End Member Geological Models Key to Full Range of Uncertainty Mapping for Development and Investment Decisions*

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Abstract

Applications of stochastic methods to produce multiple realizations are being widely used to showcase the ability to capture uncertainty. However, the practical and feasible approach to simulate single model for performance prediction is widely abound. Obviously, most practical case studies therefore use stochastic methods to generate single model focused to manage best case scenario close to deterministically arrived number and supporting low and high cases managed conveniently around this best case. The so called best case of non-measurable confidence and unknown probabilities are then subjected to future performance and business decisions. This may lead to unpleasant surprises and affect the business. This can be reduced or avoided by generating complete distribution of resource to support conscious business decision. This can be achieved by creating only two stochastic models as end members to define the complete statistical distribution of outcomes. There exists larger uncertainty in all parameters of interest than it can be captured through hard/soft data. Conventional methods of generating multiple realizations are heavily guided by histogram of sampled properties, local conditioning probability, and modeled spatial variability. Often various complex characterization and modeling parameters and its effect on the "big picture" is beyond the grip of working geoscientists to generate models delinked to known data averages. It is proposed to incorporate independent variability in all parameters for geostatistical propagation between the end members aimed at generating geological possibilities of most pessimistic and most optimistic scenarios. The premise is that the multiple realizations as outcome of single input parameters (e.g. variogram, histogram, facies proportion etc.) fail to capture the much needed full range of uncertainty. The proposed method helps to capture all possibilities of the phenomenon which may causes uncertainty. Models at different uncertainty levels can be physically extracted between end members using simple improvisation of processes within the modeling tool. A large advantage of this method is that all possibilities and interrelationship between different types of data with uncertainty are automatically managed between two end members. Such geologically consistent range of

possibilities of individual building blocks of a model shall help to ensure that the final reality fall almost always between the two end members.

Introduction

Application of stochastic methods to reproduce multiple realizations are being widely used to showcase ability to capture uncertainty.These methods are often considered practical equivalent to age old classical Monte-Carlo kind of process in 3D space. However, the practical and feasible approach to simulate single model for performance prediction is widely used. Obviously, most practical case studies therefore use stochastic methods to generate single models. We focus to manage best case scenario close to deterministically arrived numbers outside the modeling arena. Entire space of uncertainty and possible ranges of outcomes are conveniently managed around this best case using areal polygons or average property variations. The so called best case output is often mistaken as close to reality and is used to predict future performance for all business decisions. This may lead to unpleasant surprises and unfavorable cash flow which in turn affects the business.

This can be reduced or avoided by creating distribution of multiple scenarios of volumetric with known probability to support conscious business decision. Discrete deterministic best case, supported by convenient low and high cases of non-measurable confidence and unknown probabilities are not suited for business decisions. This continuous distribution of outcome can be achieved simply by creating only two end members of volumetric scenario. Focusing on creation of only two end members gives ideal opportunity to integrate geological concepts and information more advantageously than it is used in conventional methods.

Conventional methods are guided by local conditioning probability and histogram of sampled properties. This paper brings out a novel concept to arrive at P50 model using simple statistical rationale from two end members. A continuous distribution of outcomes thus arrived can help risk-sensitive decision making with full range of numbers associated with probability. This paper aims to provide a simple conceptual design to help generate the full range of uncertainty for geoscientists with limited knowledge and control over stochastic processes and having conventional mindset.

Why the so called best case is not the best case?

