Reply to Fabrizio Balsamo

We thank the reviewer for his extensive review, and many helpful comments. We have implemented, most, of the changes suggested and address some of his points in detail below. In other cases we clarified our arguments. The reviewer has made his concerns into three mainsections, which we will address below:

(1.1) comments from referees/public

> 1a) amount of structural data presented

(1.2) author's response

The reviewer is correct in stating that the measured data point represents the vast majority of measurable slip planes in this outcrop. Some slip planes were simply of too low a quality to measure, or were in positions (on cliffs, in cavities) where measurements were not possible.

(1.3) author's changes in manuscript

We have added lines 192-194.

(2.1) comments from referees/public

> 1b) the completion of the structural map in Fig. 3a with the real fault strands (not only straight isolated lines) and the arrows indicating fault kinematics

(2.2) author's response

We thank the reviewer for this comment. Indeed, the map as it stands now represents more a sketch then a map. The maps published by Johansen et al (2005), however are excellent (see also next comment) .

(2.3) author's changes in manuscript

We have redrafted figure 3, to include the positions , orientations and type (Thin vs thick / set number) from Johansen et al (2005), and also included our own observations.

In addition (not part of this specific comment, but mentioned else were), we included the number of measurements in the steroplots.

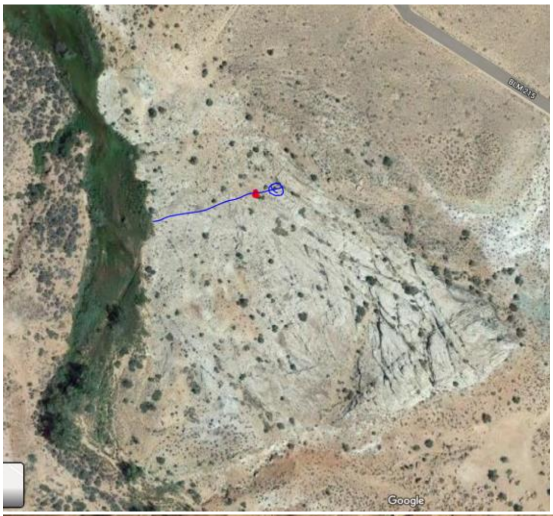
(3.1) comments from referees/public

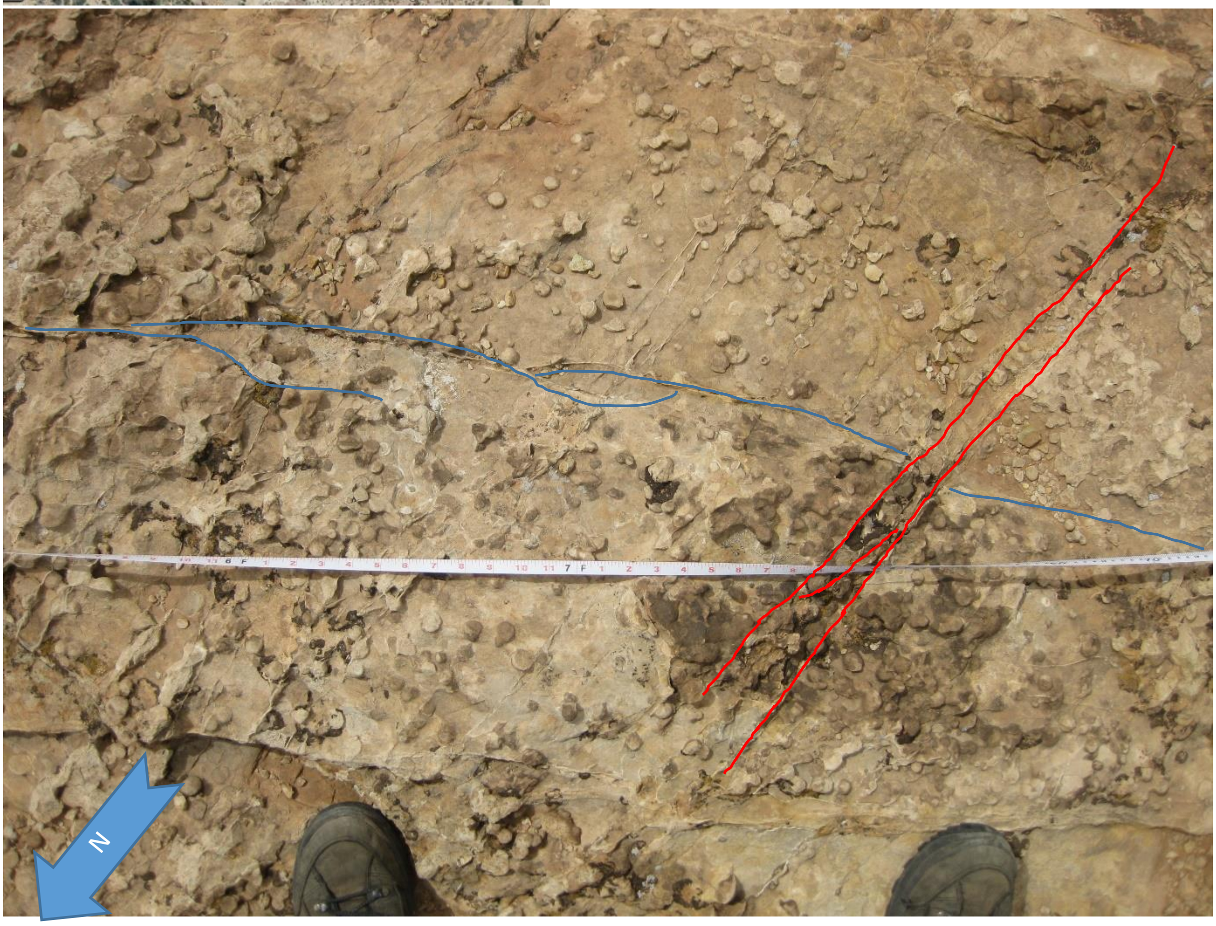
> 1c) more clear evidence (photos) of crosscutting relationships between the different fault sets should be provided (at least for the 3 groups which constrain the evolutionary model in 3 steps).

