PETROTYPING: A BASEMAP AND ATLAS FOR NAVIGATING THROUGH PERMEABILITY AND POROSITY DATA FOR RESERVOIR COMPARISON AND PERMEABILITY PREDICTION

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This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Abu Dhabi, UAE, 5-9 October, 2004

ABSTRACT

Various definitions of ‘rock typing’ have been suggested in the literature, both geological (lithotypes) and petrophysical (hydraulic units). We suggest that the term ‘petrotype’ is used to define a specific set of petrophysical rock types. Our definition of ‘petrotype’ is based on an *a-priori* set of global hydraulic elements (GHE) which have been defined by a regular progression of flow zone indicator (FZI) values. The FZI values have been chosen with consideration to:

- The range of porosity and permeability in typical reservoirs.
- The variability allowed, from an engineering perspective, within a hydraulic element for a given porosity.
- The need for discretisation of the porosity-permeability space to eliminate less important, from an engineering perspective, variations or ‘noise’, from significant variations or ‘model data’ in the core plug dataset.

The plotting of plug data on the GHE ‘basemap’ allows trends to be easily determined. Shallow marine reservoirs show clear progressions across GHEs as the sandstone coarsens upwards and cleans upwards. On the other hand, other types of reservoirs may be limited to a single GHE (for example, chalk) or a limited combination of GHEs. This mapping approach allows for the ready comparison between reservoirs, wells, fields, core data and simulation data. Patterns can be recognized and exploited for permeability prediction.

The GHE palette can also be potentially applied to core data for the identification of other significant trends in a wide range of crossplots for different parameters. Petrotyping, or the systematic classification of petrophysical data against a global standard reference, provides a new framework for comparative reservoir description and extrapolation (identifying single, bi- or multi-petrotype reservoirs, as well as ordered or unordered petrotype reservoirs). It may also provide a new tool for comparing 3-D models.

INTRODUCTION

A subsurface reservoir comprises volumetric elements of rock with porosity and permeability. A numerical grid block simulation model on a computer also comprises volumetric elements (cells) with a porosity and permeability. Through the various up-scaling procedures the porosity and permeability of the cell should represent the effective permeability and porosity of the volume of rock represented by the cell. With smaller and smaller grid cells these volumetric elements should converge and at this point the elements can be considered the basic elements of porosity and permeability (defining hydraulic elements). It is assumed that these elements are likely to be larger than a single core plug and this is considered a reasonable assumption in most clastic reservoirs.

The concept of hydraulic (flow) units has been in the literature for some time [1] and is used to classify or cluster core plug data according to simple relationships derived from fundamental concepts. On the other hand, flow units were originally described [2] to represent larger scale correlatable units between wells. The combination of hydraulic units (a classification based on core plug data) with flow units (a large scale reservoir volume) to form hydraulic flow units has lead to a confusion of terms as a “unit” implies a large scale body to a geologist. Additionally, there is a problem with flow units in that they do not necessarily flow into the well bore. However, the hydraulic unit approach remains a pragmatic way of classifying the porosity-permeability data into a reduced number of elements in a single population (such as a well).

Traditional hydraulic units have been determined by various methods in a number of case studies [3,4]. In each case, the hydraulic units correspond to textural (i.e., grain size and sorting) elements. In these studies, it was demonstrated that four to seven hydraulic units were present in the various wells. It was also demonstrated through the use of the ordered and unordered (previously modified) Lorenz plot and production logs that the contributing hydraulic units to flow were limited to one or two elements [3].

In each of these studies, the definition of hydraulic units has consistently followed the same published technique. However, the resulting hydraulic units are different in each particular case. In one study the data from a number of wells in one field were combined and hydraulic units for the total field were calculated. A similar number of hydraulic units were found as observed in the individual wells, suggesting that, for this reservoir, a limited number of hydraulic units are representative across the field.

Recognizing that even very heterogeneous reservoirs can be classified in terms of a relatively limited number of hydraulic units allows the petrophysical elements to be quickly and systematically characterised. We therefore propose the use of a universal pre-determined template, on which are constructed a series of GHEs. Core plugs and petrophysical data plot in ‘clusters’ between the predetermined GHE lines. In clastic reservoirs, where the GHEs are often texturally defined, the petrophysicist using a limited number of GHEs is akin to the sedimentologist using a limited number of pre-defined grain size classes (fine, medium, coarse, etc).

