[PS]The Influence of Resolution on Scale-Dependent Clustering in Fracture Data*

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Search and Discovery Article #41670 (2015)**
Posted August 24, 2015

*Adapted from poster presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015

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Abstract

Fracture spacing data is widely studied as its application allows for characterizing fractured reservoirs and identifying preferential flow paths. Such data can be acquired from scanlines, cores and well logs (e.g., dip meter, OPTV) at various resolutions. However, the influence of resolution of the data obtained from various methods on the results is not well known. Lacunarity is a parameter that quantifies the scale-dependent clustering of spatial patterns. It has been previously used for delineating differences between a set of nested fracture networks with similar fractal dimensions but collected at different resolutions. Recently, lacunarity has also been used for identifying scale-dependent pattern changes from scanline data. The current research illustrates the application of this technique for delineating differences between scale-dependent clustering attributes of data collected at various resolutions along the same scanline. Specifically, data was collected from outcrop exposures (i.e., road-cuts and dip slopes) of the Cretaceous turbititic sandstones of the Chatsworth Formation widely exposed in southern California (USA) at various resolutions. The same scanline at low (aerial photograph) and high resolution (ground measurement) is analyzed for its scale-dependent clustering attributes. It is found that while the coefficient of variation indicates an overall near random arrangement for the low-resolution data, lacunarity curves of high-resolution data identify clusters at the meter-scale. This observation is consistent with the findings from an earlier study that analyzed scale-dependent fracture clustering in maps from a different location.

The Influence of Resolution on Scale-dependent Clustering in Fracture Data

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Abstract

Data on fracture spacing is commonly acquired from scanlines and well-logs (e.g., dip meter, OPTV) at various resolutions and analyzed for characterizing fractured reservoirs. However, question remains whether the ***resolution*** *or* ***scale*** *at which the data is collected has any influence on results obtained.* ***Lacunarity*** *is a parameter that quantifies the scale-dependent* ***clustering*** *of spatial patterns. Our research illustrates the application of this technique for delineating differences between clustering attributes of fracture data which is critical for assessing sub-surface fluid flow.*

I. The Dataset

Fracture spacing data was collected at the Bravo pavement from sandstones belonging to the Chatsworth Formation (southern California, USA) at two different resolutions. One dataset was obtained by identifying fractures along a ~ 20m scanline, S1 from aerial photography (**Fig. 1**) and the other set, was collected by laying a tape on the ground along the same location as S1 and measuring the fracture spacing values in situ.

