Enhanced Two Dimensional Grain Size Analysis through the Use of Calibrated Digital Petrography*

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Abstract

Reservoir quality (porosity and permeability) of clastic sedimentary rocks is directly related to grain size and variance. A range of techniques is typically used to measure grain size and variance, including mechanical sieving and laser granulometry. Each of these techniques are bulk 3D grain size analysis methods, unable to differentiate individual grains, grain coatings, diagenetic phases, agglomerates and fragments. In order to assess each grain in 3D, these methods also require rock samples to be disaggregated, leading to the loss of any possible structural information present. Furthermore, these bulk textural methods cannot account for compositional variation across a sample, with quantitative compositional information traditionally obtained through petrographic analysis. Conversely, grain size, variance and shape analysis from petrographic studies are usually recorded in a qualitative way, which is a limitation. The principle reason for this is that textural analysis based on observations from a 2D plane is not an accurate representation of 3D texture, but rather an apparent view. Using PETROG™, a point-counting digital petrography system, we derive a statistical, stereological (2D-3D) relationship through comparison of apparent (2D) and actual (3D) grain size and grain size variance from artificial rock samples constructed from combinations of glass, basalt and carborundum. Applying this relationship to real world rock samples taken from the Brent oil field reveals that using this enhanced petrographic method can produce grain size variance data to within similar error ranges as those determined from bulk 3D methods. This additional utility for PETROG enables the user to simultaneously collect and analyse textural and compositional data, which is essential for the evaluation of reservoir quality.

Introduction

Grain size distributions within a given lithological interval are considered fundamental information, particularly when characterising reservoir quality and considering attributes such as porosity and permeability. Many methods, both three-dimensional (3D) and two-dimensional (2D), are used to investigate grain size. Each method has benefits and limitations, inherent in the method of measurement as well as dependent on the textural properties of the sample material.

3D methods, such as sieving, liquid suspension sedimentation (Mirza and Richardson, 1979), centrifuging (Barbanti and Bothner, 1993) and laser granulometry (Di Stefano et al., 2010), typically benefit from the ability to measure grain size distributions based on the full 3D extent of the grains. However, along with method specific drawbacks, all 3D methods suffer from some inherent limitations:

1) Based on the cohesive state of a sample, it may not be possible, or desirable, to disaggregate a rock sample for 3D grain size analysis;
2) Disaggregation methods may lead to a range of unquantifiable errors, arising from failure to completely disaggregate materials, which could lead to an overestimation of grain size. Conversely, over energetic crushing of sample materials would cause an underestimation of grain size resulting from the fragmentation of individual grains;
3) 3D methods cannot make the distinction between the original grain and original grain with overgrowth. Additionally, they are unable to recognise original fragmented grains, instead regarding each fragment as an individual grain;
4) They are also subject to inherent loss of structural information, such as fabrics, contained within the original sample lithology, due to disaggregation;
5) Invaluable information such as bulk mineralogy and composition of the sample, and of grain size classes, is lost.

Based on these known limitations, 2D methods of grain size analysis, such as optical microscopy and image analysis are often preferred. Thin sections or slabs can be cut from almost any lithology, regardless of cohesive state, enabling the direct observation of grains on an individual basis. This allows for the differentiation of original grains from fragments, secondary coatings, diagenetic phases and agglomerates. In addition, thin sections represent the original lithology, allowing for more detailed investigations and present the opportunity to collect multiple data sets synchronously, including textural, fabric and compositional information. However, investigating a 3D material via observations made from a 2D planar section cannot be considered an accurate representation of the 3D texture. This is because it is an apparent view, with the full 3D extent of the grain's size unknown. This can provide insight into apparent grain size distributions, but cannot be considered an absolute value. This may be suitable for direct comparison between like data sets, but problems arise when attempting to calculate absolute, as opposed to relative, properties, and when comparing with data sets derived via alternative methods which are able to assess the full 3D extent.

