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Interactive comment on "Devonian–Mississippian collapse and core complex exhumation, and partial decoupling and partitioning of Eurekan deformation as alternatives to the Ellesmerian Orogeny in Spitsbergen" *by* Jean-Baptiste P. Koehl

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Comments to the manuscript "Devonian-Mississippian collapse and core complex exhumation . . ..." by Jean-Baptiste P. Koehl (MS No.: se-2019-200)

General Comments: The manuscript "Devonian-Mississippian collapse and core complex exhumation, and partial decoupling and partitioning of Eurekan deformation as alternatives to the Ellesmerian Orogeny in Spitsbergen" presents a dramatic and rev-

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olutionary change in the hithero existing knowledge and interpretation of the structural evolution and geological development in the geological history of the archipelago of Svalbard. The argumentation and conclusion in this manuscript is based on (i) fieldwork in a small outcrop area in the vicinity of the Balliolbreen Fault near the Pyramiden Mine, (ii) on interpretation of a satellite image at the Groenhorgdalen/Triungen Fault Zone, (iii) on some seismic sections in the Tempelfjorden area and on publications (iv) on the Adriabukta Section (Hornsund) (Bergh et al. 2011) and (v) on a Devonian core complex in NW-Spitsbergen (Braathen et al. 2017). Reading the manuscript, I have the impression, that the author hasn't done any structural fieldwork except for the outcrop at the Pyramiden Mine. Except for this outcrop, all arguments are based on indirect observations (satellite image, seismic section) or on interpretations within the literature. For such a far-reaching hypothesis that the Ellesmerian Orogeny has not affected the Svalbard archipelago, the analysis of a single outcrop (with only 130 measurements!) is absolutely inadequate. The assumption, for example, that the base of the Billefjorden/Gipsdalen groups north of Isfjorden is a detachment instead of an unconformity, was not proven by the author, and the (Ellesmerian) structures directly west of the Balliolbreen Fault were not studied and compared with the Eurekan structures along the BFZ. In his manuscript, the author has also compared tectonic structures within the centre of the Devonian Andrée Land Basin in Andrée Land, but it is not obvious in the text, that he has really seen and worked on the structures in Andrée Land. However, that question, if the Ellesmerian deformation has affected Svalbard or not, is too important to be solved by the anaylsis of just one outcrop. For such a revolutionary idea, the presented data are too poor.

The question if the Ellesmerian deformation has affected Svalbard or not would really be of scientific significance and would represent a substantial contribution to scientific progress concerning the tectonic evolution of the Arctic. However, as stated above, the conclusions that the Ellesmerian Orogeny is not present on Svalbard, and that the structures earlier described as Ellesmerian structures, can be explained by the results of a Devonian core complex and a de-coupling and partitioning of the Eurekan

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deformation are based on very poor structural outcrop results restricted to an extremely small area.

The scientific approach and applied methods are not very valid. Apart from the field observations from the outcrop area at the Pyramiden Mine, the manuscript is full of assumptions, and most of the interpretation is not based on hard geological and structural field data. Hence, the results are often not discussed in an appropriate and balanced way. In many aspects, the selection of published work and references is one-sided, so that related work and many publications are not considered.

The manuscript is too long, and many descriptions, argumentations and conclusions can be condensed. I am very impressed by the number of references and the work on the literature research. The quality of the figures can be improved: most of the figures are much too small, and it is difficult to recognize the structures, names and symbols mentioned in the text.

Specific comments: It does not happen very often, that an entire fold-and-thrust belt and an entire orogeny are suggested to be abolished and disappear, and being replaced by a (possible) combination of (a) the formation of core complexes all over Spitsbergen and (b) the extent and enlargement of the Paleogene Eurekan deformation across entire NW-Spitsbergen towards the areas which were interpreted as part of the Ellesmerian Orogeny before. However, although the Ellesmerian (Svalbardian) Fold-and-Thrust Belt on Svalbard was object of many controversial discussions in the literature especially concerning the kinematics and its timing, the geoscientific community from the first observations in the beginning of the 20th century until now has generally agreed that the Svalbardian deformation event has taken place without a doubt. I am not against new ideas and open to new interpretations, however, the consequences presented in Koehls' manuscript are eminent to such an extent, that this ideas and the resultant change of the well-established geological history proved by thousands of hours of mapping and structural observations in the field with countless samples and measurements by so many geologists within the last hundred years

across entire Svalbard in the field should be very carefully formulated and should be, of course, based on really extensive, well-documented and significant new field data. If the argumentation of the author is only based on field observations restricted to a small outcrop at Pyramiden near the Balliolbreen Fault, he should be really careful to suggest an overall, regional detachment across northern Spitsbergen.

