

Reviewer #1 (R1)

Dear authors,

You provided a very nice paper. With some minor (mainly technical) corrections your manuscript can be published, to my opinion. I added my comments in esurf-2022-20-supplement.pdf

All the Best

We appreciated the comments and suggestions and reworked the original manuscript accordingly. The remarks really helped to improve the quality of the paper. Wherever we cross-reference changes in our response, we refer to the revised manuscript with accepted changes, as the numbering of Figures had to be updated, and also the line numbers.

title: Maybe you could think about a more simplified title.

We appreciate this comment and changed the title. We tried to find a good balance between process understanding and specialties of the study area.

line 10: Because there is no existing Lake Bonaduz you should call it paleolake Bonaduz throughout the whole text.

Thanks for this suggestion. We thought about changing that, but then figured that we would then, consequently, have to call also Lake Ilanz “Paleolake Ilanz”. In the Flims community, however, Lake Ilanz is widely used, although there is no present lake, so we keep Lake Bonaduz, accordingly. We adapted that throughout the text.

line 15: Cresta hills are not defined in the text. Just keep it simple and include them in the word Toma hill or describe the difference between Toma hills and Cresta hills.

We agree that the termini are confusing. Especially around Flims, many different words for the diverse hills can be found in the literature. According to Arbenz and Staub (1910), the long hills situated in the Bonaduz plain are called ‘Cresta’, whereas the round or cone-shaped hills containing rockslide material are called ‘Toma’ around Ems, and ‘Put’ around Bonaduz. Piperoff (1897) and Arbenz and Staub (1910) interpreted the caps on top of the hills as moraine deposits, but only few outcrops were known.

Hereafter, we call all hills in our manuscript Toma, as this term is widely used in the community, and we can be sure that they all have a rockslide source, regardless on which side of Ils Aults they are situated.

We added this explanation in lines 43-48.

line 26: catastrophic rock-slope failure. Other types of non catastrophic rock-slope failures can reach even higher dimensions.

We changed that.

line 45: At Tschirgant no Toma hills are known, but Toma hills are developed at the rock avalanche in Almtal (Van Husen, D., Ivy-Ochs, S., Alfimov, v., 2007: Mechanism and age of late glacial landslides in the Calcareous Alps; the Almtal, Upper Austria. Austrian Journal of Earth Sciences, 100, 114-126,) and Pragser Wildsee. (Ostermann, M., Ivy-Ochs, S., Ruegenberg, F., Vockenhuber, Ch., 2020: Characteristics and Dating of the rock avalanche at Pragser Wildsee/Lago di Braies (Dolomites, Italy). Alpine and Mediterranean Quaternary, 33(2), 183-189, doi.org/10.26382/AMQ.2020.07)

We changed that and added the suggested references to our manuscript.

Fig. 1: The orange line at Tamins indicates the scarp, but at Flims it doesn't and the arrows at Flims should be placed more distributed.

Maybe you add a insert map with better visible ERT profiles and drilling sites.

“gravel pit of Reichenau” Please indicate on the map.

We reworked the map in Fig. 1 for better visibility of the measured profiles and now indicate Reichenau and some other locations, as R2 asked for.

Fig. 3: Indicate what the numbers in the circles stand for. Enhance the quality of the labels.

We changed Fig. 4 accordingly. The numbers in the circles correspond with the evolution phases 1-4. We now clarify that in the caption.

Fig. 4: The numbers of the drill logs are more confusing than they support the content of your sketch. Indicate that the black bars are drilling sites. The numbers in the circles correspond to the phases, but this is not indicated in the figure.

The signature for remobilized Bonaduz Gr. is very hard to identify.

Thanks for these suggestions. We deleted some of the numbers of the drilling sites, except for e.g. “B5/90”, as this drilling site is cross-linked to Fig. 2f. We adapted the caption, accordingly. We also improved the signature for the remobilized material.

