Selected References

[1] Permeability Characteristics of Magnus Reservoir Rock. Heaviside, Langley and Pallatt, 8th Formation Evaluation Symposium Trans. Mar. 1983. London.

[2] Errors in Laboratory Measurements of Formation Resistivity Factor", by A.E. Worthington. S.P.W.L.A. 16th Annual Logging Symposium 4-7 June 1975.

[3] Comments on obtaining Accurate Electrical Properties of Cores, by Hoyer, S Spann. S.P.W.L.A. 16th Annual Logging Symposium 4-7, June 1975.

[4] Calculation of Relative Permeability from Displacement Experiments, Johnson, Bossler and Nauman, Pet. Trans. AIME (1959), 216, p.370.

[5] EHRLICH, R., CRABTREE, S.J., HORKOWITZ, K.O. & HORKOWITZ, J.P. 1991. Petrography and reservoir physics 1: objective classification of reservoir porosity. *The American Association of Petroleum Geologists Bulletin*, **75**, 1547-1562.

Abstract: Porosity observed in thin section can be objectively classified using a combination of digital acquisition procedures and pattern recognition algorithms. Pore types are derived from the frequency distributions of sizes and shapes of patches of porosity exposed in thin section. Each pore type is represented by a characteristic distribution of sizes and shapes found in thin section. Most sandstone reservoirs contain fewer than six pore types. Much of the variability in reservoir physics is associated with changes in pore type abundance. The advantages of this approach to porosity classification are (1) the criteria for classification are objectively defined, (2) classification procedure is rapid, accurate, and precise, (3) pore types are understood easily in terms of conventional genetic classification schemes, and (4) pore type data are related strongly to petrophysical properties.

[6] MCCREESH, C.A., EHRLICH, R. & CRABTREE, S.J. 1991. Petrography and reservoir physics 2: relating thin section porosity to capillary pressure, the association between pore types and throat size. *The American Association of Petroleum Geologists Bulletin*, **75**, 1563-1578.

Abstract: Porosity in reservoir rocks is configured into a few types of pores whose size and shape are controlled by depositional fabric and processes. The size, shape, and abundance of each pore type can be objectively determined from thin section using image analysis and pattern recognition procedures. Each pore type tends to be associated with a limited range of throat sizes. The association between pore type and throat size can be determined using regression procedures linking pore type data obtained from thin section with capillary pressure data. To do so, a set of samples is required wherein the association between pore type and throat size is fixed, but where pore type proportions vary between samples. This condition is met by a sample suite representing reservoir facies from a single core or, in many cases, from a single field. The relationship between pore type and throat size is an effective means to relate reservoirs in terms of the efficiency of the porous to multiphase flow. Parameters derived from the relationship can be used to construct accurate physical models that subdivide physical response in terms of the contributions of each pore type.

[7] EHRLICH, R., ETRIS, E.L., BRUMFIELD, D., YUAN, L.P. & CRABTREE, S.J. 1991. Petrography and reservoir physics 3: physical models for permeability and formation factor. *The American Association of Petroleum Geologists Bulletin*, **75**, 1579-1592.

Abstract: Permeability and formation factor are physical properties of porous rocks useful for assessing reservoirs. Neither property varies consistently as porosity varies. The relationship of both properties to porosity is complex, being sensitive to the structure of the porous microstructure, i.e., the sizes of pore throats, the numbers and sizes of pores, and the relationships between pores and throats. Physical models to account for these factors require parameters that describe physically relevant properties of the microstructure. A partial characterization of the relationship between pores and throats is embodied in the relationship between pore type and throat size. This relationship is derived by combining data obtained from thin sections, from which pore types are derived via image analysis, and mercury injection porosimetry, which quantifies throat size information. Parameters derived from such a combination are sufficient to construct simple physical models for permeability and electrical conductivity (inverse formation factor). These models assume a porous medium that has large numbers of flow paths parallel to the potential gradient, such that flow has little tortuosity (i.e., flow parallel to bedding). The contributions of each pore type to permeability and electrical conductivity are computed. Calculated values are close to measurement values. A constant of proportionality is the same for all samples from a reservoir, but can vary between reservoirs, is required, and must have values ranging (for sandstones) from about 2.5 to 3.5 for permeability and 5.0 to 7.0 for conductivity. These values are consistent for an efficiently packed fabric. One result of such modeling is a physical model of Archie's cementation exponent *m* as the ratio of the logarithms of the cross sectional throat area to pore area (per unit area).

[8] WARDLAW, N.C. & TAYLOR, R.P. 1976. Mercury capillary pressure curves and the interpretation of pore structure and capillary behaviour in reservoir rocks. *Bulletin of Canadian Petroleum Geology*, **24**, 225-262.

Notes: A classic on this subject. Explains the reasons behind various aspects of injection and withdrawal curves, by looking at SEM of rocks studied.

[9] VAVRA, C.L., KALDI, J.G. & SNEIDER, R.M. 1992. Geological applications of capillary pressure: a review. *The American Association of Petroleum Geologists Bulletin*, **76**, 840-850.

