Grain Size Geostatistics Enhance Reservoir Characterisation*

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Abstract

Are we making valid assumptions when relying on correlations to underpin the construction of stochastic reservoir models in Petrel™? (www.slb.com) Many times during the course of constructing a geostatistical reservoir model we rely on significant correlations to allow a densely sampled secondary variable (typically derived from a seismic data set) to augment a primary variable such as porosity or permeability. This may or may not be justified but straightforward petrographic analysis performed in PETROG™ (www.petrog.com) can readily confirm or otherwise the assumption. Further, the same analysis, without further effort, can validate the principle assumptions of first and second order stationarity required for our data to give us unbiased models. That this is not routine is a symptom of a decline in ground-truthing, which not only dismays old-school geologists, brought up on the principle that the rock itself is central to the story of the reservoir, but also confounds geostatistician, seeing their subject built on unreliable foundations.

Introduction

We show here that there is further reason for concern, and that this ground-truthing should be only the first step towards a more rigorous basis for geostatistical analysis. We show that some of the most powerful techniques of stochastic reservoir analysis depend on assumptions that are generally not even acknowledged, and hence remain untested in practice. Specifically, techniques such as collocated cokriging, and the stochastic simulation equivalents, rely on a correlation between variances which is sufficient to allow one variance to stand in for the other, and yet the correlations which are routinely used to justify this usage are not of second order (variances) but first (values). Practical studies on field data in modern-day analogues, combined with laboratory analysis of thin sections from North Sea reservoirs, show that these assumptions may well be met in many cases but that when they are not met, the predictions from reservoir models may be significantly biased.

Reservoir Model

We look first at the requirement for first and second order stationarity and what it really means for a reservoir model. The requirements for de-trending data prior to analysis in Petrel is generally justified by the statement that some geostatistical analyses require first order stationarity and others additionally require second order stationarity. However, this is a purely geostatistical statement, which, without geological explanation or justification, frequently leads practitioners to downgrade the importance of the requirements, with potentially significant effects on the quality of the resultant reservoir model.

If instead we re-cast the requirement by stating that geostatistics is the study of stochastic processes, and that we should ensure that as much as possible of the deterministic information has been already accounted for prior to geostatistical analysis, then the requirement should be more obvious and the route to achieving it clearer. In other words, we accept that variation in reservoir characteristics consist of aspects which can be explained geologically in terms of process and effect (the deterministic component) and aspects which cannot be explained physically (the random variation from point to point: the stochastic component). It is the geologists' task to explain and thence model the deterministic component; it is the role of geostatistics to model and, if not actually explain, then at least quantify the stochastic component. If the two are conflated, then neither will be modeled optimally and the reservoir model will be at best suspect.

Hence, it is necessary to make the best possible job of modelling the deterministic component to leave only the stochastic. This is the process of achieving first order stationarity. However, it does not necessarily imply second order stationarity, which is concerned with variance rather than just values. This is why we have modeled Coefficient of Variation, which shows us whether achieving first order stationarity does or does not result in second order stationarity as well.

Grain Size as a Proxy for Reservoir Properties

Given the clearly-observed relationships between measured rock properties, in particular grain size distributions, and the primary variables of concern in reservoir modelling [porosity, permeability], a necessary (although not actually sufficient) pre-cursor to achieving these stationarity conditions can be seen as requiring that grain size distributions have been normalised. Although grain size is clearly a major influence on reservoir properties, it is well known that, in idealised or simple cases at least, grain size itself has no effect, in as much as the packing of equal spheres is independent of the size of the spheres. Porosity and permeability are determined by complex interactions amongst size, shape and sorting, at least: i.e. mean and variance of size and variance of sphericity.

There have been several attempts to characterise modern and ancient fluvial systems by reference to a similarity variable: a variable which is characteristic of the physical system and which appears to be independent of the scale of the system within which it is measured. Typically, this has involved the ratio of, on the one hand, the difference between individual values and their collective mean and on the other a measure of variance or standard deviation. However, since the latter is effectively the expected value of the former, this could be seen as almost circular.