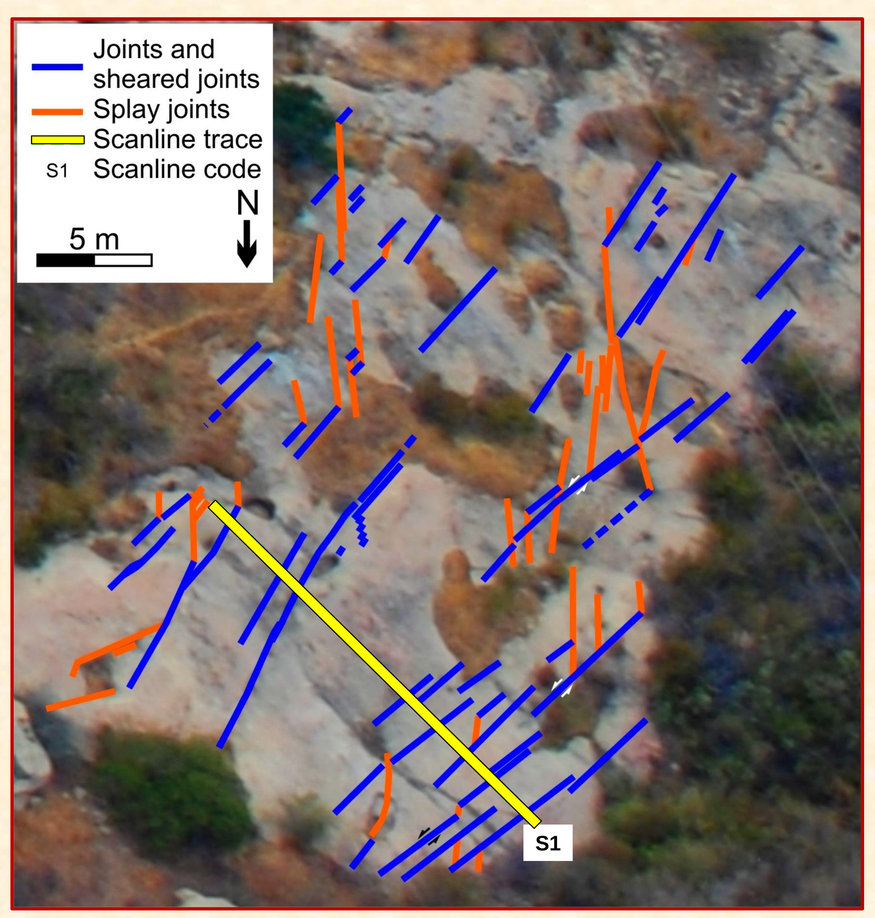


FIG 1. Outcrop map of Bravo pavement showing joints and sheared joints (in blue), splay joints (in red) and location of scanline , S1 (in yellow).

The data thus obtained were discretized on the centimeter scale following Priest and Hudson(1976). A unit length is 1cm i.e. a 1cm spacing is represented by a 0 and a fracture by 1 thus yielding a sequence of 0s and 1s. **Fig. 2** shows data from aerial photo (line A) & ground measure (line B).

FIG 2a. Line A: low-resolution data from photo.

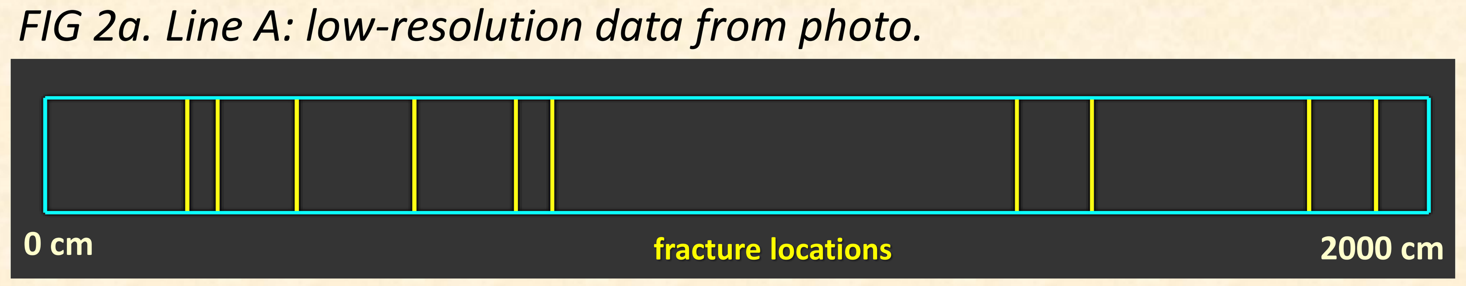
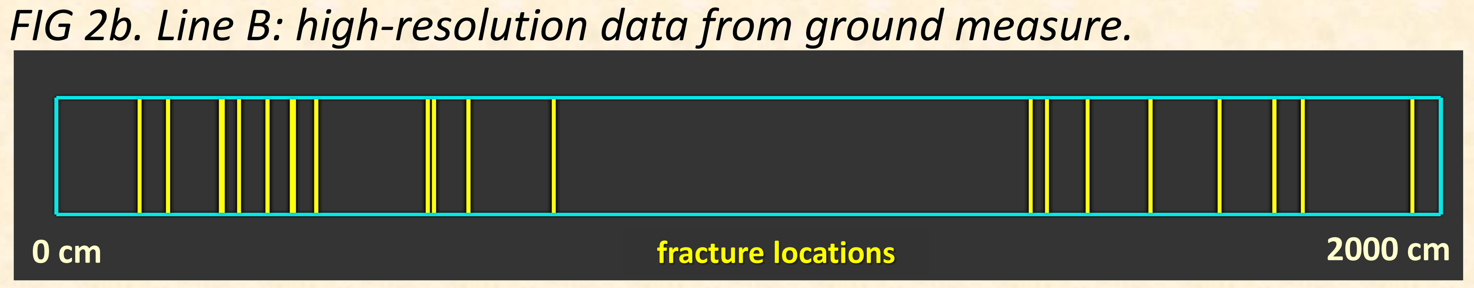


