Answer to Anonymous Referee #1:

We thank the anonymous referee for the positive feedback and comments that help to improve the manuscript. In the following we answer to all comments and state corrections and changes we made to the text following the referee's suggestions.

Kind regards,

Michael Kettermann

1. *"In reading the manuscript, with its length, the 24 figures, the Appendix, the 3D model to be viewed with Matlab, the Matlab code in supplement material to evaluate the evolution of clay-sand gouge, I was wondering if it would be better to split this huge work in at least two manuscripts: a) one dealing with geometrical characterization of fault and clay smears; b) the other dealing with 3D models, detailed analytical outcomes (for example at lines 289-290 the sentence "The measured thickness data show a lognormal distribution" and the associated figure seems to be not well explained), and the modeling part."*

   → **We agree that the manuscript is quite long and presents different approaches and techniques. However, we think that it is important to keep the different sections as part of one coherent manuscript. The mentioned 3D thickness map and model for instance essentially need the description of the respective outcrop to be of value. In agreement with referee #2 we will keep the work as one manuscript.**

   In accordance with Referee #2 we also agree that the presented Matlab mixing model mainly points out some of the relevant parameters for mixing, which are admittedly quite intuitive and this doesn't justify the length of the paragraph with three figures. However, we see a value in pointing this out to the reader as some kind of invitation to further investigate the processes of grain-scale mixing. The details of the model and the figures are not required in the text, though, and we moved most of it to Appendix B to shorten the main text distinctly.

   The shortened paragraph now reads:
   "To explore the effect of clay fragment size and rate of mixing on the evolution of sand-clay gouge, we designed a simple simulation (Matlab, 2015; code in online supplement) where circular clay fragments in a sand matrix are subject to homogeneous simple shear. A detailed description and figures of this model can be found in Appendix B. The results show a logarithmic relation between rate of mixing, distance between particles and the strain required to produce an effective seal by mixing. The initial packing will have an influence on the required strain as well as the distribution of mixing (e.g. stronger mixing at the top of clay fragments), however this will be subject of further research."

   Appendix B now has the three Figures 20, 21 and 22 (now B1, B2 and B3) attached and reads:

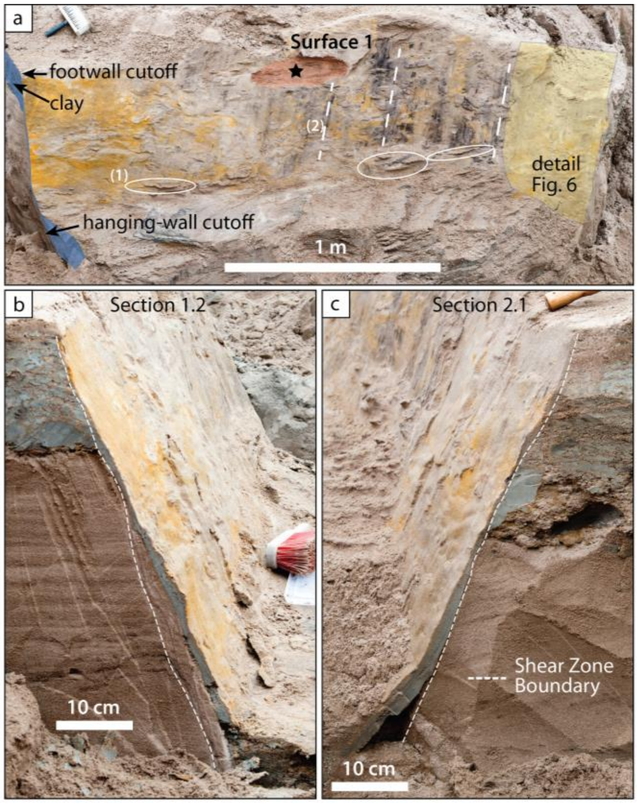
"The general idea of this model is to investigate parameters controlling grain-scale mixing in clay sand sequences. As a basic geometry we chose a number of circular clay fragments with dimensions in the order of mm to cm as observed e.g. in Sample 1.2 (c.f. Fig. 12a) which are embedded in a sand matrix (Fig. B1). This sediment package is then faulted with a certain shear-band width using a simple simulation (Matlab, 2015; code in online supplement). With increasing shear strain a sand-clay mixed seam around the fragments develops and increases in thickness. We ran five series of simulations with initially circular objects representing clay fragments. The rate of mixing is defined as m = ΔT/Δγ, where ΔT is the change in thickness of the mixed seam per unit shear strain and Δγ is the change in shear strain. The thickness of the mixing seam at a given shear strain is then T = γ * m. Simple shear is then applied to the model and shear strain is increased in steps of 0.05. This was done for five distances between clay fragments (0.1, 1, 2, 5 and 10 cm radius) and four rates of mixing (0.001, 0.01, 0.1 and 0.5). Using the 'intersections' algorithm (Schwarz, 2010) the code finds the strain at which the ellipses intersect (i.e. clay fragments touch). While a mixing rate of 0.5 is certainly unrealistically high, it serves well for illustrating the procedure (Fig. B2). The results show a logarithmic relation between rate of mixing, distance between particles and the strain required to produce an effective seal by mixing (Fig. B3)."

