Advanced Well-Site Geochemistry While Drilling: Improved Wellbore Positioning and Formation Evaluation Of Unconventional Reservoirs*

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Abstract

Instrumentation for rig site elemental analysis, developed during the 2000s for conventional reservoirs, was expanded in 2009 to include additional technologies to enable a more complete characterization of shale reservoirs. Since then, hundreds of shale wells have benefitted from combined XRF, XRD, and programmed pyrolysis to determine chemostratigraphic zonation, mineralogical composition, and key organic parameters (S1, S2, TOC, and Tmax) while drilling. To further enhance characterization, critical fluid data such as alkanes (C1-C8) and aromatics (benzene and toluene) distribution can be obtained from advanced mud gas analysis, helping to characterize fluid type, density, and mobility. A workflow combining cuttings-based mineralogy and geochemistry, gas analysis, and open-hole log data from vertical pilot wells enables rapid and effective formation evaluation for selection of target zones for laterals.

Integrated well site geochemical analyses were used to verify the reservoir quality of a target zone while drilling a vertical pilot hole in the Woodford Shale in Hughes County, Oklahoma. Results indicated:

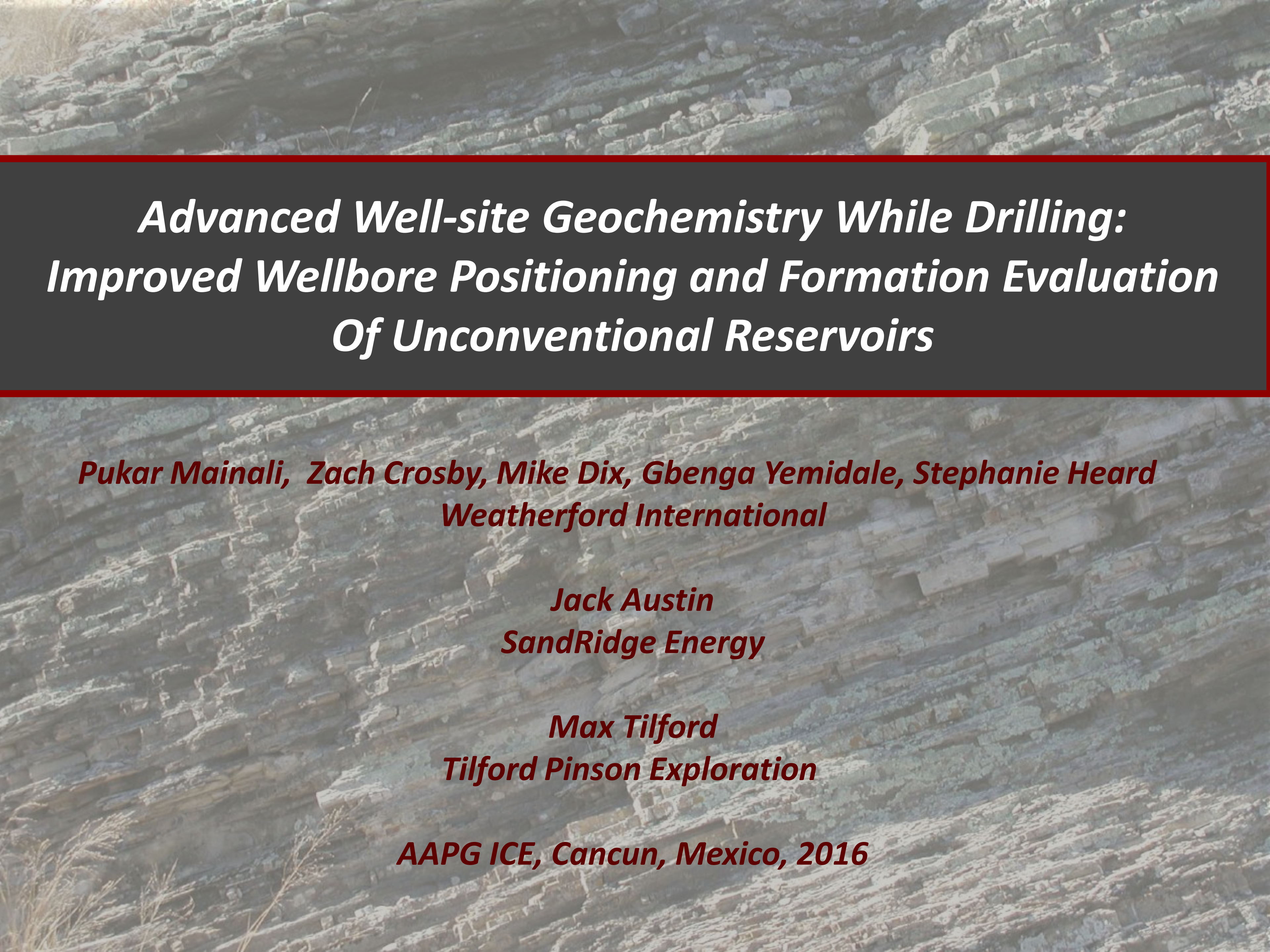
- Total Organic Carbon (TOC) of 3.8 to 7%, Total Hydrocarbon Content (THC) up to 10 times the background gas levels, and enrichments in redox-sensitive elements associated with organic matter (V, Ni, Cu, As, Mo and U).

