Bittersweet Encounters in the Wellbore: Application of the Wellsite Mass Spectrometer in 3D Unconventional Resource Development of Niobrara and Mowry assets in the Powder River Basin

Scott Field and Maria N. Slack

The literature abounds with technical information to locate the sweet spot in an unconventional asset, but the inverse concept has been largely neglected. This is usually attributed to the lack of suitable tools and interpretive expertise. The wellsite mass spectrometer is an exception to this generalization when the raw data is suitably utilized in comprehensive interpretive schemes. This is accomplished in data analytic deconvolution of the collective mass spectra signal to determine hydrocarbon and non-hydrocarbon composition during real time in the drilling mud system. Critical "bittersweet" components include the influx of water, inorganic dilutant (e.g., hydrogen sulfide, carbon dioxide), leaky top seals, and the potential for depleted compartments. The individual wellbore mass spec data is post-processed to provide visualization of the key parameters that are particularly insightful when the full gambit of well bores are viewed simultaneously in 3D. This includes the systematic influx to the wellbore of a particular bittersweet component, such as water via fractures and/or faults. The method is likewise extended to the predictive realm as prior wells can be used to build a predictive 3D model by taking advantage of the interchangeable format of data manipulation from fluid inclusion stratigraphic (i.e., FIS) analysis. This approach is effective at resolving the under-utilized field data conundrum by providing a platform for the proper alignment of people, processes, and technologies to provide the answers to issues like well spacing in asset management.

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Scott Field[2] and Maria Slack[1]

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Abstract

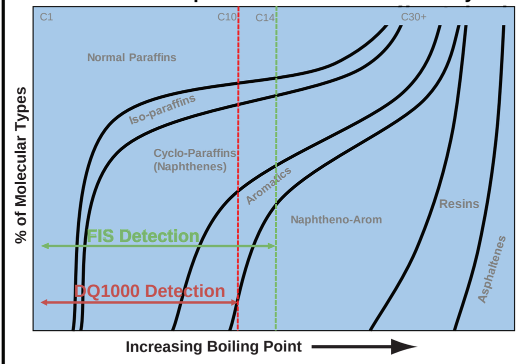
The literature abounds with technical information to locate the sweet spot in an unconventional asset, but the inverse concept has been largely neglected. This is usually attributed to the lack of suitable tools and interpretive expertise. The wellsite mass spectrometer is an exception to this generalization when the raw data is suitably utilized in comprehensive interpretive schemes. This is accomplished in data analytic deconvolution of the collective mass spectra signal to determine hydrocarbon and non-hydrocarbon composition during real time in the drilling mud system. Critical "bittersweet" components include the influx of water, inorganic diluitant (e.g., hydrogen sulfide, carbon dioxide), leaky top seals, and the potential for depleted compartments. The individual wellbore mass spec data is post-processed to provide visualization of the key parameters that are particularly insightful when the full gambit of well bores are viewed simultaneously in 3D. This includes the systematic influx to the wellbore of a particular bittersweet component, such as water via fractures and/or faults. The method is likewise extended to the predictive realm as prior wells can be used to build a predictive 3D model by taking advantage of the interchangeable format of data manipulation from fluid inclusion stratigraphic (i.e., FIS) analysis. This approach is effective at resolving the under-utilized field data conundrum by providing a platform for the proper alignment of people, processes, and technologies to provide the answers to issues like well spacing in asset management.

Wellsite Mass Spectrometer (open pores)

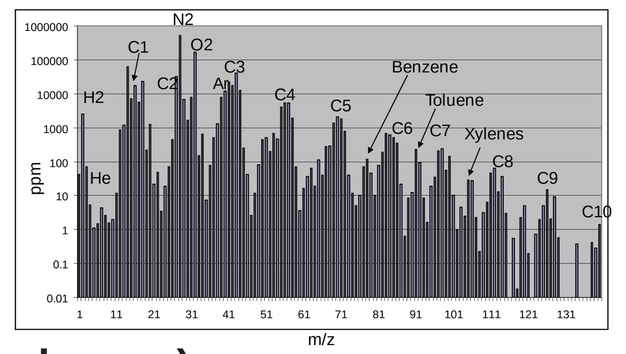
The wellsite mass spectrometer was developed by FIT as a complimentary tool (i.e., analysis of open pore content) to the fluid inclusion stratigraphy approach (i.e., closed pores), as well as providing an alternative to the analytical limitations of conventional wellsite gas chromatographs (GC). That is, the conventional GC has a limited scope of analysis (e.g., alkanes only), poor performance at low concentration, inorganic compounds are not evaluated, and it is difficult to account for drilling fluid contributions (e.g., oil-based mud, additives).

In contrast, the mass spectrometer provides data on 1 to 140 amu (atomic mass units) which enable the deconvolution of organic (e.g., paraffins, naphthenes, aromatics) and inorganic (i.e., hydrogen, helium, nitrogen, hydrogen sulfide, etc.) components in the mud gas stream. As such, we can make better estimates of petroleum type and quality, identify fluid contacts, delineate hydrocarbon charge, establish reservoir compartmentalization, understand drilling artifacts (e.g., bit burn) and identify bed components (e.g., hydrocarbon-filled fractures).

