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Analysis aids evaluation of unconventional plays

Advanced mud gas and rock fluid studies provide valuable and otherwise unobtainable information.

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Although unconventional oil and gas plays are highly variable in terms of geology, geochemistry, and structure, many of the key factors within these disciplines are repetitively quoted as influencing successful exploitation. Many aspects of these complex systems can be evaluated before, during, or even instead of expensive logging programs by using the unavoidable byproducts of the drilling process, namely borehole gas and drill cuttings.

Direct quadrupole mass spectrometry of mud gas

Recent developments in application of membrane-gas chromatography (GC), GC-mass spectrometry (MS), and direct MS analysis to mud gas, along with improvements in mud gas extraction instrumentation and techniques, provide datasets that are light years ahead of historical hot-wire/GC methods. Of these new techniques, direct quadrupole MS (DQMS) is by far the most comprehensive, sensitive, and flexible tool for compositional evaluation of formation fluids in near real time. DQMS evaluates C_1 to C_{10} petroleum species and inorganic compounds such as CO_2, helium, hydrogen, atmospherics, and sulfur-bearing volatiles. It can discriminate among the major classes of volatile organic compounds as well as contributions from the drilling fluid. Evaluation of such a broad range of chemical compounds allows for unsurpassed chemical fingerprinting.

Additionally, a number of inorganic/organic species combinations are indicative of specific subsurface processes. The instrument is uniquely suited for organic-based mud systems, which typically hamper data analysis from other devices, and works in low-pressure reservoirs where conventional gear is ineffective. Within unconventional plays, DQMS has been used to distinguish among producible hydrocarbon fluid types, identify lower quality or residual systems, evaluate potential for water production, assess compartmentalization, and recognize fractures and faults. These data have been used to optimize completions for less costly and better producing wells, allowing some operators to rethink and minimize logging runs.

Trapped fluid and elemental rock analysis

A new procedure for cuttings or core analysis in the lab has been developed during which the rock is first photographed under visible and UV light, then crushed and analyzed for included hydrocarbon and nonhydrocarbon species with a sensitive mass spectrometry system, and

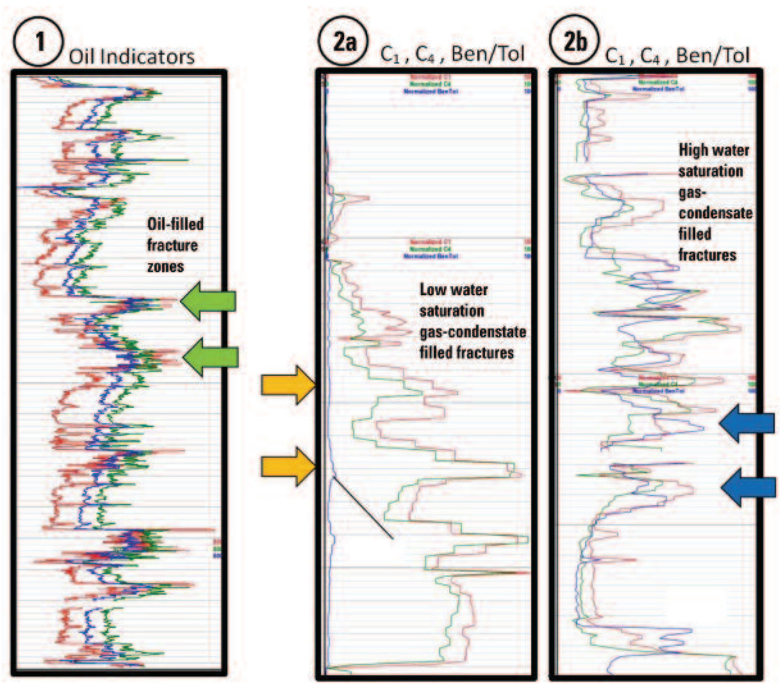

FIGURE 1. Application of DQMS to completions is shown, including (1) a fractured oil reservoir drilled underbalanced, and (2) a fractured gas-condensate reservoir with high (2a) and low (2b) water saturation. (Images courtesy of Fluid Inclusion Technologies Inc.)

