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Forget Better Statistics – Concentrate on Better Sample Selection

Patrick Corbett, David Potter, Khalifa Mohammed[2]*, and Shujie Liu*
Department of Petroleum Engineering, Heriot-Watt University, Riccarton, Edinburgh, EH14 4AS,
[2] Repsol Oil Operations, Tripoli, Libya

Introduction

The API's "Recommended Practices for Core Analysis" makes very little reference to sampling. Core plugs are to be taken at the "selected locations". The only comments concerning sample volume are for vugs and conglomerates – "it is necessary that sample size be sufficient to include all pebble sizes" (p. 3-5, API, 1998). There are instructions on core orientation: That core plugs should be oriented horizontally and vertically with respect to the core axis or with respect to the bedding planes. The technical procedure for core plugs, probe permeameter and whole cores – including handling and cleaning – is laid out for these industry standard measurements. Similarly, textbooks on Petrophysics do not have sections on sampling (Tiab and Donaldson, 1996).

There is therefore no guidance to industry on how samples should be located. There is also nothing to say that core plugs must be taken every foot either, even though this is widely held to be standard industry practice.

In this paper, we review the statistical, petrophysical and geological issues for sampling. We propose a series of considerations and are working on a fully recommended procedure.

Sampling criteria

A set of sampling criteria can be developed by considering the various issues in the various technical interest groups. We consider, in our approach, that the ultimate use of the core data is to sample heterogeneous rocks to get average properties and to build geological models for computer simulation. Other uses of core data are not considered in this short paper.

Statistical issues

Measurement usefulness: For use in statistical models – this is where much data ends up these days – the key issues are the statistical support and stationarity. Support refers to the appropriate volume of a sample to capture local homogeneity, and stationarity refers to the lateral variation in statistical parameters (averages and variances) associated with that support volume (see Corbett *et al*., 1999 for further discussion). These issues are well illustrated at the laboratory scale (Figure 1) by comparing probe permeameter data used in clastics (where the support volume is appropriate) with those in carbonates (where there is inappropriate volume support). In this case, either of the measurements in the sandstones could be used in modelling and upscaling, but neither of the measurements are usable in the carbonate – except in the limited intervals of oomoldic grainstone (between 9 and 9.5 cm) where the measurements are consistent. Upscaled flow experiments on cubes support the conclusions that can be made simply by observing the differences between the series of apparent permeability measurements at different scales (Corbett *et al*, 1999).

This issue is partly addressed in the recommended practices with respect to conglomerates and vugs (API, 1998) – but the issue applies to many rock types at various scales. We recommend that support should be assessed by multi-volume scaled measurements in many more rock types as a part of the routine core analysis. The geostatistician needs to know that the data have an appropriate support volume for any property that is to be used in modelling. Stationarity, or more specifically local stationarity, is shown by the modest changes between adjacent points in the sandstone, as opposed to the dramatic changes for the carbonate. The geostatistician also assumes that this holds for the data and should also be assessed and recorded in a routine core analysis programme.

Estimation of averages: The concept of sample sufficiency was introduced to develop rules-of-thumb to estimate the appropriate number of samples that are needed (Corbett and Jensen, 1992). The optimum sample number of clastics ($10Cv^2$) to give estimates within ±20% were expanded for carbonates ($4Cv^2$) to give estimates within ±50% (Corbett and Jensen, 2000). Whilst there is still discussion over the application of these guidelines (Sanir and Sahin, 2000), it remains logical to vary the number of samples according to variability – rather than the length of core, as is the case with the one sample per foot approach. Techniques for determining the appropriate number of other measurements (capillary pressure and relative permeability) need to be developed.