The argumentation within the present manuscript is mainly based on four or five columns: a) The timing of the Ellesmerian deformation on Svalbard b) Structural implications (detachment at the base of the Billefjorden Group) c) The assumption of core complexes on Svalbard d) Field observations, aerophotographs and seismic sections

Below, I would like to focus on the items listed above: (a) The timing of the possible Ellesmerian/Svalbardian deformation on Svalbard: The author is talking about the Devonian to Mississippian sedimentary succession overlying Early to Middle Devonian sedimentary units throughout the manuscript. But the author should mention that there are different opinions and that the age of the Billefjorden Group is still a matter of debate: Our group and other geologists have suggested that the onset of sedimentation of the Billefjorden Group started in Viséan times and that the age of the uppermost Mimerdalen Group is Famennian (which is very similar to the Okse Bay Formation on Ellesmere Island (Beauchamp et al. 2018)). This is in contrast to Berry, Marshall and colleagues who suggested an older age for the Plantekloefta Formation and a Fammenian age for the base of the Billefjorden Group. This different opinions and interpretations on the ages of the sedimentary units (and therefore the Ellesmerian deformation) should be discussed in the manuscript. The author is, of course, free to use one of the two opinions, but he should mention, why he is choosing one of the two opinions. It is not a good scientific way to ignore other opinions. Therefore, it would be probably much better to use the neutral names of the stratigraphic units (Billefjorden/Gipsdalen groups overlying the Andrée Land Group/Mimerdalen Subgroup) instead of using confusing time segments (e.g., Devonian – Mississippian, Upper Devonian – Mississippian, Mississippian to Pensylvanian). Apart from the ages of the sedimentary units, the au-

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thor should use the existing stratigraphic division of the upper part of the Devonian Old Red Sandstone: the Mimerdalen Subgroup and subordinary formations and members, which is not mentioned by the author, was accepted by the Norwegian Stratigraphic Committee und should be considered. However, the exact timing of the Ellesmerian deformation (Late Devonian (Frasnian?) or Tournaisian) is not important for the question, if the Ellesmerian deformation exists on Svalbard or not. Both time frames are possible for the Ellesmerian (Svalbardian) deformation on Svalbard, North-Greenland and the Canadian Arctic.

(b) Structural implications (detachment at the base of the Billefjorden Group): For the conclusion in the presented manuscript that the Ellesmerian deformation does not exist on Svalbard, the nature of the contact between folded/thrust-faulted Andrée Land Group/Mimerdalen Subgroup and overlying mostly horizontal Billefjorden and Gipshuken groups is extremely important. The central interpretation in the manuscript is the statement, that this contact is poorly constrained (unconformity or detachment) in the Mimerdalen area (Fig. 1) and between Dickson Land and Oscar II Land (Fig. 2). This may be correct for the small described outcrop at the Balliolbreen Fault near the entrance of the Pyramiden coal mine. But I don′t know, if the author has paid attention to or has seen and investigated this contact in the areas in central Dickson Land west of the Balliolbreen Fault (Fig. 1), in James I Land and further west towards the West Spitsbergen Fold-and-Thrust Belt (Fig. 2). It makes the impression, that the author is convinced that the contact of the Billefjorden/Gipsdalen groups on top of the ORS is poorly constrained everywhere. This indicates that it would be possible that the entire base of the Billefjorden/Gipsdalen groups between the BFZ and the WSFTB in the west might be a huge, regional detachment (Fig. 2). As this question is extremely important for the interpretation that the Ellesmerian deformation is not present in Svalbard, this fact should be more supported in the manuscript, either by own structural data and field analyses in those areas or by existing geological maps and publications. It is clear and well-known from seismic data, mapping and detailed structural fieldwork from a number of authors and publications that detach-