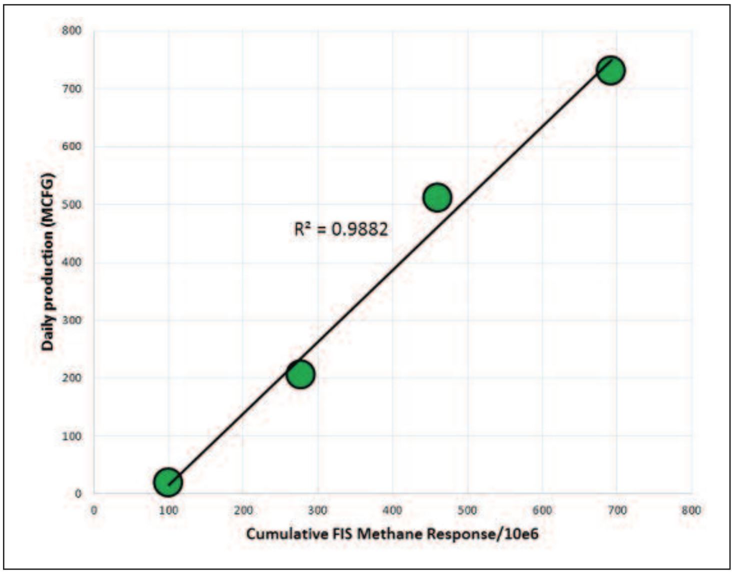

FIGURE 2. The summed cuttings methane response is correlated against daily production in four horizontal wells.

finally probed for its elemental composition with a customized X-ray flash (XRF) analyzer. A key aspect of the process is that all analyses are conducted on the same 1-gm rock sample with an automated system, thus preserving interrelationships among rock type, fluid type, and rock chemistry. Automation and rapid analytical cycles allow collection of large datasets and encourage analysis of entire wellbores from first returns to total depth.

Individually, the techniques are useful. Together, they provide unique insights into controls on hydrocarbon, reservoir, and pay distribution; represent an additional tool for well placement; and allow organized archival of rock type and fluid and rock chemistry information that is easily retrieved and studied in the context of future wells, even in the absence of the original rock material. Of interest is that these analyses can be performed on historical samples of any age drilled with any mud/bit type.

DQMS impacts completions

Figure 1 illustrates selected DQMS data from two geographic regions. The first is an oil-bearing fractured reservoir that was drilled underbalanced such that fracture definition was impossible from light gases analyzed with conventional gas-detection equipment. DQMS data readily identify the fracture-bearing intervals by emphasizing specific high-molecular-weight organic species associated with oil. The other two wells in Figure 1 are from a gas-condensate-bearing fractured reservoir containing both high water saturation and low water saturation fracture sets. The ratio benzene/toluene (blue curve) distinguishes high and low water saturation gas-condensate zones, allowing the operator to selectively complete low water saturation zones.

FIS anticipates eventual production

Figure 2 shows a simple example of using cuttings volatile analysis to anticipate and rank eventual production in unconventional reservoirs. It illustrates the summed fluid inclusion stratigraphy (FIS) response vs. average stabilized daily production over a two-month period. Clearly, the eventual relative production from these wells could have been anticipated immediately after drilling, and actual production statistics from future wells in the area can be reasonably predicted from this calibration set. Furthermore, contributions to the total production from specific portions of the wellbore can be ascertained, and measurement of the intrinsic gas content of the samples can distinguish between wells that have been damaged or improperly completed and those that were drilled in a gas-poor section of rock.