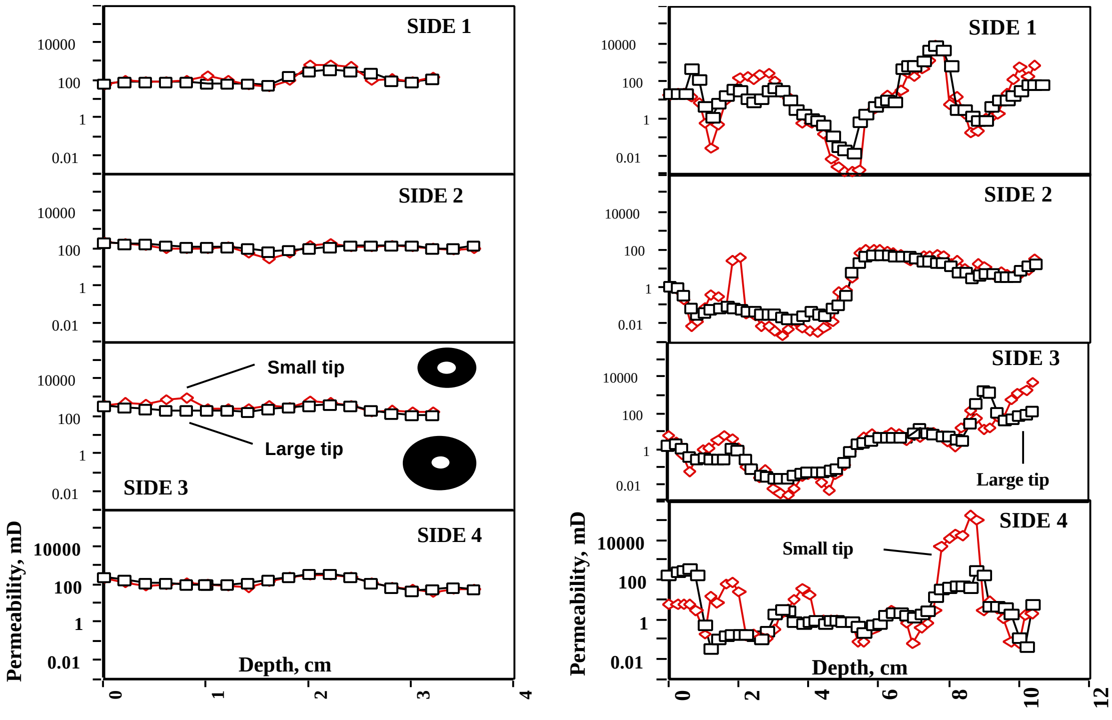

Figure 1: Probe Multi-tip upscaling experiment in (left) a sandstone and (right) a carbonate. In the sandstone the two different volume (support) scale measurements give the same value of permeability. In the carbonate the support volume is clearly inappropriate because of the difference in value for each measurement (from Corbett *et al*, 1999).

Petrophysical issues

Petrophysical classes: Amaefule *et al*. (1993) showed that reservoir sandstones can be classified into a number of discrete units (Hydraulic Units, HU's). It is recognised that these are important for the appropriate petrophysical description at the well. In some reservoirs there may be a number of HU's identified (Figure 2). One issue concerns how many HU's there should be and how important each of them is. In figure 2, the rare core plugs in HU7 represent very thin stylolite zones (Mohammed and Corbett, 2001). These features are much more common in the reservoir (occuring at least 1 per foot) than appears in the core plug data set. Within each HU the properties are effectively uniform, so multiple cores of the same hydraulic unit may not be adding to the petrophysical description of the well. Seeking out new hydraulic units or hydraulic units not well represented may be a strategy for improved permeability classification.

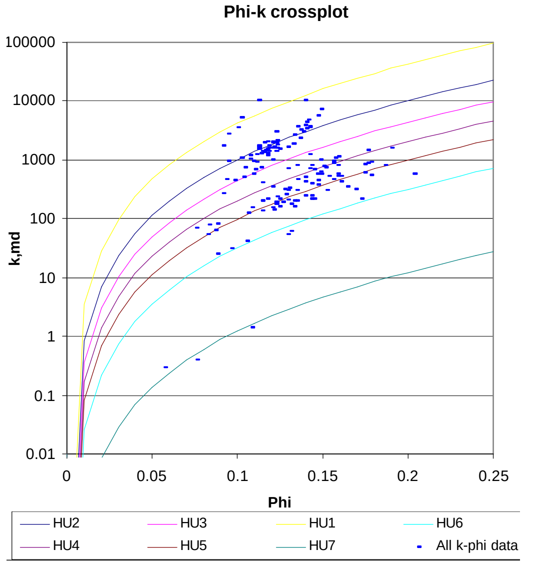

Figure 2: Hydraulic units (Mohammed and Corbett, 2001) from a field. Whilst most of the data cluster well above 10 mD, there are a few plugs around 1 mD. HU7 seems to be a minor component in this reservoir from this core plug data set (from Mohammed and Corbett, 2001).