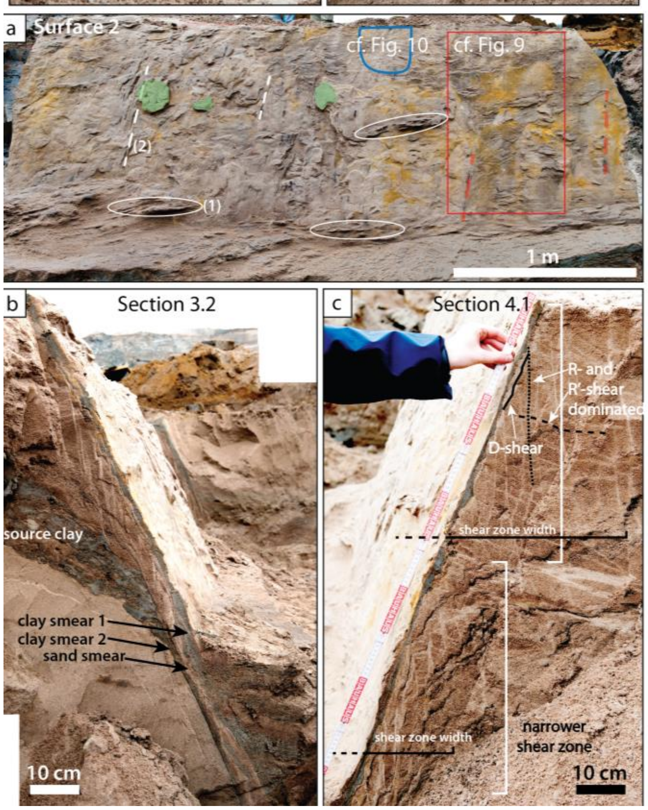
2. *For example at lines 289-290 the sentence "The measured thickness data show a lognormal distribution" and the associated figure seems to be not well explained.*

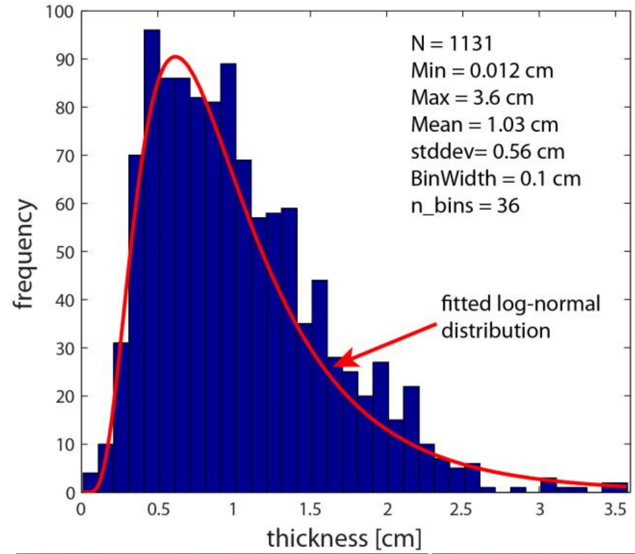
→ We agree that this sentence lacks clarity and information and is somehow badly positioned in the text. We move the sentence backwards in the text and rephrased. The paragraph now reads:
"The thickness map (Fig. 9e) shows that the clay smear is patchy, with a gradual change between profiles. A general trend is towards thinner clay in lower left, but horizontally elongated thicker patches are distributed over the entire area. Thick clay smear is located in the lower central part as well as the upper 50 cm of the smear. However, even close to the footwall cutoff of the source clay, thin clay smear (less than 1 cm) occurs in sections 3, 10 and 11. Plotting the measured thickness data in a histogram (1 mm bin size, N = 1131) results in a log-normal distribution similar to those shown by Navarro (2002) from 2D profiles. The histogram including a fitted log-normal distribution and all essential data is shown in Figure 11."