To work around this problem, petrographers and mathematicians have proposed correction factors: factors by which the apparent measured length can be adjusted to gain a more accurate representation of grain size distribution. This has been performed both theoretically (Krumbein, 1935, Greenman, 1951, Sahu, 1966, Packham, 1955, Kellerhals et al., 1975, Johnson, 1994, Sahagian and Proussevitch, 1998, Jutzeler et al., 2012) and empirically (Friedman, 1958, Adams, 1977, Harrell and Eriksson, 1979, Kong et al., 2005, Jutzeler et al., 2012). Both the importance of obtaining a satisfactory result and the difficulty of achieving this goal are clear from the number of times this has been revisited over the years, and the number of different calculation methods that have been employed.

The technique used to collect and process data varies between each 2D method. Measurements of 2D grain size can be achieved manually, which is time consuming and labour intensive, but often allows for more detailed data capture. Alternately, it can also be achieved through image analysis techniques, which through the use of computational software, are often more rapid, but are less suited to collecting multiple data sets or picking up compositional and textural subtleties. Both techniques often also require the use of multiple pieces of equipment or software, requiring the merging of additional data sets. The aim of this work is to utilise PETROGTM digital petrography system in order to determine

the relationship between grain size distribution in 2D (apparent) and grain size in 3D (absolute). This will be done concurrently with compositional and structural data collection, which will enable us to define appropriate error bounds on grain size distributions collected in 2D.

Methodology

The investigation makes use of a number of grain size analysis techniques: standard dry sieving; laser granulometry; X-ray computed tomography (CT-scan); image analysis; and QEMSCANTM, alongside an enhanced, perimeter-based digital point-counting method, using PETROG. The samples investigated are a combination of artificial and real rock samples.

Artificial Samples

The artificial samples were constructed of a mixture of glass, basalt and carborundum each constituent apportioned a 1:1 ratio. The size distribution of each was constrained using sieving, before being measured and further characterised using laser granulometry and image analysis techniques. The materials were then mixed in combinations that let us explore/assess the effect of size distribution and shape variation error. Three samples were made from: sample a; unimodal glass beads with spherical shape (Figure 1a), sample b, bimodal glass and basalt with spherical shape (Figure 1b), sample c, bimodal glass and carborundum with varying shape (Figure 1c). These materials were combined with blue-dyed epoxy resin, evenly mixed and fixed into a mould.

Each sample was initially analysed as a whole using a CT scanner. The samples were then cut for thin section analysis using PETROG digital point counting, image analysis and QEMSCAN.

Real World Samples

To assess whether our error analysis of artificial samples is robust real world samples were also used, representing a variety of depositional environments and displaying deformation bands and fragmentations (Figure 2a) and grain overgrowths (Figure 2b). Both samples were CT-scanned, in order to build up a 3D representation of the internal structure. Following this, part of each rock sample were disaggregated for investigation with sieving, laser granulometry and image analysis techniques, and the remainder cut into thin sections for investigation using point counting, image analysis, and QEMSCAN.

Discussion and Conclusions

The main aim of this work is to quantitatively assess the effect of known grain size variance, and to a lesser degree grain shape, on the inherent error of mean and variance of an apparent 2D compared to that of the 3D sample. By doing this, we are able to derive a stereological correction based on variance. Efforts to generate a correction factors for 2D grain size distributions have focused on mean grain size or some other singular statistical measure. This is a major limitation given that primary output of stochastic reservoir models is variance, something that is severely overlooked. Our work aims to establish, for the first time, the dependence of the mean value upon the variance and, more importantly,

the robustness of the variance (i.e. the variance of the variance). Concerning the formulation of 2D to 3D correction factor(s), we use variance rather than mean. There is no current way of doing this and so this work represents a first attempt at the problem.