Schematic Representation of Oil Chemistry

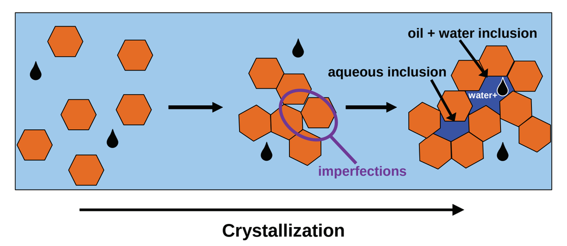


Mass Spectra of Oil in Mudgas



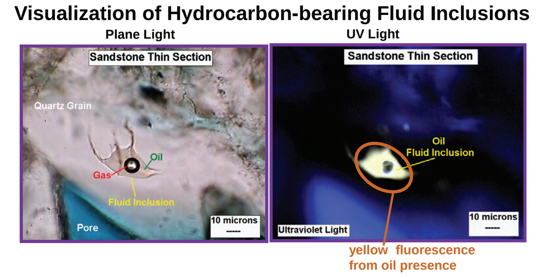
FIS (closed pores)

Fluid Inclusion Formation

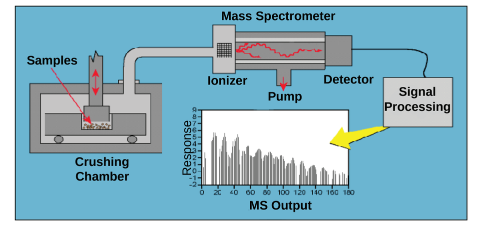


The mass spectrometry data derived from fluid inclusion analyses are quite detailed, but can be divided into five primary classes: non-hydrocarbons, gas-range hydrocarbons, liquid-range hydrocarbons, molecular fragments species enriched in aqueous phases, and signals associated with sulfur compounds. The raw data consists of 1 to 180 amu fragments that are manipulated into vertical profiles of ratio-based displays and quantitative signals. The PSI-generated output includes additional output that is generated by chemometric data analyses along with an interpretive summary (i.e., right margin) to address interpretation of discoveries and failures, optimization of field/reservoir characterization, hydrocarbon charge analysis, secondary alteration, etc. The results also allow reservoir intervals to be highgraded for direct analysis of gas and liquid-hydrocarbon phases (i.e., designated on left margin).

Visualization of Hydrocarbon-bearing Fluid Inclusions

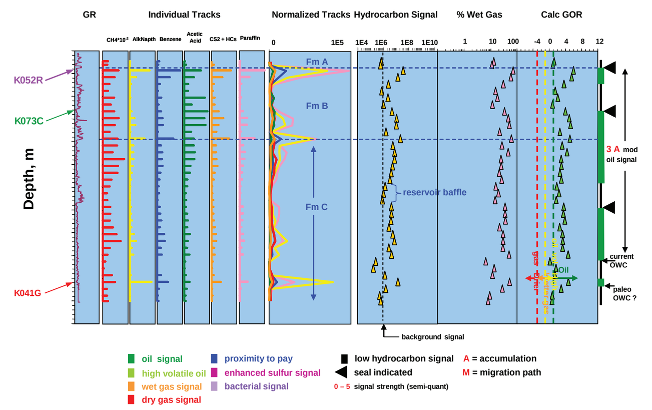


Bulk Analysis Step by Mass Spectrometer Instrumentation



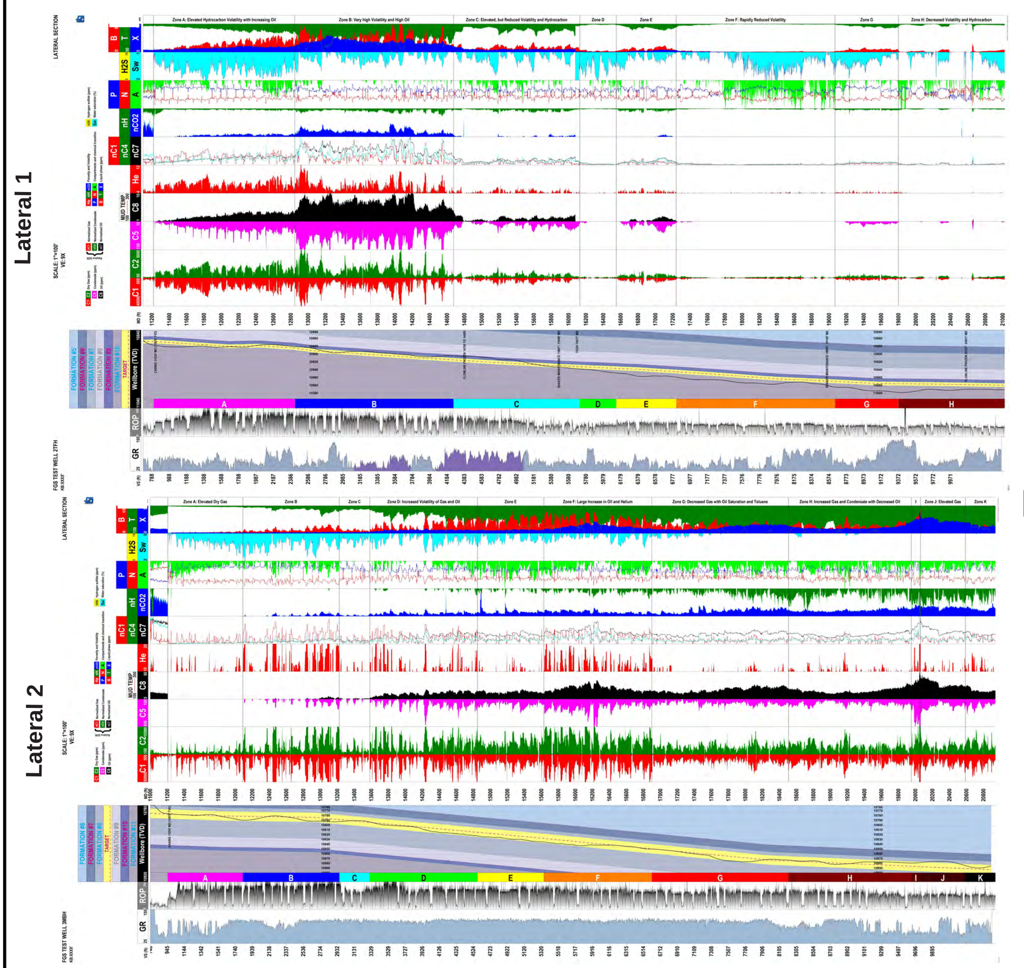
original design "Moon Rocks" - Colin Barker, Univ Tulsa 1970's
proprietary applications – Amoco Research Center – Tulsa 1980-90's
commercialization – Fluid Inclusion Technologies – Tulsa 2000's

