A Novel Approach of Modelling Integrating Fractals and Geology of Stochastic Reservoirs

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Abstract

The term "Reservoir Characterization" is creating a digital replica of physical reservoir, both in terms of static and dynamic domains. It demands deciphering the geometrical arrangement of building blocks the reservoir. Such arrangements (Reservoir Architecture) have been classified by Webber into three types of reservoir architectures, representing highly continuous to stochastic reservoir through hybrid types as per their appearance. Till date only two geometric approaches have been attempted to tackle the issues of stochastic reservoir modelling, e.g. Marked Point Algorithm (Boolean) and techniques based on fractal geometry. Boolean approach of using geometrical ratios of geo-bodies is premier work in this field; but has failed in test of time. Controlling fractal algorithms is mathematically quite complex, when applied on natural systems, thus building bridge between geology and mathematics is too slow.

The approach of the present study is radically different. Sequence of litho-genesis was adopted as sequence of computation of intermittency, instead of starting from the top pseudo-layer, i.e. from bottom to top. The challenge of maintaining data stationarity was met by computing thickness of geo-body on randomly picked triangulated grid. Simulated fidelity was achieved by optimizing number of iteration at which the value of Hurst Index stabilizes. Resulted pseudo-logs were validated by randomly correlating the pseudo and real logs at all control points. The results thus achieved, validate that the method evolved is not only capable of generating time and space continuous, high definition data cube; but detecting data anomaly pertaining to polychronous "cut-and fill" geo-entities and input data fidelity.

Introduction

Reservoir Characterization is the process to replicate the physical reservoir in order to enlighten the basic process involved, both in static and dynamic domain, and to provide better understanding about the reservoir. The outcome of the process is shared-earth model (Deutsch and Journel, 1995) which provides a platform for the creation of 3D model by efficiently updating critical information. Basic elements of preparing shared-earth model comprises determining reservoir architecture, establishing fluid-flow trends, constructing reservoir model, and identifying reserve growth potential. Out of many steps discussed above this paper deals with capturing the reservoir architecture by bridging the gap between fractal and geology.

Modeling of any reservoir requires two step procedure, viz, identification of the reservoir architecture followed by determination of continuity, shape, distribution etc of the sand bodies in the space. It is accomplished with the help of Geostatistics, branch of statistics deals with the spatial variability of the parameters, using the input data. There are two types of model e.g. deterministic and probabilistic. Most of the Layercake architecture models are the deterministic with little or no probabilistic input. Participation of the probabilistic input increases in the case of Brick work or Jigsaw puzzle reservoir and Labyrinth architecture models are mostly probabilistic with very little or no deterministic input. Since the uncertainties related to the probabilistic model is considerably higher than the deterministic model therefore several alternative scenarios with different confidence interval required to be generated in order to model any Labyrinth type of reservoir. Well density, spacing and coverage plays very important role for the preparation of robust model. Layercake type reservoir, being the simplest type, can be modeled with sufficient accuracy with relatively less no of data. On the other hand Labyrinth type of reservoir requires high volume of data since these reservoirs can rarely be correlated, therefore the only way out is probabilistic model. Successful demarcation of reservoir architecture is important as since it is the only way to make robust reservoir model and in turn will provide key to reservoir characterization as flow properties, and texture are inherently related to the architecture of the reservoir.To tackle the challenge of modeling Labyrinth type of reservoir two geometric approaches have been applied till date. These are Marked Point Algorithm (Boolean) and application of fractal geometry.

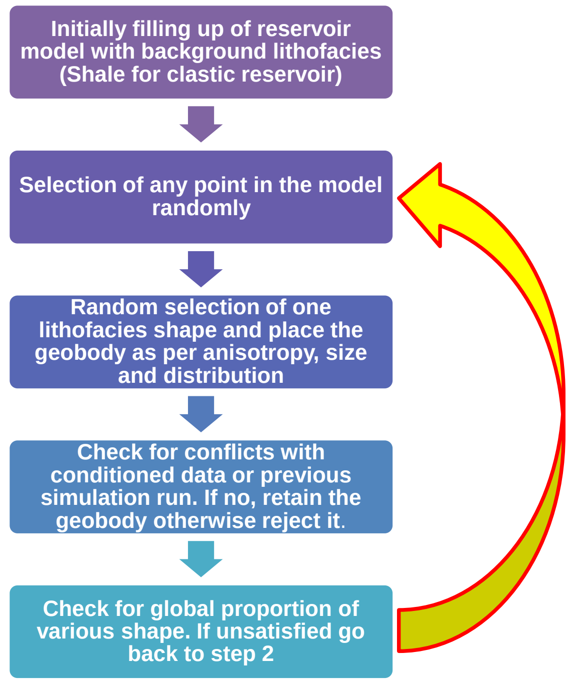

Figure 1: Flow chart of Marked Point Algorithm (Boolean)