Due to rapid technological advances, complex and computationally intensive seismic attribute analysis, inversion, log processing, core measurements, fluid property measurements, complex geostatistical propagation etc. are in vogue. Characterization attempts have significant effect, which in turn leads to differences in the “big picture” from one study to another. Often the understanding of physical significance of various complex stochastic procedures in modeling, being highly specialized branch, and its effect on the “big picture” is beyond the grip of working geoscientists. This leads to unnoticed errors in discrete modeling results. Unfortunately none of the so called “hard data” input in any modeling exercise are really hard. All soft and hard data input in any modeling exercise is always from indirect measurements e.g. seismic, logs, lab measurements transformed to reservoir conditions etc. and therefore have large uncertainty and a range of possible interpretation.It is not possible to generate a unique reservoir model or few discrete deterministic models from available geological, petrophysical, and geophysical information which themselves are non-unique as input. The conceptualized geological details needed in modeling (depositional conditions and related properties e.g. shape, size, rock properties etc.) for a given reservoir is non-unique and are always uncertain in nature. The average or the histogram of the known data samples no way represents average for the field (Figure 1). Even in case of known and similar geological settings the parameters influencing the field resources and performance may vary greatly in space from one field to another and from one location to another. No two fields are similar to be used as analogue for quantitative assessment. Ignorance of such geological realities often makes us believe a deterministic discrete characterization as “best case” or “most likely” case (somewhat equivalent to P50). Though they are called as best case, low case and high case, these discrete deterministic models have unknown associated probability or confidence. Any discrete polygon cannot have only one possible single volume associated with it as every parameter has some uncertainty. Unless the end members are known mid case cannot be known (Figure 5). Mid case has to be mathematically close to 50% probability with regards to end members irrespective of deterministic or probabilistic methods used (Figure 5). Financial simulations require possible volumes with associated probability and therefore non-standard “best case” (mid case), low case, and high case with unknown confidence is not the requirement of E&P business.

Long term perspective

In principle the best case scenario (equivalent to P50) should come true only for half the fields (50% of the fields) given there are large number of fields within the kitty of assets for statistics to be valid. Therefore validation of assessment methodology and claim for successful track record is not in providing the best case model close to reality or being true for any individual field or few fields. Validation of a forecasting methodology requires the reality to fall between the two end members, rather more than the lower end member number for more number of fields than close to best case number (P50). Therefore discretely carved best case area and volume can never be really meaningful best case of 50% probability for a successful track record in long run. For a long term perspective it is important to arrive at P50 model from end members to guarantee average of ultimate recoverable volumes, for enough number of fields to be close to average of P50 EUR’s.

Geological uncertainty and importance of statistics

In E&P the volume of rock/fluid sampled typically represents a minute fraction of the total volume of a reservoir. Un-sampled volume of a reservoir for which the estimation of parameters has to be run is generally multi million times bigger than the sampled volume. Under such circumstances uncertainty for this huge un-sampled volume cannot be overlooked. Uncertainty has been widely considered synonymous with stochastic, statistic, random or probabilistic, and therefore has not been fully imbibed by geoscientists and engineers in day to day work. We geoscientists and engineers are educated and trained to work deterministically and associating large uncertainty attaching to our own estimates may mean our incompetence. Notion of statistics and probability brings resistance amongst geoscientists. Conventional mindset considers use of probability and uncertainty as statistical evaluation. Realization of geological uncertainty brings statistics only as tool to make evaluation geologically sensible in contrary to general belief that it makes it statistical. Statistics is actually used only as a tool because probability distributions are the only meaningful way to represent the range of possible values of a parameter of interest with apparent randomness of spatial variations which is wide spread in geoscience. Stochastic models are used because it is analytically simple to characterize randomness of possible estimation. Hand drawn geological maps used since ages are made simply by statistical principles in backdrop (Figure 1). Curving contours in between two values, maintaining proper distance and satisfying most values and rejecting few aberrations are simply statistical. Therefore statistics existed in everyday work whether we accept it or not. All modern software for mapping and modeling has one thing in common i.e. statistics; it is different that we still sometimes call our maps and models deterministic due to ignorance of probabilistic/stochastic algorithm in the background. Statistics is the only known appropriate tool to capture geological uncertainty. It is the knowledge of geology and not statistics that favors statistics as important tool.

End member models

The proposed concept to model uncertainty by modeling end members of a distribution of outcome in a specific context provides choices by using multiple geological scenarios and is not limited to the data samples gathered for the field. This provides space to capture all features of the phenomenon which may cause uncertainty (e.g. area, property variation, facies proportion, geological possibilities etc.).

