity was strong enough to prevent the development of any lateral non-equilibrium in soil water pressures. It is this lateral non-equilibrium in water pressures during flow that is a fundamental characteristic of PF.

Confusion over terminology: Considering the underlying physical mechanisms, there are three main types of PF (macropore flow, finger flow and heterogeneous flow) and this is indeed the basis of the classification system that the authors make use of in the paper. However, the authors unnecessarily introduce some confusion at a couple of places in the paper by referring to another classification scheme, one that is not especially useful in my opinion:

i.) page 2 (lines 18/20): There is no good reason to distinguish crack flow from burrow flow (does burrow flow include flow in channels created by root decay?). These can all be lumped into macropore flow (as you do later). If you want to define some sub-groups according to the origin of macropores, you should talk about flow in biopores (which includes both root and faunal channels) not burrow flow.

ii.) page 17, line 34: "In the clay layer, no significant macropores were identifiable, which is why it is assumed that the water is transported in cracks . . .". Cracks are also macropores. You should replace the term macropores by biopores.

Corrections

1. The text at the end of the Introduction should be re-arranged. The hypotheses at lines 6-11 don't make much sense at the moment, because they are specific to the case of glacial moraines. It's not clear to the reader where these hypotheses come from. If you move this text to line 19 (after ". . .impacts water flow paths"), I think it will

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make more sense, especially if you add ". . . in glacial moraines in the Swiss Alps" after ". . .landscape evolution", and delete the last sentence in the first paragraph.

2. Abstract, Line 1: you should delete "The presence or absence of . . ."

3. page 3, line 1: add "volcanic" after ". . .younger"

4. page 4, lines 15-16: delete "by the project partners . . .. Germany"

5. Page 7, line 10: maybe you could add ". . ... and flow mechanisms" after "different properties"

6. Page 8, line 1: add ". . .. moraines of differing . . ." after "four"

7. Page 8, line 6: replace "the entire" by "all"

8. Page 8, figure 3 caption: I presume that these results are % of the fine earth fraction (< 2mm). It would be good to state this here.

9. Page 10, line 5: I don't think you should talk about hillslopes as you haven't mentioned anything about site topography. You could just replace "hillslope" here by "moraine"

10. Page 12, line 7: This is ambiguous, but I think you mean: "For all four moraines, the volume density is largest in the top half of the soil profile"

11. Page 13, line 2: interpreting dye tracing patterns can be tricky, since you only get a snapshot in time of a dynamic process. In this particular case, I think it's possible that even if the staining was homogeneous, it doesn't necessarily mean that PF didn't occur. PF could have occurred from the soil surface, but the signs of this may have been obliterated by the later (slower) downward movement of a uniform wetting front in the soil matrix. I am not saying that this is what happened (I'm confident that your interpretation is correct), but I think you could recognize this possibility.

12. Page 16, lines 26-27: I don't understand how the decrease in bulk density in the

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first 160 years can be related to a change of particle sizes, since this was marginal. It must be primarily due to the increase in SOM content.

13. Page 16, lines 26-34: there is no need to have separate discussions for porosity and bulk density, because they are very closely linked (via the particle density). You could simplify and shorten the text between lines 18 and 34: you only need to write that the increase of porosity and decrease of bulk density was presumably a result of organic matter build-up in the soil due to the development of a denser vegetation cover.

14. Page 17, lines 2-3: it should be briefly explained (with a supporting reference) how the change in texture could affect bulk density. Presumably the finer particles fill the spaces between the coarser particles? However, I think that the effects of texture on bulk density are usually considered to be relatively small. I think that the increase in SOM content (and associated biological activity in the soil) must be the main reason for the decrease in bulk density.

15. Page 17, line 20: "texture" in this context is quite a vague term. Was it clay content? Please be more explicit.

16. Page 17, line 30: the coarse nature of the material must be important too?

17. Page 18, line 27: replace "lower" by "shallower"

18. Page 18, line 32: should be: ". . .. cover was removed to decrease . . .."

References

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