Ref: se-2019-202

2nd round of review

Title: The role of pre-existing jointing on damage zone evolution and faulting style of thin competent layers in mechanically stratified sequences: a case study from the Limestone Coal Formation at Spireslack Surface Coal Mine (Changed to: "The growth of faults and fracture networks in a mechanically evolving, mechanically stratified rock mass: A case study from Spireslack Surface Coal Mine, Scotland" in the revised MS).

Journal: Solid Earth

During the 2nd round of peer-review our manuscript received one reviewer report from David Sanderson that pointed out a number of minor edits that were missed during the previous rounds of editing. Please find below our point by point response and we would like to thank David Sanderson for his detailed and thoughtful reviews that have significantly improved the manuscript. We hope the completed edits mean that that the paper is ready for publication,

Many thanks,

Billy J Andrews (on behalf of the authorship team).

R1: Dave Sanderson			
Major comments			
#	Line no. (sub. MS)	Comment	Response
1	-	The term 'self-juxtaposed fault' as "self-juxtaposed" describes the relationship between the wall-rock stratigraphy across a fault. This should be "self juxtaposing" to be logically and grammatically correct. A fault that juxtaposes different lithologies is later referred to as a "non-self-juxtaposed fault" - does this really help communication of the simple idea that faults may juxtapose the same or different lithologies?	We appreciate that grammatically "self-juxtaposed fault" is incorrect and instead of the fault itself being juxtaposed it is the lithologies/facies on either side. As such, we have taken your suggestion to change the term to "self-juxtaposing". We however, do feel that the concept of self-juxtaposition is a very useful concept within mechanically layered sequences and have therefore not removed the term altogether from the MS.
2	-	The use of "Riedel shear" (lines 277-287) seems both un-necessary and at variance with the original description of fractures developed above basement shears.	The mention of Riedel shear has been removed from this section of the text as suggested.
3	-	The authors use abutting, cross-cutting and off-set relationships to suggest relative ages of the different fractures and faults. This results in 8-10 "phases" of fracturing, that they relate to 4 (or 5) stages of development (Table 4). Aspects of this analysis are clearly documented with field photos and summarized in Fig 8. Many of the off-set relationships used to infer faults post-dating joints vary along the faults, with some large offsets close to fault tips. I think some of these features could be interpreted as "trailing".	While the presence of trailing segments would enable the simplification of the deformational history, and a reduction in the number of required phases, no direct evidence was observed during fieldwork. This however does not discount there being subtle evidence (e.g. lineation's along pre-existing joints) that was missed and therefore we have added the following line to the to the revised MS: "This may be due to the development of 'trailing segments' (i.e. sections of a previous structure reactivated during subsequent deformation (c.f. Nixon et al., 2014)), however, no direct field evidence was observed as part of this study (e.g. mineralisation and/or evidence of shear)." [Line 431-434]. And added the following to the figure caption of Fig. 8: "Please note that while it is possible some joint's and/or faults acted as trailing segments (cf. Nixon et al., 2014) no direct field evidence was observed." Despite the effect trailing segments would have on the deformational history (i.e. a reduction in the number of required stages),

			we stand by our interpretation of 4 primary deformation phases, that are also preserved in other aspects of the site (e.g. the coal and faults) of 1) pre-existing joints, 2) joints and faulted joints related to early sinistral shear, 3) joints and faults related to dextral shear and 4) minor joining that post-dates the two primary deformation phases.
4		The authors defend the interpretation of joints (unmineralized) pre-dating faults and veins (mineralized), but I still find this odd.	While we appreciate the reviewers view, which is shared by others in the fracture community, it is the opinion of the authors that mineralisation will occur only when the chemical and hydrogeological conditions are favourable. A fluid will only flow along the 'path of least resistance' and hence can bi-pass significant parts of a network (as discussed on lines 494 to 506). An additional point is that mineralisation will only occur when then chemical conditions are correct to do so (e.g. through a rapid drop in pressure).
5		There is still inconsistency and lack of clarity in the topological analysis; the procedures are still not explained in sufficient detail. For example: (a) Nodal % in Table 3 do not sum to 100%; (b) I cannot calculate the given Pc from numbers of nodes using equation 1 (excluding E nodes); (c) I still do not see how these node counts were done. It looks as if a lot of the fault I-nodes are in fact Y-nodes with termination of the fault at a joint (and *vice versa*).	(a) Thankyou for pointing this out! It seems that during the redrafting of T3 that the number of nodes did not carry across correctly from the excel file. This has been amended and for clarity the # of nodes has been included, with nodal % included in a bracket. The rest of the table has been checked against the extracted data and is correct. This will also explain your point (b), with Eq 1 now returning the Pc as detailed in the table. (c) We feel that a further explanation of node counting is indeed required and you are correct in your point that fault i-nodes and joint i-nodes can represent y-nodes in the combined network. The rational and explanation of our methods are as follows: "The digitisation and analysis of the fault network separate from the 'joint' dataset meant that where faults terminated against pre-existing joints (i.e. a y-node in the combined network), this was classified as an isolated node. This was done to provide the network properties (i.e. connectivity, trace length and fracture intensity) of the 'active' fault network where evidence of shear and mineralisation is present. Because the mineralised fault network will be sealing to flow, and therefore not hydrologically connected to the joint network, it is not

