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Interactive comment on "How do we see fractures? Quantifying subjective bias in fracture data collection" *by* Billy J. Andrews et al.

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This is an interesting article. Using outcrops to understand the attributes of fractures at depth is a very important challenge right now for structural geology. With the advent of drone-based outcrop imaging, many fracture trace pattern data sets are being collected, interpreted, and used to build DFN models. So it is critical to understand biases in the data collection and interpretation. This is a useful contribution to understanding those observations. Some of the problems documented in this paper, like how to objectively document length, are ones that need further thought. Marrett (probably in Marrett and Ortega) concluded that length and connectivity were too subjective to measure meaningfully, which is part of the reason he advocated linear scanlines and careful aperture size measurement (as in Ortega et al. 2006). It should be standard

practice to specify aperture size cut offs in linear scanline data, and using cutoffs and other rules may be useful for acquiring reproducible length data sets.

In a report on subjectivity in fracture data collection, there are some other important problems that should at least be mentioned. As S. Holmes said in Silver Blaze, 'I saw it because I was looking for it' and the fracture community seems to have some highly obscuring blinders on when it comes to some aspects of fractures. In my opinion because we're used to looking at fracture patterns in a certain limited way (Laubach et al. 2010, J. Struct. Geol.) For example, if we're interested in constructing DFN models for fractures at depth, are barren joints in outcrop a useful structure to measure in the first place? Fractures in core commonly have some amount of mineral lining; they've been subject to hot fluids for sometimes millions of years (references in Lander & Laubach 2015, GSA Bulletin). The problems with the specific methods we use may not be as important as the unexamined subjectivity of the choices we make about which outcrop to study.

In the interest of supporting this open comment format, here are a few additional remarks keyed to page and line number (why not use continuous numbering?).

2/9 In general I think the advantages of circular scanlines tend to get over sold, at least as applied to sedimentary rocks outside of intensely deformed fold and fault zones. For regional fractures, which may have a few or only one simple fracture set with sparse, widely spaced fractures, linear scanlines may be the only way to get meaningful data on fracture occurrence; they are not subject to the interpretation problem of picking fracture 'ends' that affect 2D approaches, and they are directly comparable to the 1D data sets available from wellbores. And there are methods available for looking at fracture spatial arrangement in a rigorous way (i.e., Marrett et al. 2018, J. Struct. Geol.)

2/25 And the diagenesis of the fracture network. In many sedimentary rock fracture systems, diagenesis is the principle control on fracture network connectivity (i.e., Olson et al. 2009, AAPG Bulletin, as you cite later) and this is often overlooked by structural geologists with their mechanics and geometry disciplinary blinders on. This is a great example of 'subjective uncertainty'.

3/30 The actual overview article should be cited (Laubach et al. 2018) rather than the very short editorial.

Laubach, S.E., Lamarche, J., Gauthier, B.D.M., Dunne, W.M., and Sanderson, D.J., 2018. Spatial arrangement of faults and opening-mode fractures. Journal of Structural Geology 108, 2-15. doi.org.10.1016/j.jsg.2017.08.008

4/10 I agree that trace length is vital to measure, and it's a fracture parameter that can only come from outcrops. But the biggest limitation, and one that seems to be in a blind spotâĂŤis the finite size of outcrops. Production and tracer data from the subsurface show that fractures capable of rapidly transmitting fluids can be really long - kilometers long probably in some instances. Outcrops of such size that are also good analogs for subsurface fractures are rare. An example, though, is shown in Li et al. (2018, J. Struct. Geol.) where extremely long fracture trace lengths are visible. The finite size of good outcrop analogs is a big challenge if the aim is guiding DFNs. Is it part of 'subjective uncertainty' what we settle for in terms of outcrop type?

4/20 I think it's worth appreciating that the reason Marrett focused on aperture measurements rather than 'length' was that he appreciated that determining 'length' was (and is) subjective.

4/27 But the concept of 'number of fractures' can also be quite subjective. For example, examined microscopically, most opening-mode fractures show evolution by linkage. Where does one fracture start or end?

And specifying fracture 'size' in connection with defining intensity should be standard practice, and should be noted in contexts like this, following the work for example of Ortega et al. (2006). Not to do so may be another hidden, subjective bias for the fol-

lowing reason. 'Joints' (that is, barren opening-mode fractures) typically have a very narrow aperture size range, so why bother to try to measure aperture sizes? But many fracture populations found in core from sedimentary basins have been known since the late 1980s to typically have wide aperture size ranges. It's possible, therefore, to use the aperture size distribution, which can be measured in outcrop and the subsurface target, to decide how similar outcrop and target likely are. Moreover, if you don't account for size in defining what you measure, you can get wilding different results for intensity. These observations are partly what motivated Ortega et al.'s work. It should be standard practice to specify a size measure when describing 'intensity'. And the potential bias of working on easily visible but possibly misleading joints as guides to the subsurface is a topic that a report on subjectivity in fracture studies ought to at least consider.

5/10 Again, this measure of 'connectivity' ignores cement.

6/5 I wonder how many participants had experience describing fractures in core?

9/4 This seems highly likely. In some of the older fracture 'topology' literature (which seems to have been missed by recent papers) this scale-of-observation effect was explicitly taken into account in connectivity measures. It's another area where it should be a matter of course to take size into account in descriptions.

9/7 Some problems like this can be taken into account by explicitly specifying size cut offs, a procedure that is a regular part of scanline studies focused on aperture size distributions (e.g., Ortega et al. 2006; Hooker et al. 2014).

15/15 These problems can be minimized with linear scanlines and explicit thresholds. Restricts you to measuring aperture sizes, though, so the problems remain for 'defining' length.

15/19 It would really introduce problems to try to determine if fractures in outcrop are fluid conduits or not. Some of the best outcrop analogs for the subsurface may have completely mineral filled fractures: they are fossilized fracture systems. In outcrop, the open, fluid conductive fractures may preferentially be obscured by vegetation, etc.

17/30 Fractures that are ‘not connected’ are only unimportant for flow if the host rock is completely tight. The arrangement and length distribution - including that of small fractures - is important if the rock has finite porosity and permeability (the typical situation for even ‘tight’ sedimentary rocks). See Philip et al. 2005, SPE Reservoir Evaluation & Engineering 8/4, 300-309.

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