The concept proposes to arrive at complete range of volumetric output numbers (distribution) from only two end member models (e.g. most optimistic and most pessimistic scenarios), which are geologically consistent, somewhat representing P99 and P1 cases (Figure 5). The two end member numbers (models) in turn can provide full range of distribution on a probability chart using simple statistical derivations. The proposed concept of creating two end members is not limited to possible ranges from conventional stochastic simulation. Conventional uncertainty modeling depends on known data statistics and probability guided random values for each cell from geostatistically propagated mean and variance. Instead the end members are completely guided by geological considerations of possibilities and not only on statistical distribution of properties from primary (e.g. well, core, log etc.) or secondary (e.g. seismic attributes) variables (Figure 2, Figure 3, Figure 4). Conventional methods of uncertainty modeling are heavily guided by captured data distribution and therefore do not have leverage to sway away either side from captured averages through collected data (samples). In fact most reports and commercial software boast upon their sound methodology by proudly presenting the matching histograms of sampled properties and modeled properties. Generally the facies distribution in 3D space (vertical and lateral extent of reservoir rock) is the single most sensitive parameter to HC volumes in conventional uncertainty modeling. All other factors (e.g. facies proportion, porosity, saturation etc.) hover around closely to the averages of wells irrespective of the considerations of drilled locations with regards to its depositional setting. Actually geological setting and depositional aspects should only decide the most sensitive parameter and is not always bulk rock volume alone. Any number of drilled wells in a field does not necessarily, in fact can never, represent average for the field with regards to facies proportion, thickness, or any other petrophysical property. Even if they represent the average for the field by accident, it can never be proved or disproved through the life cycle of a field. Therefore matching the field average with the averages of sampled properties is not valid. Neither the uncertainty can be modeled by random simulation of the known histograms of sampled data. Sampled data can only help envisage possible ranges for the average for the field. With these considerations capturing the possible end members for each property delinking it to sampled histogram is the only way to determine best case value for each property which is guided mostly by geoscience using statistical principals but not from statistically sampled averages.

The method to capture end members for each property uses variation in parameters for geostatistical propagation to generate most pessimistic and most optimistic outputs which are geologically conceived. This is a paradigm shift from generating parameter (e.g. variogram) from known data and accept the outputs which results from such parameters which in turn are heavily guided by collected data samples. Perturbation and simulation of few non-logical parameters (e.g. seed number) cannot capture the full range of possible values without delinking itself to sampled data and distributions. As data collection is cost intensive therefore any amount of data collected can never be sufficient enough to conclusively define the geostatistical structural analysis and spatial variability models. Structural analysis in the presence of drift (space varying mean) due to systematic spatial trends of multiple depositional elements (e.g. channel, levee, fan, splay regions) can never be unique and single. Quantifying spatial variability through such geostatistical structural analysis conclusively may yield low variance for the output volumetric distribution keeping the mean (P50) largely influenced by known samples.

The clue is to carefully distinguish the input models and parameters from the reality it attempts to capture. Probability does not exist in natural phenomena but is there only in our models. Phenomena at unknown places may be radically different than anything observed or sampled (radical error). Geostatistics associates randomness with the regionalized variable itself, by using stochastic model in which the regionalized variable is regarded as one among many possible realizations of a random function. The objective meaning and relevance of a stochastic model under such circumstances are therefore heavily guided by the input of hard and soft data and interactive control of geological concepts are mostly lost in such processes.

It is proposed to incorporate and provide variability in all input parameters for geostatistical propagation which may include all possible scenarios starting from, internal stratigraphic layering and lithofacies relationships with properties linked to depositional processes, to variation in structural variability models between two end members. The premise is that the two end members should not be the outcome of same input parameters (e.g. variogram, histograms etc.) dependent only on different sequencing of propagation process. It is attempted to provide more interaction and intervention of geoscientist at every stage and for every parameter of modeling based on concepts and analogues for finding end possibilities. There are several methods and tools available and published to use predesigned weights for kriging/simulation to achieve the geologically defendable end-members. Methods and tools are beyond the scope of this paper. It is only the necessary to adhering to the proposed underlying principle.

Conclusions

The concept proposed here is applicable to both conventional and unconventional reservoir modeling efforts. This method provides opportunity to delink personal bias and anchoring for discrete scenarios. Conventionally hard data (e.g. well data) is favored in modeling exercises, whereas in reality the various possible geological scenarios must be captured by integrating additional information through geologically guided propagation parameters and scientifically derived confidence for each scenario. It is proposed to use more geological instincts than being dependent upon known data. Geological end member must be used in assigning confidence to various scenarios guided by statistical principles and not personal judgment. The multiple scenarios thus can be generated statistically under geological possibilities and used for future performance prediction with known probability. Single or few models at different uncertainty levels (Pmean, P50, P60 etc.) then can be extracted between two end members using simple improvisation of processes within any modeling tool. As different corporations have different strategic risk taking ability it is prudent to provide management with a full range of possible outputs with known confidence. A large advantage of this method is that all possibilities and interrelationship between different types of data with uncertainty are automatically managed between two end members including connectivity variation within depositional elements. Though the scope of this paper is limited to geological modeling concepts, simulation studies from proposed two end members in turn would then provide full range of recovery factors for business decisions. Such geologically consistent range of possibilities of individual building blocks of a model shall help to ensure that the final reality falls almost always between the two end members. The spatial phenomena are too complex for a precise deterministic description for designing polygons of intermediate probability and therefore should not be used. The goal of modeling is not to provide any specific possible volume but it is to provide a range of possibilities of known confidence.