Geologists often consider the term ‘rock type’ to be synonymous with lithology (sandstone, limestone, granite, etc) or lithotype (cross-bedded sandstone, massive sandstone, laminated sandstone, etc). These definitions may or may not be significant with respect to variations in petrophysical properties and may or may not help de-cluster the porosity-permeability data. Often similar porosity-permeability variation is present within and between lithotypes, suggesting that these are not always the fundamental building blocks for reservoir modelling.

DEFINITION OF HYDRAULIC UNITS

A hydraulic (flow) unit (HU) was defined as the representative elementary volume (REV) of the total reservoir rock within which geological and petrophysical properties that affect fluid flow are internally consistent and predictably different from properties of other rock volume [1]. The HUs for a hydrocarbon reservoir can be determined from core analysis data (porosity and permeability). This technique has been introduced by Amaefule et al. [1], and involved calculating the flow zone indicator (FZI) from the pore volume to solid volume ratio (ϕ_z) and reservoir quality index (RQI) via Equation 1. From FZI values, samples can be classified into different HUs. Samples with a similar FZI value belong to the same HU [4,5]. Figure 1 shows an example of the HU approach applied to a well where seven distinct HU’s are evident with different hydraulic properties. Other wells in the same field had different numbers of HU’s and these were defined by different FZI relationships. This study raised the issue of how many HUs should you select and how can these be related from well to well.

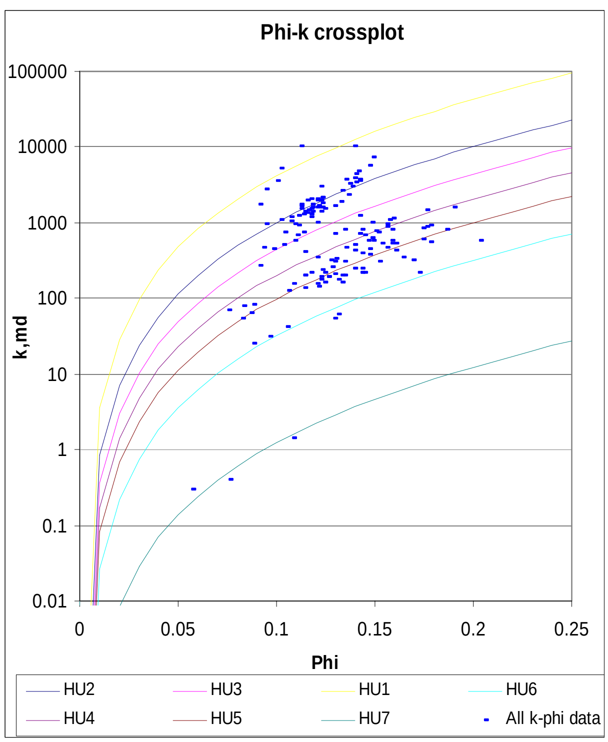


Figure 1. A porosity (phi) versus permeability (k) crossplot showing hydraulic units for routine core plugs. Note that these curves were based solely on the plug data in the well and represents a declustering based on statistical criteria: straight line sections on a cumulative probability plot [4].

HUs are recognized by their Flow Zone indicator (FZI) determined as follows:

$$FZI = \frac{RQI}{\Phi_z} = \frac{0.0314\sqrt{\frac{k}{\phi}}}{\left(\frac{\phi}{1-\phi}\right)} \tag{1}$$

GLOBAL HYDRAULIC ELEMENTS

For a given porosity, the permeability can be calculated by a rearrangement of Equation 1 as follows,

$$K = \phi\left(\left(FZI\right) x \left(\frac{\phi}{1-\phi}\right) \Big/ 0.0314 \right)^2 \tag{2}$$

and using this equation, lines for constant FZI can be determined. Selecting a systematic series of FZI values allows the determination of HU boundaries to define 10 porosity-permeability elements (global hydraulic elements, GHEs). The definition of these boundaries is arbitrarily chosen in order to split a wide range of possible combinations of porosity and permeability into a manageable number of GHEs.