Marked Point Algorithm (Boolean)

The beauty of this technique lies in its approach to model the reservoir from its genetic significance. This process takes the basic shape, proportion and distribution of each litho facies as input e.g. half ellipse for the sand channels in turbidite system in cross section, triangular shape for the delta fans in map view etc. The parameters that represent shape proportion, distribution are size, anisotropy ratio, and orientation of its long axis. With the existing depositional and tectonic model the relative positioning of the

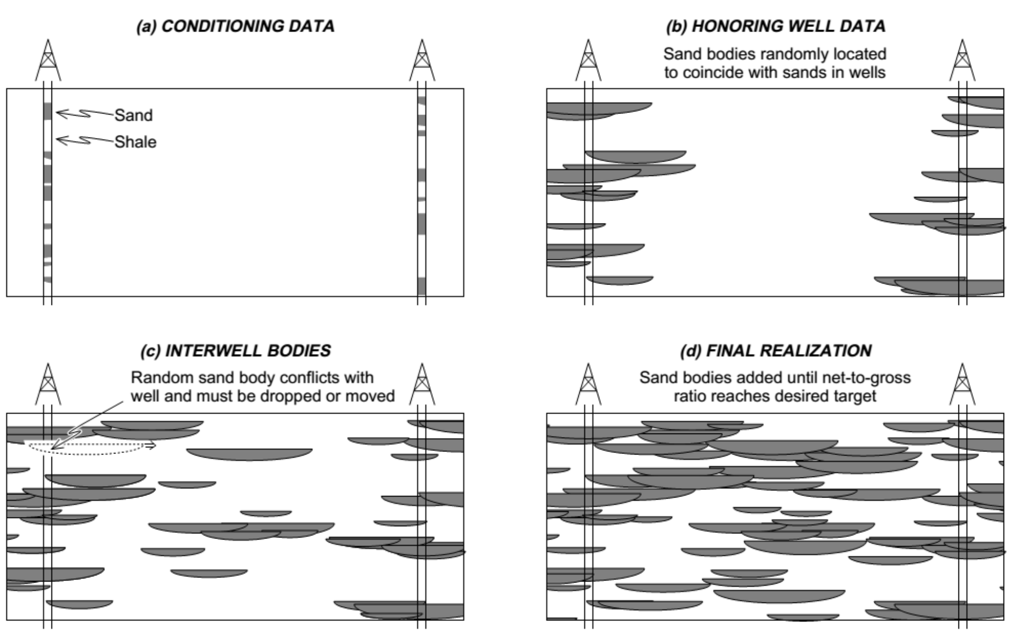

Figure 2: Boolean simulation of sand channels (After Srivastava, 1994)

shapes can be controlled. Flow chart for this algorithm is shown in **Figure 1.**
Above all the well data must be honored first followed by simulation in the interwell region (**Figure 2**). But this approach is not full proof. The algorithm is basically based on the geometrical ratios of the geobody and identical geometrical ratios can be found in geobodies from diverse depositional setup. Therefore simulation simply based on the geometrical ratio is not good enough to model the variability of the different types reservoirs.