PSI Data Re-processing Output



FGS UBR Output from DQ1000 Acquisition

Example 1

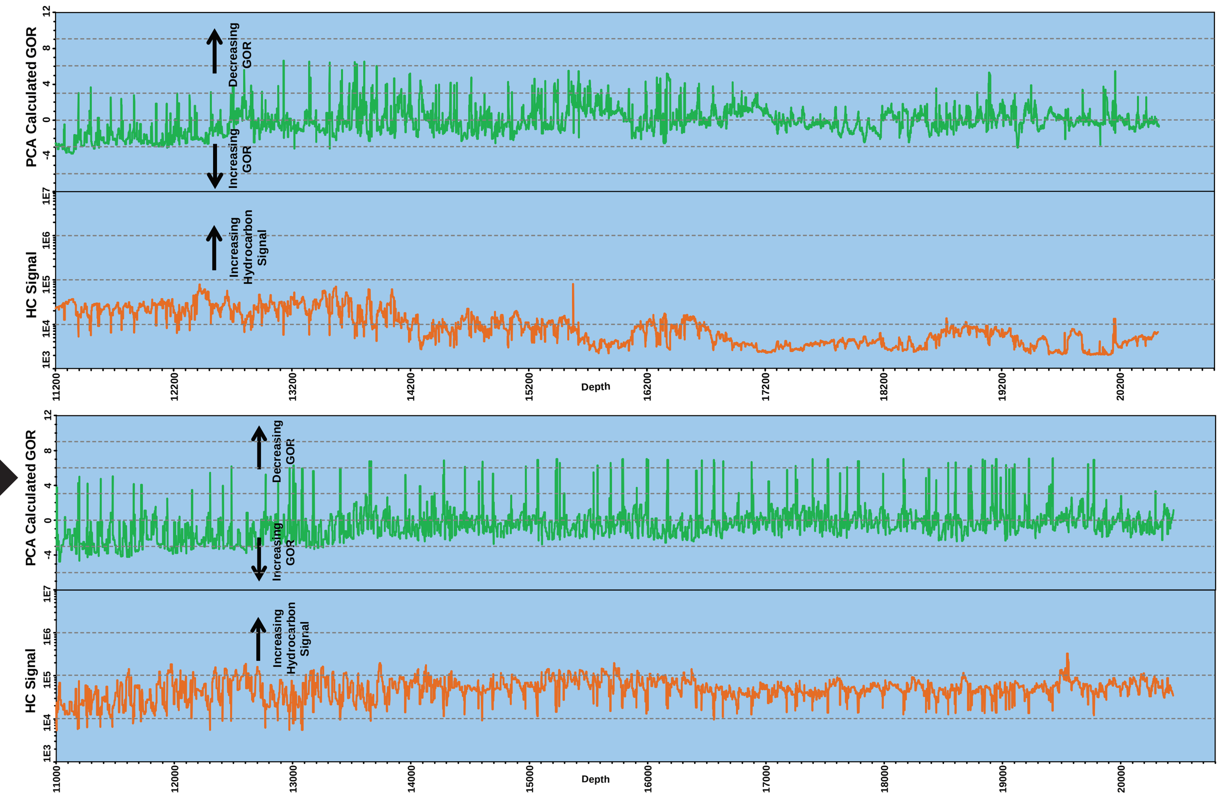


The mass spectrometer acquisition (1-140 amu) provides an enormous amount of chemical data that is deconvoluted in the FGS UBR processing to define 25 separate tracks, from which six main categories are presented in the graphic display: alkane content (dry gas, wet gas/condensate, oil), inorganics (helium, hydrogen, carbon dioxide), relative PNA (paraffin-naphthene-aromatic), water saturation, hydrogen sulfide and BTX (benzene, toluene, xylene). These components are displayed with a 2D depiction of geologic target, gamma ray log, and rate of penetration.

In this particular example, the mass spectrometer data show changes in the GOR (Gas Oil Ratio) as the well bore laterally penetrates the rock in two stacked formations. The main point to illustrate is that the GOR variation in the deeper target does not occur in the shallower target. The geosteering maintains the well bore within the target, hydrocarbon and inorganic signatures indicate significant differences in the connections of the higher and lower GOR sections within the deeper target. A concurrent (e.g., isotube collection) and/or subsequent (e.g., FIS, conventional methods) are applied to unravel the genetic cause of the observed trends.