Reviewer #2 (R2)

The manuscript is well structured, the text is well written and the figures are attractive. The authors present a short review of the work done so far in the area, then present data obtained by electrical resistivity tomography, ERT, and discuss the interpretation of these data in the light of the geometry of the rockslides and the gravels around Bonaduz. The authors then go on to interpret the formation of the landforms mainly based on published data and the observations made in three case studies. The conclusions they draw are far reaching and as such require much more discussion on other localities where observations of rock avalanche deposits and mobilized substratum can be made.

We appreciated the comments and suggestions and reworked the original manuscript accordingly. The reviews really helped to improve the quality of the paper. Wherever we cross-reference changes in our response, we refer to the revised manuscript with accepted changes, as the numbering of Figures had to be updated, and also the line numbers.

Here, we would like to point out publications with geophysical data on rock avalanches and mobilized sediments/substratum, which are now all referenced in the paper:

- *Knapp, S., Mamot, P., Lempe, B., & Krautblatter, M. (2021). Impact of an 0.2 km³ Rock Avalanche on Lake Eibsee (Bavarian Alps, Germany)–Part I: Reconstruction of the Paleolake and Effects of the Impact. Earth Surface Processes and Landforms, 46(1), 296-306.*
- *Ostermann, M., Sanders, D., Ivy-Ochs, S., Alfimov, V., Rockenschaub, M., & Römer, A. (2012). Early Holocene (8.6 ka) rock avalanche deposits, Obernberg valley (Eastern Alps): Landform interpretation and kinematics of rapid mass movement. Geomorphology, 171, 83-93.*
- *Prager, C., Krainer, K., Seidl, V., & Chwatal, W. (2006). Spatial features of Holocene sturzstrom-deposits inferred from subsurface investigations (Fernpass rockslide, Tyrol, Austria). Geo. Alp, 3, 147-166.*

There are some shortcomings:

In some instances, the text is vague leaving the reader wonder what exactly is meant. For example, in line 158 it is not clear what is meant with “the Toma.”

Thanks for this remark. Here, Tuma Padrusa is meant, which we refer to in the preceding sentences. We now changed the sentence in line 165, accordingly.

The geographic locations are given in very general terms. It is difficult to place location names to the ERT lines or the map. A more detailed map than the one shown in Fig. 1 would be helpful.

We appreciate this suggestion and reworked our map in Fig. 1. We zoomed into the study area and added location names and cross-linked them in the text for better orientation, e.g. in lines 46-47.

The description of the lithologies is very crude. For example, it is stated that the composition of Bot Dagatg and Tuma Padrusa are more or less the same. However, Bot Dagatg is composed of Cretaceous limestone, Tuma Padrusa of Jurassic limestone (Quinten and Tros limestone). The description in lines 125-134 are interpretations and do not reflect the actual situation. In fact, the authors do not present data for the interpretations (sound descriptions of field observations by the authors or by previous workers).

We value this comment and want to clarify what is meant. In line 129, we mean the granular composition, as observed in the ERT profiles. The petrographical composition was missing so far, and we now added a new sentence in line 129.

Concerning descriptions of field observations: We improved Fig. 2 and added pictures of Bonaduz Formation and Toma outcrops. Fig. 2f shows how we conducted fieldwork at Bot Dagatg based on the available sedimentological data, and rolled the ERT cables over the drilling sites for best possible correlation. We also added a reference for Tuma Padrusa in line 131 (Fig. 155.4 published in Calhoun and Clague, 2015).

In section 4.4 the authors reiterate what Calhoun & Clague said and one wonders why they put a question mark behind the title.

ERT-profile P4 provides insights into the geometries of Tuma Padrusa. There is certain evidence that this Toma hill was transported eastwards. And the coarse rock material at the front and in the back of Tuma Padrusa may indicate a “connection” to close Toma hills in the neighbourhood. This observation supports Calhoun and Clague (2018) in their theory of the torn apart Tamins deposits. Unfortunately, the Toma hills in Domat/Ems are more or less completely encircled by cultivation or residential areas and it is almost impossible to do more ERT measurements there.

We deleted the question mark.