ments exist in the Carboniferous/Permian evaporates and Triassic and Jurassic shales underneath the Central Tertiary Basin that transfer the deformation from the WSFTB ENE-wards to the BFZ and the LFZ. However, a large-scale detachment at the base of the post-Devonian sedimentary succession (base of Billefjorden/Gipsdalen groups) is nowhere indicated, described, shown or published in any existing geological map or stratigraphic, sedimentological or structural publication between BFZ in the east and the WSFTB in the west: this base is shown and described almost everywhere as a sedimentary contact and unconformity. The author has argued that the folds, reverse faults and thrusts described as Ellesmerian structures between the BFZ and the west coast of NW-Spitsbergen before, can be explained by de-coupling during the Eurekan deformation. Again: we are absolutely not against Eurekan structures in the vicinity of the BFZ or Lomfjorden Fault Zone (see Piepjohn et al. 2019) and reactivations of older structures during the Cenozoic deformation: such structures exist and have been earlier described by a number of authors. But the author should really compare the small-scale tectonic structures he has described in the manuscript in one single outcrop at Pyramiden with the kilometer-scale fold structures and thrusts in Dickson Land (Fig. 1) and in Andrée Land and in the Liefdefjorden area. It is a characteristic of the Ellesmerian/Svalbardian deformation, that all structures (except for Soerkapp Land – and this question is still unsolved) are characterized by tectonic transports to the west (Fig. 2), indicated by west-vergent folds, west-directed thrusts and by a formation of an intense fracture cleavage. This direction is perpendicular to the general ENE-directed transports (fold structures, thrusts, fracture cleavage) of the Eurekan deformation (Fig. 2). In the Kongsforden area, the Eurekan structures turn into a NW-SE direction (NE-directed transports) forming a big angle with respect to the N-S trending, W-directed Ellesmerian structures (Fig. 2). This is not explained in the manuscript. From our point of view, and after observations of both orogenies along the entire west coast of Spitsbergen and in entire NW-Spitsbergen, there is a big difference in the architecture of the Ellesmerian and Eurekan structures. And the relative age control is proven in the Mimerdalen area in central Dickson Land by the Billefjorden Group unconformably

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overlying large-scale folds and thrust faults. If the assumption of a regional detachment underneath the Billefjorden/Gipsdalen groups should be correct, some questions appear: the dimensions of the fold-and-thrust zones in the Devonian (and also pre-Devonian rocks at the west coast of Spitsbergen north of Kongsfjorden) are quite big, and they are often characterized by out-of-sequence thrusts. How should it be possible that, if all the deformation is Eurekan, a sub-Billefjorden Group detachment was developed carrying the entire post-Devonian sedimentary succession westwards and cutting through all the fold-and-thrust zones (Fig. 3)? The author argues that, e.g., the Balliolbreen Fault and the lower Munindalen Thrust are not truncated by the post-Ellesmerian unconformity using this as an argument for the absence of the Ellesmerian – but the author does not take into account that there is a kilometer-scale Dicksonland Fold-and-Thrust Belt which is overlain by Billefjorden Group in central Dickson Land (Fig. 1).

(c) The question of the core complexes: The author refers to a publication by Braathen et al. (2017) who suggested the existence of a large-scale, long-lived crustal detachment throughout Devonian times in the northwest part of Spitsbergen. From our knowledge of this area based on structural works during my own PhD-thesis and detailed mapping together with the NPI-colleagues over at least 6 or 7 field seasons, the existence of such a crustal detachment or core complex is improbable: (a) the geological situation is much more complex, (b) the documentation and description of the presented data is not convincing, (c) the age determinations are partly from areas 30 km away or are wrongly located, (d) the existence of structures (folds, thrusts, cleavage) of the E-W contraction of the Ellesmerian deformation is not even mentioned, (e) the mapped sedimentary contacts of the Devonian on top of the brecciated, weathered and karstified basement marbles is ignored, and (f) the relation of ductile shear zones within the pre-Devonian basement rocks to the structures within the overlying Devonian rocks is not really taken into account. However, even if the existence of such a core complex would be correct, the author refers to this core complex assuming that a lot of other locations along faults like the Pretender Fault or faults in Soerkapp Land