Coefficient of Variation

In part to avoid this possibility, as an alternative, the less glamorous but more established variable called the Coefficient of Variation (CV), defined as the ratio of standard deviation to mean, should at the least be a way of combining two out of three of these primary variables (size, shape and sorting).

If this were the only reason for wanting to analyse the CV, it would be a good enough reason for giving it much greater emphasis than it has received hitherto. However, an even more critical reason, and the one we wish to discuss here, arises when secondary variables are required to characterise variation, which is frequently the case when building reservoir models. The critical step of populating a grid with values by extrapolating from control values at wells, referred to in Petrel as ‘petrophysical modelling’, can be significantly improved if we can use more densely sampled data – typically, 3D seismic - to control the distribution between wells.

However, given that geostatistics, in contrast to deterministic modelling methods, is primarily modelling variance; it is the ability of the secondary variable to provide information about variability that is the quality we seek. In other words, when we use, for example, Acoustic Impedance (AI) to provide information on variability of porosity in-between the wells, we should check that there is adequate reason for assuming that the variability in AI does indeed correspond to the variability in porosity. This is rarely, if ever, done in practical reservoir modelling. Instead, it is the correlation between AI values and porosity values that is used to determine the suitability of AI to predict variation in porosity; how valid is that?

The CV is traditionally described as a parameter that measures the variability of a series of numbers independently of the unit of measurement and is often used to compare distributions obtained with different units. Here we are not interested in the units and all the data are measured in the same units, but the CV effectively gives us a measure by which we can judge the question just posed: How valid is it to use correlation between values to presume a correlation between variances?

The Geological Justification

We frequently see that mean and standard deviation appear to be correlated, in that large mean grain sizes have associated large variance, and vice versa. In a fluvial system, the geological justification for this is obvious; in other environments, perhaps less so. By way of example, we may look at time-averaged grain size data from a single ‘time-surface’ within the Montsor fan succession, Spanish Pyrenees (Duller et al. 2010). There is an overall deterministic trend to grain size as the stream loses energy away from its source, but there is a considerable stochastic component to the measurement of grain size at each location, as illustrated by the error bars (Figure 1). What is of primary interest here is that the size of the error bars seem to be roughly proportional to the mean grain size they are describing. The question is, apart from the heuristic geological explanation, can we rely on this statistically?

The Statistics Part

We are primarily concerned with investigating the proposition that the ratio of standard deviation to mean, amongst all of the data sub-sets (i.e., in this case, at all stations), is roughly constant and hence that correlation between means and a secondary variable is indicative of correlation between standard deviations and that secondary variable. This would mean, for example, that if we had a sparsely-sampled variable, such as porosity (‘sparse’ in this sense meaning simply that measured values are only available at wells) then it may be augmented by a secondary variable, such as AI, which is available between the wells (is more densely sampled) and therefore that the secondary variable is able to guide the modelling of the primary variable between wells.

If we can find such a secondary variable, then the model becomes more reliable, and hence the search is important. However, we should be wary of using a secondary variable where it does not fulfill the basic requirements: does correlation of values (porosity values at the well control points with AI values at the same locations) imply that we can use the latter to stand in for the variation in the former? If so, we can legitimately use the secondary variable in the petrophysical modelling. However, the statistical tools available to provide this information are not simple.

Another example is an ancient alluvial fan succession in the La Pobla Basin, Spanish Pyrenees, where grain size data was collected to test geological models for down-system grain size fining that necessarily requires a constant value CV. In this example the coarse and fine end-member samples (n = 100) were collected at each sampling station to characterise the time-averaged, geological, grain size distribution. This was done at a number of sites along the length of the system.

Do the data appear to provide some support and indicate that this is worthwhile investigating further? The study of sample populations from this particular system, and eight more systems, does suggest a constant CV but this requires rigorous statistical testing and comparison with the variability in mean and standard deviation (Figure 2).

Discussion and Results

So, whilst at first sight it would appear that the hypothesis (that CV is approximately constant, and hence that correlation with mean implies correlation with standard deviation) is likely to be correct, one problem at present is that there is insufficient body of work on how this hypothesis should be tested. To quantify the confidence we would have in making this deduction would require the application of a statistical test for significance, but which one to use is far from clear. Using stochastic simulation circumvents the paucity of theory and demonstrates that for these data sets, the assumptions are valid, and hence that reservoir models built upon them can be trusted.