Table 1. Hydraulic unit lower boundaries (shown as FZI values) for 10 Global Hydraulic Elements (GHEs).

FZI	GHE
48	10
24	9
12	8
6	7
3	6

FZI	GHE
1.5	5
0.75	4
0.375	3
0.1875	2
0.0938	1

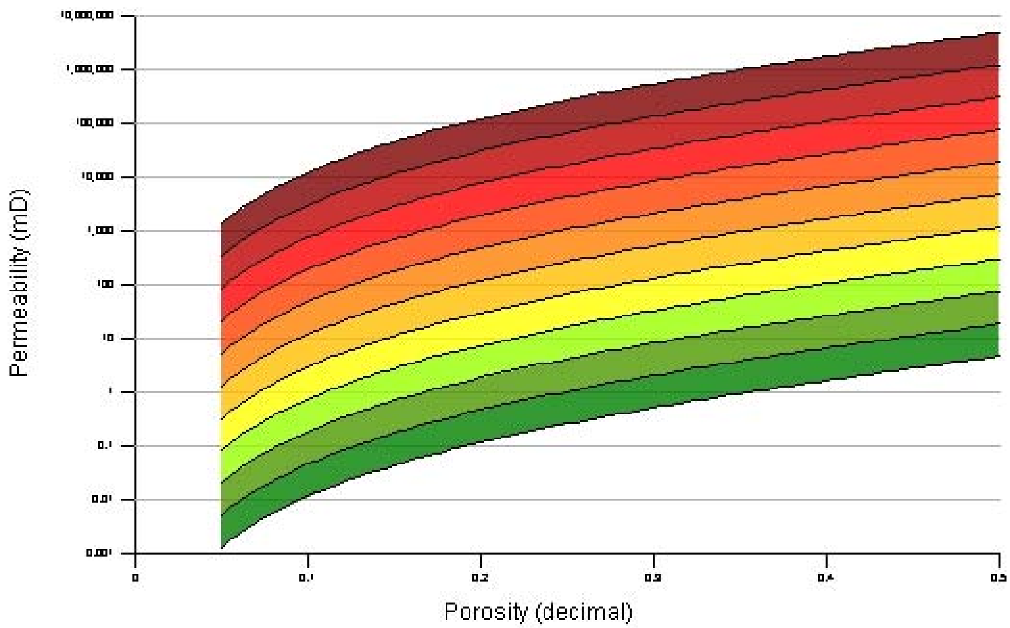


Figure 2. Global hydraulic element "basemap" template showing GHE1 at the base to GHE10 at the top. Colours for standard GHE are given in the appendix.

PATTERNS OF GLOBAL HYDRAULIC ELEMENT VARIATION

A reservoir characterization study of a Jurassic aged, tidal sandstone reservoir in Siberia [6,7] considered the variation in porosity and permeability on the GHE basemap. A clear trend can be seen (Figure 3). This variation is reflected in the coarsening-up nature of this sand body (Figure 4). In this case, the FZI has been calculated from air permeabilities, rather than liquid permeabilities as in [7].

From a single well in a Siberian oil field, it is useful to examine the porosity and permeability data from other shallow marine reservoirs. Similar trends are shown in such reservoirs from the North Sea and North Africa (Figure 5). Interestingly, for the upper shoreface sands in GHE8 and 9 of the North Sea example the permeability is significantly higher than would be predicted from the trend observed in the lower part of the shoreface in the Siberian example (Figure 3), where most of the upper shoreface appears to be missing. Upper shoreface sands are very well sorted and relatively free of clay. Thus, the knowledge that the reservoir is a shoreface should lead the petrophysicist to predict non-linear porosity-permeability relationships (Figure 6).