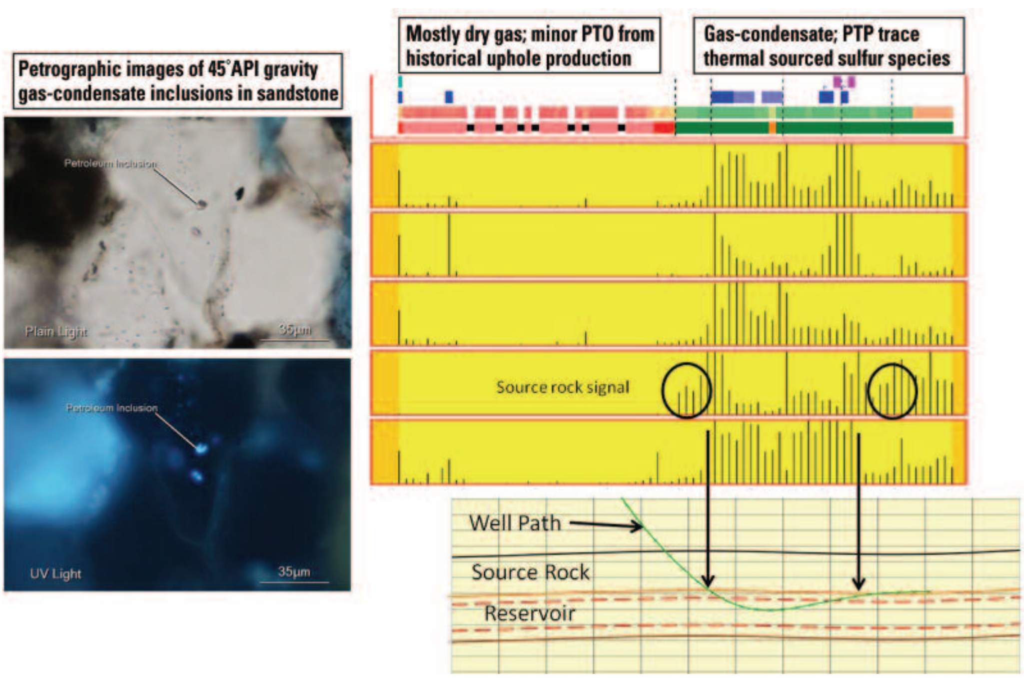

FIGURE 3. The sweet spot of this horizontal tight sand well (dashed red lines) correlates with FIS responses and high condensate inclusion abundance.

FIS identifies optimal reservoir location

Figure 3 provides an example of combining FIS and petrographic data to identify and understand sweet spots. FIS data clearly indicate the sweet spot of this gas-condensate-bearing reservoir as well as the location of the overlying source rock and potential elevated water saturation intervals. Sulfur species suggest the potential for influx of mature gas from deeper in the basin. Quantitative petrographic work verifies the presence of 45°API, undersaturated gas-condensate fluid inclusions.

Putting it all together

Figure 4 represents an example that uses both DQMS data and advanced cuttings analysis. The zone, from approximately 3,733 m to 2,778 m (8,960 ft to 9,110 ft), displays a prominent DQMS anomaly characterized by C_1 to C_7 species and gas ratios that suggest light oil or condensate (Panel A). A slightly drier anomaly occurs within a restricted zone and may represent a discrete gassier phase as suggested by FIS data. Water saturation indicators (e.g., benzene/toluene and benzene/cyclohexane) suggest trace movable water within this section, and presence of the sulfur species carbon disulfide and carbonyl sulfide suggests that sulfur-bearing volatiles may be produced. Trace CO_2 is present as well, particularly in the thin drier gas or mixed gas-oil interval.

XRF elemental data and element ratios (Panel B) indicate that the main zone of interest is a mixed siliciclastic and carbonate (dolomite and limestone) section with both biogenic and terrestrially derived silica. The gamma ray correlates fairly well with sulfur given the differences in sample spacing.