A second problem is that there is no expectation that the analysis would generalise. Therefore, whilst this study offers good justification for continuing this work on other sedimentary systems, each of which may be expected to have their own preferential value of CV, establishing the crucial interpretive and predictive bases for each, from formative process and sedimentary dynamics is likely to be a formidable task. At present, we can at least say that there is good reason to continue to investigate the fundamental questions, with more data and different geological settings. Ultimately, we would hope to be able to answer the opening question: can some of the fundamental assumptions of geostatistical reservoir modelling be truly thought of as a firm foundation for the science.

Reference Cited

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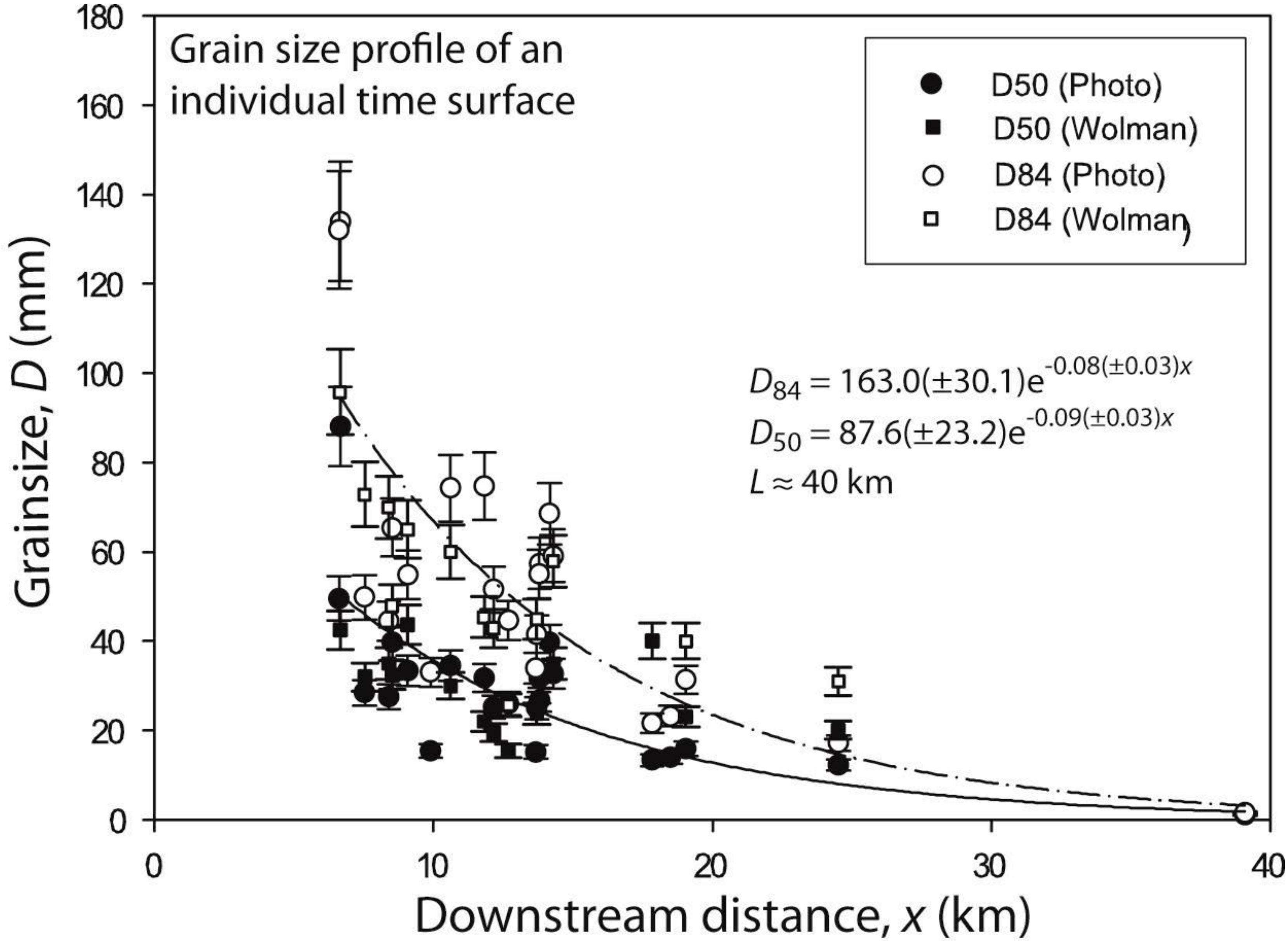

