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**TITLE:** Novel Insights to the Unconventional Reservoir: Unlocking the Mystery of GOR Variations

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**Poster Consideration:** Yes

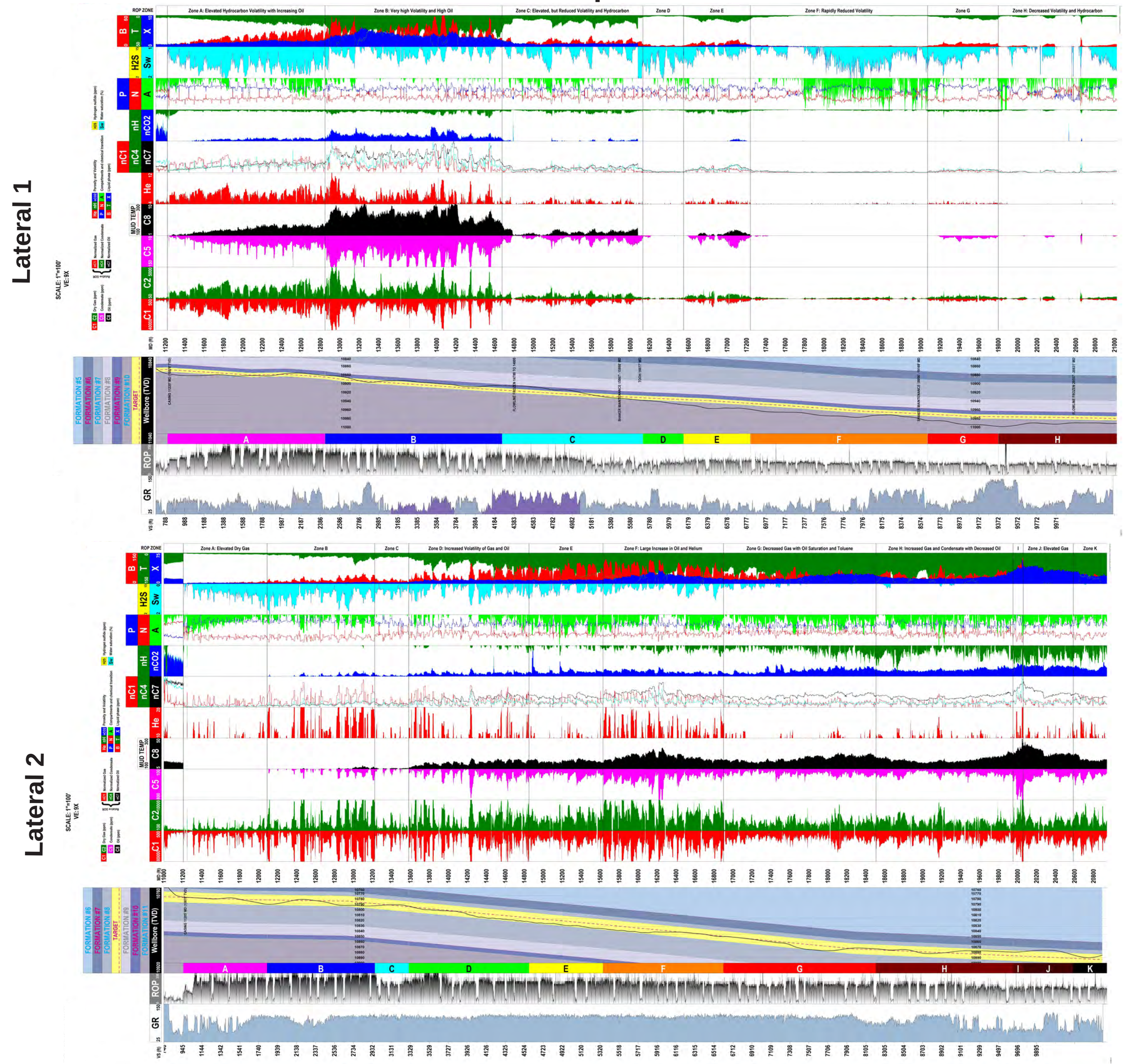
**ABSTRACT BODY:** A key aspect to the unconventional reservoir definition is whether or not the rock permeability and/or fluid viscosity needs to be altered to achieve a commercial flow rate (e.g., Cander, 2012). As viscosity is usually assumed to be static, the alteration is usually applied to the rock matrix by virtue of fracking. Using a pivot logic perspective, the focus is redirected to the identification of variables in the hydrocarbon phase encountered in the pilot hole (e.g., to plan the landing) or lateral that are associated with lower viscosity hydrocarbon fluids (i.e., higher gas-oil ratios). Examples of petroleum system processes that lead to higher GOR include auxiliary hydrocarbon charge that can be migrated or generated in-situ, whereas the inverse scenario is often accomplished with a leaky top seal. There are several strategies to unlock GOR variations. An initial assessment of relevant trends can be achieved with a data ferret, often within the public domain. When the project advances to drill stage, the best practice utilizes a wellsite mass spectrometer. This is attributed to the ability of this instrument to understand the distribution of molecules that exert control on reservoir energy within penetrated rock in real time. This is accomplished by deconvolution of the collective mass spectra to determine hydrocarbon (e.g., gas, condensate, and oil) and non-hydrocarbon (e.g., helium, hydrogen, acetic acid, carbon dioxide, hydrogen sulfide) components in the drilling mud system. Critical parameters directly determined include total hydrocarbon signal, gas-oil ratio, porosity and volatility, and water saturation and mobility. Interpretive extensions include initial assessment of top seal efficiency, bit wear (i.e., without a trip), determination of optimal landing, completion design, geosteering, and suitability for enhanced oil recovery. When integrated with more conventional methods in the geochemical toolbox, critical components of the petroleum system can be identified and quantified, such as indigenous versus migrated hydrocarbons (i.e., latter is more common than implied by the prevailing paradigm, especially in hero wells / fields), moveable oil can be quantified, and top seal efficiency determined (i.e., critical role to understand under-performing wells). Dramatic operational cost savings to the entire resource development are demonstrated with case studies in the Wolfcamp (Texas), Bakken (North Dakota), and Mancos (New Mexico) petroleum systems.