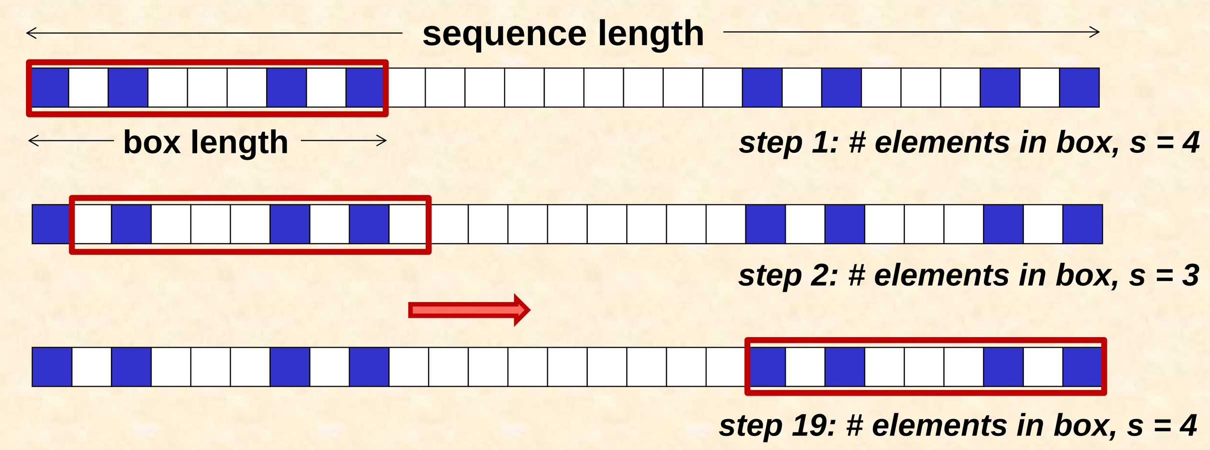
FIG 2b. Line B: high-resolution data from ground measure.



The two datasets clearly look different from each other and this is because of the effect of resolution. We attempt to capture this difference in a more meaningful manner as follows.

II. The Technique: Lacunarity

FIG 3. Lacunarity measure explained using a Cantor-bar.



The pattern in **Fig. 3** shows a 3rd order Cantor-bar which has 8 elements distributed in an array of 27 cells. **Lacunarity**, ***L(r)*** at scale r = 9 is calculated by gliding a box of length 9 across the pattern and counting the number of elements, ***s*** at each step. This yields a distribution of s $(r)$from which L (r) is found as:

$$L(r) = \frac{s_s^2(r)}{< s(r) >^2} + 1$$

$s_s^2(r)$ ≡ variance; $<s\,(r)>$ ≡ mean

Log transformed lacunarity values, **log *L*(*r*)** for different box-sizes, ***r*** plotted against **log *r*** (**Fig. 4**).