(3.2) author's response

We have based our work extensively on Johannsen et al. (2005). When working this outcrop we often confirmed their observations, but felt that from a structural mapping/cross cutting study of Johannsen et al (2005) was of such high quality we would not be able to add much. As a result, these cross-cutting relationships were not the focus of our work in this this study.

One example of a crosscutting relationship is in the image below, along a scanline of photo's perpendicular to the main fault (scale is in inches). Main fault Segment A is several meters to the left edge of the image and the set of deformation bands of set 3&4 (highlighted in blue) is off-set by the set highlighted in red (from set 5-6-7).





(3.3) author's changes in manuscript

We have re-written lines 99-108 and added line 108-109 to demonstrate more clearly we rely on Johansen et al (2005) for cross-cuting/age relations.

(4.1) comments from referees/public

2) Figure quality

(4.2) author's response

All comments here are justified and we will make these changes prior to submitting the final version.

(4.3) author's changes in manuscript

We have made the following changes:

Fig 1: improved readability by increasing font size. Moved a) and b) underneath, rather then next to each other. Moved some text from behind the legend box. Added segment names in b). Added * in b).

Fig 2: replaced figure c) by another (higher resolution, more zoomed) image of the same slip plane, as the reviewer mentioned slickenlines were not clearly visible.

Fig. 3: redrafted a) to include the deformation band sets of Johansen et al (2005) and our own observations (with lengths > 5 m). Added number of observed structures next to the stereograms. B) no changes. C) Added number of observed structures next to the stereograms.

Fig 4. No changes

Fig 5. Changed symbology of measurement stations. Added the number of observed structures in the stereogram

Fig 6. Added number of observed structures next to the stereograms. Increased font size and removed a couple of tickmarks /values along the histogram axes to improve readability.

Fig 7. Added number of observed structures next to the stereograms. Increased font size and removed a couple of tickmarks /values along the histogram axes to improve readability.

Fig 8. Added fault ticks. Added segments names. Increased “crispness” of lines.

(4.1) comments from referees/public

3) Typos and text modifications

(4.2) author's response

We want to thank the reviewer for including the scanned document, that was very useful!

(4.3) author's changes in manuscript

We have implemented all these changes (or slightly modified the text where needed to make the point more clearly. We refer to the attached manuscript with tracked changes for more details.

Reply to anonymous reviewer

The authors would like to express their thanks to the reviewer for his or her extensive review, and the helpful comments. We have implemented, most, of the changes suggested and address some of his points in detail below. In other cases we clarified our arguments. Points not addressed here section are accepted and will implemented/changed in the final document.

(1.1) comments from referees/public

1) Authors claim to deal with "thin deformation bands" (cataclastic shear bands), and then interpret their conjugate geometries according to the Navier-Coulomb-Mohr failure criterion. In order to support their interpretation, robust microstructural evidences should be provided.

(1.2) author's response

We thank the reviewer for raising this point and would like to use this opportunity to explain a little bit better.

As described, and published in Johannsen et al. (2005), this outcrop contains 8 sets if "deformation band bundles". In the following we will use the nomenclature of that paper. The bundles of "thick deformation bands" consist of deformation (or most likely: disaggregation bands", sensu Fossen et al. (2007 – J Geol Soc L, vol 164 pp 755-769) consisting dominantly of undeformed grains, and 7 sets of different orientated sets of "thin deformation bands" in which the grain size is significantly reduced by cataclasis. The use of "thin" and "thick" is taken fom Johansen et al (2005) there for a representation of the relative grainsize (thickness of deformation bands being roughly 3 times the grain size).

