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Interactive comment on "Control of 3D tectonic inheritance on fold-and-thrust belts: insights from 3D numerical models and application to the Helvetic nappe system" *by* Richard Spitz et al.

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Author's response to

Interactive comment on "Control of 3D tectonic inheritance on fold-and-thrust belts: insights from 3D numerical models and application to the Helvetic nappe system" by Richard Spitz et al.

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Review of Spitz et al. se-2019-173

General comment

All in all this manuscript addresses an interesting topic in a clear way. My comments in this review are meant to improve the manuscript.

Abstract is too long. The first three sentences is not what you found. They should be in the aims part of the introduction. The important statements are found from line 10 to 24.

We have shortened the abstract.

1 Introduction is OK

2 Geological overview is OK, but a few corrections needed (see specific comments).

3.1 Numerical method OK, but the mathematical part is not my field of experetise. Fig. 3 is hard to read (dark red color hinders 3D visualization, model types are too small to read) 3.2 Model configuration: description is OK. But I think that the simple geometry of a graben getting narrower linearly is not the best solution. It might well be that the passive margin is fragmented as shown by Trümpy for the Early Jurassic in eastern Switzerland with NS-striking synsedimentary faults (transformlike). Considering the en echelon pattern of the hinge lines of the Morcles and Doldenhorn nappes it seems more logical to use a fragmented basin (an offset placing the northern graben bounding fault farther South for the Doldenhorn area). Fragmented passive margins are more the rule than the exception (see papers by the Manatschal group in the Austroalpine units, the Pyrenees and the Atlantic off Portugal).

We modified figure 3 a bit and increased, amongst others, the graphics in panel c). However, we kept the original colors. We kept the linearly narrowing graben for simplicity, but we discuss that the natural situation might have been more complex. The aim of our modelling is to understand and quantify the first-order effects of laterally varying graben structures, which is the reason why we tried to keep the initial geome-

try as simple as possible.

4 Results 4.1 Section on 3D Model evolution is OK, Fig. 4 is a nice summary graph, which would fit into section 5.1 4.2 Section on 2D numerical cross-sections. Cross-sections are clearly presented, but the wealth of data seems somehow “too much”. The figures could be condensed by showing two cross-sections, at x=0 and x=40 km. The intermediate states show basically the same features and do not exhibit significant changes. The text would of course need to be modified (shortened) accordingly. The full detail could be provided as supplementary material.

We kept all the original panels, because we want to show in detail the lateral variations in the model. The fact that these lateral variations are sometimes not significant is in our opinion also an important result. Since we have the possibility to show these results, we prefer to present our results in the figures, rather than describing the results by words.

4.3 Nadai strain and lode’s ratio is OK, but I asked myself what you wanted to extract from this information. The deviation from plane strain has been a problem in structural geology that never has been satisfactorily been resolved. Your 3D modeling could give us some clues. But even in the discussion and conclusion you do not take advantage of the data the model provides.

We agree that a discussion and analysis of the deviation from plane strain is not done in detail in our study. We focus here on the major, first-order results, which show that significant deviation from plane strain only occurs in narrow zones around the nappe boundaries.

5 Discussion 5.1 Impact of lateral geometry variation is OK. Fig. 4 would be well (better) placed in this section! 5.2 Comparison with the Helvetic nappes is OK, witha few corrections that need to be included (see specific comments). 5.3 Comparing geological with modeled cross-sections, Morcles nappe. This section has important flaws (see specific comments) such that I tend to suggest deleting it.

A main aim of our modelling study is the application to natural fold-and-thrust belts, in particular to the Helvetic nappe system, so that we keep this section. We are aware that there are different, and partly opposing, geological interpretations, in particular concerning the tectonic relationship between the Morcles nappe and the Chaînes subalpines in the considered region. We extended our discussion and tried to clarify our interpretation. We also extended the discussion concerning the different cross sections. Geological cross sections can be considered as geometrical models, which depend on several assumptions such as choosing an appropriate projection method. However, such sections represent the main, summarized information from geological field work and represent one of the few "data sets" which can be used for the comparison with numerical models. Therefore, we keep our discussion on the different sections, but discuss their uncertainties and alternative interpretations.

6 Conclusions are a bit lengthy. They contain statements that belong to the abstract. True conclusions (what was learned from the research) formulated to the point. Some of the language is a bit cumbersome (see specific comments)

We modified the Conclusions and tried to make them more concise.

Specific comments

55 You mention analogue models but do not discuss them at all later. If you wish to make reference to analogue models you need to add a few explanations with references.

Since our manuscript is already quite long and entirely focuses on numerical modelling, we do not want to discuss and explain the analogue results. We, therefore, deleted the references to the analogue models.

123 It is important to note here that it is the Early Jurassic basin that plays the major role in the development of the internal structure of the nappe. This basin is restricted to the area west of the Aar massif. In eastern Switzerland the Early Jurassic basin is

restricted to the area south of the Aar massif. “North Helvetic basin” is misleading as term (it is also used in conjunction with flysch basins).