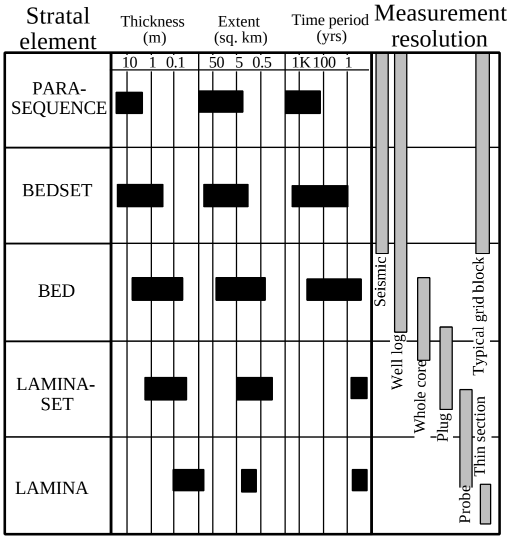

Figure 3: Stratal units for shallow marine environments and measurement resolution (Corbett *et al*., 1992, from van Waggoner *et al*., 1990).

Geological issues

Representative Units: The basic building blocks of reservoir sandstones are stratal elements or genetic units (Figure 3). For reservoir modelling the relationship between HU's and these architectural elements is important. In shallow marine sediments the basic building block is a parasequence comprising lower middle and upper shoreface sandstones. A parasequence is therefore a representative element for the reservoir.

Using a single 24 ft parasequence element, Potter and Corbett (2000) were able to predict the permeability for the entire well sequence. The 24 ft interval was a sub-set of the 400 ft of core available in the well (Figure 4). The fact that a representative section was chosen is due to geological selection. There is wide variation of the estimated mean property from all the possible 24 ft sections in this reservoir. However, the estimated mean for the selected section lies close to mean of the full 400 ft of core. In this case, measuring a small interval in detail can be effectively used to estimate the properties of a much larger interval. Statistical techniques can be used to support the selection of samples on geological criteria as representative elements.

Summary

An appropriate sampling strategy should consider the following:

- Assessment of property support and stationarity and choosing the right volume scale(s) and measurement device(s).
- Definition and analysis of the range of HU's for petrophysical representivity of reservoir properties.

- Acquisition of sufficient samples to estimate required properties within a certain tolerance.
- Measurement of geologically-representative intervals, checking these statistically and exploiting this in prediction.
- Rigidly acquiring one sample per foot at a fixed volume scale should be avoided.

There may also be some other criteria (Rock Mechanics, Rock Physics and Reservoir Engineering aspects) to further influence the selection of sample type and measuring device. However, if these data are to be considered in a model then the above issues will also hold.

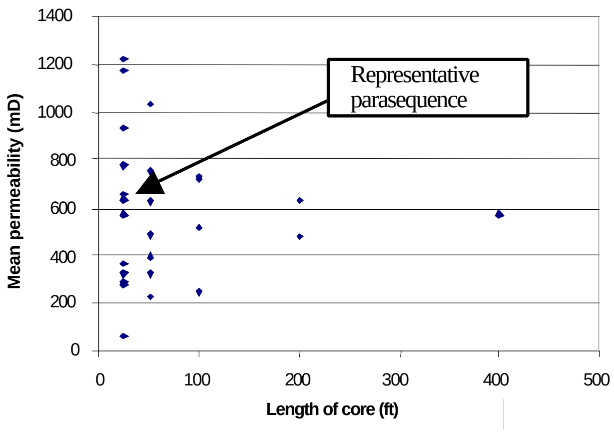

Figure 4: Variation in estimates of mean permeability for subsets of a 400 ft core. One selected interval covers a representative geological unit and can be used to effectively capture the properties of the sequence.

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