

## Investigating Scale-Dependent Clustering and Flow Behavior in Multifractals

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### INTRODUCTION & AIM

Subsurface geological formations exhibit multi-scale heterogeneity and scale-invariant behavior, that can be effectively described only using multifractal geometry

Lacunarity has emerged as a powerful descriptor for distinguishing between fractal and multifractal patterns that possess the same correlation dimension but exhibit different degrees of spatial clustering (Roy et al, 2014)

Unlike fractal dimension, which reflects how detail changes with scale, lacunarity quantifies the distribution of gaps and the heterogeneity of mass across scales. In our earlier investigations (Sahu and Roy, 2024)

Distinct fracture or permeability patterns may share identical correlation dimensions while exhibiting significantly different clustering behaviors (Roy et al, 2014)

The present research explores whether lacunarity, a metric quantifying heterogeneity and spatial clustering can serve as a predictor of fluid flow behavior in multifractal permeability fields

### METHOD

A set of four multifractal patterns (three deterministic and one random), each characterized by identical correlation dimensions and defined by the parameters:  $b = 7$ ,  $p = 40/49$ , and 3 iterations is generated through MATLAB algorithm (Roy et al. 2014)

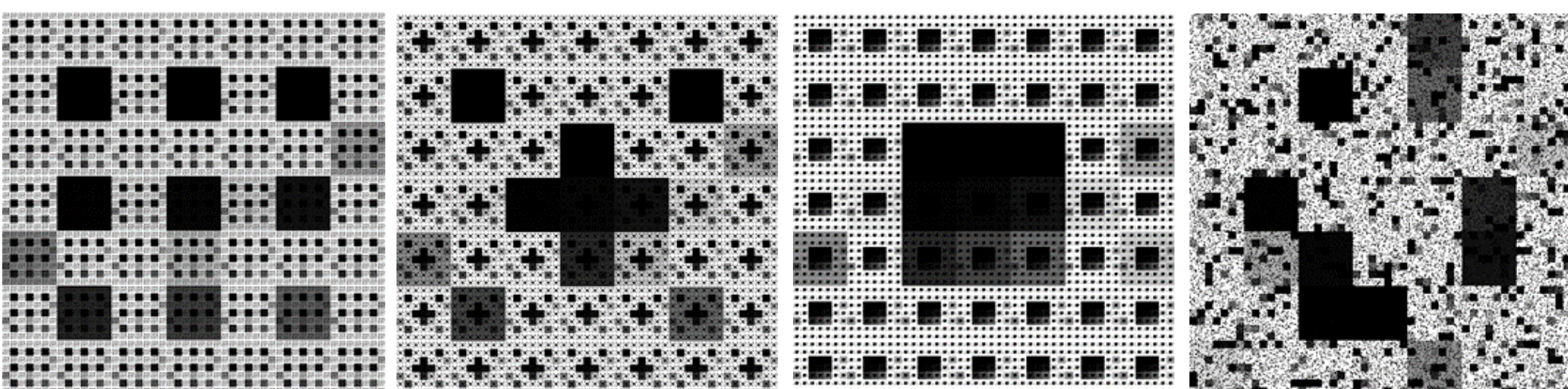


Fig.1: A set of four multifractal patterns (3 deterministic and 1 random at extreme left)

These patterns are subjected to lacunarity analysis using the gliding-box algorithm to quantify their scale-dependent clustering, where lacunarity ( $L$ ) is related to the correlation dimension,  $D_2$ , by the equation:

$$d\log(L) / d\log(r) = D_2 - 2$$

This equation is empirically tested using two-dimensional multifractal grayscale patterns with known correlation dimensions

Subsequently, flow simulations are performed on these permeability fields using a streamline-based simulator, Trace3D (Dattagupta and King, 2007)

In these simulations, the occupied regions of the multifractal fields are assumed to be highly porous (70%) and permeable ( $10^6$  md), enabling all fluid flow to occur exclusively through these zones.

The fractal dimension, lacunarity analysis and fluid recovery values of this multifractal permeability fields are correlated to check which parameter has a more dominant influence on flow behavior.