Figure 1. Grain size vs. downstream distance.

CV: fine	CV: Coarse
0.945	0.834
0.894	1.195
0.872	0.838
0.897	0.854
0.840	0.707
0.976	0.966
0.795	0.763
0.941	0.920

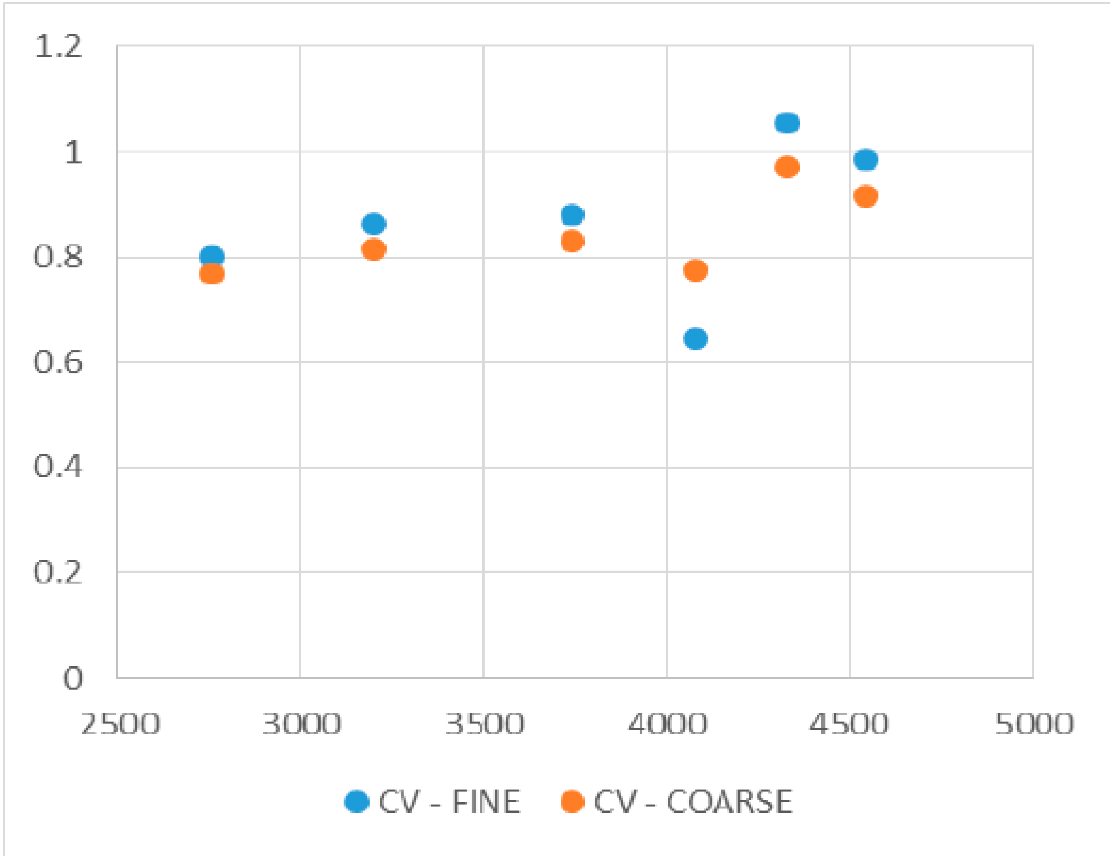

Figure 2. Sample populations suggest a constant Coefficient of Variation.