			appropriate to classify joint-fault abutting relationships as connected nodes. Therefore, where a joint terminates against a pre-existing fault in the 'joint' dataset this was also classified as an i-node. The combined network represents the fault-fracture network that is typically digitised and analysed for topological analysis." [Lines 463 to 473 of the revised MS]. We have also added the following to the figure caption of Table 3: "Please note, because the fault network is superimposed onto the joint network, i-nodes (i.e. where a fault terminates) can represent a y-node in the combined network. Similarly, where a joint terminated against a fault, due to the sealing properties of the fault, it is no longer appropriate to classify this as a connected branch and as such is classified as an i-node in the 'joint network'."
Minor comments			
7	58-76	It would be good to link these two paragraphs, as it only becomes clear why the first is included in the introduction after one reads the second. Detail repeated later in the paper need not be given here. *Otherwise this is a very clear introduction to the paper.*	Thankyou for your suggestion, we have merged these two paragraphs, moved the definition of self-juxtaposing faults to the methods section [line 121 to 125 of the revised MS] and removed some of the detail. [For revised paragraph please see lines 58 to 69 of the revised MS]
8	84-91	"Midland valley" does not need to appear in every sentence of this paragraph.	Thankyou for your suggestion, this has been amended in the revised MS.
9	182-183	Variables are best expressed by a single letter; thus "tl" could be simply "t" as it is not the product of two varaibles "t" and "l". "Area" is not easily mis-interpreted, but might be better a "A" for similar reasons.	To avoid confusion with t = time, we have changed the trace length variable to *L* and as suggested changed Area to A. [please see Line 186 of the revised MS]
11	196-207	CRITICAL OBSERVATION OF AGE RELATIONSHIPS IS IT CORRECT????	The description of the age relationships provided in this paragraph is consistent with field notes, photographs and maps/sketches made during fieldwork. It is possible that 'tailing' (cf Nixon et al., 2014) occurs locally, however, no direct evidence (e.g. mineralisation stepping along barren joints and/or shear evidenced along joints) was noted in the field.
12	305-310	I see no reason why a fault with some constant stratigraphic separation (s) could /would not juxtapose layers with	Please see our response to major comment #1.

		thicknesses t << s and self-juxtapose layers with t >> s. As a result, I still find this use of "self-juxtaposed FAULT" odd as it is the LAYERS that are juxtaposed or not. At least "self-juxtaposing" would be a more correct adjective for "fault" A fault that juxtaposes different lithologies is later referred to as a "non-self-juxtaposed fault" - does this really help communication of the simple idea that faults may juxtapose the same or different lithologies? No wonder the rest of the science community often thinks geology is little more that a heap of terminology and coloured maps!	
13	363	The mapped relationships appear to show the dyke off-set by the fault, with similar fault-parallel separation of dyke and rock layers. This needs to be discussed more carefully. There is some discussion of this in Table 4, but a lot of emphasis is being placed on not finding dolerite in the fault rocks.	We have expanded our discussion slightly in Table 4 to outline the evidence and our interpretation into how the dyke will have likely intruded. "No fragments of dyke are observed within the fault core in Fig 7a and no white trap is observed in the coal within the fault. This provides evidence that the tertiary dyke, that post-dated faulting did not intrude along the fault plane. Instead, it is likely that the dyke either injected around the tip of the fault, or broke through the fault core out of the plane of observation." [Table 4] Additionally, we have added the evidence of white trap to the figure caption "A later Paleogene dyke, associated with the British Tertiary Igneous Provence, intrudes across the fault, however, no evidence of white trap or dyke material is observed in the fault core [See table 4 for discussion]" [Lines 366-368]
14	T3	Why do % of node types not sum to 100?	Thankyou for pointing this, this was an error in the redrafting of T3 from the extracted excel data. This has been remedied in the revised MS.
15	T3	These should this be 8a, b c - as indicated in caption..	Thankyou. This has been fixed in the revised MS.
16	429-431	These appear to be the sample areas in Fig 8; column 1 needs updating. I do not see how joint sets 0-4 and faults 0-4 relate to the "phases" in Fig. 8.	Thankyou, this has been updated The sets presented in Table 3 do not relate to the phases in Figure 8. Instead "Trace length data is presented as orientation sets, that were derived following visual assessment of length weighted rose

