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

Ankur Roy¹, Atilla Aydin², Antonino Cilona², and Tapan Mukerji¹,³

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¹Energy Resources Engineering, Stanford University, Stanford, California, USA (royankur@stanford.edu)
²Geological and Environmental Sciences, Stanford University, Stanford, California, USA
³Geophysics Department, Stanford University, Stanford, CA, USA

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 turbiditic 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

Ankur Roy¹, Atilla Aydin², Antonino Cilona² and Tapan Mukerji¹,³

¹Energy Resources Engineering Department, ²Geological Sciences Department, ³Geophysics Department, Stanford University, Stanford, CA

ABSTRACT

Data on fracture spacing is commonly acquired from scanslines and well-logs (e.g., dip meter, OVPK) 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 subsurface 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 scansline, 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.

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). 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:

\[
L(r) = \frac{s_2^2(r)}{s(r)} - 1
\]

The use of lacunarity in identifying clustered, random and unclustered fracture patterns is shown below. Fig 5a is an example scansline, Line C of length ~21m, collected from the Monterey 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.

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.

<table>
<thead>
<tr>
<th>Box length</th>
<th>Sequence length</th>
<th>step 1: # elements in box, ( s = 4 )</th>
<th>step 2: # elements in box, ( s = 3 )</th>
<th>step 10: # elements in box, ( s = 4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>9</td>
<td>8</td>
<td>7</td>
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<tr>
<td>8</td>
<td>80</td>
<td>79</td>
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</tr>
</tbody>
</table>

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

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 scansline, Line C of length ~21m, collected from the Monterey 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 4. Lacunarity curve of a Cantor-bar.

Lacunarity curves of lines C and D 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 5b. Line D: Randomized fractures from C.

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

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.

Conclusions: 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.

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References