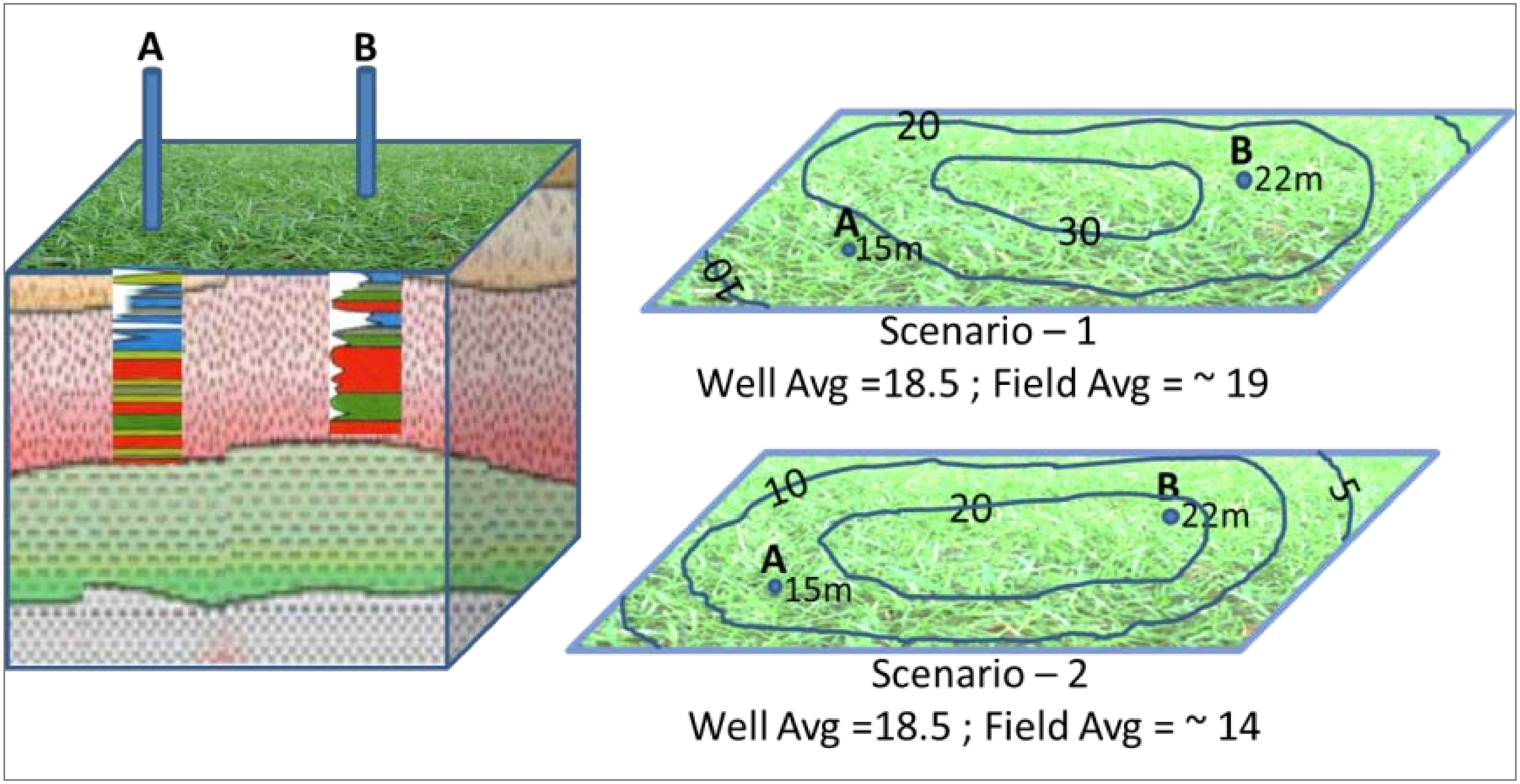

Figure 1. Two scenarios of thickness map. The range of uncertainty in field average cannot be determined from known well data unless models (e.g. maps here) are made for geologically possible end members. Conventional algorithms do not reproduce possibilities very different from known data averages.