# Novel Insights to the Unconventional Reservoir: Unlocking the Mystery of GOR Variations

David A. Wavrek[1] and Scott Field[2]

## FGS UBER Output from DQ1000 Acquisition

### Example 1

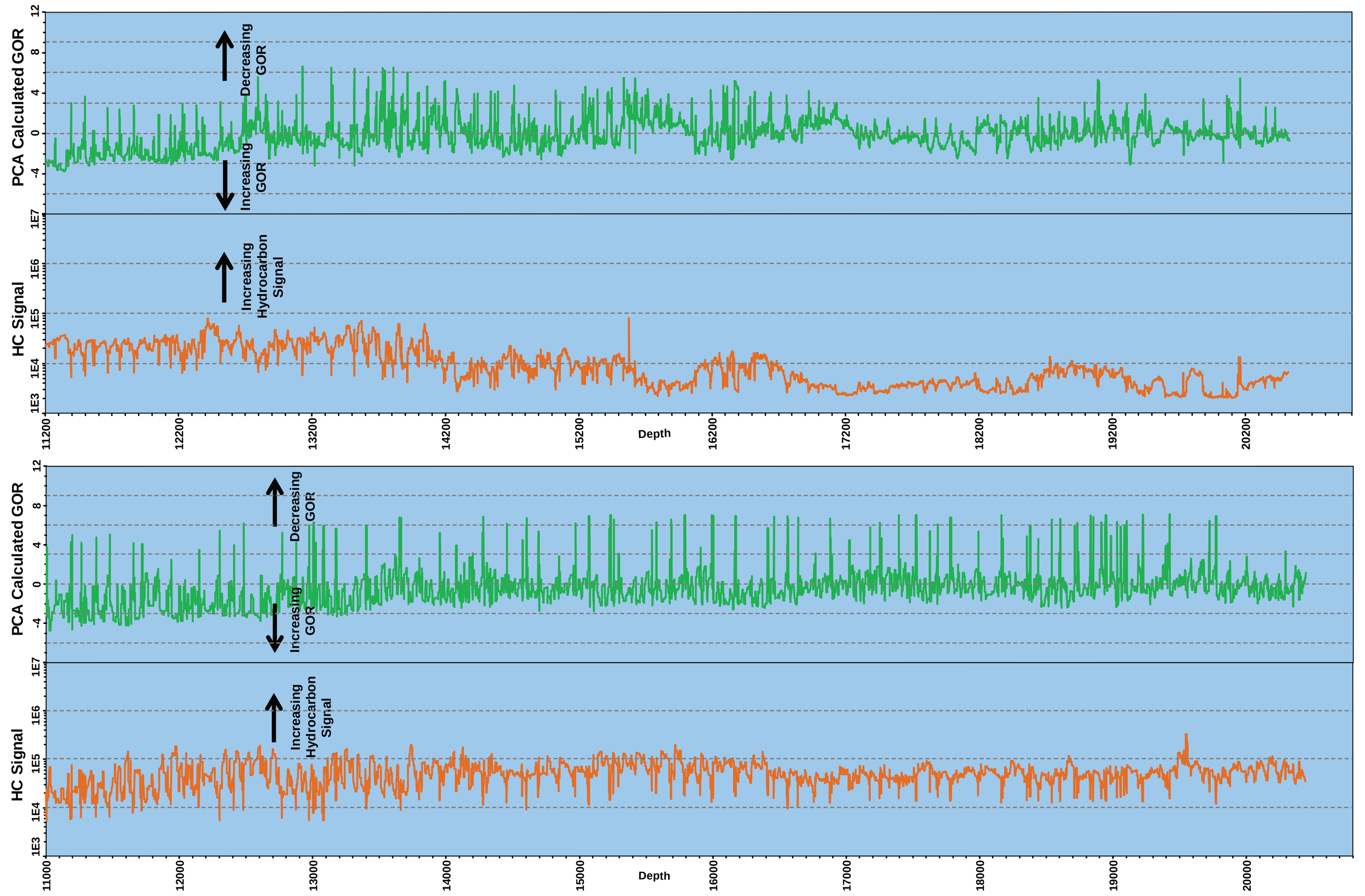



The mass spectrometer acquisition (1-140 amu) provides an enormous amount of chemical data that is deconvoluted in the FGS UBER processing to define 25 separate tracks, from which six main categories are presented in the graphic display: alkane content (dry gas, wet gas/condensate, oil), inorganics (helium, 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 contents 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