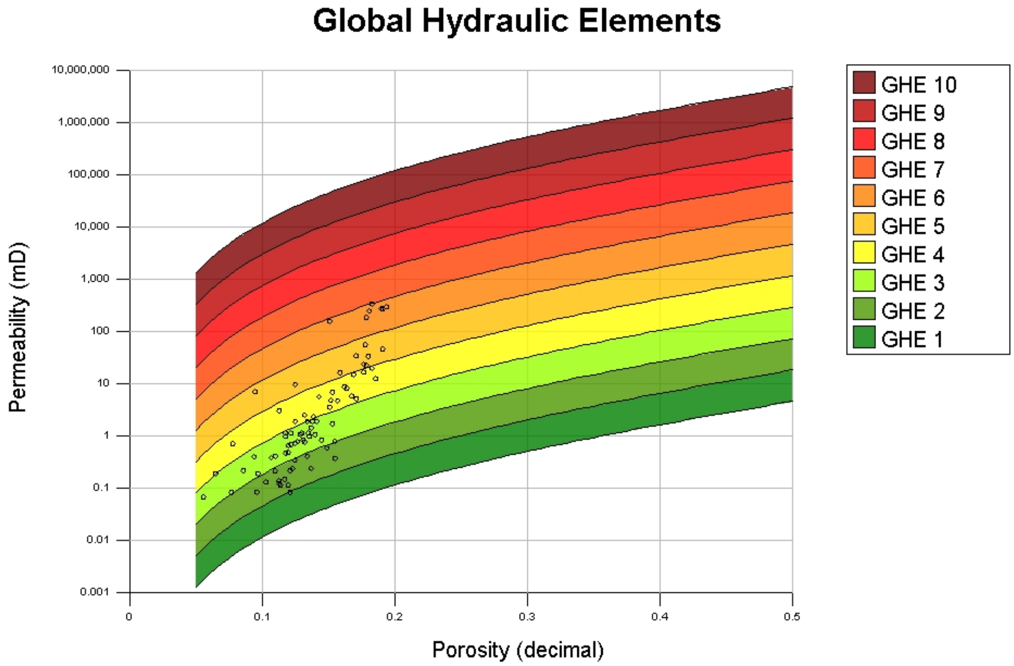


Figure 3. Petrotype characterization of a Siberian shallow marine reservoir. GHE 1 is at the base and GHE 10 is at the top of the template.

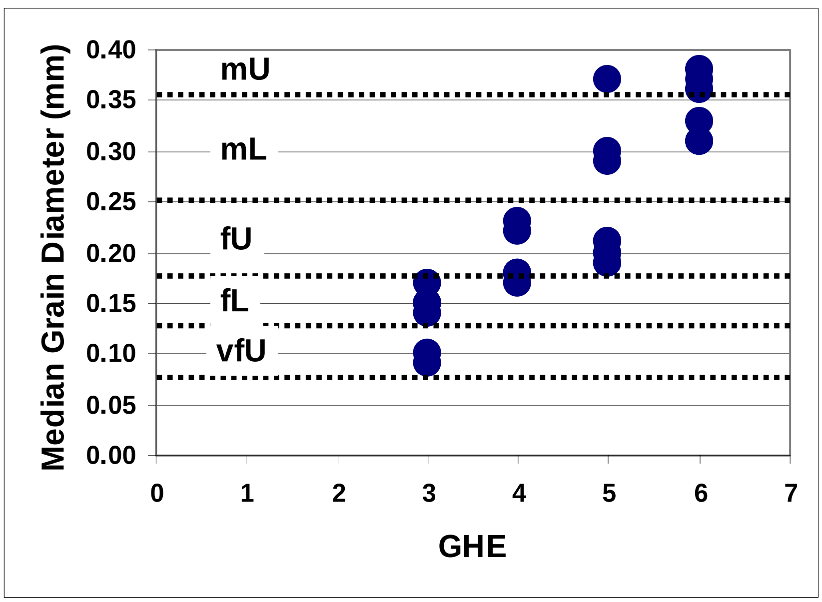
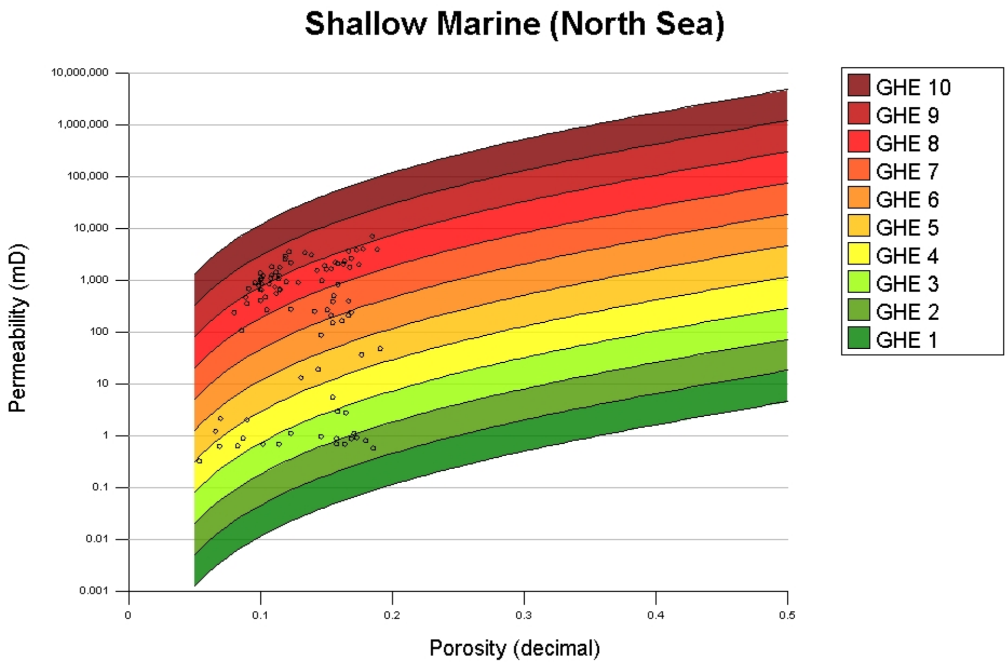