- Fluid type, quality, and thermal maturity for Type II/III kerogen as shown by Tmax (442-455 °C; oil window), C1/THC indicative of light oil, higher fluid mobility and relatively low amounts of water associated with hydrocarbon indicated by fluid saturation curve (FS), and fluid mobility (FM), and water saturation (Sw) curves.
- Variations in mechanical properties as estimated by the mineralogy-derived Relative Brittleness Index (RBI), and by C1/ROP gas data.

The landing point(s) in the Woodford was chosen using TOC values, fluid type and quality, and mechanical properties necessary for an optimal completion design. A robust three-unit chemostratigraphic zonation was developed for the cherty Woodford from the vertical well. This section was characterized by higher SiO_2, lower detrital-affinity elements (TiO_2, Zr, Nb, and Th), and enrichments in the redox-sensitive trace elements. Elemental data acquired from cuttings on the lateral well was tied back to this zonation while drilling. This verified stratigraphic position for the 5200-foot lateral, and assisted in keeping the wellbore in the target zone despite penetrating several faults.

Selected Reference

Houseknecht, D.W., W.A. Rouse, S.T. Paxton, J.C. Mars, and B. Fulk, 2014, Upper Devonian–Mississippian stratigraphic framework of the Arkoma Basin and distribution of potential source-rock facies in the Woodford–Chattanooga and Fayetteville–Caney shale-gas systems: AAPG Bulletin, v. 98/9, p. 1739-1759.