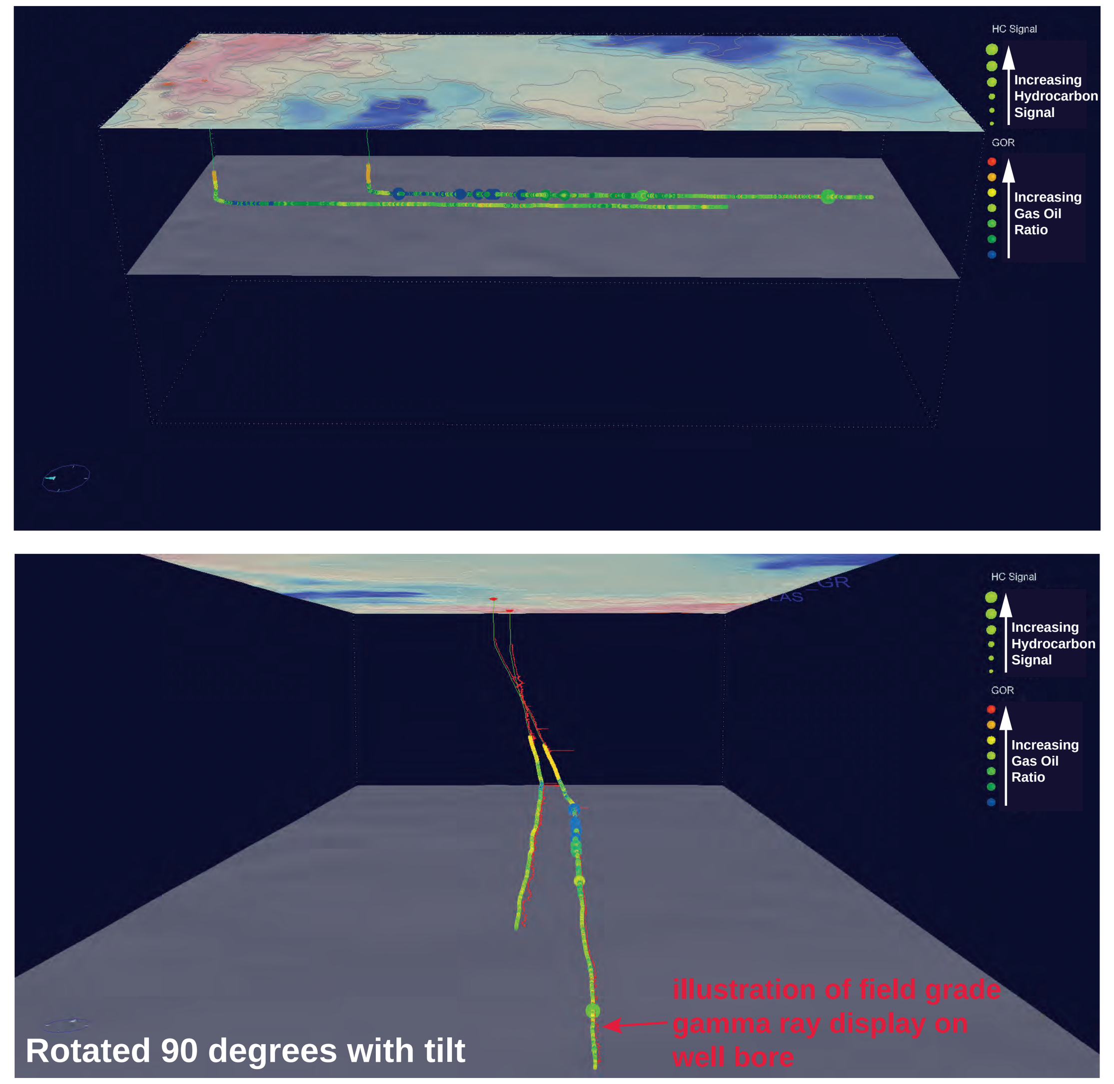
### Example 1




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.