These deformation bands occur in bundles, of anywhere between 2 to "dozens" of sub-parallel striking, anatomizing deformation bands. Locally within these bundles, highly polished, striated planes are found, which are interpreted by Johannsen et al. (2005) as slip planes, and the striations representing the slip direction. Other authors (Nicholas C. Davatzes et al., 2005; Eichhubl et al., 2009) have interpreted these as (sheared) joints, but the consistent nature of these slip directions, as demonstrated by the NDA analysis shown here, strongly suggest that this is not the case. Also our cross-sections show a marked increase in deformation band density towards the slip plane (fig. 2). In fact, the fact that the NDA analysis of the data clustered according to the sets published by Johannsen et al. (2005) into three apparently internally consistent evolutionary steps, shows that these slip planes have not formed under a single stress regime, but are part of bundle they are part of and formed as this bundle is developing. As these slip planes have formed by dominantly frictional processes, the use of the Navier-Coulomb-Mohr failure envelope is justified as first approximation.

(1.3) author's changes in manuscript

We have re-written section 99-112, and added a reference to Komoroczi (2015) in line 181.

(2.1) comments from referees/public

2) I do not understand the reasons behind the choice of grouping together Sets 5, 6 and 7 made by the authors. According to stereoplots shown in figure 6, the forementioned failure criterion does not justify this choice. Please explain in the revised text.

(2.2) author's response

We agree that the stereo plot shown in Figure 6 does not demonstrate these sets to be conjugate, like sets 1 and 2, and sets 3 and 4 are. During the analysis we found that NDA analysis of these three sets of data (5, 6 and 7) were very similar, which led us to combine these sets into one. This point is glossed over in the text.

(2.3) author's changes in manuscript

We have changed the text in lines 217-218 and elsewhere to reflect this

(3.1) comments from referees/public

Since the authors report that crosscutting relationships among Sets 1&2 and Sets 3&4 were not documented in the field, their relative timing of formation should be better justified.

(3.2) author's response

The cross-cutting relationships between the deformation band bundles with in the triangular Courthouse Junction outcrop were indeed not the main focus of this work. Those relationships have been published in detail by Johannsen et al. (2005), and we have only observations that confirm their work. We will clarify this in the revised text. We do however mention that we did not observe any cross-cutting relations ships, between the two sets of slip-plane data points in location I (section 4.3), in the canyon directly south of the outcrop.

(3.3) author's changes in manuscript

To improve the text we have rewritten lines 99-107 and 250-254.

(4.1) comments from referees/public

4) Finally, I recommend to improve the quality of the field structural maps shown in Figure 3 by adding details on attitude and abutting/crosscutting relationships among the various structural elements

(4.2) author's response

We agree with this point and will include more structural detail into the map.

(4.3) author's changes in manuscript

We have redrafted fig. 3a) to include the deformation band sets of Johansen et al (2005) and our own observations (with lengths > 5 m).

Specific Comments (comments not adressed here will be adopted in the final document)

(5.1) comments from referees/public

- Please re-write the first paragraph (too much information, and too many references)

(5.2) author's response

We thank the reviewer or this point and will improve the readability of this section. We feel that most references are relevant, but will remove a number “double citations” from the same authors.

(5.3) author's changes in manuscript

Lines 27-36, removed a number of refernces that were not used elsewhere in the manuscript.

Lines 39-42, removed a reference that was not used elsewhere in the manuscript

(6.1) comments from referees/public

- explain how you know that fractures “results from unloading or weathering close to the surface” (line 163, as well)

(6.2) author's response

This is an assumption not based on data (other than some prior references that indicate “late fracturing”). We will change the text to better reflect this.

(6.3) author's changes in manuscript

We have completely removed the reference to the brown, amorphous iron oxide.

(7.1) comments from referees/public

- please explain the reasons behind your interpretation of Segment A being older than Segment B (line 241)

(7.2) author's response

The courthouse junction is assumed to be the result of a breached relay (Foxford et al., 1998, Fossen and Rotevatn, 2016), i.e. two initially parallel faults, where one rotates and grows towards the second until they abut (Rotevatn, 2007, 2009a). In these cases, the parallel faults develop during the same period of time but the abutting fault needs a pre-existing fault to abut against. Therefore we use the term “older” when describing segment A, compared to segment B but that is only valid **at** the location of the branch line. However, it is reasonable that further along the fault, there are sections of the faults that are active at the same time.

(7.3) author's changes in manuscript

We have adopted the text to make this point clearer

(7.1) comments from referees/public

- please explain why you assessed the formation of Sets 1&2 ahead of the of the fault tip of Segment B;

(7.2) author's response

One model of fault growth in lithified rocks is by segment linkage, i.e. the coalesce of smaller, isolated deformation structures into a single through going fault plane (see for example, but not limited to Cartwright et al. (1995 , J Struc Geol, Vol. 17, No. 9, pp. 1319 -1326), but also Peacock et al 2017b. One of these early isolated deformation structures in high nett/gross sandstones are deformation bands.
We assume therefore that on the current trajectory of Segment B, prior to this segment becoming a fault a range of different deformation structures (fractures, faults, deformation bands) were present. As segment B grew, it incorporated more and more of these isolated structures into its tip line, and essentially freezing those structures that it passed by, as the strain was taken over by the much larger slip plane of segment B. This why we have placed the formations of sets 1&2 in front of the tip of segment B, as they need to exist, prior to being able to be incorporated into the tip line.

(7.3) author's changes in manuscript

We have included a reference in the caption of figure 8 to point to Peacock et al 2017b