represent Devonian core complexes as well and that those assumed core complexes, instead of the Ellesmerian deformation - are typical and characteristic for entire Spitsbergen – again without checking and comparing this in the field at all questionable locations! There is also the contradiction between the assumed northward transport of the Devonian on top of the core complex, and the observed structures in the Devonian (folds, thrusts, cleavage formation) which prove an overall E-W contraction in this area. In my eyes, this is very dangerous! In the Devonian, there is no evidence for north-directed movements. Especially concerning such an important question if an entire Orogeny is present on Svalbard or not! Concerning the question of the assumed core complex in NW-Spitsbergen. It would be a good practice in science not only to refer to Braathen et al. (2017) but also to the field data and mapping results of previous work. The observations and interpretations of the “pro-Ellesmerian” people and the “pro-core complex” people are conflicting and disputed to such an extent, that the question of Ellesmerian structures versus core-complex structures should be discussed in the present paper. For this purpose and the conclusions in the present manuscript, the scientific differences are too big, and the author should take a form stand why he prefers the core-complex interpretation. However, Braathen et al. (2017) also haven′t discussed this elementary question in their paper also. As an example: from line 1175, the author writes that “A possible trigger for the steep eastward dip of Devonian (-Mississippian?) sedimentary strata of the Mariekammen and Adriabutka formations (after restoration) in Adriabukta (Fig. 1; Fig 5) MAY BE a core complex exhumation of Neoproterozoic basement rocks in the west (Fig. 7a-d), AS OBSERVED in central (Koehl, 2019; Koehl et al., in prep) and northwestern Spitsbergen”. This is unbelievable: How can the author conclude the existence of a Devonian core complex just because the Devonian rocks are tilted? And this conclusion is only based on Bergh et al. (2011) from NW-Spitsbergen and on the authors assumption from central Spitsbergen? Without any fieldwork and structural observation? However, there is a very easy explanation for the tilted Devonian rocks in the Adriabukta based on mapping and 3 days of structural fieldwork along the Adriabukta section: the Devonian rocks were

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folded (F1 and F2 in the Adriabukta Fm) and thrust-faulted including the formation of e distinct fracture cleavage before the deposition of the Billefjorden Group: the Ellesmerian deformation! This scenario is much easier to explain than the existence of an assumed core complex. If there is a core complex: please give me evidence!!!

(d) Field observations, aerophotographs and seismic sections: Many interpretations in the presented manuscript are based on structural fieldwork within a very small outcrop area at the Balliolbreen Fault near the entrance of the Pyramiden Mine (Koehls' Fig. 2, 3a, 3b). That is great, because no geologists have paid attention to this outcrop before. And I completely agree that many structures in this outcrop represent Eurekan structures, especially in the sedimentary rocks of the Billefjorden Group and younger stratigraphic units, but also partly in the Early Devonian Wood Bay Formation to the west of the Balliolbreen Fault. On the other hand: some structural observations restricted to a single small outcrop (with a total of just 130 measurements!!) are not enough to really present serious arguments for a fundamental change in the geological history of Spitsbergen and in the elimination of an entire Orogen. The second outcrop presented and described in the manuscript is reduced to a satellite image of the Triungen-Grønhorgdalen Fault Zone west of Triungen (Koehls' Fig. 3c). Disregarding that nothing is really visible on the images, not a single field observation has been done in the Triungen area, and no real field data are described or presented in the manuscript. Regardless, the author uses the very poor to nonexistent evidence from the satellite images to support his assumptions. The third outcrop area is located along the Adriabukta profile in inner Hornsund. Again, I have the feeling that author has not visited this outcrop, because own field data and measurements are not described in the manuscript. And the author again does not take into account that previous detailed work has been done along the Adriabukta outcrop, e.g., von Gosen and Piepjohn (2001), who have presented different ideas. His interpretation is therefore only based on some selected publications, e.g., Bergh et al. (2011) - this avoids discussion and dispute on the very difficult geology at Adriabukta. However, the author concludes again, that the Ellesmerian deformation was not present in southern Spitsbergen but a

Devonian core complex has developed instead. This is really a dangerous conclusion (similar to the authors statement on the Pretender Fault): the author does not present serious arguments, field data and observations, but assumes all the time in several locations from very poor considerations that the Devonian/Carboniferous history of entire Svalbard is dominated by the absence of the Ellesmerian deformation and the presence of Devonian core complexes. Very fast assumptions turn into “truth” in this manuscript! The author uses and presents seismic sections from Tempelfjorden and Reinsdalspasset (by the way: it is a lot of work to look for and to identify the locations of the seismic sections on Figure 1a, b). In my eyes, most of the seismic sections presented in the manuscript, are over-interpreted. The question, for example, if Devonian deposits are present east of the Billefjorden Fault Zone in eastern Nordenskiöld Land, cannot be really answered. As I know from colleagues working on the interpretation of seismic sections at BGR, it is always difficult to interpret the stratigraphy in seismic sections if there are no drill holes or outcrops near the section. In the presented manuscript, the interpretation is careful (the existence of Devonian sediments east of the BFZ might be possible), but later in the interpretation, this weak argument becomes important and almost fact to argue against the Ellesmerian deformation. It would be better to be a little bit more careful using the seismic sections really as arguments. In addition: the presented seismic sections in the figure are unfortunately not really readable: what is described in the text, cannot really be recognized in the figures.