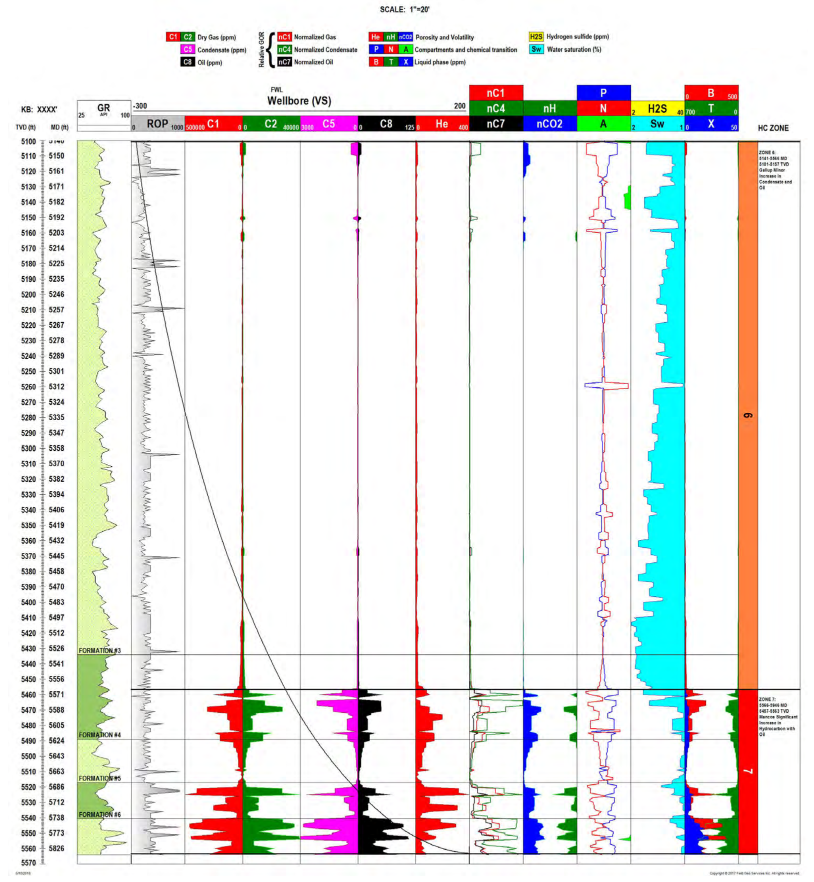
## PSI-FGS 3D Representations

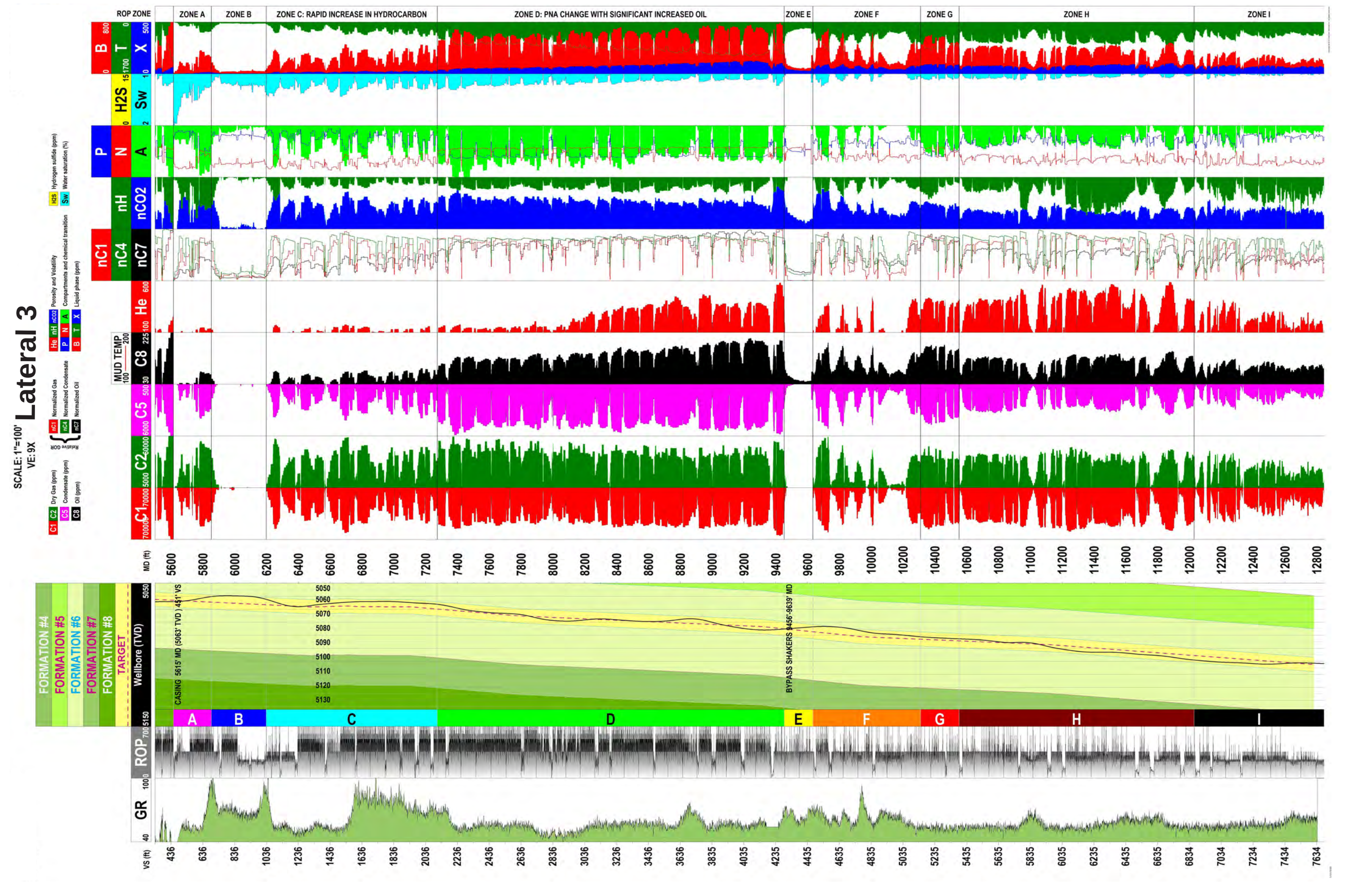
### Example 1




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.