Figure 4. Relationship between grain size and GHE for a shallow marine reservoir.



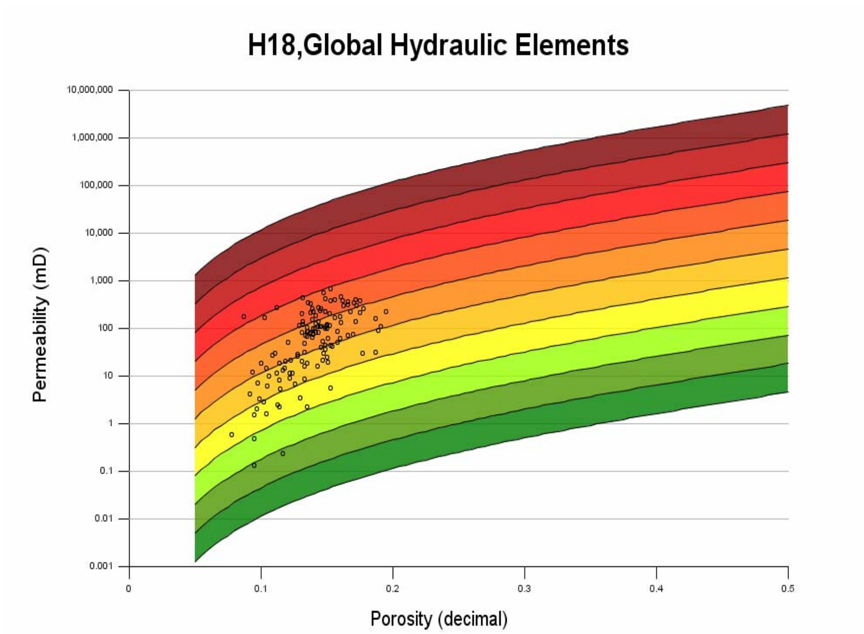


Figure 5. GHE trends in a North Sea (upper) and North African (lower) shallow marine reservoir. GHE 1 is at the base and GHE 10 is at the top of each template.