We mention now explicitly that the term North Helvetic basin refers in our study to the Jurassic rift basin, and not to the much younger North Helvetic flysch basin that is part of the North Alpine foreland basin.

134 see 123

See our reply to 123.

136 which carbonates are your referring to by saying “in between”? The carbonates are of Late Jurassic and Cretaceous age and rest on the marly-shaly Early and Middle Jurassic sediments.

We removed the “in between” confusion. We omit a detailed description of the lithologies here, as it is not essential for our study.

137 I disagree with these differences: for Morcles shearing at its base is really prominent as well and the internal folds of the Doldenhorn are isoclinal in part, and the length of the overturned limbs are comparable.

We agree that the current sentence is not clear enough. We removed this sentence, since a clarification of this statement would need a significantly longer and detailed explanation, which is out of the scope of the study. The statement is also not important for our study.

150 The Rawil depression is not a “topographic” feature (Wildhorn and Wildstrubel are among the higher peaks). It is a structural depression.

We agree and replaced ‘Due to the topographic Rawil depression’ with ‘Due to the structural Rawil depression’.

152 The Early Jurassic basin is not proven to be continuous. As a matter of fact the hinge lines of Doldenhorn and Morcles are clearly not lined up and can therefore not

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be correlated. These hinge lines are most likely controlled by the basin architecture, which is a primary target for this study. By saying that the basin is continuous your are making an assumption that you want to investigate by your study. If the hinge lines of Morcles and Doldenhorn reflect the orientation of the northern basin border then this border must have a jog. Some people (e.g. Burkhard) explained this jog as a NS-striking strike-slip fault. But in reality we do not have any data on this. The seismic data of NRP20 are inconclusive on this.

It is, of course, true that a continuous basin is not proven, but most geological studies assume, or propose, a continuous basin, or depositional environment, between the Morcles and Doldenhorn regions. Also Burkhard, 1988, in his figure 3a, proposed a continuous deposition of the Malm limestone between the Morcles and Doldenhorn region. For simplicity of our numerical model, we assume that the basin is linear and linearly shallowing towards the Doldenhorn region. But of course, in reality this basin could have had a much more complicated internal geometry that was potentially responsible for the miss-alignment of the hinge lines.

154 The statement “absence of significant nappes in the Infrahelvetic complex” does not correspond to reality: there are three major nappes (Kaminspitz, Calanda and Tschep), all of which have significant displacements. But what they lack are recumbent folds, a fact that reflects the absence of an Early Jurassic basin and the Middle Jurassic sediments being very thin in comparision to the Late Jurassic and Cretaceous carbonate sequences.

We agree and we actually wanted to state what the reviewer says. We, hence, replaced ‘which explains the absence of significant nappes in the Infrahelvetic complex below the Glarus thrust.’ with ‘which explains the absence of significant recumbent fold nappes in the Infrahelvetic complex below the Glarus thrust.’

155 The Doldenhorn nappe is much much closer in style to the Morcles nappe; it displayes long inverted limbs which are absent in the Glarus nappe complex in eastern

Switzerland.

We agree and we reformulated the sentence.

160-162 This interpretation is contested sharply by Pfiffner et al. (2011).

We are aware that there are different, partly opposing, interpretations. We clarify this. In our interpretation, the regions around Mt Joly and Aravis are part of the Subalpine chain. However, we follow the interpretation of Epard 1990 (and also Collet,1943) and argue that this region of the Subalpine chain has been deposited in the same North Helvetic basin as the Morcles nappe. Therefore, in our simplified model, the Subalpine chain results also from extrusion out of the North Helvetic basin during its closure.

509 The Chamonix-zone does not show a synclinal structure in nature. The Mesozoic sediments show a consistent younging from the Mont Blanc massif to the NW. The youngest sediments then but against the Aiguilles Rouges massif's basement. This is clearly visible form the structural maps 1:100'000 that you cite earlier on (Pfiffner et al. 2010).

We are aware that Pfiffner et al. 2010 do not interpret the Chamonix-zone as a syncline. However, several geological maps clearly show a synclinal structure with respect to the younging direction of the cover sediments of the Aiguilles-Rouges and Mont Blanc massifs (e.g. Paréjas, 1922; Ayrton, 1980; Oulianoff, 1924; Ayrton et al., 1987). These younging directions, indicating a synclinal structure, have also been verified in the field by one of the authors. We, therefore, maintain our interpretation in the manuscript, but mention the different interpretation of Pfiffner et al., 2010.

498 This statement about the Helvetic nappes needs a reference.

We added a reference to Pfiffner 1993 and reformulated the sentence.

512/13 Fig 14 The intention of this figure is much appreciated. I have some worries though if strain ellipses determined from pressure shadows are directly compared to strain determined from deformed oolites. And what are the contributions to the figure

by Bastida, Dietrich & Casey, Casey & Dietrich? Strains or cross-sectional geometry? Or are all the strain data from Ramsay & Huber? And I miss the effect of the Permo-carboniferous graben in the Aiguilles Rouges massif (it is partially inverted and folds the Morcles thrust above.