If it is correct that the Ellesmerian deformation has not affected the Devonian ORS sandstone and underlying basement rocks, another question appears: before the Late Devonian, the geological history of Svalbard (and the Pearya Terrane) on the one hand and North Greenland and the Canadian Arctic on the other hand was completely different. Already some million years later, Spitsbergen was located somewhere north of northern Greenland at least since Early Carboniferous times. This is proven by the similarity of the post-Devonian sedimentary successions in the sedimentary basin on Svalbard, the Wandel Sea Basin in northern Greenland, and the Sverdrup Basin in the Canadian Arctic. Just before, the northern margin of Greenland and the Canadian

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Arctic were affected by the formation of the 100 – 350 km wide Ellesmerian Fold-and-Thrust Belt. What happened in between? There must have been an approach and collision of Svalbard/Pearya with the northern margin of Laurentian – which is the Ellesmerian Orogeny. How does the author explains the absence of Ellesmerian structures on Svalbard, when Ellesmerian structures exist to the same time not very far away to the south?

Figures: I like the figure captions very much. They are describing the situation on the figure well and are very detailed. Figure 1: The overview map of Svalbard is ok. But the arrows and localities (Re, Kg, Rs etc.) are too small and only readable with magnifying glasses. The geological map Fig. 1b is too small and very difficult to read. Figure 2: Nice picture – it is a little bit dark. The geological symbols can be bigger and the lines thicker. The lines are difficult to distinguish. And there is enough space for a legend: I don't like always to go from the figure into the figure caption to get the information for a symbol or line – put it in a legend! Figure 3a: same as Figure 2. There is space enough to enlarge the text and symbols in the figure. Figure 3b should be enlarged. It shows some important features which are explained in the text. And again: put the explanation for the lines in a legend on Figure 3b. Figure 3c: this figure is useless and shows nothing which is important for the conclusions in the manuscript. Figure 4: With magnifying glasses, I can see a little bit on Fig. 4a-g, but most of the structures described in the manuscript are invisible on the seismic sections. May be, a higher contrast would be helpful. In any case, the seismic sections should be enlarged and distributed in several figures. Figure 5: It would be very nice, if the documentation in this manuscript would be a bit better: where is the profile in Fig. 5a located? The legend shows that the Adriabukta Fm is Upper Devonian to Mississippian in age. Does it mean that this unit belongs to the Billefjorden Group? In the legend, a Mississippian age is indicated for the Hornsundneset Fm – in the stratigraphic lexicon (Dallmann 1999) the age is indicated as Viséan. By the way: the Hornsundneset Fm is not even indicated in the cross section! This is quite confusing for the reader! In the restored profile Fig. 5b, the restored Adriabukta Fm underneath the Hyrnefjellet Fm is 5-6 km

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thick? And unlimited to the east? And the Mariekammen Shear Zone is a normal fault now? We have interpreted the Mariekammen Shear Zone as a dextral strike-slip fault, Bergh et al. (2011) follows that it is a sinistral fault. Figure 6: This succession of cross sections through time does not show the geological situation exposed in Dickson Land and Bünsow Land across the BFZ: - First of all, the existence of Devonian deposits (Andrée Land Group) east of the BFZ is not proven and is only based on the authors interpretation of the seismic section Fig. 4g. - The Devonian ORS-deposits west of the Balliolbreen Fault are extremely thin near the fault and thicken towards the west. There is no evidence for this assumption. One should also take into account that the base of the ORS-sandstone west of the Balliolbreen Fault is absolutely unknown. Neither the depth of the basement is know nor the nature of the basement. - Fig. 3d shows the situation during Cenozoic thrusting with an anticline including the basement, the Devonian and younger deposits west of the Balliolbreen Fault. Such bending with an eastward dip of the eastern limb of the assumed anticline would suggest downfaulting of the eastern block along the Balliolbreen Fault but not west-directed reverse faulting. And my major question is: where are the kilometer-scale folds and thrusts of the Dickson Land fold-and-thrust zone (compare attached Fig. 3)? - Fig. 6e: there is absolutely nothing to recognize because the little diagrams are much too small. In the figure caption it is written that these parts of the cross section . . . fit into the field observations in key localities discussed in the text. I have not seen that, except for the outcrop at Pyramiden, any of the other outcrops was presented with new and own field observations and field data. And all observations do not argue against the Ellesmerian deformation! Figure 7: This is a very oversimplified sketch as well. Is there any field evidence for the existence of a metamorphic core complex? Going to the area south of Hornsund, Adriabukta Fm is unconformably overlying crystalline basement rocks east of the main Devonian exposures. This is not taken into account in the presented cross sections. I also cannot see the Hornsundneset Fm in the cross section in Fig. 5a.