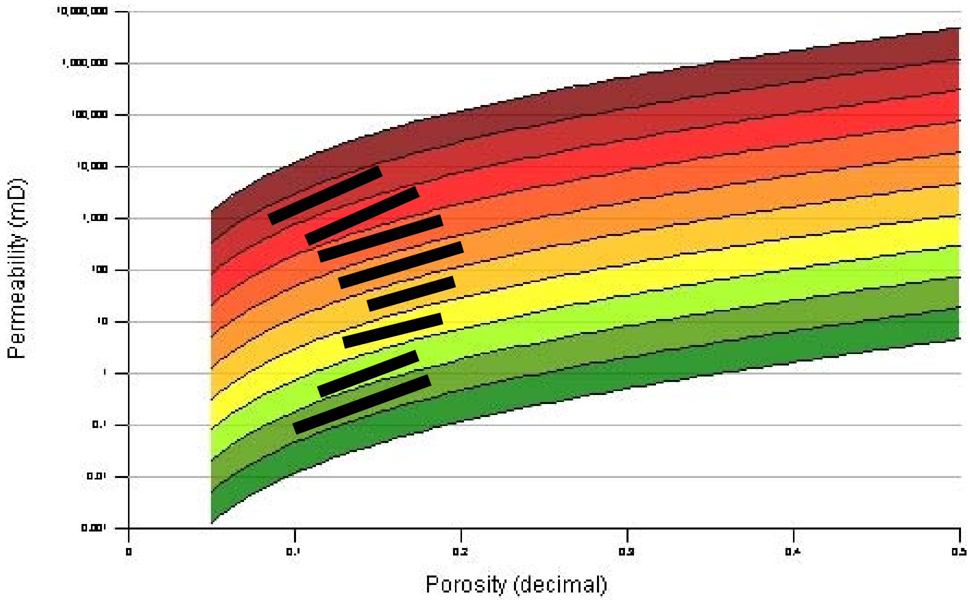
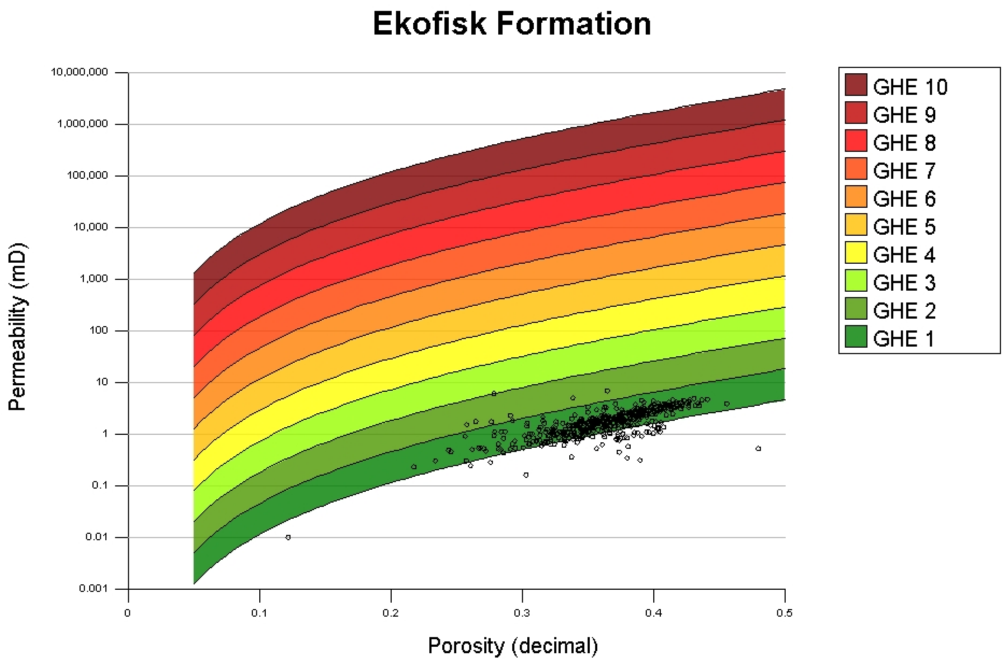


Figure 6. General Petrotype trends for shallow marine reservoirs.