### RESULTS & DISCUSSION

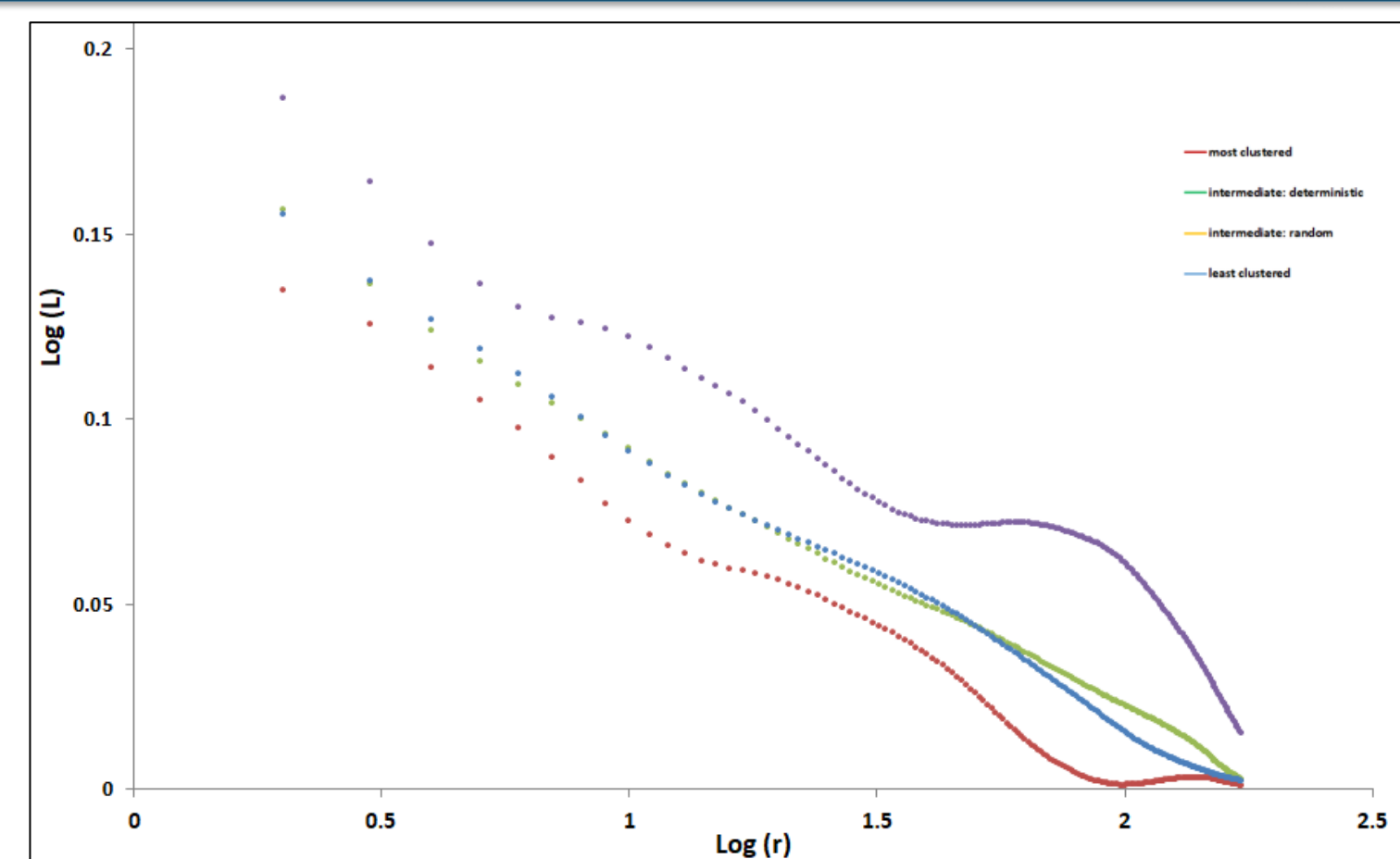


Fig.2: Lacunarity of four multifractal patterns

The lacunarity plots distinguishes the multifractal permeability field based on their clustering attributes.