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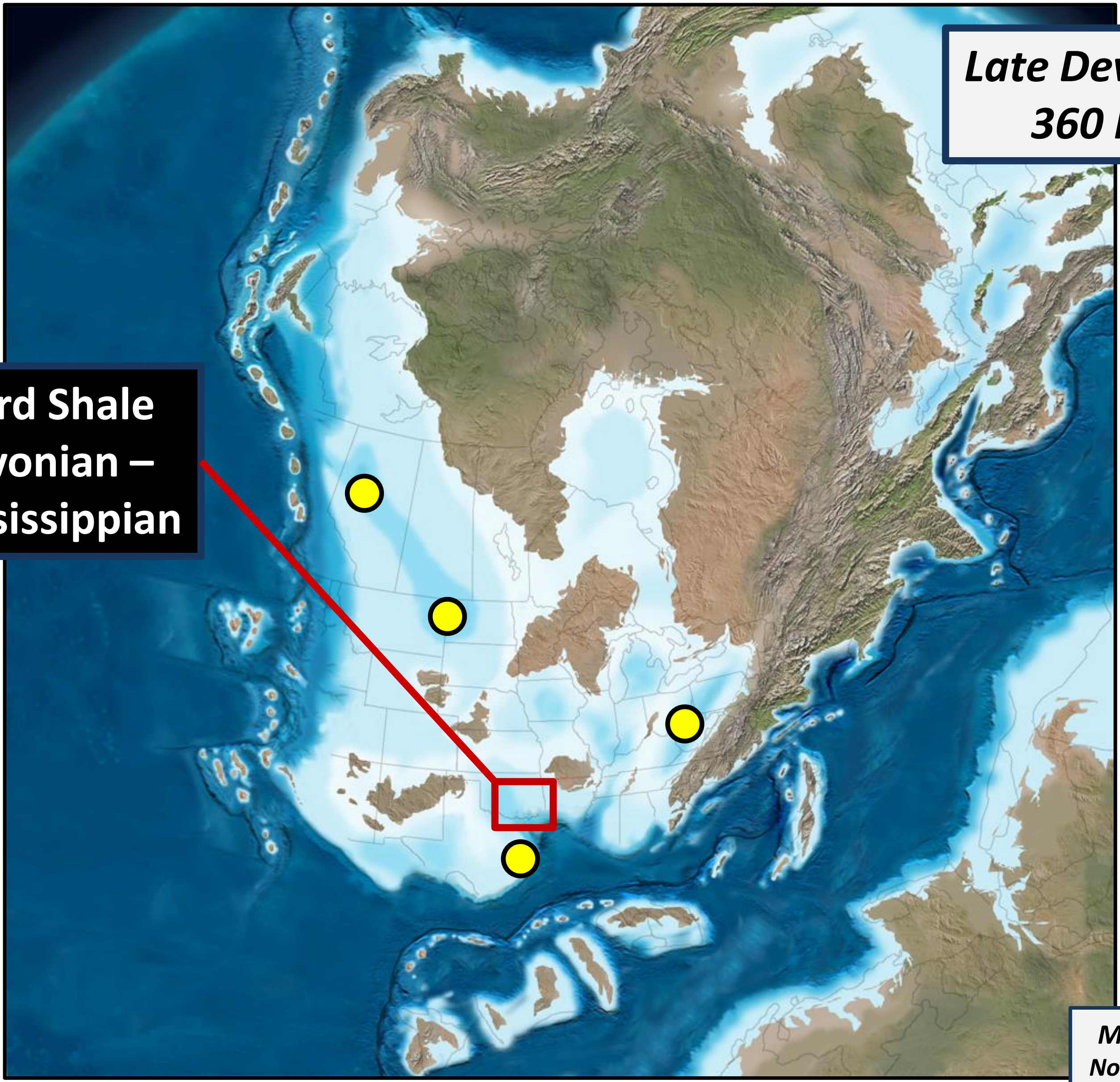
AAPG ICE, Cancun, Mexico, 2016