FIS data (Panel C) indicate species to C_{11} to C_{12} with bulk mass spectra that resemble light oil. Upper moderate-gravity light oil inclusions are abundant in chert, indicating high petroleum saturation. Some gas condensate is noted as well, suggesting the possibility of a dual-phase reservoir and consistent with the DQMS observations. FIS C_1 and C_7 relationships imply two discrete charges (oil and drier gas). Sulfur species are present in FIS data as previously described for mud gas data, suggesting that some sulfur species and minor CO_2 may be produced from this zone. These species are interpreted to be of high-temperature origin and related to dry gas interpreted to have migrated into the structure from deeper in the basin.

The combination of advanced mud gas analysis by DQMS and advanced cuttings analysis via integrated FIS, XRF, and photography provides valuable and otherwise unobtainable information with broad application to petroleum exploration and development. Data can be used to help understand the key aspects of conventional and unconventional reservoirs that most commonly contribute to successful exploitation. Data also can aid in optimizing wellbores and completions to lower costs and allow for more efficient drilling campaigns. E&P

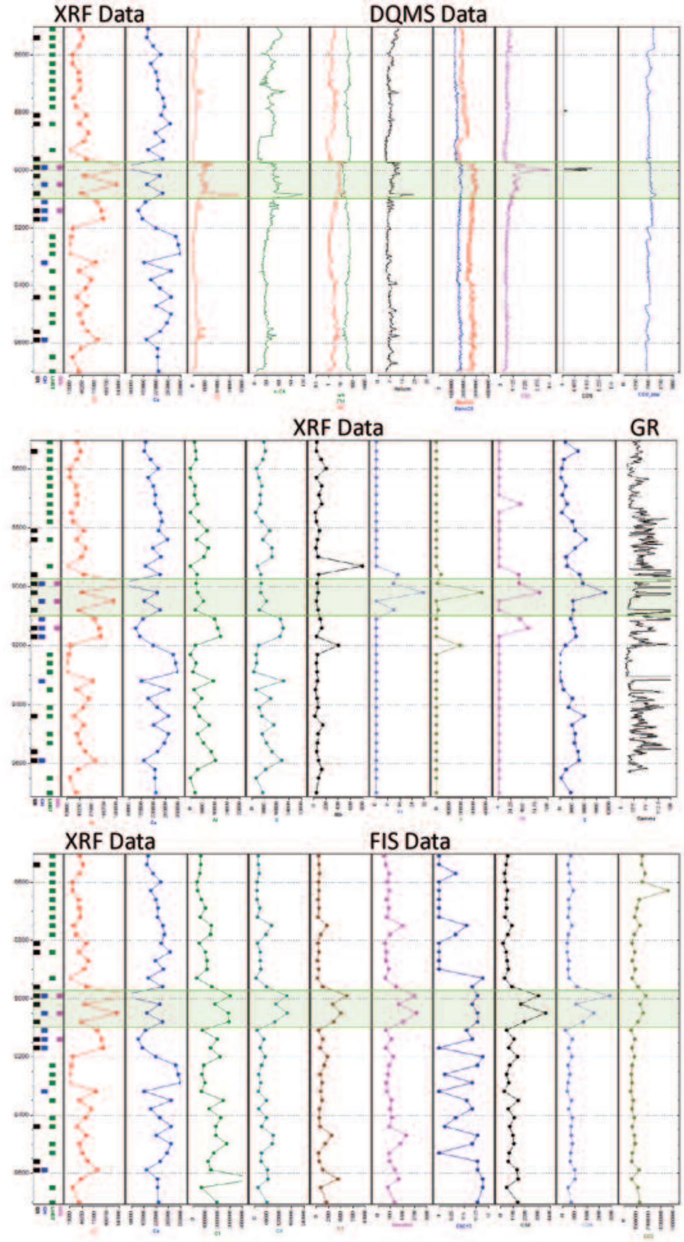

FIGURE 4. DQMS, XRF, and FIS data are combined to characterize a liquids-rich fractured cherty carbonate play.