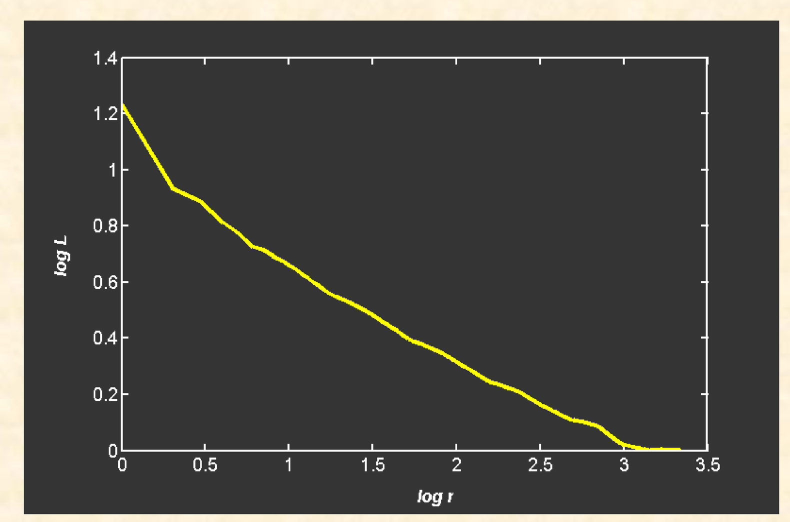


FIG 4. Lacunarity curve of a Cantor-bar.

III. Determining Scale-dependent Clustering

The use of lacunarity in identifying clustered, random and unclustered fracture patterns is shown below. **Fig 5a** is an example scanline, Line C of length ~21m, collected from the Monterrey salient, Sierra Madre Oriental, NE Mexico (Gomez, 2007) showing highly clustered fractures. **Fig. 5b** is generated by randomizing the fractures in Line C. 1unit spacing ~ 1mm.

FIG 5a. Line C: Clustered Veins.

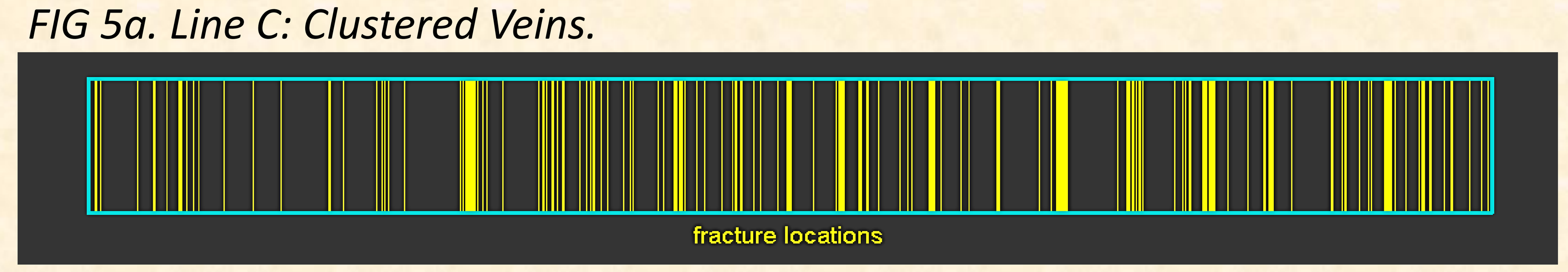


FIG 5b. Line D: Randomized fractures from C.