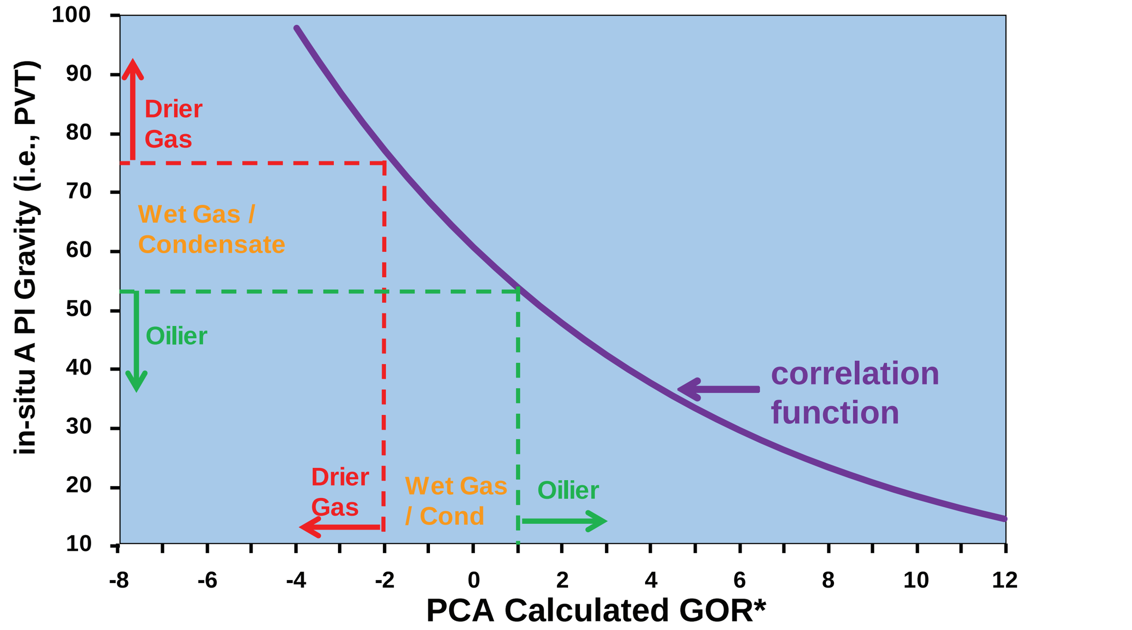
### Example 2




In this second example, the vertical well bore shows two distinct hydrocarbon fingerprints in the target. The paraffin-naphthene-aromatic (PNA) signatures show the deepest lens in this well has a lower paraffin to naphthene signature, whereas the shallower lenses show a higher paraffin to naphthene signature. Normalized hydrocarbon ratios also show the lower paraffin show has a higher oil content and lower GOR, relative to the shallower shows. The lateral well bore shows these same relationships with the initial oil shows displaying the high paraffin to naphthene signature associated with the higher GOR signal, whereas further along the lateral encounters the shift towards lower paraffin to naphthene signature (i.e., lower GOR). Helium is also showing a shift midway into this lower paraffin compartment indicating higher porosity within this compartment. This may indicate that there are two sources of migrated hydrocarbon present, which can easily be verified with the tools in the conventional geochemistry toolbox. The collective value of the wellsite mass spec is enormously important to resource, both within reducing total development costs and increasing knowledge for the decision-making process. For example, the vertical portion of the well derives benefit from determination of the top/base of the hydrocarbon zones; comparison of GOR in stacked zones; determine relative oil saturation; avoidance of high water saturation when planning the lateral; identify potential frac barriers and establish the potential for top seal properties. In the lateral portion, special benefit is realized with the ability to remain in the target (i.e., speed of mass spec data indicates when well bore moves out of target); determination of GOR across the lateral that may affect production; identify elevated water saturation zones to avoid during completion; locate fractures that may absorb the frac energy; and establish compartmentalization trends that may indicate lateral discontinuity (or indicate geosteering issues).

