

# ***Interactive comment on “From widespread Mississippian to localized Pennsylvanian extension in central Spitsbergen, Svalbard” by Jean-Baptiste P. Koehl and Jhon M. Munoz-Barrera***

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In their manuscript, Koehl and Munoz-Barrera present new insights on the Carboniferous tectonic and structural evolution of central Spitsbergen. Using observations from satellite images and field evidence from newly exposed outcrops, the authors provide a thorough examination of the local geology and comprehensive discussion of their observations and interpretation. The key results of the study are i) that Mississippian strata was indeed deposited during Mississippian extension, and ii) that Mississippian fault activity and sediment deposition was likely controlled by pre-existing basement-rooted faults and lineaments. As such, the study represents an important contribution

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to the understanding of the Paleozoic tectono-stratigraphic history of Svalbard, but also has implications for the understanding of pre-existing structure reactivation. Many recent studies on structural inheritance use relatively low-resolution seismic reflection data, but this study provides actual field evidence for the potential reactivation of basement structures. In general, the manuscript represents a well written and thought-through piece of work. The arguments for the interpretation made are clear and sound. Outcrop photographs are of good quality and support descriptions and interpretations made in the text. My detailed comments outlined below can be grouped into three key recommendations which will further improve the communication of the study results and make the manuscript applicable for a wider audience. If these recommendations are addressed sufficiently, I would like to recommend this manuscript for publication in SED.

Key recommendations:

1) Throughout the manuscript, detailed descriptions of geological structures, formations etc. and the correlations of observations made in Svalbard with similar structures in e.g. the Barents Sea or northern Norway are made. However, in many cases, the location of structures, outcrops etc. is not shown on maps and it is unclear over what distances structural correlations are made. Therefore, some of the correlations and interpretations between structural trends can appear a little farfetched and undermine the good work, especially for readers who are unfamiliar with the geology and tectonic history of the wider study area. Supplementary structural element and plate-tectonic reconstruction maps may help to support the interpretations made by the authors. In general, more references to relevant figures are needed throughout the text.

2) In general, the description of field observations is very detailed and easy to follow. However, I recommend being more quantitative when it comes to extension direction, fault dip, amount of displacement, bed thickness etc. This additional information gives the reader a better idea about the size of structures and enables a better comparison with observations from other field or subsurface studies. In addition, most figures

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presented in the manuscript require horizontal and vertical scale bars.

3) The current manuscript is very focused on the reconstruction of the Carboniferous tectonic history of Svalbard, but wider implications of the study results are not discussed. Obvious additional discussion themes could address the role of structure reactivation and stress field perturbations in more detail. Another possibility could be the use of this study as a potential analogue to subsurface studies in the Barents Sea or a comparison of the findings to other studies (e.g. field, subsurface, or modelling studies). Addressing the wider implications of this study will increase the impact of the manuscript and make it applicable to a wider scientific audience.

In addition to these three key recommendations, the following aspects should be addressed in the revision of the manuscript:

Specific comments (text):

Abstract:

The abstract is currently very long and contains complex sentences (e.g. the last two sentences). The rationale and motivation of the study is briefly stated in the middle of the abstract (L19-20). However, to emphasize the importance of the study, I suggest moving statements about the study motivation to the first part of the abstract and to add comments on the wider implications of the study. For example: Why is this study important locally and how can the results improve our understanding of e.g. the tectono-stratigraphic evolution of Svalbard? What are the implications for studying basin evolution in the presence of pre-existing basement structures? What is the role of local stress perturbations in fault reactivation? etc.

L24: What is the strike of these basin-oblique, NNE-dipping faults? How do they relate to WNW-ESE-directed extension? Could it be that strike and dip got mixed up and that the faults strike NNE?

L32: pre-existing, not existing

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L33: transverse faults, not fault

L37: add commas and write décollements with an é: ...and shallow dipping, bedding parallel, duplex shaped décollements...

L37-38: Out of curiosity – Why would mechanically softer layers such as shales prevent further fault movement? Wouldn't thrust faults preferentially move along the shales? Please clarify your thinking here/in the main text (see later comment L571).

Introduction:

The rational and local importance of the study is well explained in the Introduction. A statement about the wider implications of the study would open it up to a wider audience, provided that a 'wider implications' paragraph is added to the discussion section as well.