GHE DISTRIBUTIONS IN CARBONATE RESERVOIRS

Petrophysical rock typing is a necessity in carbonate reservoirs. Occasionally carbonate reservoirs will occur as a single GHE class (uni-petrotype) such as the case of chalk, which is a texturally controlled media with a very fine grain size (Figure 7). Appropriately, it falls in GHE1, since it has one of the finest textures found in reservoirs. In other cases, many pore types exist, and the carbonate field may cover a much broader parameter space encompassing several GHEs. An example is the Middle East carbonate shown in Figure 7. Such multi-petrotype reservoirs also need to take into account that much of the porosity may not be effective. In clastics the porosity and permeability are often controlled both by sorting and grain size, so simpler relationships may be observed.



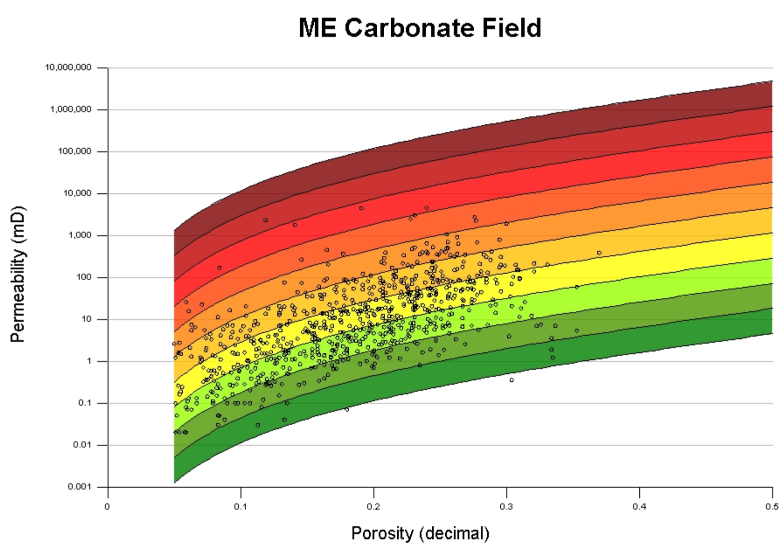


Figure 7. Two carbonate reservoirs. Upper: a North Sea chalk (data provided by Peter Frykman), and lower: a Middle East (ME) Carbonate. The chalk is uni-petrotype and the ME carbonate a multi-petrotype reservoir. Chalk is one of the finest textures that are found in reservoirs, appropriately falling as GHE1.

OTHER ROCK TYPING METHODS

Winland (as described by Spearing et al in [8]) established an empirical relationship between porosity, permeability, and pore throat radius from mercury injection capillary pressure (MICP) measurements in order to obtain net pay cut-off values in some clastic reservoirs. In the empirical relationship the highest statistical correlation was at the pore throat size corresponding to the 35th percentile of the cumulative mercury saturation curve, and this pore throat radius was named R35. Winland rock typing is based on samples with similar R35 values belonging to the same rock type. Essentially, Winland rock typing and HU rock typing give a consistent (in terms of the numbers of flow units in a dataset) breakdown of the porosity-permeability data. An R35 value can be determined for the same clusters of rock types as determined by an FZI value, and vice versa. The analogy between using an 'effective' pore entry radius to determine GHEs is even more consistent with the grain size classification approach used by sedimentologists. The FZI value is easier to calculate than a R35 value, requiring only a single porosity and a permeability value, but the GHE concept could be expanded to also include an R35 value classification (this is already used by some workers).

ADVANTAGES OF THE GHE APPROACH

- Petrophysical parameters (in this case porosity and permeability) for any reservoir are referred to exactly the same reference frame.
- The template saves you time in that you do not need to separately determine conventional HUs for every well in any particular study.
- The template helps you to select minimal, representative training data for prediction purposes [9] from whatever porosity and permeability core data is available to you, even when core data is relatively limited.