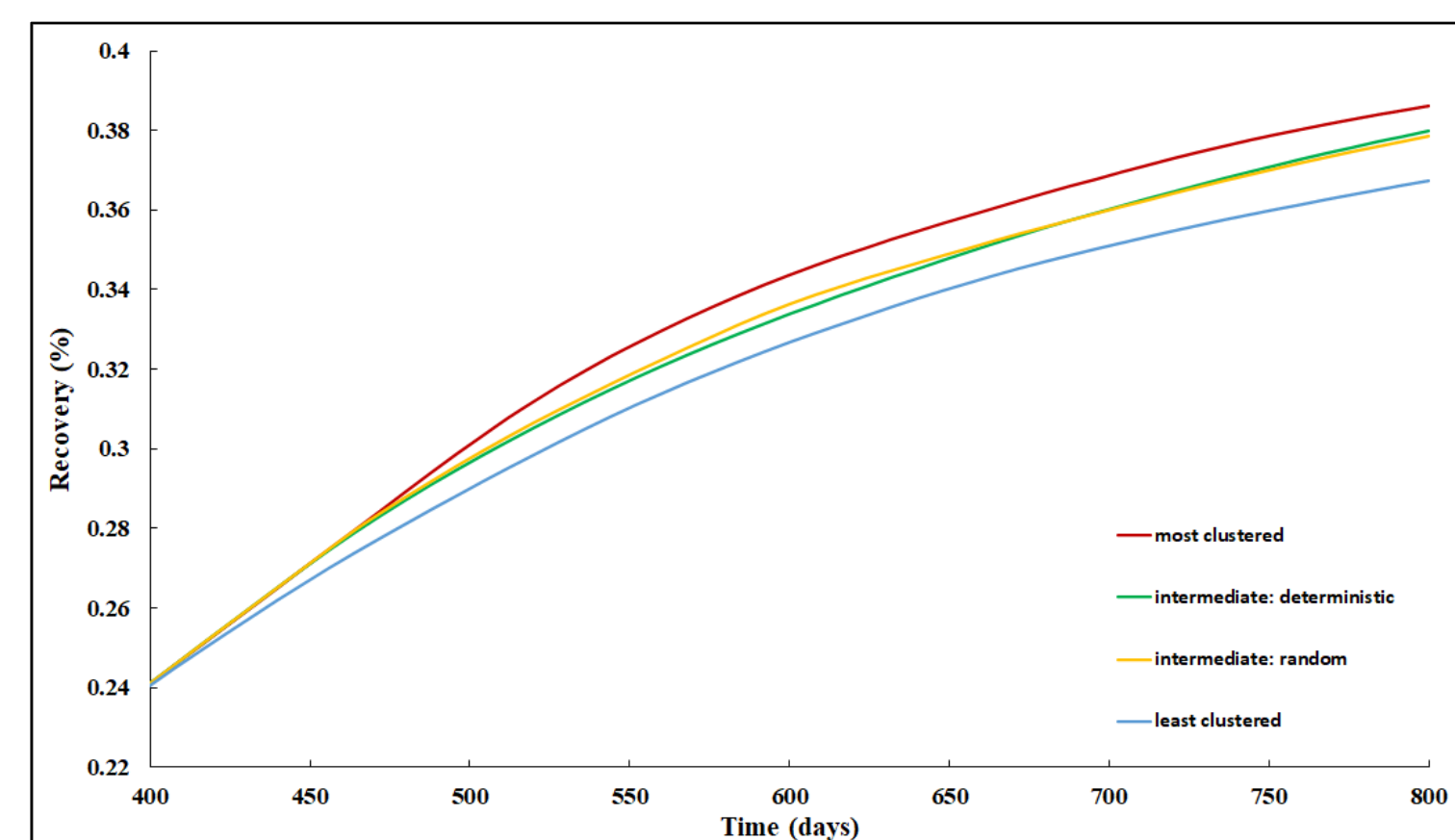


Fig.3: Fluid Recovery of four multifractal patterns

The fluid recovery is highest for most clustered multifractal permeability field, followed by the intermediate deterministic and random ones, it is least for the least clustered one

A cross plot of lacunarity and fluid recovery reveal a strong positive correlation (approx 95%) between scale-dependent clustering and flow behavior

### CONCLUSION

Flow simulation results reveal a strong positive correlation of 95% between lacunarity and fluid recovery, indicating that increased clustering enhances flow efficiency in such heterogeneous systems

Hence, rather than the fractal dimension it is the clustering which controls fluid flow in multifractal permeability fields

The use of lacunarity parameter can potentially generate an informed decision on reservoir characterization and field development modeling strategies.

### FUTURE WORK / REFERENCES

This study can be further extended to its implementation on real field bore-hole images for analysis of flow in vuggy carbonate reservoirs

- Sahu, A. K., and Roy, A., (2024), Predicting Fluid Flow in Reservoirs: analysis of Fracture Clustering in Outcrop Analogues, Petroleum Geoscience Journal. 30, 1- 9, petgeo2023-091, <https://doi.org/10.1144/petgeo2023-091>
- Roy, A and Perfect E., (2014), Lacunarity Analyses of Multifractal and Natural Grayscale Patterns, Fractals, Vol. 22 (3) 1440003, <https://doi.org/10.1142/S0218348X14400039>