L: 70: 'control' would be a better word than 'influence'

Geological Setting:

The geology of the study area is very well described, but the structural elements, formations, and localities that are introduced throughout this section are not shown in Figure 1 (apart from the Billefjorden Fault Zone).

I suggest adding a figure that shows the location and geometry of the geology and structural elements present in the study area in more detail. This will also provide a bit more context and spatial reference to the outcrop photographs shown in later sections of the manuscript. In addition, a regional cross-section across the area may help to illustrate the deformational history and vertical and horizontal relationship between formations better. In general, more references to figures are needed to better guide readers who are unfamiliar with the area. As a suggestion, the authors could include a couple of plate-tectonic reconstructions and structural elements maps in the supplementary material to illustrate the Paleozoic plate configuration of Svalbard, Greenland and Norway, as well as major extensional and compressional events.

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L83: Neoproterozoic as one word

L140-141: What was the direction of contraction/plate movement during the Ellesmerian Orogeny? Was it SW?

L145: successions in the footwall and hanging wall of faults?

L168. kilometer-scale

Methods:

The description of the methodology is rather short. The resolution, age, and workflow to interpret the satellite images is not provided.

L201: rephrase; e.g. In areas that are difficult to access, satellite images of exposed basement rocks were used to identify brittle faults in exposed Proterozoic basement rocks. . . .

Results:

Basement rocks: L219-221: Can you indicate the faults that cross-cut the Atomfjella on a map? Where is Ny-Friesland?

L224-225: See previous comment. Please indicate the mentioned localities on a map, otherwise the reader has no idea about the location and distance between areas with WNW-ESE-trending faults and basement structures. A map will help to support your interpretation.

Sedimentary rocks: L234: south-to-southwestward

L241: How thin are these beds? Be quantitative.

L244: ' . . .previous descriptions. Plural.

L248: Remove 'However'. Start sentence with: Iron nodules found in the upper part. . .

L250: Replace 'On the contrary' with 'However',

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L259 and throughout this paragraph: How thick are the described sandstone and shale beds? There is no scale in the photograph in Figure 7.

Brittle faults: L276: You state the amount of displacement along these faults in the figure caption, can you also add it in the text?

L278: Can you quantify the amount of thickening?

L288: décollements

L292: décollements

L307: cross-cut

L301 & 303: cross-cutting

L315: cross-cut

L320: Is it possible to estimate the amount of displacement across the Overgangshytta Fault? e.g. order of magnitude. I see that you provided an estimate on L355, but it would be nice to also have this in the results section.

Discussion:

The discussion section represents a very thorough examination and discussion of possible interpretations for the observed structures. Parts of the discussion/interpretation can be supported by additional figures to support the author's arguments and to better guide the reader. The current manuscript does not include a section on the wider implications of the results of this study. I suggest to add a paragraph on this at the end of the discussion section.

L325: The first sentence of the Discussion section repeats the last sentence of the previous paragraph (L318-321). I suggest rephrasing these sentences to avoid too much repetition.

L328-330: This sentence suggests that, based on the fault core width and amount of

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deformation, the Overgangshytta Fault does not terminate nearby. Can you support this interpretation with a reference to studies that investigated the relationship between fault length/displacement and deformation zone size?

L345: kilometer-thick

L348: meter-to-kilometer-scale, down-to-NNE

L360-381: It is difficult to believe how basement structures in Spitsbergen correlate to fault zones in northern Norway without showing plate-tectonic reconstructions (see earlier comments on the lack of supporting figures). The Timanian Orogeny has not been introduced at the beginning of the manuscript. At the moment, the interpretation of the WNW-ESE-striking faults appears to be based on long-distance, map-view correlations and may seem a little farfetched. However, additional figures illustrating the geometrical and plate-tectonic relationship between the correlates basement structures in Spitsbergen, the Barents Sea, and northern Norway may support and clarify the presented interpretation.

L410-411: Can you quantify the amount of reverse displacement along the fault? e.g. meter-scale or tens-of-meter?

L412: décollement

L416: What is the scale of these 'minor thrust faults'?

L428: décollements

L435 and following paragraph: What is the dominant extension direction during the Mississippian? How does it relate to the N-S, NE-SW, and WNW-ESE-striking faults observed in the area? Was there a preferential reactivation of faults oriented perpendicular to the extension direction? Or may local strain perturbations be responsible for the activation of basin-oblique faults?

L439: Can you quantify the amount of thickening? It looks very minor on the outcrop

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photograph in Figure 8. Please add vertical and horizontal scales to every figure.