From our analysis of artificial rock samples, we calculate appropriate stereological correction factors, the values of which appear to be validated by our 2D and 3D grain size analysis of real rock samples. We suggest, by using variance rather than mean, that one universal stereological correction factor is unrealistic.

As the grain size distributions and shape characteristics are known quantities for each artificial sample, the grain size measurements made using subsequent 2D technique (point-counting, CT-scanning and image analysis) have been corrected and used to derive correction factors directly through comparison of data sets. The factor varies from sample to sample, due to factors including the increase in complexity of the samples and the size and shape variation. As expected, the amount of error also increases.

Using the errors defined by the artificial samples, these margins can be expanded by applying the same error bars to the real world samples and repeating the grain size measurements using each technique available. The effect of various structural features, coatings and fragmentations has therefore been quantified.

In addition to comparing the correction factor amongst size and shape variants, we have also compared these with correction factors derived previously in the literature. We propose that the correction factors derived here explicitly demonstrate the variation in expected error with grain shape and structure (fabric and packing) variation, unlike previous empirical investigations.

The relationship between grain size distribution and of the error, which is a critically important input to stochastic reservoir modelling, has not been considered in any previous study. This provides us with the first reliable means for its estimation, allowing for the relationship between error, size distribution and shape variation. This quantification of expected error also allows the development of protocols for variance quantification. With variance being the primary output of stochastic reservoir models, this work provides a step towards validation of stochastic models and, hence, provides greater accuracy and resolution to reservoir quality investigations.

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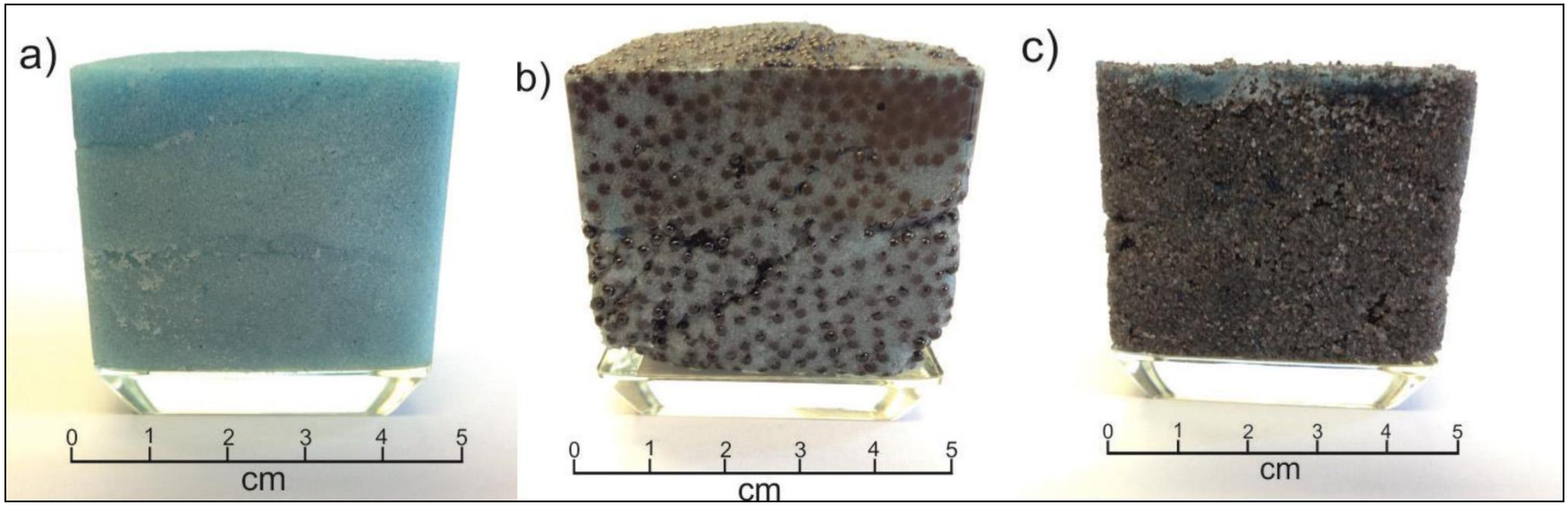

Figure 1. (a) Unimodal distribution of 160-200 μm glass beads (b) Bimodal distribution of spherical glass 160-200 μm and basalt spheres 1600-1800 μm (c) Bimodal distribution of spherical glass 160-200 μm and non-spherical carborundum 315-400 μm.