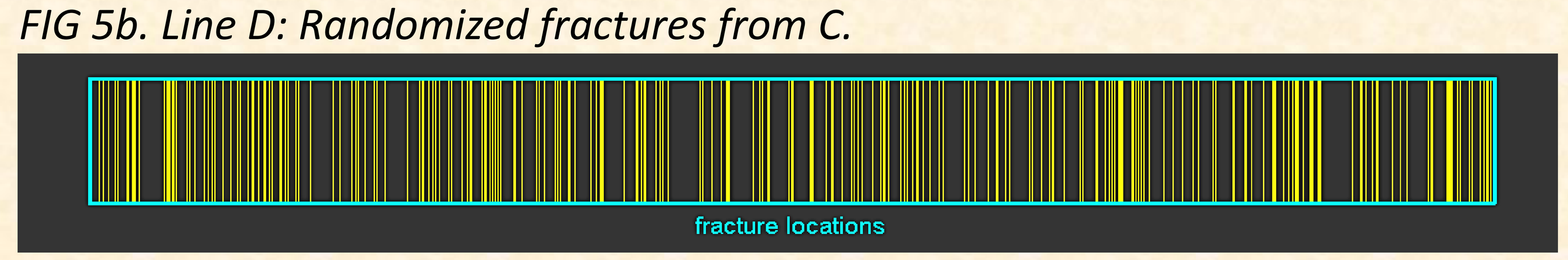
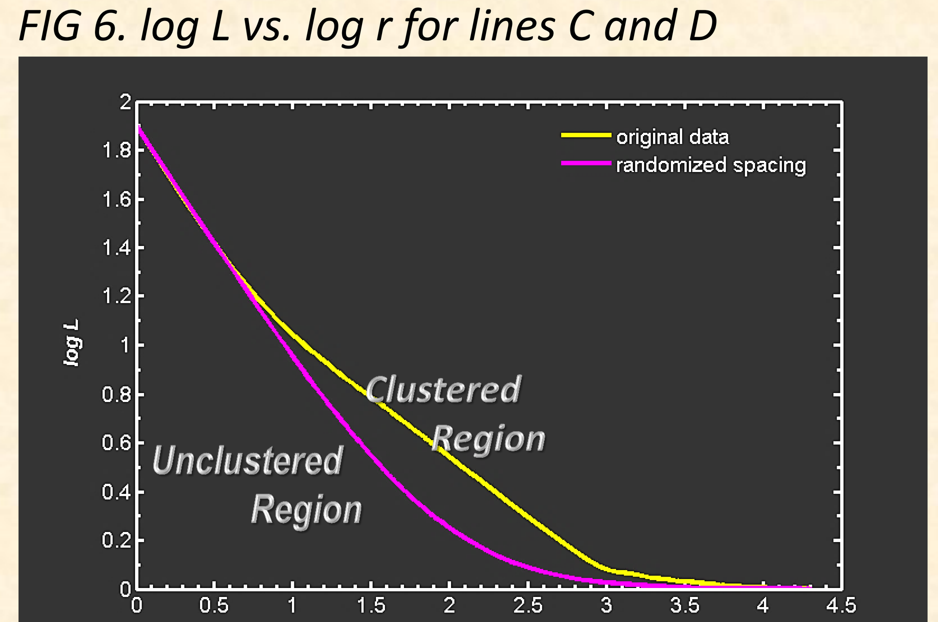


FIG 6. log L vs. log r for lines C and D



Lacunarity curves of lines C and its randomized counterpart, D is shown in **Fig. 6.** The latter (purple curve) divides the plot area into ***clustered*** and ***unclustered*** regions

The fractures in line C (yellow curve) appear clustered when observed over a certain range of scales (Roy et. al., 2014)

IV. Results from Bravo Pavement Scanline

Lacunarity curves (**Fig. 7**) show that line A is no different from its random counterpart at all scales of observation. Line B shows higher values of $L(r)$ than random mostly for log r > 1.5 and is therefore more clustered.

FIG 7. Lacunarity curves of lines A and B compared to random counterparts.

