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Goals, Strategies, and Tactics in Sampling and Characterization of Unconventional Reservoirs – Developing a New Playbook

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SUMMARY

Sampling and testing of core and cuttings poses particular challenges for unconventional reservoir lithologies owing to – (a) their thickness, (b) subtle but significant heterogeneity, (c) the small scale of the textural and compositional elements (extending down to 10-10m), and (d) their susceptibility to irreversible changes in composition and properties. The details of any testing program will depend on a project-specific set of Goals, Strategies, and Tactics. Goals - which information is required and its relative importance, Strategies - the general approaches required to ensure that these goals are met, and “Tactics” - the specific procedures required to meet the strategic goals. Together these lead to developing a sampling/analysis work flow that optimizes risk, cost and time. The overriding purpose of any reservoir characterization program is to provide data that is meaningful, accurate, representative of in situ condition, and reflective of inherent statistical variability.

Analysis of core and cuttings is a critically important component in the assessment of unconventional petroleum reservoirs. Core material in particular is obtained at substantial cost and must be utilized efficiently. The resulting data are used for diverse applications, including geomodeling, petrophysical log models, basin analysis, drilling and stimulation design, reservoir simulations, production analysis, resource and reserves evaluation. Data may be utilized both forward looking, to predict characteristics that have not yet been directly measured, as well as backwards looking, to aid interpretation of problematic aspects of reservoir behavior. This implies that the sampling and analysis program should be designed to satisfy both immediate and anticipated future needs.

Ultra fine-grained lithologies containing sedimentary organic materials pose particular challenges for both sampling and analysis, owing to their: a) heterogeneity, expressed at dimensions ranging from millimeter-scale lamellae to meter-scale bedding features to basin-scale, b) the small physical dimensions of their structural and compositional elements, extending down to molecular sizes ($\text{\AA}$ to nm), and c) susceptibility to changes in composition and properties, which may be irreversible. All of this is complicated by an incomplete and continually-evolving understanding of which parameters are

most important, and the best way to measure them. In contrast with coal and sandstones, which have been studied for many decades, there is no standard set of protocols for carbonaceous shales and limestones. Rather, specific details emerge from a well-conceived

set of *Goals*, *Strategies*, and *Tactics*, which are unique for each project. *Goals* describe a compilation and prioritization of what information is needed. *Strategies* describe the general approach to ensure these goals can be met, and *Tactics* refer to the specific, detailed procedures required to meet the strategic goals. A well designed program must consider all three simultaneously, as conflicts will inevitably arise, requiring pragmatic compromises to be made.

The overriding goal of any reservoir characterization is to provide information describing some significant aspect of the reservoir system that is meaningful, accurate, and useful. Reservoir aspects fall under three headings: i) resource concentration, ii) producibility and iii) the likely response to production technologies. Examples of specific goals might include providing data for reservoir modeling, resource estimation, geo-steering, or frac design. These goals imply certain strategies, including: representative sampling, compositional preservation, and selection of tests from amongst a diverse menu of possibilities. These strategies, in turn, give rise to specific tactics, such as procedures for protecting samples from oxidation and desiccation, a sample processing protocol that will provide sufficient quantities of properly prepared samples for each test, and use of lab procedures adapted for

ultrafine-grained lithologies. Goals are generally fairly easy to define, as they are fundamentally similar to those for conventional reservoirs, although prioritization of goals can be challenging, particularly when allocating limited quantities of core materials. Strategies tend to remain consistent over time as well, but

Principal Goals:

- Estimate Resource Concentration
- Predict Resource Producibility
- Understand and Predict Responses to Drilling & Production Technologies

differ from those typically used in conventional reservoirs. Tactical details pose the greatest challenge for unconventional reservoirs, and are under perpetual revision to optimize the outcome.

The myriad test methods available at the tactical level provide two categories of information: *Composition*; What is it made of and what is its physical structure? and *Properties*; How does it behave? Properties, such as mechanical strength, fluid transmissibility, and sorption capacity, are of the greater importance from the standpoint of reservoir engineering. Thus, one of the strategic goals is to produce a data set that will enable properties to be predicted on the basis of composition. For example the value of rock mechanics parameters, such as UCS and elastic moduli, are determined both by composition and physical structure. The choice of which parameters will be the most meaningful and useful is a tactical detail to be addressed in the planning stage.

In order to yield meaningful results, tactics should be based upon realistic, meaningful understanding of reservoir characteristics and processes, mitigated by the inherent limitations of available methods. Unconventional reservoirs pose unique challenges in this regard related to scale, as certain concepts developed for conventional reservoirs do not translate readily to nanometer scale. For example, traditional reservoir concepts make a fundamental distinction between a) the *reservoir*, i.e. the volumetric fraction that acts as a container, and b) *porosity*, the volumetric fraction representing the contents, which are in the form of fluid phases. Tactical implementation of this concept is problematic and to a certain degree arbitrary, however, for systems containing hydrated clays and sedimentary organic matter. The results obtained depend strongly on the specific tactical procedures; yet reservoir engineers continue to request these measurements, largely because they are what traditional reservoir models have been based upon. Labs may be able to generate numbers, but this does not imply they are accurate or meaningful. Similar problems pertain to traditional measurements of fluid saturations of oil (S_o), gas (S_g), and water (S_w). Conceptually, they may be meaningful. Tactically, however, they are difficult at best, and meaningless at worst.

Further complicating the situation is that certain key reservoir components, notably water and light hydrocarbons, occur in a variety of phase associations, with a continual exchange among them in a state of dynamic equilibrium. Phase changes are induced by disrupting this equilibrium, leading to bulk transfer of materials into or out of the rock.

A more practicable approach for characterizing unconventional reservoirs is to treat them as heterogeneous, multi-component multi-phase, systems, which are subject to changes in state and composition when fundamental state variables, particularly temperature and pressure, are altered. The

strategic goal should be to understand and properly describe the physico-chemical processes occurring during sampling and production. The tactical goal is to apply methods and terminology that accurately describe and measure these processes. Rather than attempting to measure porosity, for example, it may be more meaningful to differentiate a mobile fraction versus an immobile fraction, determine the conditions under which the mobile fraction is mobilized,

the rate at which re-equilibration occurs, and net impact on bulk composition.

Another overriding concern in implementation of a sampling and analysis program pertains to representative sampling, and maintaining equivalency in composition of the sub-samples split out for different analyses, taking heterogeneity and scale into account. The tactical approaches to accomplish this will depend on specific goals, budgetary limitations, and logistics. The essential requirement is to give these issues full consideration to ensure that a “one time opportunity” will not be lost. In too many cases, the required tactical details are neglected, either because they involved unwelcome added complications, or due to fundamental misunderstanding of the reservoir, particularly the organic fraction.

Considerable advantage can be gained by adapting certain tactical approaches used in coal analysis, which have had 100 years “head start” in their

development. For example, established methods used in coal sampling and sample preparation are applicable with minor modifications to unconventional reservoir lithologies.

Taken in sum, the preceding issues can be applied to design and execute an optimal sampling & analysis program aimed at achieving specific goals. Following a predefined “cookbook”, based on conventional reservoirs will likely lead to avoidable errors and oversights.