Outburst floods/fluvial deposits: these are very specific terms. You don't say what they actually look like in the field. Please note that there are two outbursts: the one caused by the Flims rock avalanche impact (Bonaduz Formation), one caused by the outburst of Lake Ilanz dammed by the Flims rock avalanche, and finally fluvial deposits related to the incision of the Ruinaulta gorge and the Bonaduz formation by the Vorder- and Hinterrhein. These all are recognized in the Rhine Valley downstream of Reichenau, and their map pattern is complex as suggested by the well data. You use specific names without giving a reason. Instead it would be more appropriate to use a very general term for the layer with lower resistivity than the limestones of the rock avalanche deposit.

We appreciate this comment and will now explain how we visualize the diverse deposits in Fig. 5 and 6. We agree that there are two outburst floods, namely the outburst of Lake Bonaduz and a succession of outbursts of Lake Ilanz, which affected large parts along the Rhine valleys. Both Toma hills and Bonaduz Formation show fine-grained sediments on top (in outcrops, e.g. Fig. 2b and ERT-profiles P2-4), which probably overran the substratum during or shortly after either of the described outburst events or was deposited fluvially later on. Because we do not know which event formed these top deposits, we summarize these top sediment layers in Figs. 5 and 6 and state that also in the caption of Fig. 4. In Fig. 5, we can distinguish outburst-flood and fluvial deposits at some locations. The outburst flood deposits are indicated in grey-beige colour. Where the profile runs through recent fluvial deposits (terraces) of the Rhein/Hinterrhein valleys, the deposits are marked with brown-beige colour. We improved the colour contrast in Fig. 5 for better visibility. We also enhanced the labels and removed some of the drilling numbers for better visibility (except for B5/90, whose location is visible in Fig. 2f), as R1 suggested.

The Bonaduz “gravel” are now defined as Bonaduz Formation (e.g. Wyss & Wiederkehr 2017*). Gravel is the main composition, but there are rip-up clasts of siltstone, sandstone on top and rock avalanche blocks contained within and “on top”.

Thank you for this remark. We changed ‘Bonaduz Gravel’ to ‘Bonaduz Formation’

throughout the manuscript and added the reference. We also added more details to the description of the Bonaduz Formation in line 41.

Onlap: I am surprised you use this term which denotes something very specific in stratigraphy, requiring higher resolution than what you see on the EFT profiles.

We value this comment. Obviously our message did not come across. We use the term ‘onlap’ because of a wedge-shaped unit which lies on top of another unit. The wedge was formed due to the diagonal transgression of hyperconcentrated gravel flow sediments onto priorly deposited blocky sediments, either built by the rising distal deposits of the Ils Aults or of a Toma hill (Bot Dagatg and Tuma Padrusa). Also Prager et al. (2006) use the term ‘onlap’ for sediments on the Toma at the Fernpass rockslide.

Concerning the ERT resolution: Our ERT equipment measures with a resolution of 2.5-5 m to depth and 5-10 m to width. Especially Profile P1, measured with 5-m- and 10-m-cables, shows down to 70 m depth the highest possible resolution. For example, in Grünwald south of Munich, we identify the Quaternary/Tertiary boundary in ~60 m depth accurate to 2-4 m.

Abstract: Sounds like a summary of what others have done. Your new data from ERT are drowned in that. And in line 16 you claim that you have new field evidence that the Bonaduz Formation rests on Tamins rock avalanche deposit. The latter is true, but you don't present field evidence. There is field evidence: Tamins RA deposits encountered in the Reichenau gravel pit during excavation (now covered) and Tamins RA deposits covered by Bonaduz Formation along the Hinterrhein (see e.g. Nabholz 1975**).

We agree with the reviewer that in Flims remarkable geological work has been done so far. Flims is famous for the largest rock avalanche in the Alps, and here is the “mother” of all Toma hills (type locality). The pre-analysis is so complex that it is necessary to recognize and summarize the work in four sentences at the beginning.