We clarified the contributions of the different authors in the figure captions.

578-605 It is no surprise that the three cross-sections chosen from along strike give different results. Cross-section shown in Fig. 15a is from the Rawil depression where the Morcles-nappe is deeply buried in the subsurface and thus drawn by projection only. The top basement beneath is constrained by seismic data of NRP20 and thus explains somewhat the reduced thickness of the nappe. However, I never put a name to the basement uplifts because of the uncertainty involved and urge the authors to delete them. One could equally well put the names of the Gastern and Aar massif in their place. The cross-section is more reliable for the Wildhorn nappe since this nappe outcrops along the trace of the cross section. The cross section shown in Fig. 15c shows a completely different nappe – and I doubt very much that it should be called Morcles nappe. In fact the Morcles nappe in the type locality “Dent de Morcles” displays hinge lines of internal folds that climb westwards over the Aiguilles Rouges massif, crossing its crest line and then plunge towards the SW beneath the Chablais and the Chaînes Subalpines thrust sheet. The structures shown in Fig. 15c are merely in the same structural position relative to the Chaînes Subalpines thrust sheet. The uncertainty emanating from the construction of (balanced) cross-sections could be extracted from the numerous cross-sections drawn along the trace of the cross-section shown in Fig. 15b. One of the main reason for divergent solutions is the observation that the lower limb is more horizontal whereas the upper limb plunges with 30âŮę to the NE (see discussion in Pfiffner 1993, a reference referred to in the manuscript). There aren’t many cross-sections constructed along curved hinge lines as is necessary in this situation. The one shown in Pfiffner (1993) is based on the construction of Langenberg et al. (1987) who did use curved hinge lines. The major effect of the differing plunges is the

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thickness of the Morcles nappe. Curved hinge lines yield a thickness of ca. 5 km, the cross-section by Escher et al. (1993) used in Fig. 15B suggests 7 km.

As mentioned before, we clarified our interpretation concerning the Subalpine chain and the Morcles nappe. We agree that different projections can yield different thickness in cross sections. This is why we show different sections, also to raise awareness that thickness and geometries from cross section should not be considered as axiomatic data when comparing them with numerical models. We clarified the text.

609-613 Does not present a conclusion. For me one important conclusion is the next following sentence (Nappe detachment, transport . . ..)

We deleted line 610 - 612 to make the conclusion more concise.

618-619 The importance of fieldwork in such a scenario is common sense.

We modified the sentence from 'Consequently, the results emphasize the importance of geological field work and reconstructions of the initial geological situation before fold-and-thrust belt formation.' to "Consequently, the results emphasize the importance of the initial geological situation before fold-and-thrust belt formation."

623 This is the place that screams for a statement on the nature of the strain in and out of the cross-sectional planes.

We added information on the strain.

628-638 These are findings that should go into the abstract.

We modified this section, but keep it in the Conclusions. We think it is a main Conclusion of our study that our model, which is based on standard rheological models and ignores micro-scale processes such as grain size reduction but considers pre-Alpine extensional structures, can reproduce several first-order features of the Helvetic nappe system.

Technical corrections

18 French-Swiss Alps is not a common denomination. I suppose you wish to include the Haute Savoie part of France. I suggest “Central Alps of France and Switzerland”

74, 108 see 18

Ok, we preplaced French-Swiss Alps by Central Alps of France and Switzerland

76-77 “laterally” instead of “along the lateral direction”?

Ok, we re-worded the sentence accordingly.

111 I suggest “Glarus nappe complex of eastern Switzerland”

Ok, we re-worded the sentence accordingly.

148 Diablerets

Ok, we re-worded the sentence accordingly.

326 2D numerical cross sections: why specify “numerical” here? All is numerical. And wouldn’t “thrust sheet” be a better term than “thrust nappe”, particularly as it is opposed to “fold nappe”?

We just want to be clear, otherwise for some readers it might not be clear whether we talk about geological or numerical cross sections. We just want to use the same term “nappe”, since otherwise some readers might ask what is the difference between a nappe and a sheet.

496-497 suggestion: The resulting model nappe stack shows laterally major structural differences.

Ok, we re-worded the sentence accordingly.

515 It would be better to formulate what is observed, and not what is not observed (contact to basement)

We also would like to mention the differences between model and geological sections.

548 report (not reports)

Ok

549 frontal part

Ok

551 Doldenhorn and Glarus nappes (or Doldenhorn nappe and Glarus nappe complex)

Ok, we re-worded the sentence accordingly.

554 suggest

Ok, we re-worded the sentence accordingly.

563 start a new paragraph with “In terms of. . ..

Ok.

624 modeled by a stress cut-off at 40 MPa (instead of “due to”)

Ok, we re-worded the sentence accordingly.

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2019-173/se-2019-173-AC1-supplement.pdf

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