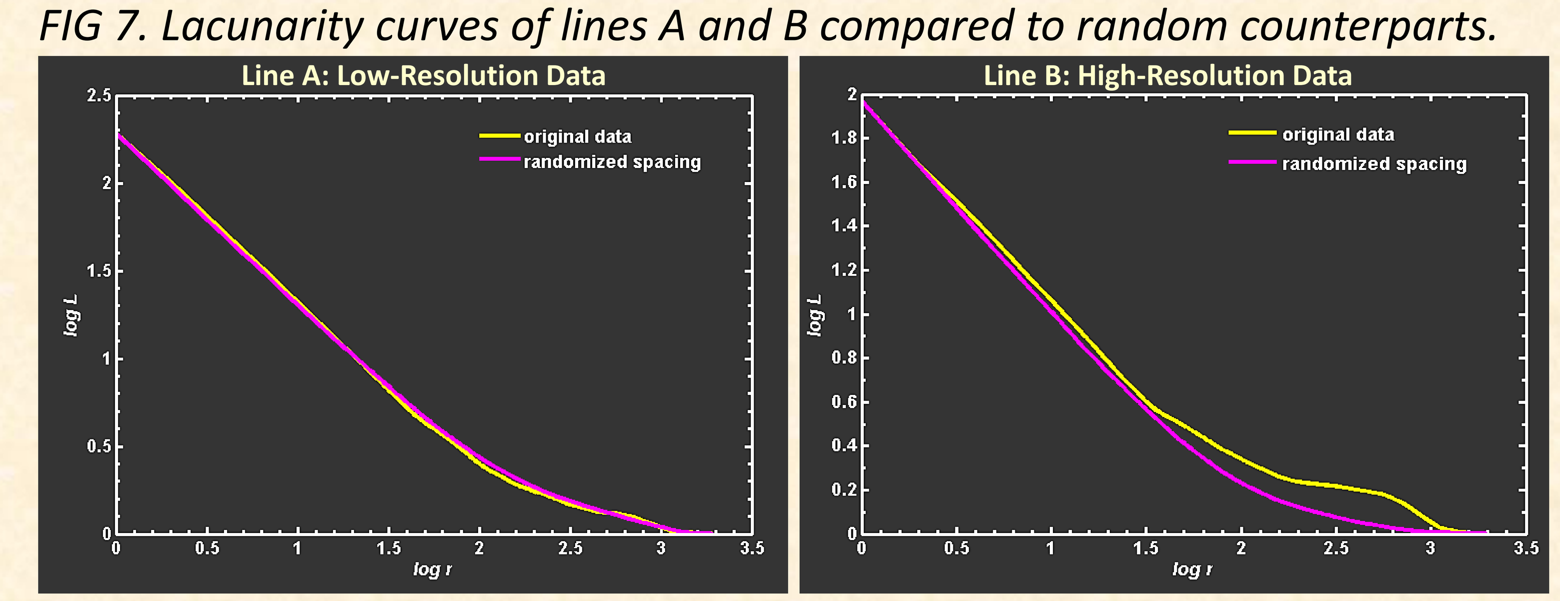
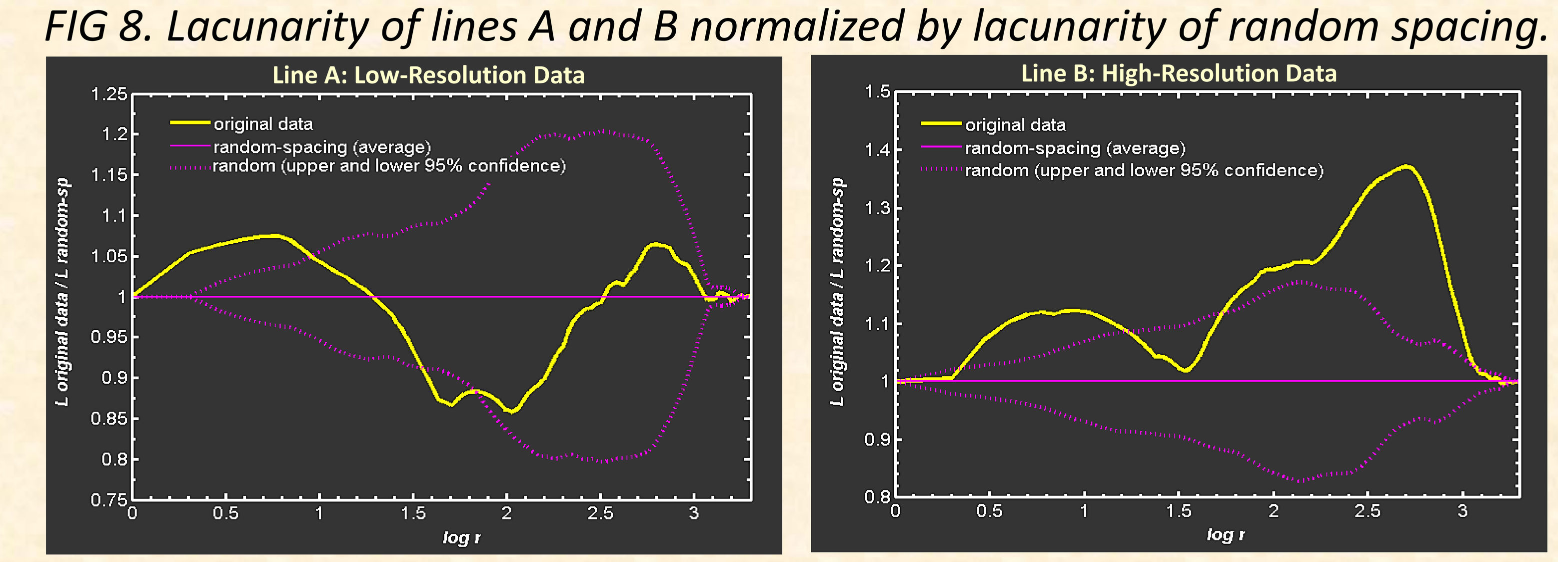