Fractal Interpolation

Fractals are defined as a set for which the Hausdorff-Besicovitch (D) dimension strictly exceeds the Euclidian dimension (d) (Mandelbrot, 1998). Resemblance at various scales is an important feature of fractal i.e. fractals can be identified at all scale (Aasum et al., 1991). This feature of self similarity is an important feature of fractal. Many geological structures show very strong scale invariance e.g. frequency size distribution of rock fragments, earthquakes, mineral deposits annual flood cycles, thickness of sediments etc. By definition self similar fractals are statistically isotropic, i.e. in 2 dimensions the results are not dependent on the geometrical orientation of the axes ($f(x,y)= f(rx,ry)$) (Turcotte, 1997).
Characteristic of geomety of fractal distribution is intermittency or spotty nature and it is quantified by fractal dimension (D). In a d- dimensional Euclidian space if N number of object with scale rL is needed to fill space of scale L then mathematically the same expression can be written as
$N=r^{-d}$
Similarly for fractal dimension the expression can be replacing d with D
$N=r^{-D}$
“The probability that an arbitrary point within fractal distribution of overall scale L lies within a part of the structure of scale l is just the fraction of the total space occupied by structure of scale l” and mathematically expressed as
$Pr(l)= (l/L)^{d-D}$
Similarly the variation in the of a property value in fractal geometry distribution will be
$Pr\{(Z(x+h)-Z(x))/l^{H}<=y\}=F(y)$
Where F(y) is the cumulative probability distribution, h is lag distance and H is Hurst Coefficient.
The approach of the present study is radically different. Instead of reservoir top and bottom as equivalence, a perfect cuboid independent of lithology covering the complete reservoir is taken. Sequence of litho-genesis was adopted as sequence of computation of intermittency, instead of starting from the top pseudo-layer, i.e. from bottom to top. The challenge of maintaining data stationarity was met by computing thickness of geo-body on randomly picked triangulated grid. Simulated fidelity was achieved by optimizing number of iteration at which the value of Hurst Index stabilizes. Resulted pseudo-logs were validated by randomly correlating the pseudo and real logs at all control points.

Methodology

Geostatistics and fractal geometry application involves following basic steps:

1. Selection of the reservoir
2. Gather background information e.g. Depositional environment, tectonic setup of the region.

3. Collect physical well logs and other petro-physical data.
4. Conditioning of input data
5. Application of fractal interpolation techniques
6. Generation of pseudo logs
7. Validation of the generated pseudo log
8. Propagation of the value using the validated parameter within the field.

In order to follow the flow chart set above fractal behavior of the well logs need to be proved in the first hand. Z-Score transformation is applied on the input logs for the normalization. Test of characteristics relating to Fractional Gaussian Noise of the normalized well logs are considered. If fractal behavior or power law dependence is established value of H is calculated for all the input logs. Using the H value thickness of the geobody is calculated at the triangulation method at the pseudolog locations and followed by interpolation form bottom to top by random successive addition method. Sequential Gaussian simulation is applied on the input logs and pseudo logs to generate the fractal cube.

Field Application

This approach is applied in the modeling of Vshale of Miocene clastic reservoir from Cauvery basin of Southern India. Till date 23 wells have been drilled in this field (**Figure 3**) but only 9 wells (demarcated in red) have penetrated the reservoir under consideration. Well logs and tops and bottoms pertaining to the reservoir in all the 9 wells have been collected. In order to apply the fractal simulation methodology z-score transform is applied on all the logs for the aim of normalization. **Figure 4** shows input and normalized logs vis a vis probability distribution function of vshale. It is apparent that z score transformation have made the probability distribution normal which was not in case of input log. Testing of input logs for fractal behavior and calculation of Hurst Index is carried out by 3 methods viz., R/S rescaled range analysis, Box Counting Method and Power Spectrum Density method.

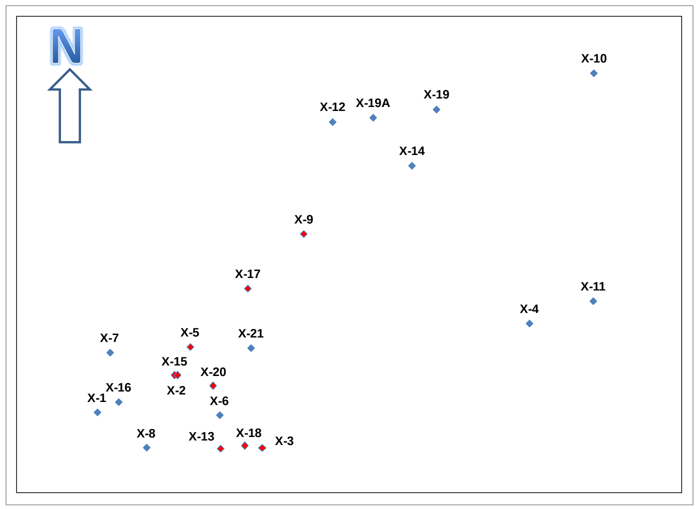

Figure 3: Location of wells in the study area

For R/S rescaled range analysis a VBA code is written in Visual Basic Plat and H value is calculated for all the normalized logs after running the code for each logs. Calculated Hurst