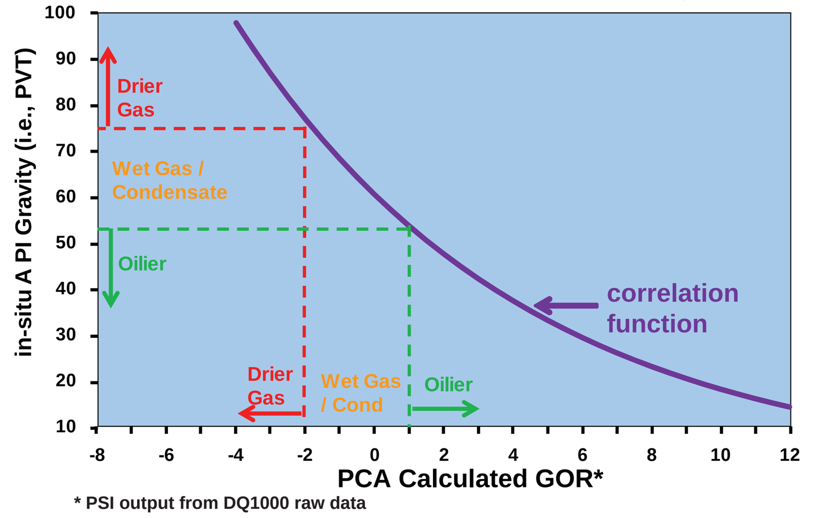
PSI Output from DQ1000 Acquisition

Example 1



The same mass spectrometer acquisition (1-140 amu) data is post-processed at the PSI facility to reduce the dimensionality of the data. This allows the most important aspects of the dataset to be extracted for graphic display, such as this example of hydrocarbon signal and gas oil ratio. Other examples could be water influx to the well bore, sulfur signals (e.g., H_2S), and/or porosity/volatility. The tools used to create these signals include principle component analysis (PCA), hierarchical analysis (HCA), and linear correlation coefficients (LCC). As the methodology for reducing the dimensionality of the DQ1000 output was modified from the extensively tested (>500 wells) FIS calculations (i.e., developed at PSI), the two independently acquired datasets have outputs that are directly comparable during the interpretive process. When needed, corrections can be applied for well bore variables such as mud weight changes. When the inevitable questions of 'why?' arise, the analysis of isotube mud gases, source rocks, oil shows (i.e., open pore hydrocarbons), fluid inclusion oil extracts (i.e., closed pores), and fluid inclusion gas extracts (i.e., closed pores) can all be integrated into the well program to be collectively interpreted.