## Calibration: Reservoir Energy

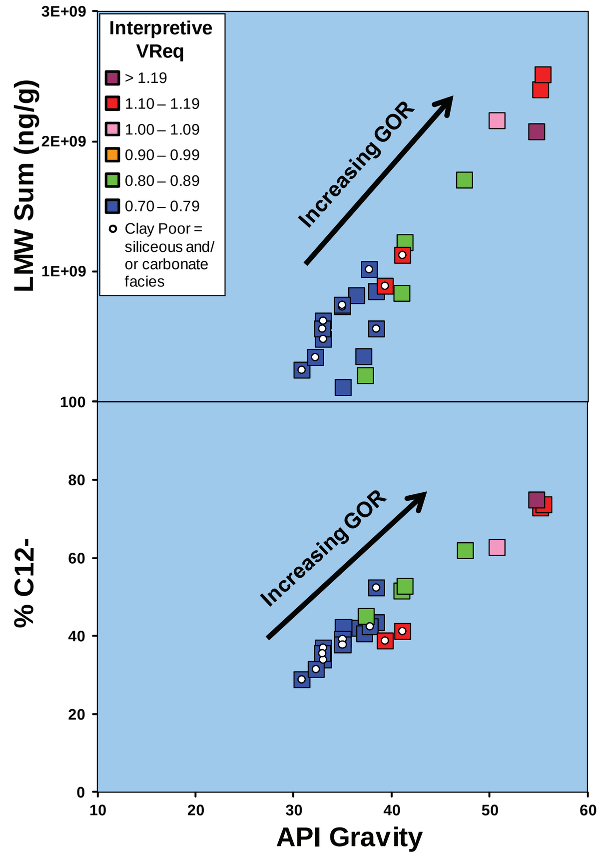



* PSAI outopt from DQ1000 raw data

## Examples of Petroleum System Variables that Influence GOR

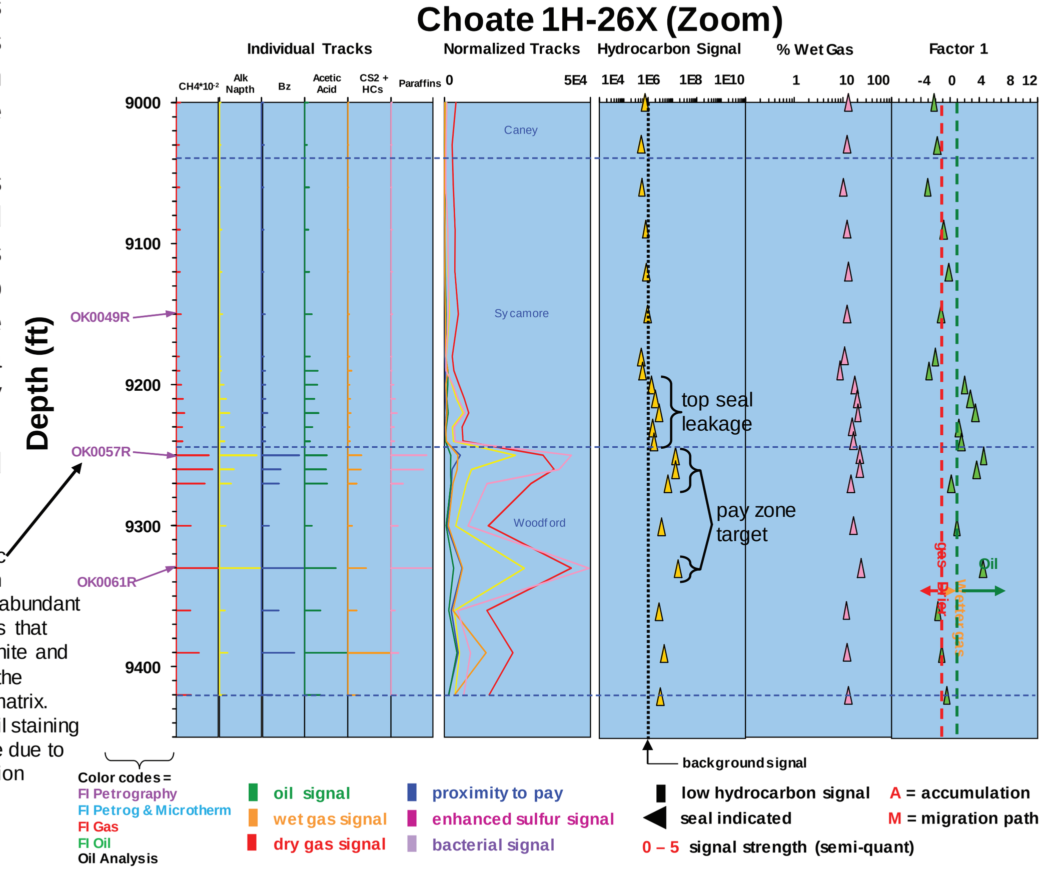
Primary control of reservoir energy (e.g., GOR) is derived from the source rock generation temperature, which is mainly a function of organic matter quantity and quality. Additional variable examples include lithology, kerogen kinetics, and expulsion efficiency. It is noted that the latter variable is often neglected in petroleum system and modeling studies, but it is often a quite profound variable to be integrated into the interpretation as it can account for GOR variation. Another important variable to include is the differential thermal stress between the mobile hydrocarbon phase (i.e., produced hydrocarbon) and the hydrocarbon indigenous to the host rock, as that variable (e.g., quantified with isotube, FIS, etc.) is used to calculate migration vectors (e.g., secondary gas charge). The secondary charges are particularly common in the 'hero' fields in a play like Parshall Field (Bakken[5]). Likewise, the influence by secondary alteration processes such as secondary gas charge (i.e., increases), phase separation (i.e., increases with volatile influx and decreases with the residual phase), and top seal leakage (i.e., decreases).