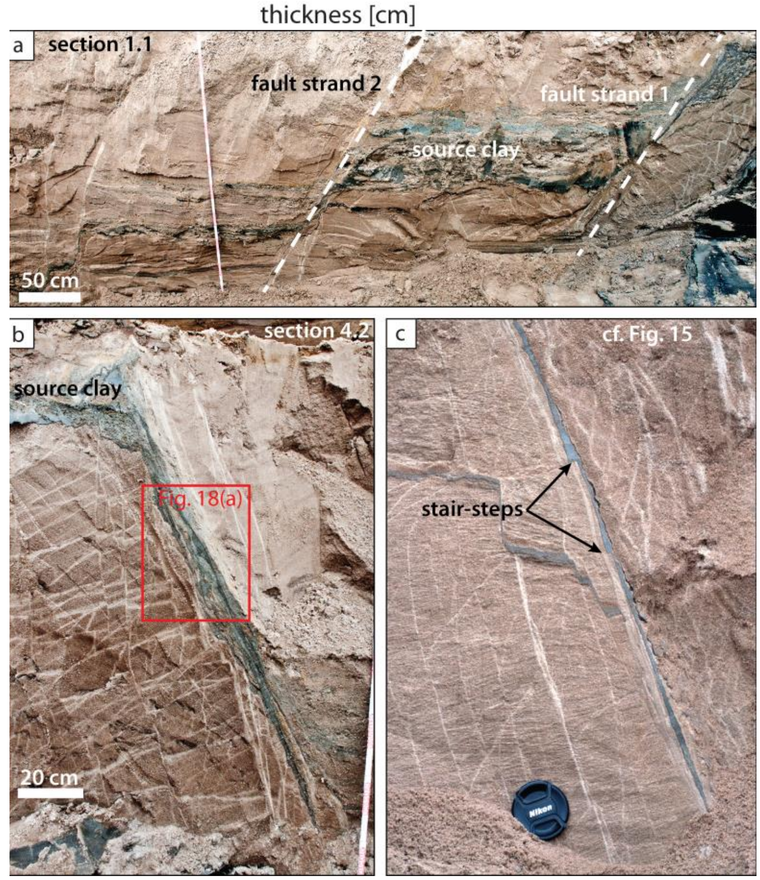
3. In some parts of the manuscript I have not been able to see in the figures, what it is mentioned in the text or the figures deserve a better labeling. For example, lines 195- 195 mentioning Figure 5: I am not able to see both hanging-wall and footwall cut off (labeling the cut-off would help the reader).

→To clarify the structures mentioned in the text we added more labels to some figures as shown below:


a
Surface 1
footwall cutoff
clay
(2)
(1)
detail
Fig. 6
hanging-wall cutoff
1 m
b
Section 1.2
10 cm
c
Section 2.1
Shear Zone
Boundary
10 cm


a
Surface 2
cf. Fig. 10
cf. Fig. 9
(2)
(1)
1 m
b
Section 3.2
source clay
clay smear 1
clay smear 2
sand smear
10 cm
c
Section 4.1
R- and
R'-shear
dominated
D-shear
shear zone width
shear zone width
narrower
shear zone
10 cm


N = 1131
Min = 0.012 cm
Max = 3.6 cm
Mean = 1.03 cm
stddev= 0.56 cm
BinWidth = 0.1 cm
n_bins = 36
fitted log-normal
distribution
frequency
thickness [cm]