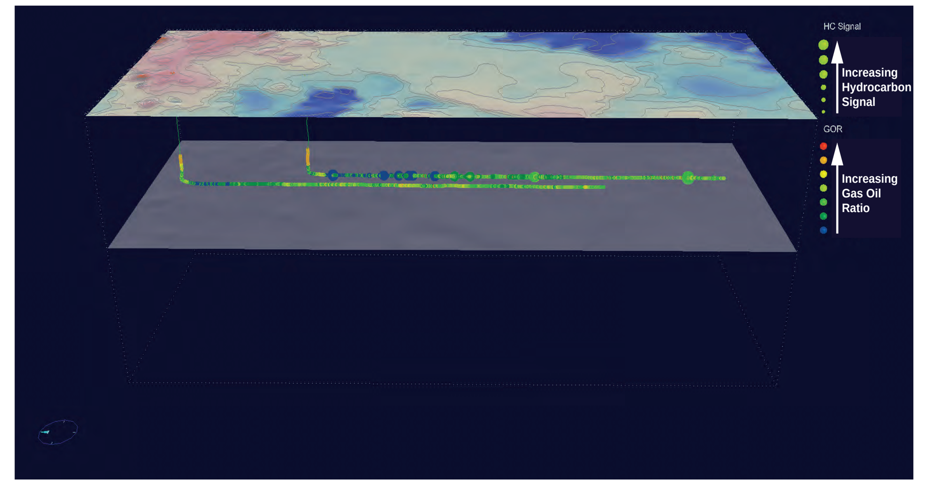
Calibration: Reservoir Energy

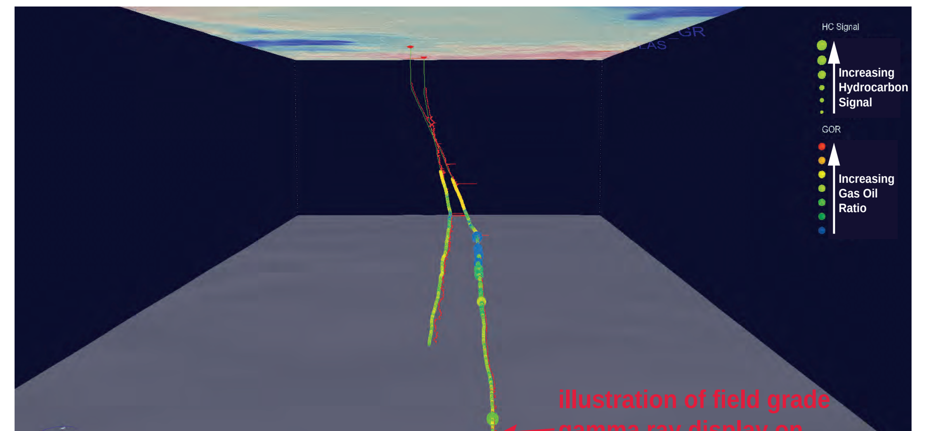


* PSI output from DQ1000 raw data

PSI-FGS 3D Representations

Example 1



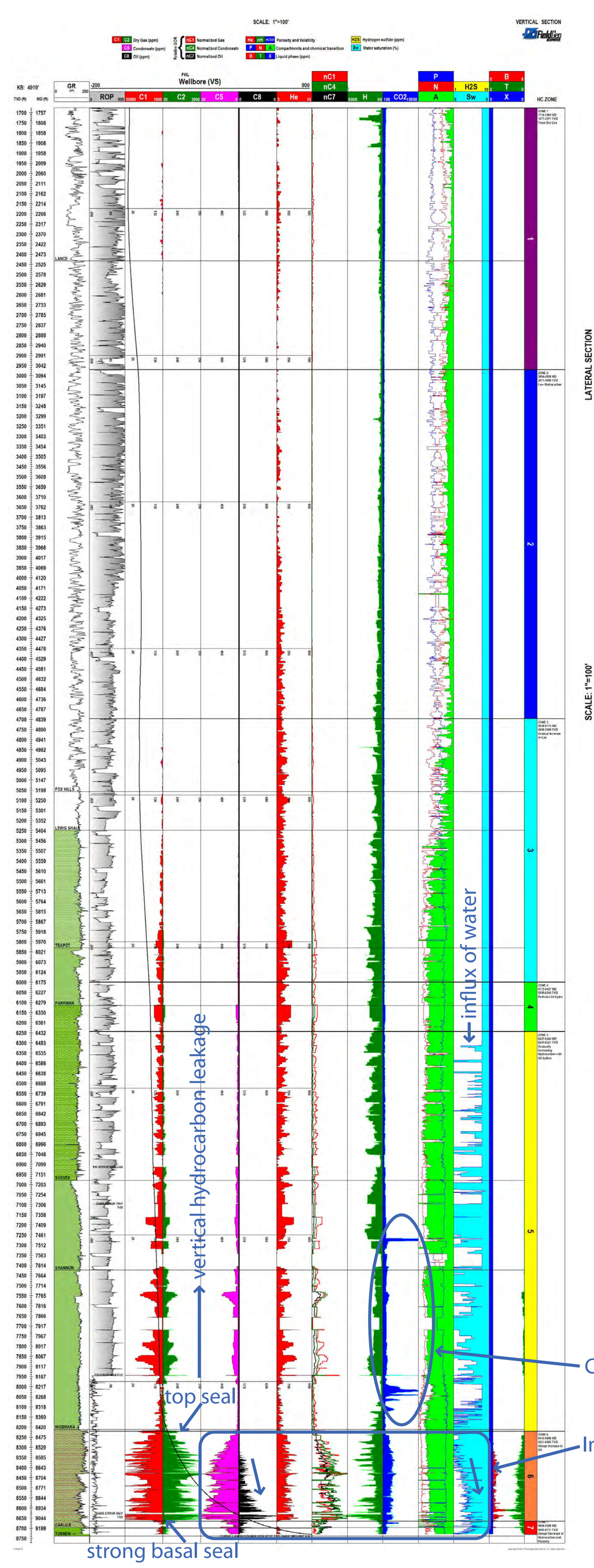


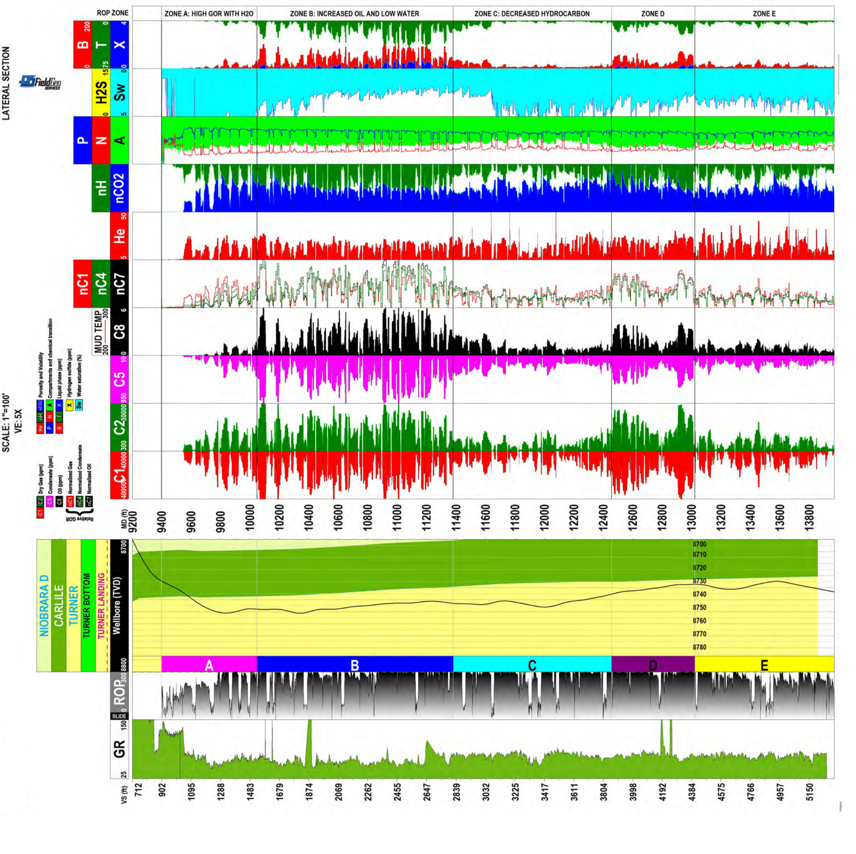
Rotated 90 degrees with tilt

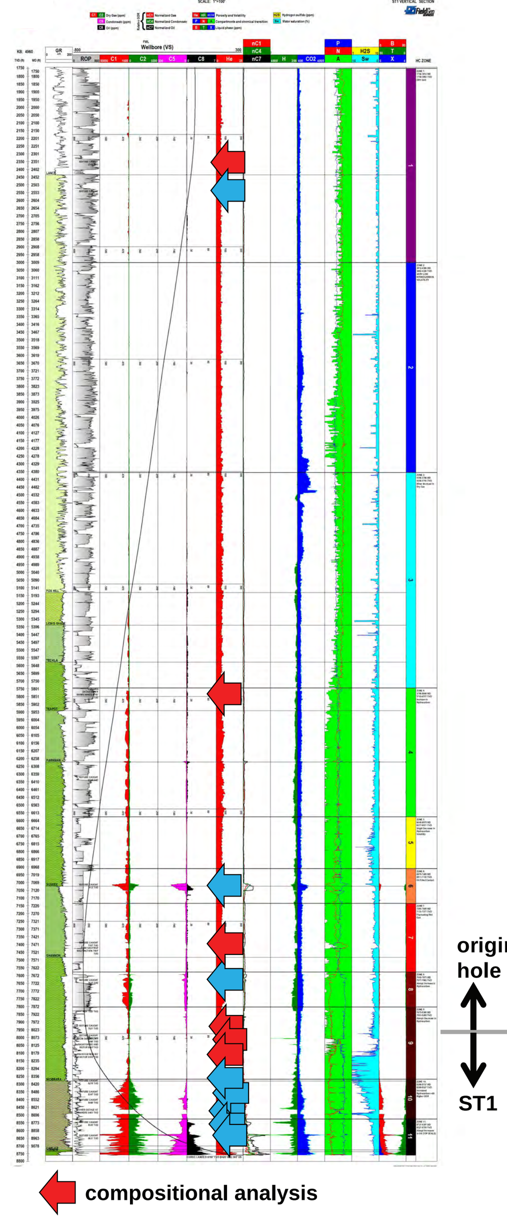
A useful visualization tool to further reduce the dimensionality of the output data to consistently correlate units is illustrated in these 3D displays using the Zetaware, Inc. software. In this example, the calculated hydrocarbon signal (i.e., size function) and GOR (i.e., color function) are viewed in 3D to better understand the relationship of the well bore measurements to the resource cube to reveal spatial relationships of production sweet spots, water influx (i.e., water management tool), and even plan for enhanced recovery methods (e.g., injection points). Additional inputs can include seismic surfaces, geochemistry, and sequence stratigraphy.

Well A

UBR models showing the vertical/curve and lateral sections of a Powder River well. Hydrocarbon signals for C1 methane (dry gas), C2 ethane (wet gas), C5 condensate, and C8 oil are displayed as curves with other important chemical components in the well. Examples of bittersweet parameters include water influx, an inorganic diluitant, and a leaky seal.