Concerning field evidence: There seems to be a misunderstanding. In our opinion, geophysical evidence is a type of field evidence in contrast to evidence from laboratory experiments. Geophysical analysis complements sedimentological data, which is often punctual (sample or small outcrop) or linear (drilling, sketch, river bed), and geomorphological data. The ERT profiles enable us to extrapolate the local information of outcrops and drillings to width and to depth (e.g. up to 160 m depth on a profile length of 800 m at the gravel pit Reichenau), and decipher middle- and large-scale structures and geometries of sediment units.

We added a small Fig. 3 and a sentence to the abstract in lines 13-14 to emphasize the novelty of the geophysical results in the framework of a complementary method application.

There is a general problem with nomenclature. The hills in the study area are denoted with a local name plus either Tuma (like Tuma Padrusa), Bot (like Bot Dagatg) or Crest (like Crest'Aulta). These three words are the romanish equivalent of hill. Toma was introduced by Alb. Heim who transcribed the correct term of Tuma respecting the pronunciation of the “u” in Tuma as “open u”. In any case it is a pleonasm to speak of Cresta/Toma hills. The signification of the three terms reflects the morphology: crest is an elongate hill, bot is a hill with a prominent steep slope and tuma is a hill with a rounded shape sticking out of the flat valley floor.

We agree that the termini are confusing. Especially around Flims, many different words for the diverse hills can be found in the literature. According to Arbenz and Staub (1910),

the long hills situated in the Bonaduz plain are called 'Cresta', whereas the round or cone-shaped hills containing rockslide material are called 'Toma' around Ems, and 'Put' around Bonaduz. Piperoff (1897) and Arbenz and Staub (1910) interpreted the caps on top of the hills as moraine deposits, but only few outcrops were known.

Hereafter, we simply refer to all hills in our manuscript as Toma, as R1 suggested, because this term is widely used in the community, and we can be sure that they all have a rockslide source, regardless on which side of Ils Aults they are situated.

We added this explanation in lines 44-48.

'Tuma Padrusa' and 'Bot Dagatg' are proper names.

The title is too farfetched: it promises evidence for evolution. A more modest title emphasizing the geometry of the various lithologies that can be derived from the ERT lines would be more adequate.

We appreciate this comment and changed the title. We tried to find a good balance between process understanding and specialties of the study area.

1: it would be better to concentrate this map on the study area (ERT lines); the head scarp on Flimsenstein is wrong in any case.

We changed Fig. 1 and added some more locations.

2: annotation of b and c would be helpful. And the vertical lines in a are not Pavoni pipes, they are recent erosional features.

We changed that. Fig. 2 contains now three pictures of Bonaduz Formation, and three pictures of Toma hills.

3: What is the horizontal scale? Give vertical exaggeration ratio. And add N, S etc for each profile.

We appreciate this comment and adapted the ERT profiles as suggested. We added the exaggeration ratio to Profile P2 and P3. The horizontal scale is given by the running meters along the morphology.

4: What is the reason why the Bonaduz Formation extends very deep down beneath the Reichenau gravel pit? And to form such a V-shaped body? What does the pattern of blue and green beneath Tuma Padrusa represent? And I suppose that the numbers 1 to 4 denote the phases you mention. Please say that in the caption.

The ERT-profile P1 and the gravel pit provide evidence that the Bonaduz Formation is ~60 m thick at Reichenau. Please mind the scale. The ERT profile depicts the Bonaduz Formation as a trapezoid body, which appears as a V-shaped body in the schematic cross section in Fig. 4, as this a projection.

We improved the visibility of the remobilized rockslide material and Bonaduz Formation beneath Tuma Padrusa. We also added the phases to the caption.

5: Why should the lake-level of lake Bonaduz correspond to the highest point at Ils Aults? Even if the diagrams are schematic it would be good to indicate the level of the lake and the basal contact of the Bonaduz Formation.

We do not know the level of Lake Bonaduz, but this is not necessary for our purpose. We assume that the lake reached high up the Ils Aults. The three lines for the lake level indicate the uncertainty of the height. The basal contact of the Bonaduz Formation is now indicated.