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Interactive comment on "An automated fracture trace detection technique using the complex shearlet transform" *by* Rahul Prabhakaran et al.

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Reviewer Comment - General This is a valuable and interesting contribution. Studies of outcropping reservoir successions - outcrop analogs - are a useful way to obtain distributed two- and threedimensional rock data that are lacking in borehole-based observations and that encompass features below the resolution of seismic methods. Outcrops are thus a source of information on the likely attributes of fractures in the subsurface. This paper is an example of recent developments in rapid, automated image-based collection and analysis of fracture sizes, patterns and interconnections that are beginning to supply from outcrops valuable input for fracture models that go beyond fracture trace data painstakingly collected the old fashioned way.

Author's Response to General Comment The authors would like to thank Dr. Laubach for the comment. We agree that photogrammetric outcrop datasets are highly valuable and there is a need for tools to efficiently process and deliver insights into fracture patterns from outcrop fracture data so that they complement hard data from boreholes.

Reviewer Comment #1 I think, however, that it would not detract from the contribution presented in this paper, to mention a fundamental challenge facing remote/automatic extraction of fracture trace data from outcrop. If fractures are open or otherwise topographically prominent and make nice, detectable features, then all is well and only more efficient detection and extraction is needed. But open and topographically prominent may not be the case for many of the outcrop fractures that are the best subsurface analogs. Fractures that are open in in the subsurface are the ones we want to know about, for their effects on fluid flow and rocks strength, but fractures that become cemented shut in the subsurface may be provide the most reliable guides to subsurface patterns: these are 'fossilized' versions of the fractures were interested in. Such fractures are frequently the easiest to interpret as representative of the subsurface (e.g., can be separated from near-surface noise), they may by virtue of their fill history be the easiest to determine timing, origins, and to relate to specific targets in the subsurface (e.g., Ukar et al., 2019) and they commonly make the largest pavements (since there is no fracture porosity for plans to latch on to). But because they are filled, they are likely the least visible, or may be invisible, to remotish imaging. Many of these issues are discussed with examples by Ukar et al. (2019).

Author's Response to Reviewer Comment #1 We agree with the reviewer that detailed investigation (using fluid inclusion studies, SEM-CL imaging etc.) into fracture cement infill can provide a more clearer picture into the evolution, timing, and stress history of fractures. Therefore, the guidelines presented by Ukar et al, 2019 on choosing outcrops representative of subsurface conditions has significant merit. This reference is added within the Introduction section of the marked down manuscript so that the reader is aware that not all outcrop fracture data can be readily extrapolated to subsurface conditions. In our case, the UAV data acquisition in France and Brazil was performed, not with a specific goal to extrapolate any observed outcrop fracturing patterns to a known sub-surface reservoir, but for a broader perspective of deformation in different carbonate settings.

The issue of identifying, on an outcrop scale, mineralized fractures is indeed a pertinent one. Extracting filled opening mode fractures, in which mineral fill has a marked colour contrast with respect to host rock, can be done with segmentation algorithms if the images have been acquired in close range. The complex shearlet transform could also be successful in such a case, provided this contrast is prominent. The photogrammetric datasets that we present in the manuscript, were unfortunately acquired at altitudes from which these filled macrofractures were below the necessary image spatial resolution. We would suggest close range UAV mounted hyperspectral imaging as a possible technique to extract opening mode fractures with cement infill. With hyperspectral imaging (or imaging spectroscopy), image data is collected in near-continuous spectral bands. The spectral response of minerals constituting the rock, owes to atomic-molecular level processes triggered on interaction with a light source (active or passive) and this may be utilized to identify mineral composition. Since mineral fill of veins are likely to have a different spectral response from the mineralogy of the host rock, this variation may be used to isolate the pixels that correspond to veins. A recent review on close range hyperspectral imaging for mineral identification identifies various previous studies performed for specific minerals (Krupnik and Khan, 2019) with spectral response bands for the most common mineral types. It would be interesting to observe, identify, and distinguish between fracture sequences (at least for the macrofractures) based on the differences in spectral response of the fracture infill material. Since hyperspectral data is much more voluminous and with significantly more complex image processing than conventional photogrammetry, such analysis could be confined to selected regions within the outcrop. Together with conventional UAV photogrammetry that covers larger spatial area, laboratory based geochemical studies, and outcrop observations (scanline sampling, abutting relations etc.), hyperspectral

methods can yield a more detailed picture of a particular outcrop setting.

References Krupnik D, Khan S (2019), Close-range, ground-based hyperspectral imaging for mining applications at various scales: Review and case studies, Earth-Science Reviews, In Press, https://doi.org/10.1016/j.earscirev.2019.102952

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