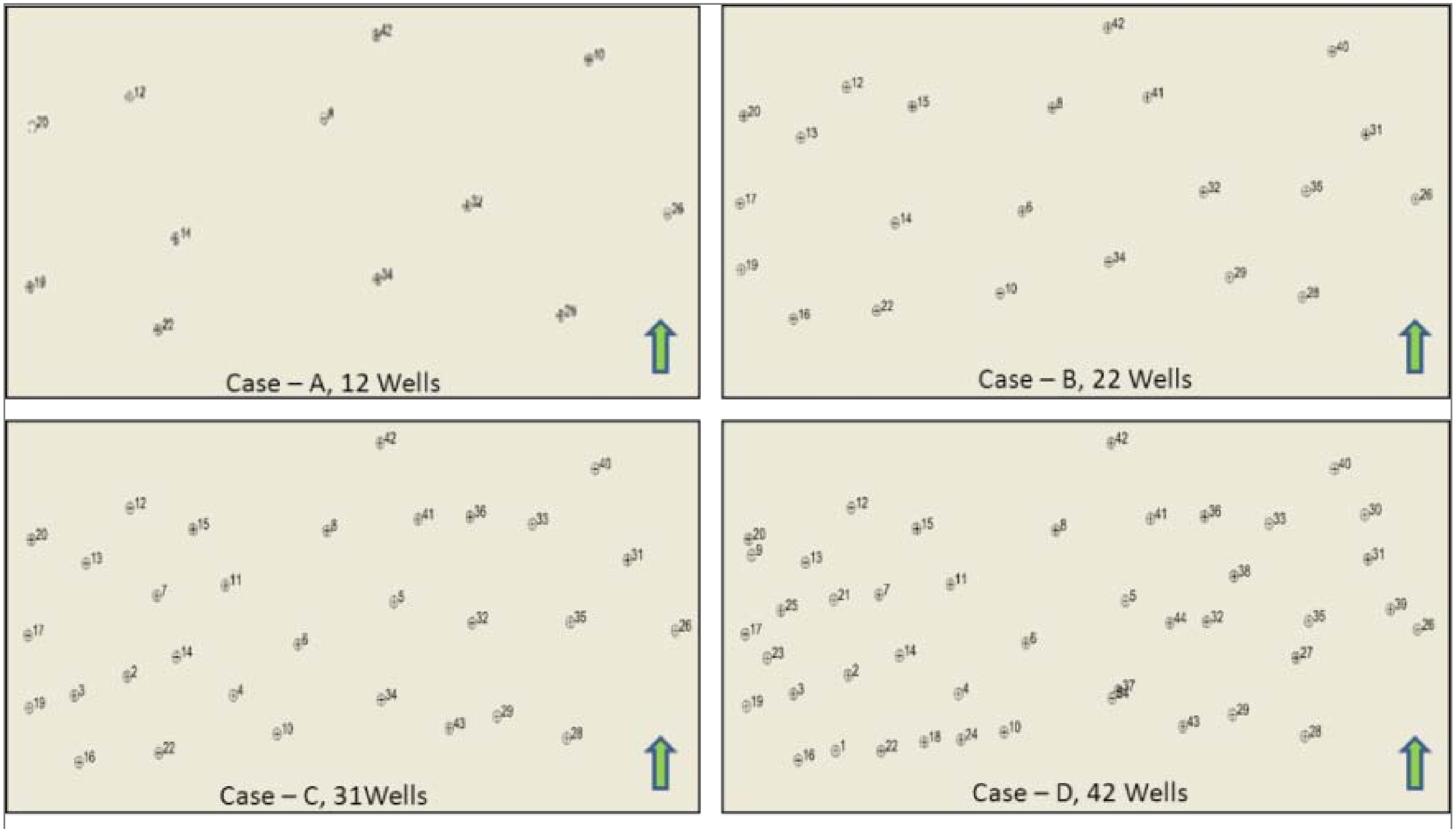

Figure 2. Four cases of different sets of wells from across the field were selected to study the impact of known data samples on variogram, histogram, and the “big picture”.