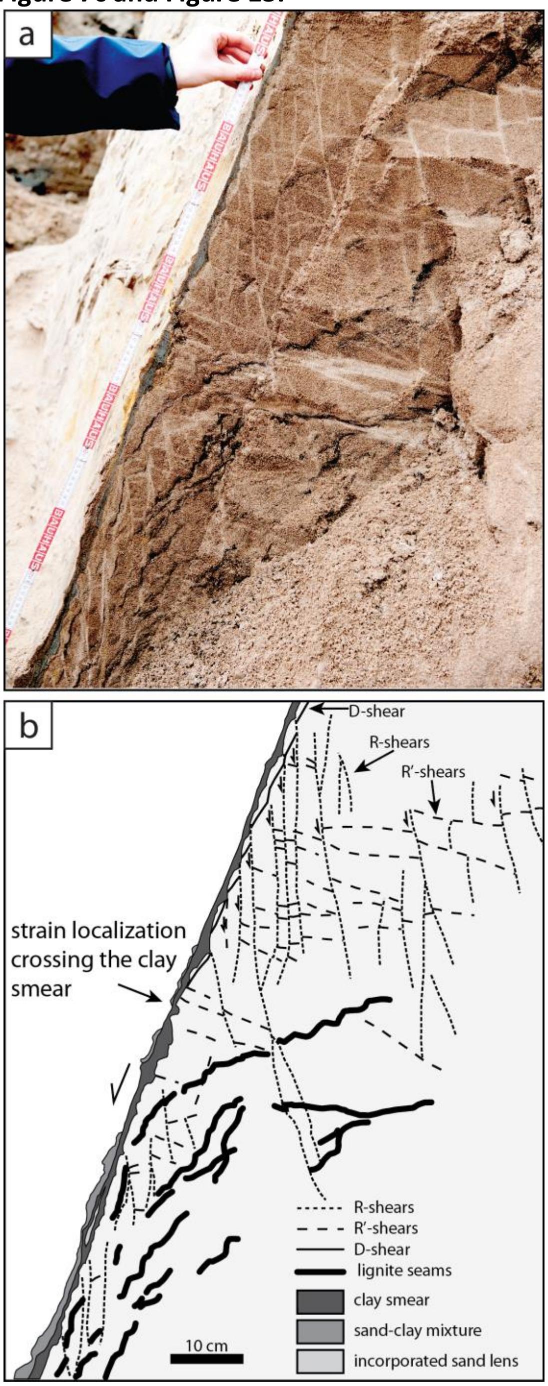

a
section 1.1
fault strand 2
fault strand 1
source clay
50 cm
b
section 4.2
source clay
Fig. 18(a)
20 cm
c
cf. Fig. 15
stair-steps

4. *The text at lines 229-231 is not clear or in other words the figures are not clearly explained by the text.*

   → Unfortunately your line numbering does not correspond to the line-numbering in the manuscript (1-~34 for each page) and hence it is not clear to us which sentences/figures you refer to here. If you clarify this, we are glad to improve the text.

5. *It would be helpful to label R R1 and D-shears in figure 7 since it is the first time this terminology, together with a fault image for it, is introduced in the manuscript. Can you label D-shear in figure 13: it took me a lot of time to pick-up the D-shear position.*

   →Yes, this would improve the clarity of the figures. We put labels for R-, R' and D-shears in both Figure 7c and Figure 13.



6. *Paragraph 5.1 on the origin of stair-stepping geometries. Some jumps forward back forward (Figure 13-14-15) in mentioning figures and model have created a bit of confusion during my reading. I suggest first describing the observations and then presenting the model.*

   → **We agree and restructure this paragraph to:**

   "In the following we show observations of three different types of stair-stepping geometries in clay smears (related to R-shears, R'-shears or abrasion) and present models explaining their formation and possible influence on the thickness distribution shown in this article's section 3.3:

   (1) In section 4.1 (see Fig. 13b for interpretation) we observe late R-shears offsetting older D- and R'-shears on the footwall side, terminating in the clay smear, and closely associated with the characteristic stair-steps.

   (2) In section 5 (Fig. 14) we observe late formed R'-shears causing stair-steps in clay smear. These R'-shears with 1-2 cm displacement offset earlier formed D-shears. While growing across the footwall they cut through the undeformed source clay beds which provide weak slip zones and allows the R'-shears to be almost horizontal. Finally, the R'-shears protrude towards the main clay smear offsetting the clay-smear/sand contact in the footwall and hence forming triangular stair-steps.

   (3) In dynamic observations of clay smear formation in sandbox models (cf. analogue models of Noorsalehi-Garakani et al., 2013; Schmatz et al., 2010b, a) steps in clay smear were observed to form without the presence of R- or R'-shears as a result of fault segmentation and erosion of clay lenses.

   The model explaining observation (1) involves a highly strained clay smear with fully developed D- and R'-shears. In a later stage R shears on the footwall side continue to accommodate offset or nucleate, truncating the clay smear and the older D- and R'-shears (Fig. 15a). This is combined with a redistribution of the shearing clay to maintain continuity. Where R-shears truncate the clay smear it locally becomes very thin. With enough offset on the R-shears this process may be able to form holes in a clay smear (cf. paragraph 5.4).

   A model explaining observation (2) is similar to the first model. In a first step faults develop clay smears and associated D-shears around the smears. Later R'-shears develop in the footwall or continue to accommodate strain while finally truncating the clay smear with low angle dips (Fig. 15b). As in the first model the clay in our outcrop has to be redistributed within the smear to maintain continuity. At locations where R'-shears truncate the clay smear it can get very thin and Kristensen et al. (2013) reported a clay smear that was disrupted by R'-shears with offsets larger than the clay smear thickness.

   Finally, observation (3) can be explained by a model consisting of two processes. First, a clay lens is incorporated into the clay smear by fault segmentation (i.e. step-wise migration of the fault dip towards the footwall). At this point there are steps on both hanging- and footwall side off the clay smear. Secondly, continuing shear on the hanging-wall side of the smear then erodes clay at the hanging-wall side (Fig. 15c). This results in a straight surface on the hanging-wall side, while on

the footwall side a step remains visible. This process forms stair-stepping geometries without the presence of R- or R'-shears and without offsetting existing D-shears. No distinct thinning of the clay smear occurs."

7. *Lines 482-483. In the model there is the assumption of circular clay fragments. Since clay minerals are platy minerals I suggest to better justify this assumption.*

   → The circular clay fragments are not intended to resemble individual clay particles, but rather clay fragments in mm to cm scale as observed and described in e.g. Fig. 12. However, you are right; this is a simple assumption, which we think is ok for a first model with the sole aim of pointing out some relevant parameters that control grain-scale mixing.