### End Member Woodford in SCOOP Thermal Stress vs. Oil Properties[3,4]

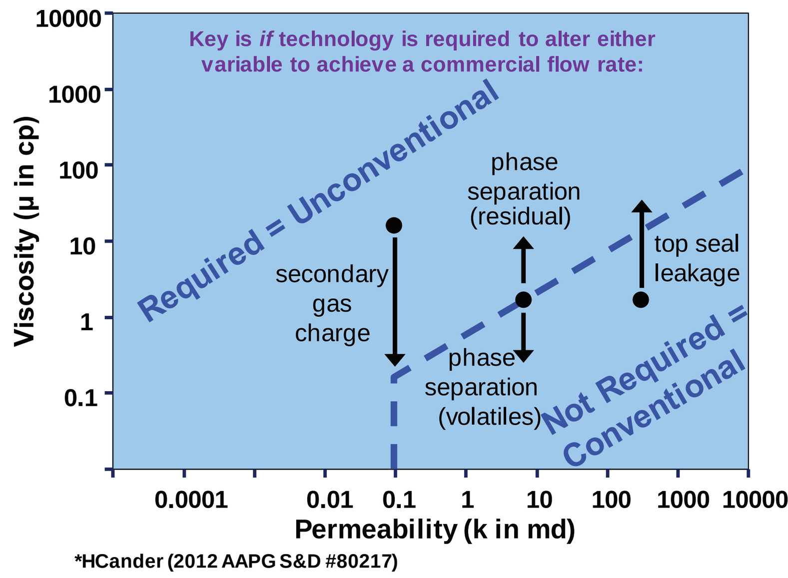



### FIS Example of Top Seal Leakage in SCOOP[3]

Choate 1H-26X (Zoom)




### Definition* for "Unconventional Resource"




*HCander (2012 AAPG S&D #80217)

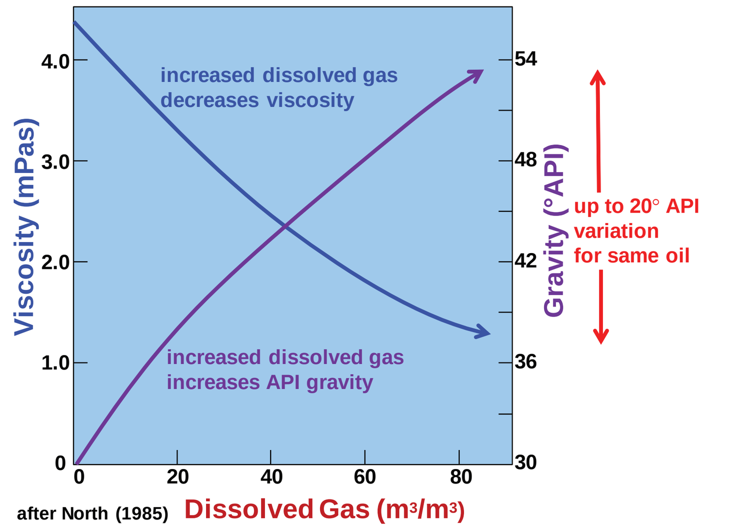
### Main Points

1. bulk properties are a function of molecular composition

2. siliceous and carbonate organic facies in Woodford generate oil at lower degree of thermal stress than over a narrower oil window, compared to the shale facies (i.e., different kerogen kinetics would be used in basin modeling)

3. Inhibited expulsion efficiency contributes to high GOR Woodford hydrocarbons

### Critical Role = Dissolved Gas Influence to Viscosity




after North (1985)

### Interpreted Condensate Types in SCOOP[3]

1. thermal cracking of oil
2. phase separation (volatile phase)
3. oil solubilized into gas phase
4. generation from Type II/III source rock facies

## Conclusions

The content of this presentation demonstrates the power of small company collaboration to create hybrid technologies and cost-effective services that directly tackle critical issues such as unlocking the "mystery of GOR variation" in the unconventional resource. Real time wellsite data acquisition, combined with geochemical/petroleum system concepts, reinforces the adage that conventional tools belong in the unconventional toolbox.