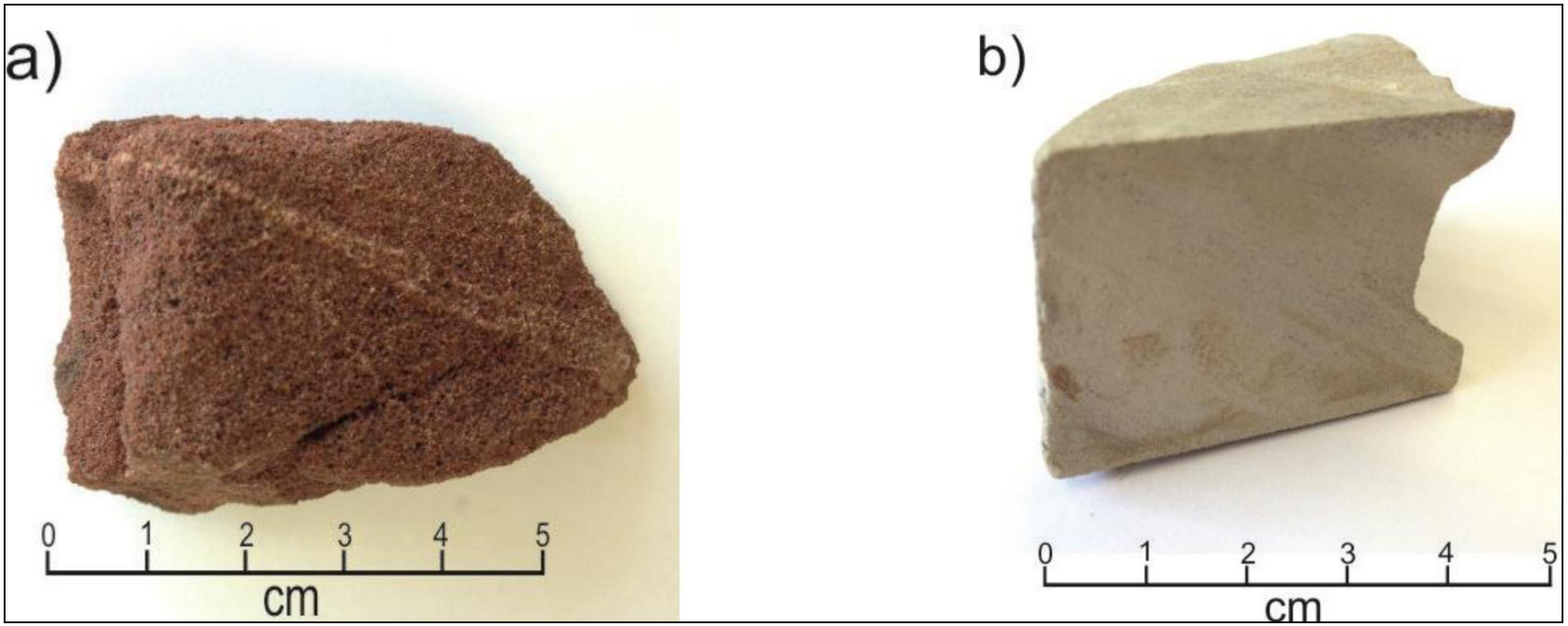

Figure 2. (a) Deformation bands within coarse-grained Sherwood sandstone (b) Quartz overgrowths of Brent Group sandstone.