CONCLUSIONS

- The use of the term 'rock typing' has various connotations for geologists and petrophysicists. The term 'petrotyping' is proposed to define petrophysical elements.
- Petrotyping elements are determined by the use of global hydraulic elements (GHEs) using specific FZI values as the boundaries between classes, in a similar way that certain median grain size ranges are used in sedimentology to define grain size classes.
- The GHE approach provides a template for the systematic representation of porosity-permeability data in petrophysics and reservoir simulation. This template provides a ready means of comparing porosity-permeability data for any reservoir, with respect to the same GHE reference framework, unlike the conventional hydraulic unit (HU) approach [1]. Plotting one's data on a pre-determined template is also much less time-consuming than calculating HUs for each well studied.
- Grain size classes and GHEs are related in shallow marine reservoirs where texture plays a vital role in determining petrophysical properties.
- Carbonate reservoirs can have very simple (uni-petrotype, such as a chalk) to very complex (multi-petrotype) distributions of GHEs.

- The GHE approach sets a framework for determining how many rock types are needed for reservoir description, and can be used for permeability prediction.
- The GHE approach can potentially be applied for identifying trends, and for prediction purposes, in a whole range of other crossplots involving different parameters.

ACKNOWLEDGEMENTS

The development of the Petrotype Atlas has been undertaken in the PEGASUS II project, funded by Amerada Hess, BG, Halliburton and Schlumberger. Tom Cross wrote the Java (J2SE) application to allow the plotting on data on a standard “basemap” template.

REFERENCES

1. Amaefule, J. O., Altunbay, M., Tiab, D., Kersey, D. G., and Keelan, D. K. 1993. Enhanced reservoir description:using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals / wells. *SPE paper* **26436**, 205 – 220.
2. Ebanks, W.J.(Jr.), Scheihing, M.H., and Atkinson, C.D., 1992. Flow Units for Reservoir Characterisation. In *Development Geology Reference Manual*, Morton-Thompson and Woods (Eds), AAPG Methods in Exploration, **10**, 282-285.
3. Ellabad, Y., Corbett, P.W.M, and Straub, R., 2001. Hydraulic Units approach conditioned by well testing for better permeability modeling in a North African Oil Field. *Proceedings of the 2001 International Symposium of the Society of Core Analysts*, paper SCA 2001-50.
4. Mohammed, K., 2002. Petrophysical characterisation of solution seams and optimisation of hydraulic units in a clastic reservoir, Unpublished. Ph.D. thesis, Heriot-Watt University, 300p.
5. Mohammed, K. and Corbett, P.W.M. 2002. How many relative permeability measurements do you need? A case study from a North African reservoir. *Proceedings of the 2002 International Symposium of the Society of Core Analysts*, paper SCA 2002-03.
6. Corbett, P. W. M., Ellabad, Y., Mohammed, K, and Posysoev, A., 2003. Global hydraulic elements – elementary petrophysics for reduced reservoir modeling. *European Association of Geoscientists and Engineers 65th Conference*, Extended Abstracts, **Volume 1**, paper F-26, EAGE meeting, Stavanger, June 2 -6.
7. Svrisky, D., Ryazanov, A., Pankov, M., Corbett, P.W.M., and Posysoev, A., 2004. Hydraulic flow units resolve reservoir description challenges in a Siberian oilfield. SPE 87056, *SPE Asia Pacific Conference on Integrated Modelling for Asset Management*, Kuala Lumpur, Malaysia, 29-30 March 2004.
8. Spearing, M., Allen, T., McAuley, G., 2001. Review of the Winland R35 Method for net pay definition and its application in low permeability sands. *Proceedings of the 2001 International Symposium of the Society of Core Analysts*, paper SCA 2001-63.
9. Potter, D. K., Le, A. H., Corbett, P. W. M., McCann, C., Assefa, S., Astin, T., Sothcott, J., Bennett, B., Larter, S., and Lager, L., 2003. Genetic petrophysics

approach to core analysis – application to shoreface sandstone reservoirs. *Proceedings of the 2003 International Symposium of the Society of Core Analysts*, paper SCA2003-35, pp.421-433.

APPENDIX

A standard colour scheme for GHE is given in RGB format.

GHE	R - Red	G - Green	B-Blue
10	0.50	0.0	0.0
9	0.75	0.0	0.0
8	1.0	0.0	0.0
7	1.0	0.25	0.0
6	1.0	0.5	0.0
5	1.0	0.75	0.0
4	1.0	1.0	0.0
3	0.6	1.0	0.0
2	0.3	0.6	0.0
1	0.0	0.5	0.0