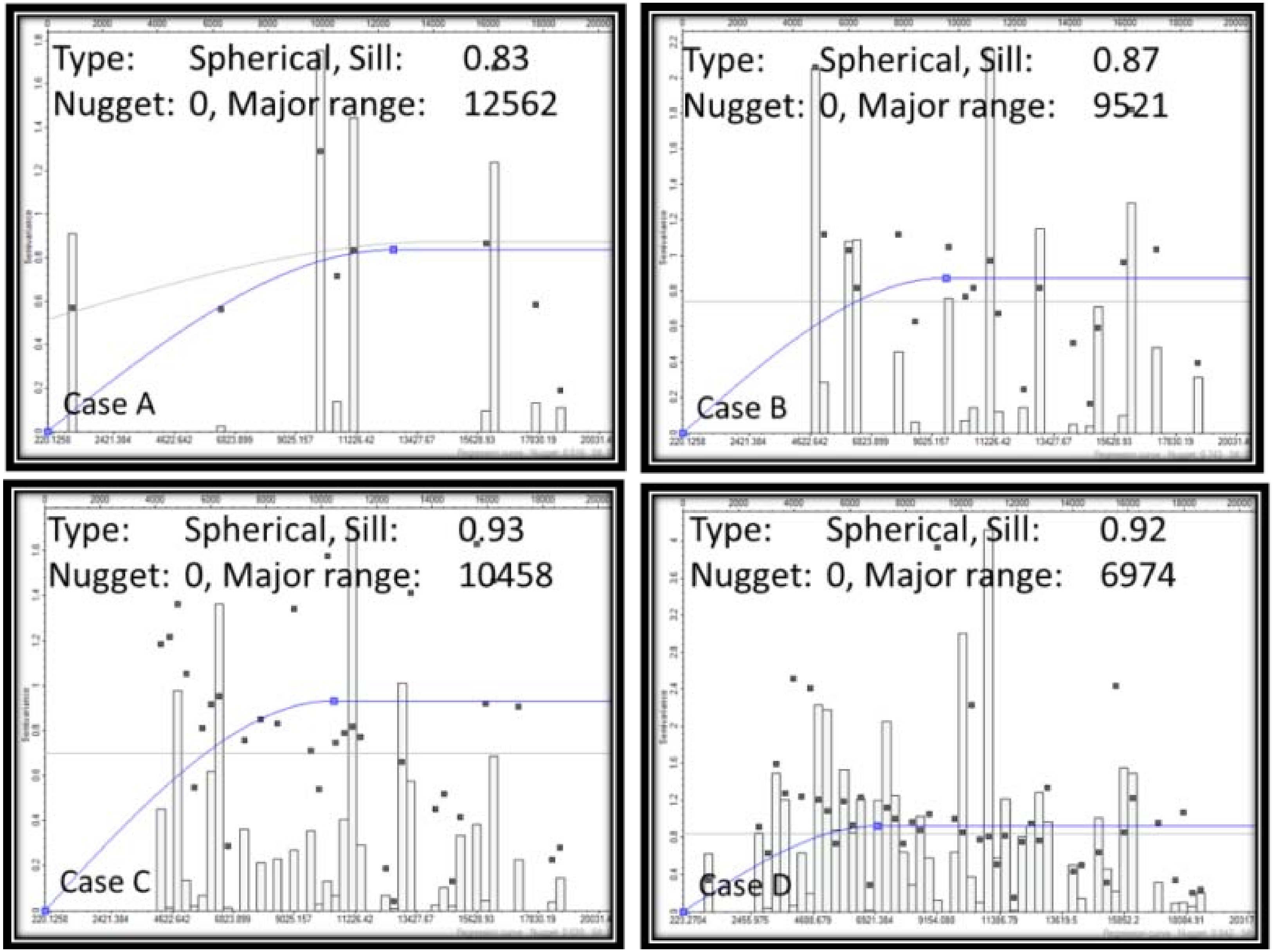

Figure 3. Changing selection of wells (hard data) from fewer to more, changes variogram drastically. There exists possibility of virtually drilling multi thousand wells in any field and hence possibility of very different variogram and hence the resulting “big picture” from one case to another.