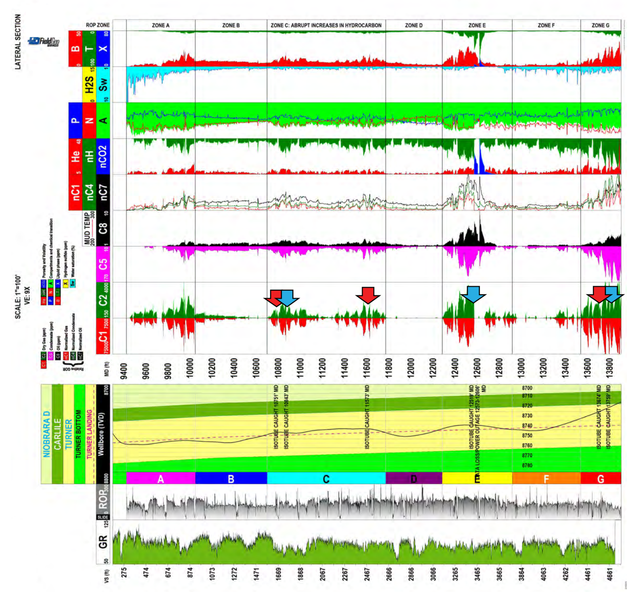




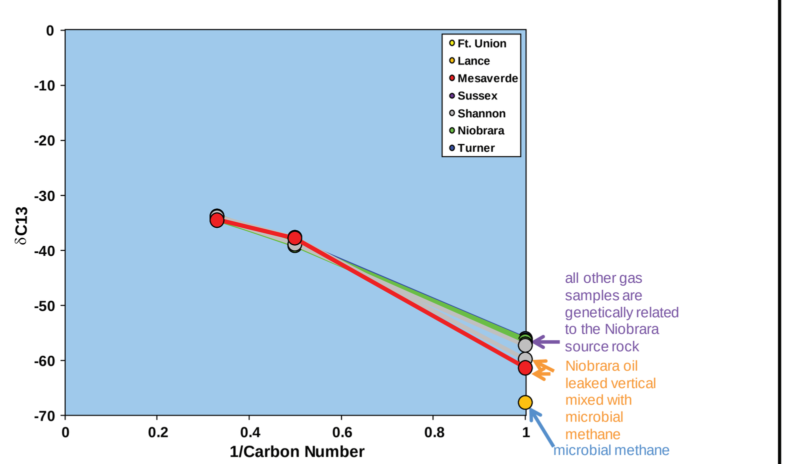
compositional analysis

compositional and isotopic analysis

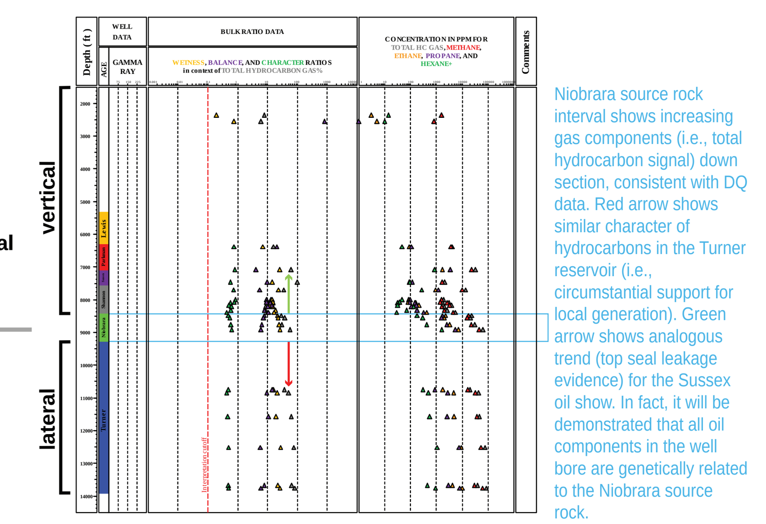
Well B

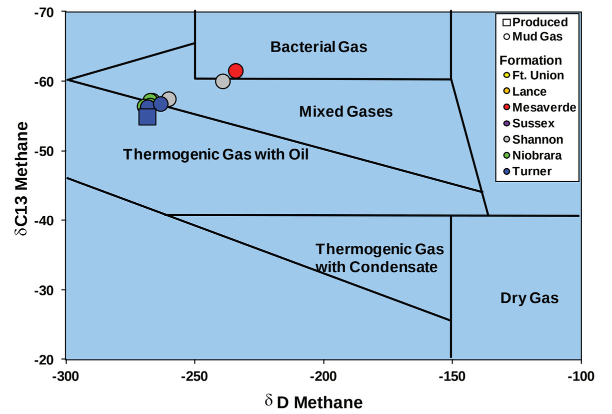


This lateral demonstrates how the dq1000 data can vary when moving in and out of the target zone.



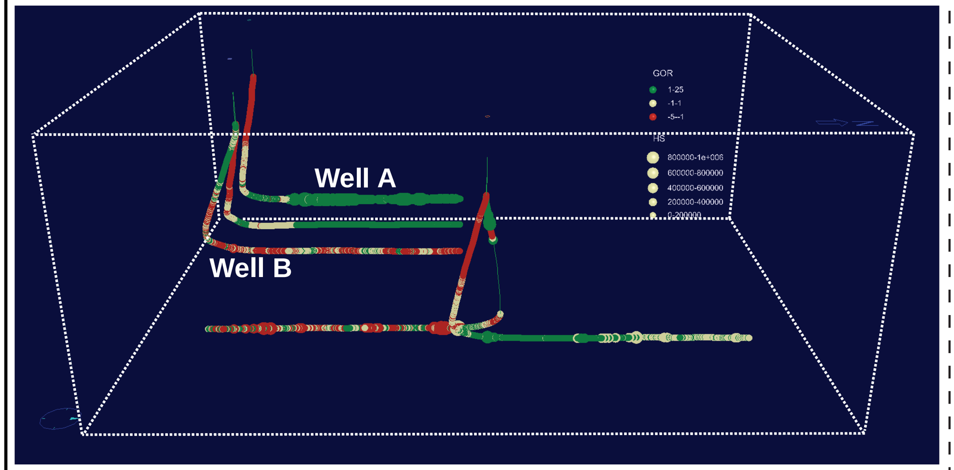
Three groups of gas resolved: microbial gas, associated gas with microbial methane mix, and associated gas from Niobrara source rock. No other secondary alteration of gas components appear to be present in these samples. Overlap of Turner reservoir and Niobrara source rock samples implies genetic correlation. Note is made that the Sussex oil show (red) is one of the samples that is mixed with microbial methane.