Literature: I am quite impressed how many publications are cited in the manuscript. However, there are some citations in the text which do not appear in the reference list,

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and vice versa. I have attached a list of missing references below.

Literature check: Baelum & Braathen 2012 – missing in the reference list! Dallmann & Maher 1989 – missing in the reference list! Frodsham & Gayer 1999 – missing in the reference list! Gawthorpe & Leeder 2003 – missing in the reference list! Haremo et al. 1990 – missing in the reference list! Koehl et al. in preparation – missing in the reference list! Lamar & Douglass 1995 – missing in the reference list! Piepjohn & von Gosen 2017 – missing in the reference list! Prosser 2013 – missing in the reference list! Roy 2007 - ok – not free availabe Roy 2009 - ok – not free availabe Roy et al. unpublished – that is not really a reference!!! Schlische 1995 – missing in the reference list! Steel & Worsley 1984 – cited in the reference list but missing in the text!! Thomas 2002 – cited in the reference list but missing in the text!! Welbon et al. 1992 – missing in the reference list! Wilson & Wojtal 1986 – missing in the reference list! Worsley & Mörk 1978 – missing in the reference list!

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2019-200/se-2019-200-RC1-supplement.pdf

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Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-200, 2020.

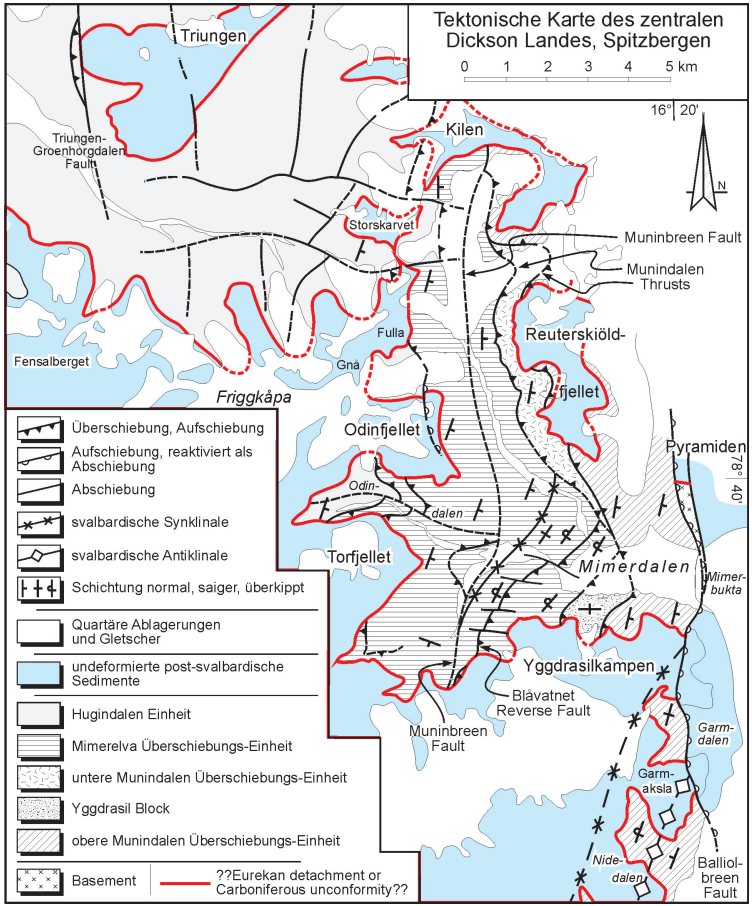

Fig. 1. Fig. 1: Geological Map of central Dickson Land showing the intense deformation within the (Ellemserian) Dickson Land Fold-and-Thrust Zone underneath the mostly horizontal Carboniferous and younger str