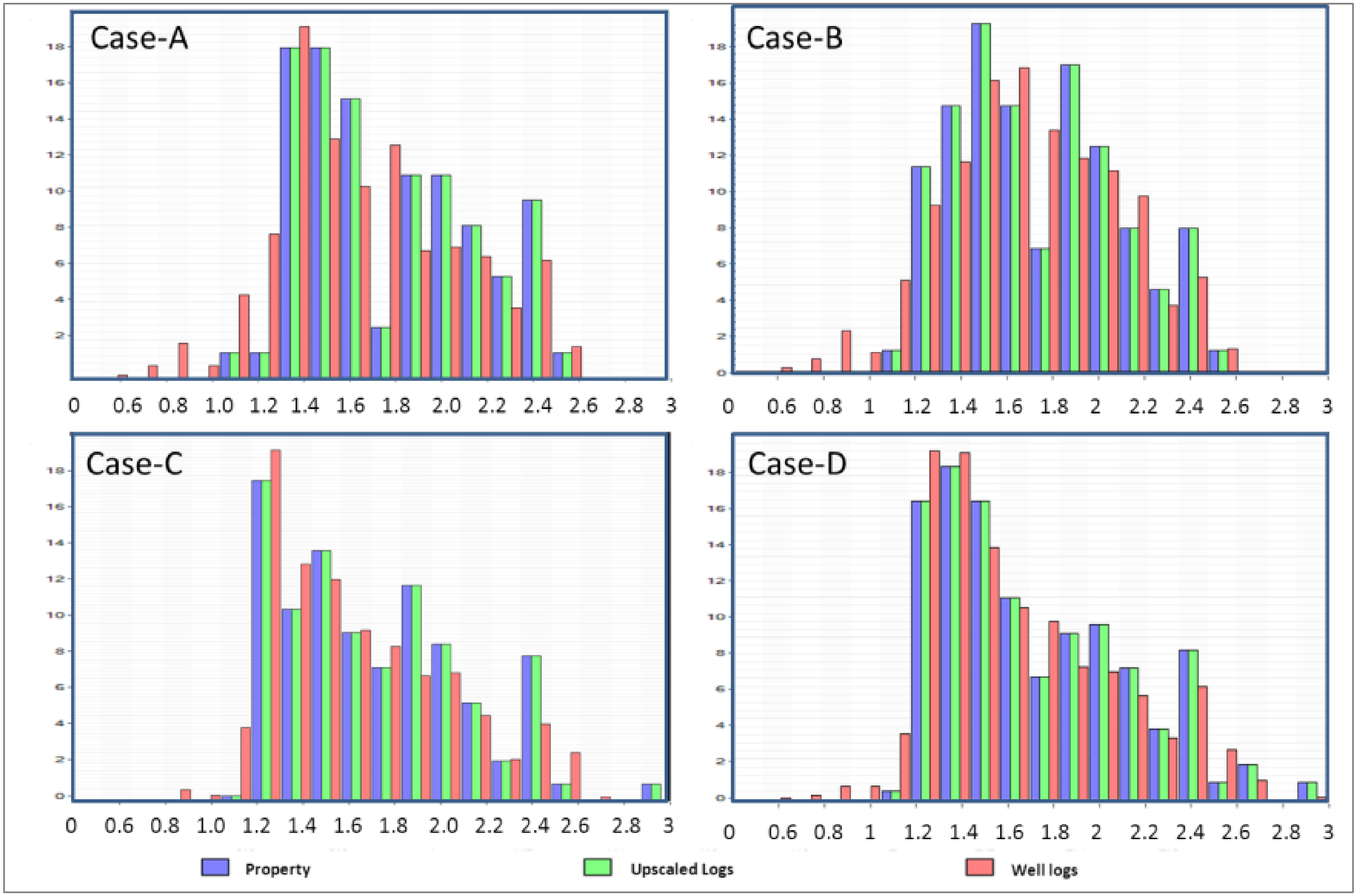

Figure 4. Changing selection of wells (hard data) from fewer to more, changes histogram drastically for conditional simulation to be very different in each case.