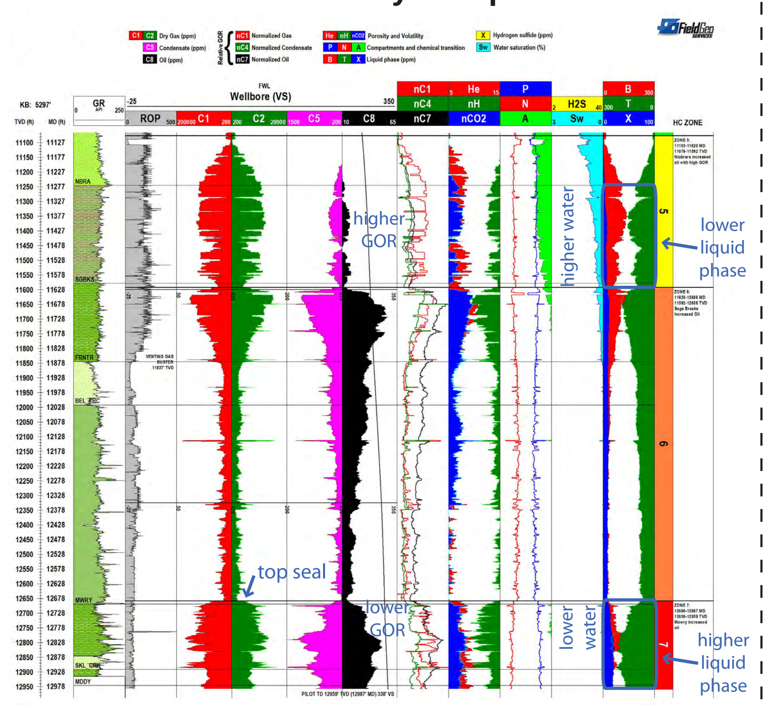
Coinciding Niobrara source rock gas and Turner reservoir samples implies correlation. Straddling the thermogenic line indicates fairly low thermal maturity. Offset samples toward right (heavier hydrogen isotope) is due to microbial mix, and Lance microbial gas is not plotted due to insufficient concentration for deuterium measurement.

3D Visualization of Powder River Dataset



3D display of Powder River wellbores highlighting relative GOR and hydrocarbon signal. Note the changes in signal relative to the lateral UBR diagrams when in and out of zone.

Niobrara - Mowry Comparison

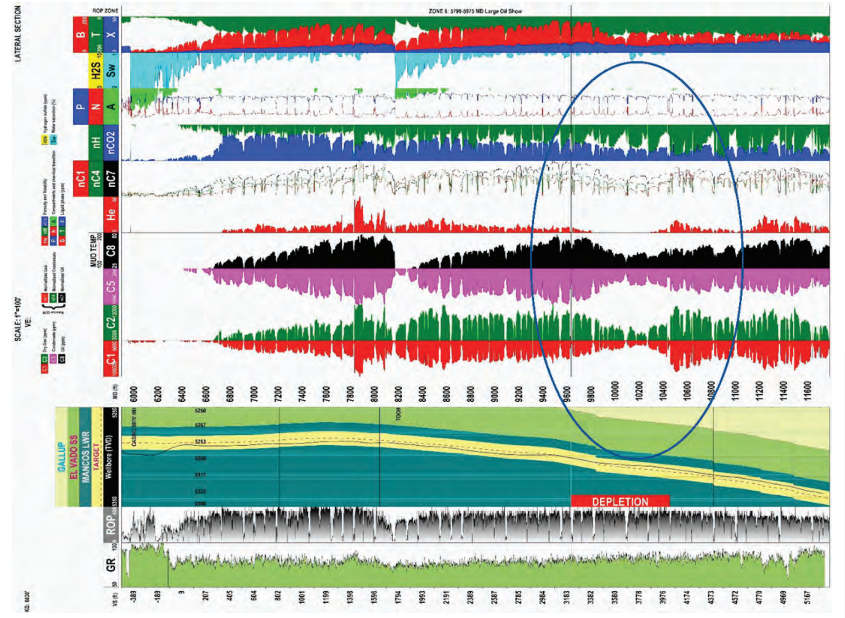


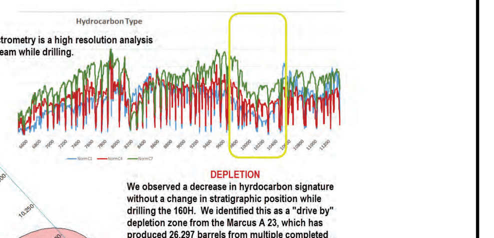
UBR model showing the pilot section of a Powder River well penetrating both the Niobrara and Mowry sections.

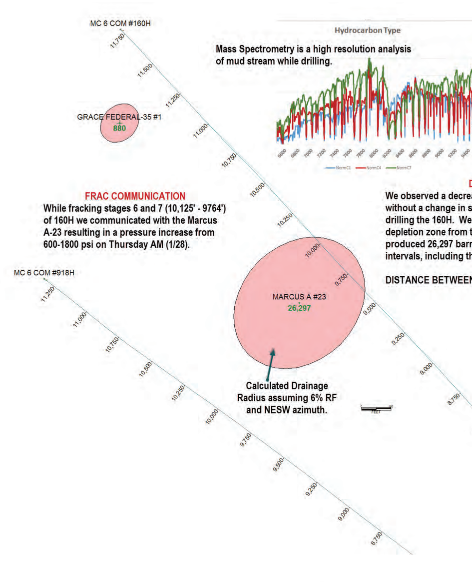
Other Mass Spectrometer Data Applications

Lateral showing depletion by connectivity. This well was drilled close to a fracked and producing well, and the two became connected. The DQ1000 output redefined the concept of the frac radius for the operator and highlights the importance of well spacing. NOTE: this well was drilling at 1,000 feet per hour, and the mass spec system responded rapidly to the changes.

Also, there is a fracture at 7850' and a trip at 8200' that shows what a reset of the mud looks like.







3D Application