Petrophysical multimineral analysis using a genetic algorithm: applications to unconventional reservoirs

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Unconventional reservoirs can vary significantly in their mineral composition. Even though the term "shale" is often used as a synonym of unconventional reservoirs, these mud rocks are a complex mixture of different types of clay, quartz, and carbonates. Organic matter in the form of kerogen is also present. Identifying the proportion of the different components of the mixture determines the estimated volumes of hydrocarbon (porosity, Sw), the deliverability of the host rock (permeability), and its geomechanics response to hydraulic fracture stimulation.

Petrophysical multimineral analysis is a tool that can help relate the complexity of the rock composition to the well log measurements by assuming the log response is a linearized combination of individual constituents of known properties or "end-points". Even though the assumption of linearity of the log response is usually valid, the assumption of known properties is typically the exception rather than the norm in unconventional reservoirs due to the complexity of the mixtures, inconsistencies in tabulated properties of the same mineral, uncertain kerogen properties, and scarce or unreliable measurements of water salinity. Often, due to the limited number of logs available, the petrophysicist is forced to create artificial, composite minerals (i.e., "matrix") whose effective properties are unknown. The fact that the fractions of constituents and their properties are both unknown makes of the current practice of multimineral analysis an "educated" guess exercise with no guarantee of obtaining usable, consistent results.

We pose the estimation of the constituents and their properties using multimineral analysis as a stochastic nonlinear optimization problem where a genetic algorithm substitutes the time-consuming, manual trial-and-error process of adjusting properties and fitting the input logs. The method still requires interpretative inputs based on prior knowledge and experience, but such inputs are provided in the form of ranges instead of single property values, facilitating the work of the analysist. By testing adaptively thousands of solutions and considerably reducing the time needed to fit the input logs with a consistent set of properties, it becomes then possible to test other scenarios of input data and constituents, quantify the uncertainty and non-uniqueness of individual parameters, and shed light upon higher level petrophysical questions such as spatial variations in water resistivity, kerogen maturity, or clay composition.

We show examples of application of this methodology to three unconventional reservoirs that illustrate how to solve for variable lithology and effective hydrocarbon pore volumes:

- Marcellus Shale gas to estimate increase in TOC thermal maturity with depth.
- Permian Basin to estimate variations of reservoir mineralogy and hydrocarbon pore volume.
- Mississippian Lm. tight carbonate to account for variations in Rw updip vs downdip.

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