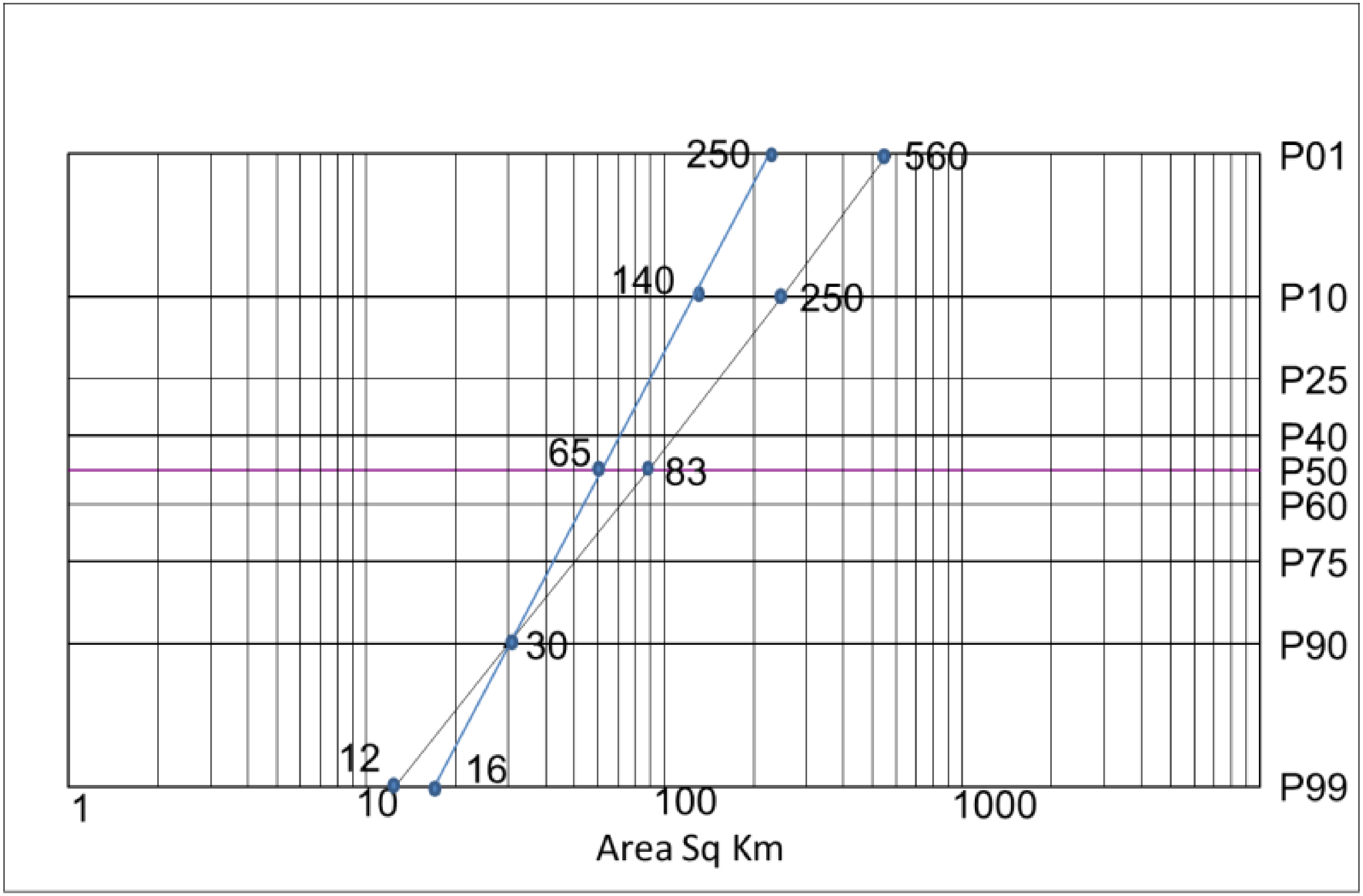

Figure 5. Conventionally area upto contact is considered as P10. If the discrete scenarios of area are plotted on a probability chart, it would be difficult to geologically defend the P01 (560 sq km) case which is much bigger than ultimate area upto contact (250 sq km). If the area upto contact is considered as P01 (Ultimate) then the P10 and P50 area changes drastically to 140 and 65 from 250 and 83 respectively. Same is valid for in-place and EUR.