L440: cross-cutting

L447: is believed

L450: paleo-current data

L465-469: This sentence is very long and complex. Please rephrase. Add commas between shallow-dipping, bedding-parallel, duplex-shaped décollements.

L470-476: See previous comment above. It is difficult to picture the spatial and geometrical relationship between WNW-ESE-striking faults in Spitsbergen, northern Norway and Greenland without any maps. These seem to be very long-distance correlations unless you show that these faults originate from the same locality during Late Devonian-Carboniferous.

L491: Again, what is the Mississippian extension direction? How does the stress field look like?

L493: cross-cutting

L497: Please quantify the dip angle of the Billefjorden Group

L508: (b) not (a)

L512: Where is Kongsfjorden and the Brøggerhalvøya located? Please indicate on a map.

L523: local absence of the Late Mississippian unconformity

L533: What is the direction of compression/transpression?

L540: How far away is the Finnmark Platform from the study area? This seems to be a very long/distance correlation.

L546 and following paragraph: What was the extension direction? Was it stable or

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did it change? Can the activity of faults that are not preferentially aligned towards the extension direction be explained by local, potentially basement fabric-controlled, stress/strain perturbations? It would be nice to illustrate fault activity (e.g. initiation phase, interaction and linkage phase etc.) and extension direction through time on map-view sketches.

L571: décollements; How thick are the shale beds? Are they thick enough to decouple faulting on N-S faults from WNW-ESE faults? It would be good to support this statement with a literature reference, e.g. studies on mechanical stratigraphy (Wilkins, S. J., & Gross, M. R. (2002). Normal fault growth in layered rocks at Split Mountain, Utah: influence of mechanical stratigraphy on dip linkage, fault restriction and fault scaling. *Journal of Structural Geology*, 24(9), 1413-1429.)

L577: cross-cut

L578: Please quantify the amount of offset

L582: small amounts: plural

Conclusions:

Each conclusion point consists of a single, very long and complex sentence. Please consider breaking them up into multiple sentences to make it easier to follow them. Consider adding a conclusion point that illustrates the wider implications of your study results.

L650: pre-existing Neoproterozoic faults; remove 'which' at the end of the sentence.

L663: décollements

L666: décollements

Specific comments (figures):

Figure 1B: The map doesn't show many localities and formations that are mentioned

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in the text. Please add them. It would also be useful to have a structural elements map for the Late Devonian-Carboniferous covering Svalbard, the Barents Sea, northern Norway and Greenland (see comments above). A map like this would make it easier to follow your thinking and interpretations.

Figure 2: The orange and green colours shown in the stratigraphic chart are not explained in the legend. Please add them.

Figure 3: Although you stated an approximate scale of each satellite image at the end of the figure caption, please add a scale bar in every image. The interpreted foliation and lineaments are actually difficult to see on the dark rocks. Is there any change to improve the image quality?

Figure 4: What do the pink and blue arrows indicate? Not all brittle faults have a dip direction indicator? Is the dip of these faults unknown?

Figure 5: Please add vertical and horizontal scales to photograph A. The label 'Fig. 4b' in photograph A seems to be wrong.

Figure 6: Please add horizontal and particularly, vertical scale bars. An approximate outcrop size is not enough.

Figure 7: Please add horizontal and vertical scale bars. Location of 7A is not indicated in Figure 4.

Figure 8: Please add horizontal and particularly, vertical scale bars – at least in B and C. An approximate outcrop size is not enough. Indicate the location of these outcrops on Figure 4.

Figure 9: Please add horizontal and particularly, vertical scale bars. An approximate outcrop size is not enough. Indicate the location of these outcrops on Figure 4.

Figure 10: Please add horizontal and particularly, vertical scale bars. An approximate outcrop size is not enough. Indicate the location of these outcrops on Figure 4. Add

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'southeastward view of the Overgangshytta Fault' for the description of A in Figure caption. Location of 10D is not shown in 10A.

Figure 11: Please indicate profile location in Figure 4 and add approximate horizontal and vertical scales. Profiles like this greatly help the reader to follow the description of your observations and interpretations. It might be useful to refer to this figure earlier in the manuscript, e.g. in the results section.

Figure captions: - Replace crosscut with cross-cut where applicable

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Interactive comment on Solid Earth Discuss., <https://doi.org/10.5194/se-2018-86>, 2018.

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