POTENTIAL OF UNCONVENTIONAL PETROPHYSICAL METHODS (ELECTRICAL, ELECTROKINETIC AND NMR) FOR ESTIMATION OF FLOW PROPERTIES OF FAULT SEALS AND OTHER TIGHT ROCKS

Michael B. Clennell

Centro de Pesquisa em Geofísica e Geologia,
Universidade Federal da Bahia, Campus Universitário de Ondina,
Salvador, Bahia, 40170-290, Brazil
Tel. 55-71-2038515 Fax 55-71-3410648 clennell@cpgg.ufba.br

Measurement of fault rock and seal rock flow properties presents considerable problems, even in the controlled conditions of the laboratory. Estimating of the sealing capacity and rate of leakage across faults or shale layers is an even greater challenge. The purpose of this contribution is to examine, with examples, how a combination of existing and novel petrophysical methods could reduce uncertainties in fault-seal and top-seal risking.

Conventionally, downhole logs are used for two main purposes. The first task is to distinguish between non-reservoir lithologies– "shales" from the target rocks of the reservoir itself, which are relatively coarse grained, porous and free of clays. The parallel aim is to estimate the saturation of hydrocarbons within the interval of "net sands". While the reservoir intervals are most easily detected with the gamma ray and spontaneous potential logs in combination with various density/porosity tools, the pay identification and volumetric calculations often rely heavily upon electrical resistivity tools of contact and inductive types. Typically, estimation of the flow performance of the reservoir hangs on data collected subsequently from sub-sampled cores and/or from formation tests in the most promising intervals. Petrophysical workflows usually take little account of the nature and flow properties of non-reservoir lithologies such as interbedded mudrocks, top-seals and fault rocks.

Part of the problem is that the resolution of typical tools and equipment do not enable permeability, porosity and capillary properties of tight rocks to be measured or even estimated, either in the field or in the laboratory. There is also a general lack of laboratory data, because testing times on tight rocks are long, and it is difficult to justify the expense of conducting specialized core analysis on rocks that are never going to produce one drop of oil. There are a number of possible strategies to rectify this in a way that adds real value to assets, and helps to reduce the risk of making a wrong decision. We can rank this in rough order of time, effort and money required:

1. Get more out of existing data and methods by focusing petrophysical effort on the parts of the geological system that will control the flow properties of the reservoir and how it is managed. That is, assess heterogeneity types and scales, and look explicitly for faults and fractures and their influences, such as diagenetic changes.
2. Develop petrophysical methods to aid understanding of the distribution and nature of mudrocks in the system. Aside from the issue of topseals, clay smear and phyllosilicate framework types of fault rocks are controlled by the types of clays and their distribution.
3. Interpret conventional downhole data in new ways to bring out information bearing on the fault/top seal problems.
4. Make more effort to sample rocks from top and fault seals, and subject them to detailed petrophysical analysis.
5. Consider existing non-conventional tools such as NMR or imaging logs.
6. Develop entirely new methodologies that look for the physical effects of faulting or fracturing in the rock mass, or detect the changes in fluid and or/pressure across flow barriers.

It is fair to say that approaches 1 and 2 are well advanced, and even mature among forward looking companies and research groups. The third strategy, which is to look at existing data with new eyes has perhaps foundered because of the wide range of expertise that must be called upon to rewrite the rules of conventional interpretation. The response of a particular tool depends upon a wealth of factors, be they of physical, geometrical or electrochemical origin, whereas the interpretation of this data must be in terms of geological structures or flow properties. However, new information can be teased out, and discarded information put back to use. A good example of this is the use of phase information from inductive electrical resistivity tools that operate over a range of frequencies. The dispersion in the resitivity with frequency, and the accompanying shift in phase between the electrical current and potential can give an indication of chargeability of the formation, which together with gamma and SP can reveal something of clay type and distribution, and even (with plenty of calibration) pore structure and permeability. This can be illustrated with measurements made on tight gas sands and shaly sands from the Reconcavo Basin of Brazil. On the same line, spontaneous potential anomalies themselves may exist across faults that act as ion selective membranes in a way similar to shale layers, and some interesting examples are known from the Tucano Basin of Brazil. The efficiency of the electrochemical membrane effect may relate in some way to the wettability characteristics, capillary properties and eventual sealing capacity of the fault.

As regards laboratory studies of the non-reservoir lithologies, permeability and mercury injection porosimetry measurements on tight rocks are now almost routine, but studies of multiphase flow, wetting behaviour and geomechanical properties in relation to flow performance are little explored. A major reason for this is expense. Tests are very time consuming because pressure and flow equilibration scales with the permeability. Recent work on transient and oscillatory flow methods has improved this picture somewhat. At CPGG-UFBA we have also developed electrokinetic methods that show how streaming potential can be used as a proxy to monitor pressure changes at points remote from any physical pressure sensor. This perhaps offers a way of studying heterogeneous flow patterns in an efficient and cost effective way, even in very tight rocks.

There is a lack of instrumentation designed to measure and monitor such low porosity and permeability rocks during testing. Both X-ray and NMR methods fail in rocks with low porosity and with a fine pore structure: the first because of pore contrast and the second because of the lack of sensitivity to signal from fluids showing very short relaxation times. Recently, Mallett and others (including the present author) showed that a new NMR method that relied on freezing of a fluid, rather than spin relaxation spectrometry was a possible method to map out pore sizes in fault rocks. There is no simple extension of this work to the downhole environment, yet other phase changes sensitive to pore size (such as the bubble point on drawdown) could perhaps be monitored in tomorrow's smart wells? And surely, NMR is a much underused tool that offers us an unparalleled view of fluids, wettability and pore sizes: hardly matters irrelevant to seal risking.

The greatest challenge is to assemble a new view of the reservoir flow system from the components that geological, geophysical and petrophysical views can give us. Here the petrophysicist does more that "paint in" flow properties on a structural and stratigraphic template. Rather, the effect of flow on the rock (cementation changes, dissolution, changes in brittleness) are accounted for in parallel with a prediction of the effects of the rocks on the flow. These elements must be related back to the problem of fault and top seal integrity throughout the life cycle of the field. In some cases, the fault will reveal itself during the initial stages of exploration, whereas in others its presence and the implications of its reawakening will only be felt during recovery. (Perhaps electrokinetic signals will picked up by the arrays of passive and/or active sensors in an instrumented field?) Making sense of these new types of data will require imaginative physics and some robust laboratory calibrations.

Reference:

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