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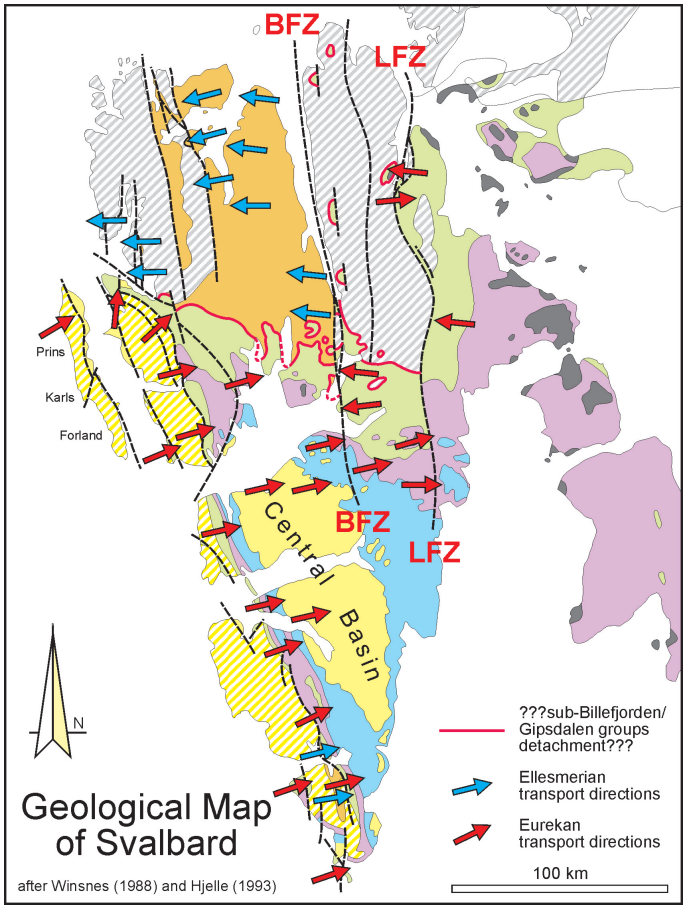

Fig. 2. Fig. 2: Except for Soerkapp Land, the Ellesmerian transport directions are west-directed – in contrast to the ENE-transport within the West Spitsbergen Fold-and-Thrust Belt. There are exceptions in Eu

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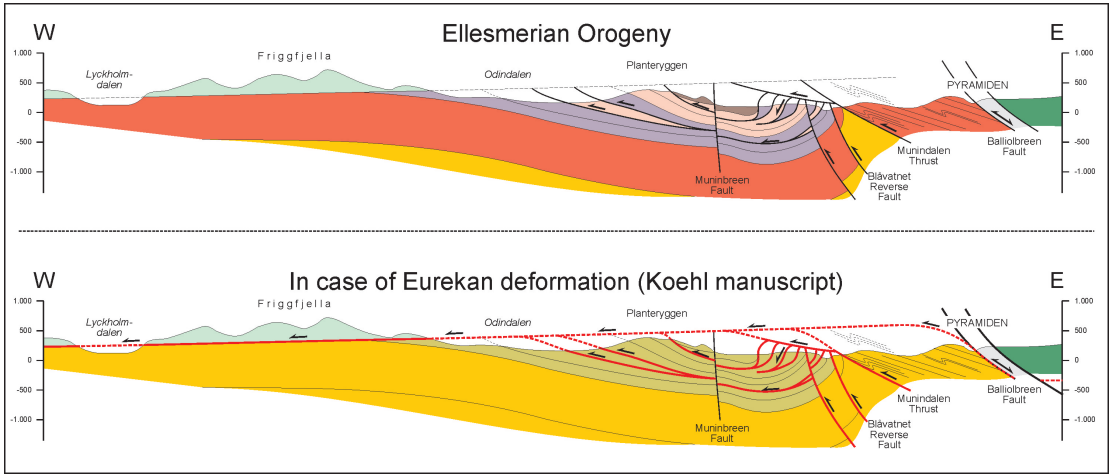

Fig. 3. Fig. 3: Interpretation of an Ellesmerian fold-and-thrust zone unconformably overlain by Carboniferous and younger deposits of the Billefjorden and Dipsdalen groups (above). In case of a Eurekan struct

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