Notes: Important discussion of interpreting mercury injection porosimetry results.

[10] PITTMAN, E.D. 1992. Relationship of porosity and permeability to various parameters derived from mercury injection-capillary pressure curves for sandstones. *The American Association of Petroleum Geologists Bulletin*, **76**, 191-198.

Notes: As mercury injection tests are expensive and not abundant, derives relationships using multiple regression on large database of samples. Empirical equations make it possible to construct pore aperture radius distribution curves from core analysis porosity and permeability.

[11] BLIEFNICK, D.M. & KALDI, J.G. 1996. Pore geometry: control on reservoir properties, Walker Field, Columbia and Lafayette counties, Arkansas. *The American Association of Petroleum Geologists Bulletin*, **80**, 1027-1044.

Notes: An oolite carbonates sequence. Useful discussion on interpreting mercury injection porosimetery results.

[12] RINGROSE, P.S., SORBIE, K.S., FEGHI, F., PICKUP, G.E. & JENSEN, J.L. 1993. Relevant reservoir characterisation: recovery process, geometry and scale. *In Situ*, **17**, 55-82.

Notes: With miscible-gas flood, large-scale geometry may be more important than the internal small-scale structure. With waterflood, small-scale structure likely to be dominant. Emphasises must think not only about the rock but also the fluids and the recovery process.

[13] CORBETT, P.W. & JENSEN, J.L. 1993. Quantification of variability in laminated sediments: a role for the probe permeameter in improved reservoir characterization. In: NORTH, C.P. & PROSSER, D.J. (eds) Characterization of fluvial and aeolian reservoirs. Geological Society special publication 73, London, 433-442.

[14] HUANG, Y., RINGROSE, P.S. & SORBIE, K.S. 1995. Capillary trapping mechanisms in water-wet laminated rocks. *SPE Reservoir Engineering*, **10**, 287-292.

Abstract: Most floods in sandstone cores are performed either in almost homogeneous samples or else in core samples of uncertain heterogeneity. As a result, the interaction of small-scale sedimentary heterogeneity with the fluid mechanics of water-oil displacement cannot be adequately understood or quantified. The results are reported from low-rate, drainage-imbibition floods in a 20 x 10 x 1 cm slab or cross-laminated heterogeneous sandstone. The laminated aeolian sandstone was characterized by detailed

probe permeameter mapping prior to setting it in a resin cast. The distribution of porosity, permeability, irreducible water, and residual oil saturation were subsequently monitored using CT scanning techniques. The low-rate imbibition floods show that between 30 and 55% of original oil may be trapped in isolated high permeability lamina. This work shows the importance of recognizing the role of core-scale heterogeneity in the laboratory measurement of waterflood behavior, i.e., the interaction of capillary forces with rock structure. The practice of performing high-rate floods on rock samples assumed to be heterogeneous is unwise and can lead to erroneous conclusions. The work has major implications for (1) 2-phase petrophysical measurements, (2) the assessment of residual/remaining oil, and (3) multiphase flow scaleup.

[15] MCDOUGALL, S.R. & SORBIE, K.S. 1992. Network simulations of flow processes in strongly wetting and mixed-wet porous media. In: CHRISTIE, M.A., DA SILVA, F.V., FARMER, C.L., GUILLON, O., HEINEMANN, Z.E., LEMONNIER, P., REGTIEN, J.M.M. & VAN SPRONSEN, E. (eds) *ECMOR III: Proceedings of the third European conference on the mathematics of oil recovery*. Delft University Press, Delft, Netherlands, 169-181.

Notes: Deriving 2-phase flow parameters such as relative permeability and capillary pressure from microscopic considerations.

[16] MCDOUGALL, S.R. & SORBIE, K.S. 1995. The impact of wettability on waterflooding: pore-scale simulation. *SPE Reservoir Engineering*, **10**, 208-213.

[17] PICKUP, G.E., RINGROSE, P.S., JENSEN, J.L. & SORBIE, K.S. 1994. Permeability tensors for sedimentary structures. *Mathematical Geology*, **26**, 227-250.

Abstract: Accurate modeling of fluid flow through sedimentary units is of great importance in assessing the performance of both hydrocarbon reservoirs and aquifers. Most sedimentary rocks display structure from the millimeter or centimeter scale upward. Flow simulation should therefore begin with grid blocks of this size in order to calculate effective permeabilities for larger structures. Several flow models for sandstones are investigated, and their impact on the calculation of effective permeability for single phase flow is examined. Crossflow arises in some structures, in which case it may be necessary to use a tensor representation of the effective permeability. Conditions are established under which tensors are required, e.g., in crossbedded structures with a high bedding angle, high permeability contrast, and laminae of comparable thickness. Cases where the off-diagonal terms can be neglected, such as in symmetrical systems, are also illustrated. The method of calculating tensor permeabilities may be extended to model multiphase flow in sedimentary structures.