		If the values for nodes ore %, why do (I+Y+X) not sum to 100? I cannot calculate the given Pc from numbers of nodes. This should be based on equation 1 and not include E nodes. I still do not see how these node counts were done. It looks as if a lot of the fault I-nodes are in fact Y-nodes with termination of a fault at a joint. The caption to this table needs a lot more explanation.	diagrams, and do not relate to the age sets outlined in Figure 8." The text in quotations has been added to the table caption to improve clarity. Please see the response to major comment # 5. Please see the response to major comment # 5. The following text has been added to the table caption to make it clear that this is the case. "Please note, because the fault network is superimposed onto the joint network, i-nodes (i.e. where a fault terminations) can represent a y-node in the combined network. Similarly, where a joint terminated against a fault, due to the sealing properties of the fault, this will be classified as an i-node in the 'joint network'."
17	435	'void' ?	Removed from the revised MS.
18	451-452	There is a long history of doing this and it seems odd to cite these two papers. Both these papers are careful to abutting relationships to deduce sequences of fracture development and NOT to assume these relate to specific tectonic events. In the case of faults (and possibly some joints) more than one orientation set may be produced in the same deformation event. This, together with local stress changes during fracturing (e.g. formation of cross-joints), makes local sequences very different from "tectonic events".	Thank you for pointing out that these references are not appropriate for backing up this point. We have changed the reference to (e.g. Vitale et al., 2012) to be more appropriate to the point raised.
19	493-509	I do not understand how these Pc values are calculated, and how values for faults and joints rea integrated to discuss the connectivity of the network as a whole. Fig 9 shows plots for the combined network. This looks perfectly sensible, but who these values are derived is not explained in caption or text.	Pc is calculated separately for the fault, joint, and combined network. The connectivity of the fault network represents the network of mineralised features that display visible offsets. While features may abut against pre-existing phase 1-4 joints (Fig.8), this is not considered as connected with regards to the 'fault-network'. The connectivity of the fault network is important as the more connected it becomes, the less hydrologically connected the open fractures on the limestone pavement become. Because the fault-network is mineralised, it is no longer appropriate to consider points

			where open-mode fractures abut against faults as being connected (Y-node) and instead they are considered as I-nodes due to the sealing properties of the fault. This explains why faulting becomes more intense and connected, the joint network (which represents the modern day connectivity of the network) decreases. To make this clear we have added the following text to the revised MS: "The drop on connected joints is shown in the trends (pink arrows) on Figure 9 and is caused by the gradual increase in abutting relationships between fault's and joints. As more joints become reactivated as faults, the fault network becomes more connected as splays (i.e. y-nodes; Figure 8) develop, whilst reducing the number of connected joints (i.e. x- and y- nodes in the 'joint' dataset) (Figure 8). Similarly, as the intensity and connectivity of the fault network increases, the number of abutting relationships between joints and faults increases. The increases the number of i-nodes in the joint network and gradually decreases the number of connected branches as the intensity of faulting increases." (Lines 524 to 530), and "see main text for a description of the trends" to the figure caption of Figure 9.
20	574-579	What happened to Stage 1b in Table 4?	We have added this into the conclusion paragraph. "Pre-existing weaknesses developed in the fluvial deltaic sequences at Spireslack SCM as cleats and joints formed during burial of the fluvial-deltaic host rocks and formation of the regional Muirkirk syncline (***Stage 1b***)." please see Lines 595 to 597 of the revised MS.