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Geological implications and controls on the determination of water saturation in shale gas reservoirs

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A significant challenge to the petrophysical evaluation of shale gas systems can be attributed to the conductivity behaviour of clay minerals and entrained clay bound waters. This is compounded by centimetre to sub-millimetre vertical and lateral heterogeneity in formation composition and structure. Where despite significant variation in formation geological and therefore petrophysical properties, we routinely rely on conventional resistivity methods for the determination of water saturation (S_w), and hence the free gas saturation (S_g) in gas bearing mudstones.

The application of resistivity based methods is the subject of continuing debate, and there is often significant uncertainty in both how they are applied and the saturation estimates they produce. This is partly a consequence of the view that "the quantification of the behaviour of shale conductivity. . . .has only limited geological significance" (Rider 1986). As a result, there is a separation between our geological understanding of shale gas systems and the petrophysical rational and methods employed to evaluate them. In response to this uncertainty, many petrophysicists are moving away from the use of more complex ‘shaly-sand‘ based evaluation techniques and returning to traditional Archie methods for answers. The Archie equation requires various parameter inputs such as porosity and saturation exponents (m and n), as well as values for connate fluid resistivity (R_w). Many of these parameters are difficult to determine in shale gas systems, where obtaining a water sample, or carrying out laboratory experiments on recovered core is often technically impractical.

Here we assess the geological implications and controls on variations in pseudo Archie parameters across two geological formations, using well data spanning multiple basinal settings for a prominent shale gas play in the northern Gulf of Mexico basin.

The results, of numerical analysis and systematic modification of parameter values to minimise the error between core derived S_w (Dean Stark analysis) and computed S_w, links sample structure with composition, highlighting some unanticipated impacts of clay minerals on the effective bulk fluid resistivity (R_{we}) and thus formation resistivity (R_t). In addition, it highlights simple corrective empirical adaptations that can significantly reduce the error in S_w estimation for some wells.

Observed results hint at the possibility of developing a predictive capability in selecting Archie parameter values based on geological facies association and log composition indicators (i.e. V_{Clay}), establishing a link between formation depositional systems and their petrophysical properties in gas bearing mudstones.

Rider, M.H., 1986. *The Geological Interpretation of Well Logs*, Blackie.