Fig. 8 is similar to Fig. 7 but lacunarity values of lines A and Line B are *normalized* by their respective *average randomized counterparts*: aids in better visualization of clustering. Line A curve stays within 95% of the random line for scales > 9cm → practically random at all scales because min. sp. = 42cm. Line B curve lies mostly above the upper 95% line. For log r > 1.7 i.e. for observation scales > 50 cm it shows very high clustering.

FIG 8. Lacunarity of lines A and B normalized by lacunarity of random spacing.



V. Application to 2D Fracture Maps

Analysis of nested fracture maps (Odling, 1997) demonstrates application to 2D data. It is found that lacunarity of higher resolution map (Map-B) shows higher clustering than low-resolution map (Map-A).

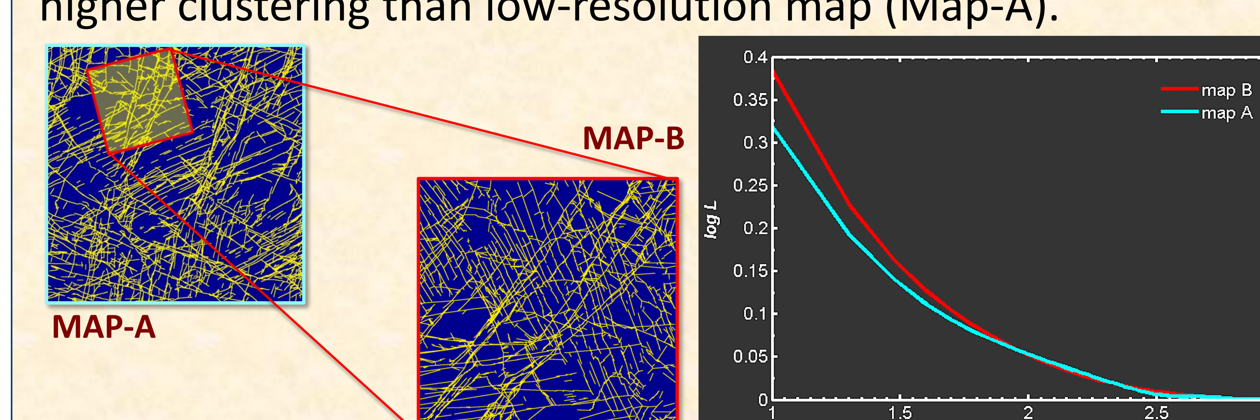


FIG 9. Fracture maps A & B, at different resolutions and their lacunarity curves.

Conclusion: Lacunarity can delineate differences between the same fracture data at different resolutions in terms of scale-dependent clustering and the technique described can be used for subsurface applications.

Acknowledgments: Research funded by Stanford Center for Reservoir Forecasting (SCRF), Stanford University and fieldwork supported by Boeing Company through a grant via University of Guelph

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