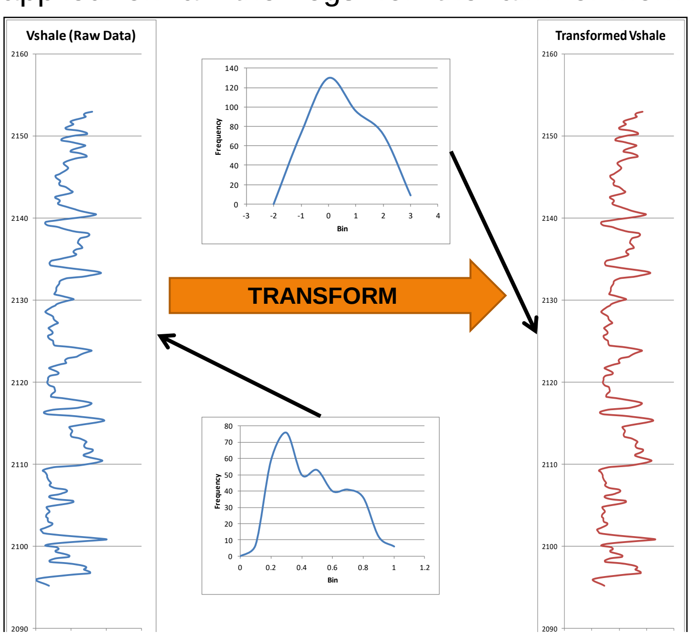

Figure 4: Normalization of input logs by z-score transform

Index (H) is validated Power Spectrum Density method. To do this autocorrelation function is calculated for each normalized logs and Fourier Transform is applied on the autocorrelation function. H value is calculated from transformed function. By comparing H values calculated for all the logs by R/S rescaled range analysis, Power Spectrum Density and Box Counting it is found that they are in good agreement, 0.7<H<1.0, implying long memory process or persistent local trend over interval.

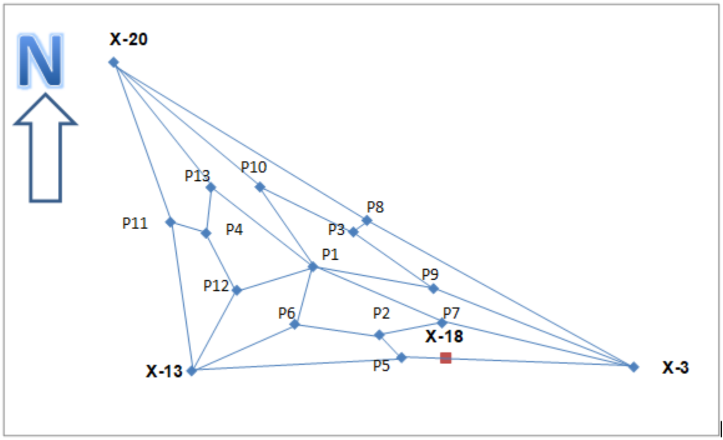

Figure 5: Iteration on triangulated grid up to 3rd level

Once the long range correlation is established next step is to capture the thickness variation of the reservoir by triangular grid. To carry out this step reservoir is divided into triangular grid keeping well locations at the nodal position. Six triangular panels have been generated keeping well No 2 and 18 at non nodal position. These two wells have been left intentionally for the purpose of validation of pseudo logs.

Method of successive random additions or midpoint displacement method, a stochastic interpolation tool for fractional Brownian motion, generates approximately random fractals between inter well region (Voss, 1988; Saupe, 1988). This is a recursive random interpolation process and it creates linearly interpolated values at the midpoint of the segment, to which a random component is added with an initial variance that decreases in every iterative or recursive level. Being acted on a line midpoint displacement method does not take into account the effect of the vector perpendicular to the line on the interpolated values.In this approach this process is modified. In case of mid point of a line, random interpolation is carried out recursively at the centroid of triangle that creates linearly interpolated values at the centroid of each triangle. This process incorporates the effect of both the orthogonal horizontal vectors at the interpolated position.

Initial variance is obtained from mean square variation of original data and it is to the estimation of the mean value of the scale variations within the space gap interval between logs. The magnitude of the variance is reduced in each recursive level according to power law determined by the Hurst coefficient (H), which is obtained for all data set. Triangular panel consists of well X-3, 13 and 20 is considered at the first step recursive interpolation for thickness of the reservoir and followed by Vshale from bottom to top is carried out in this panel. Interpolation from bottom to top is considered in order to declare time equivalence between two input logs and to replicate the rock deposition history. In this paper iteration level up to 3rd order have been conducted and 13 pseudo well have been generated (**Figure 5**). Next step is to validate the intermittence coefficient or Hurst coefficient by matching the logs of well 18 (Saffron Curve) to nearest pseudo log P-3 (Blue Curve) (**Figure 6**). Fairly good match is observed and H value is determined to be 0.81. Using this H value pseudo logs for rest of the 5 panels have been generated.

Conclusion

The approach of the present study is radically different. Instead of reservoir top and bottom as equivalence, a perfect cuboid independent of lithology covering the complete reservoir is taken. Sequence of litho-genesis was adopted as sequence of computation of intermittency, instead of starting from the top pseudo-layer, i.e. from bottom to top. The challenge of maintaining data stationarity was met by computing thickness of geo-body on randomly picked triangulated grid. Simulated fidelity was achieved by optimizing number of iteration at which the value of Hurst Index stabilizes. Resulted pseudo-logs were validated by randomly correlating the pseudo and real logs at all control points.

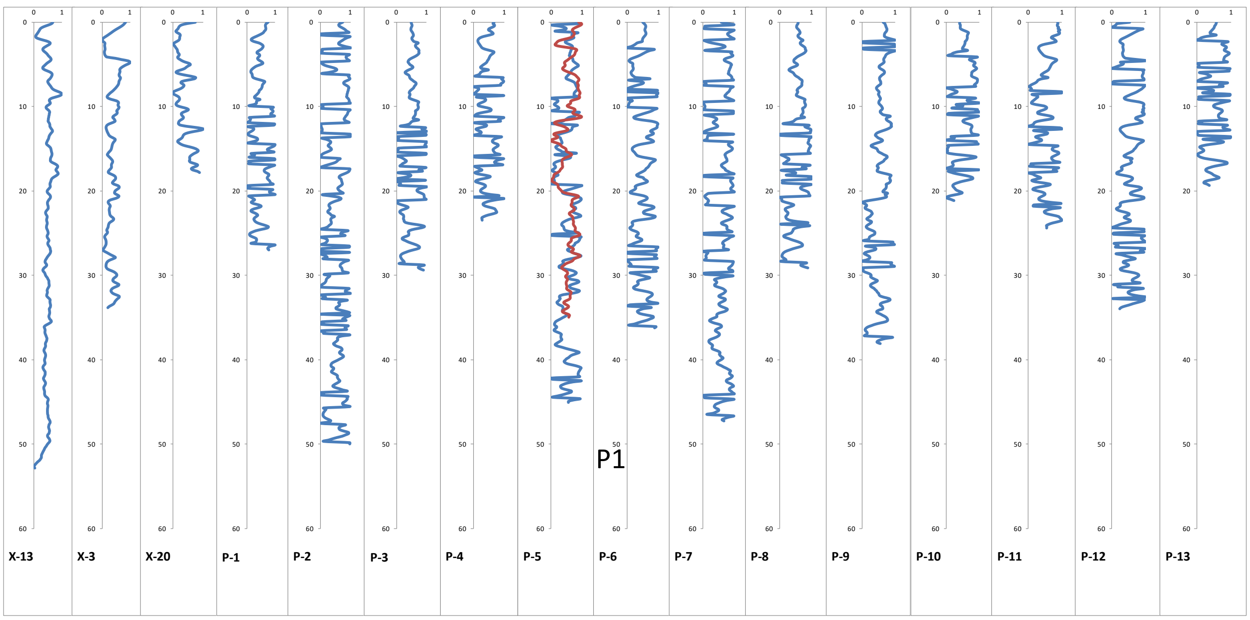

Figure 6: Generated pseudo logs in the triangular panel having nodal well X3, 13 and 20. Matching of well X-18 (Saffron curve) has been done with pseudo log P-5 (Blue Curve).

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