Regional Setting of Woodford Shale Deposition

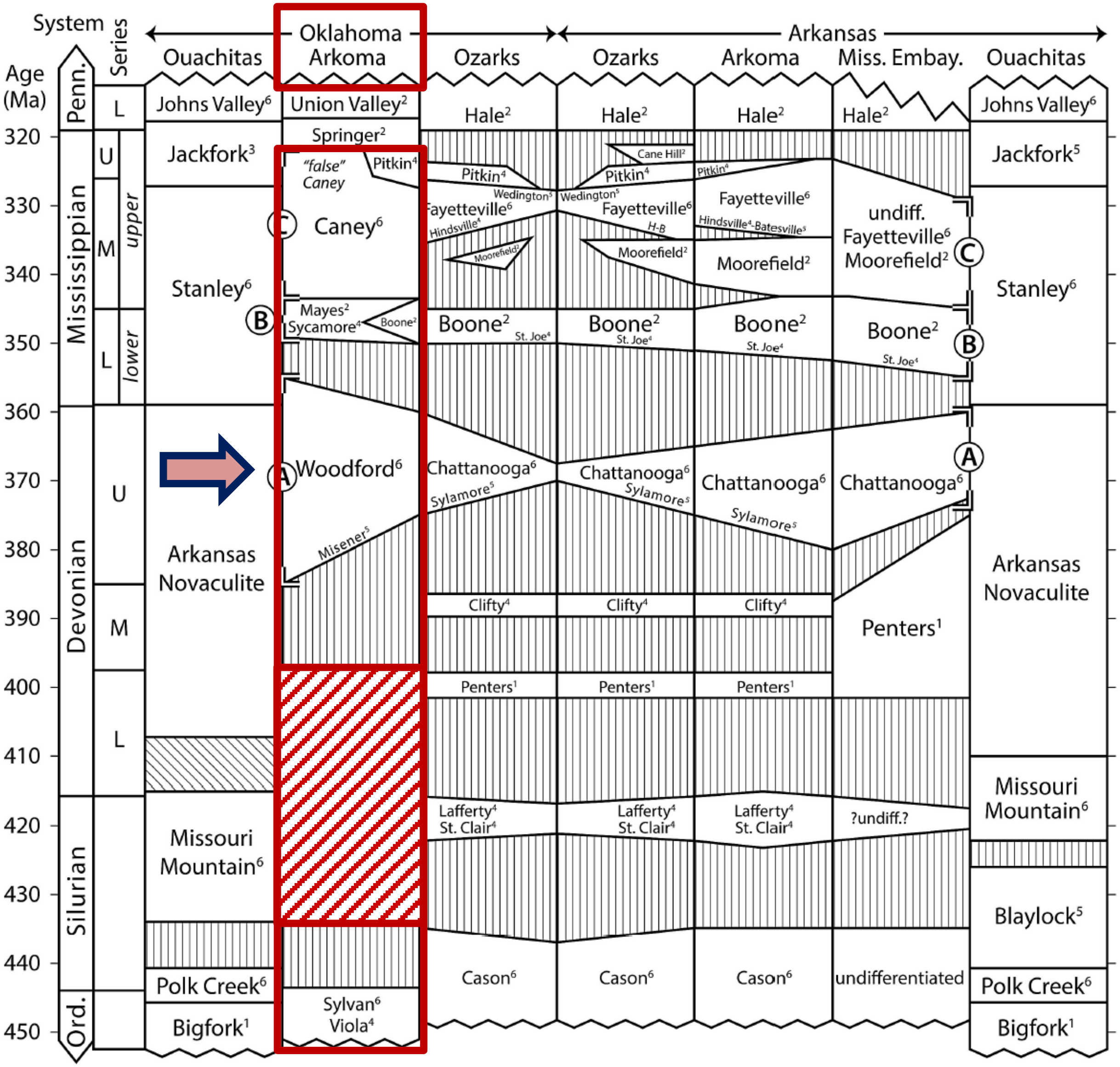


Late Devonian
360 Ma

Woodford Shale
Late Devonian –
Early Mississippian

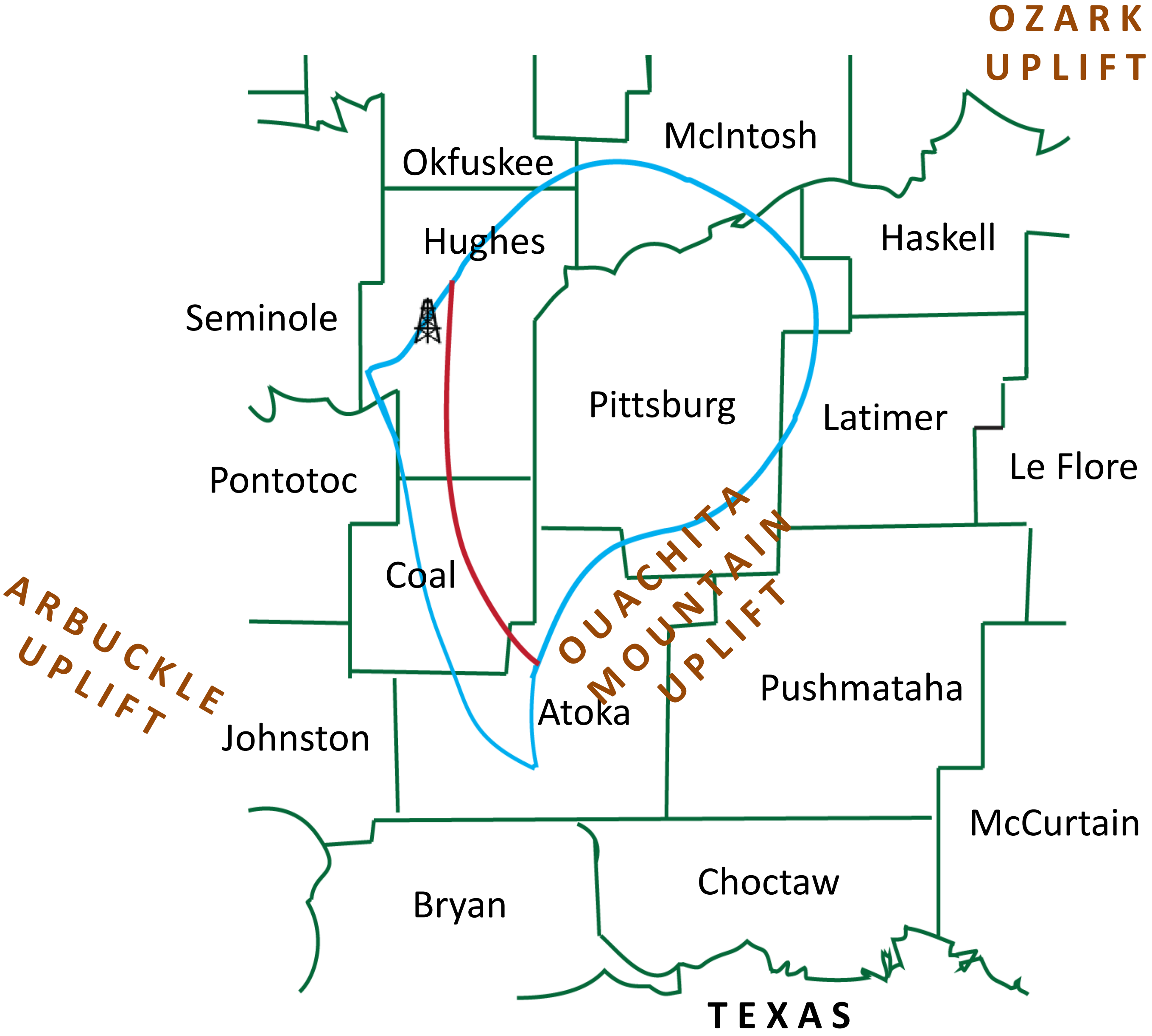
Map from Blakey (2008)
Northern Arizona University
www2.nau.edu/rcb7/nam.htm

Regional Stratigraphy for Woodford – Chattanooga Shales



Stratigraphic Chart from Houseknecht et al. (2014) AAPG Bulletin

Study Well Location in Western Arkoma Basin of Oklahoma



Objectives

1. **Evaluate the vertical pilot well using cuttings and mud gas while drilling**
    a. *Formation Evaluation to identify target zones*
    b. *Establish chemostratigraphic zonation for geosteering*

2. **Aid in rapid decision-making while drilling the lateral**
    a. *Land well in selected target zone*
    b. *Monitor stratigraphic position during geosteering*
    c. *Monitor organic richness and brittleness in lateral*

3. **Provide an overall integrated FE solution to carry forward in the drilling program**

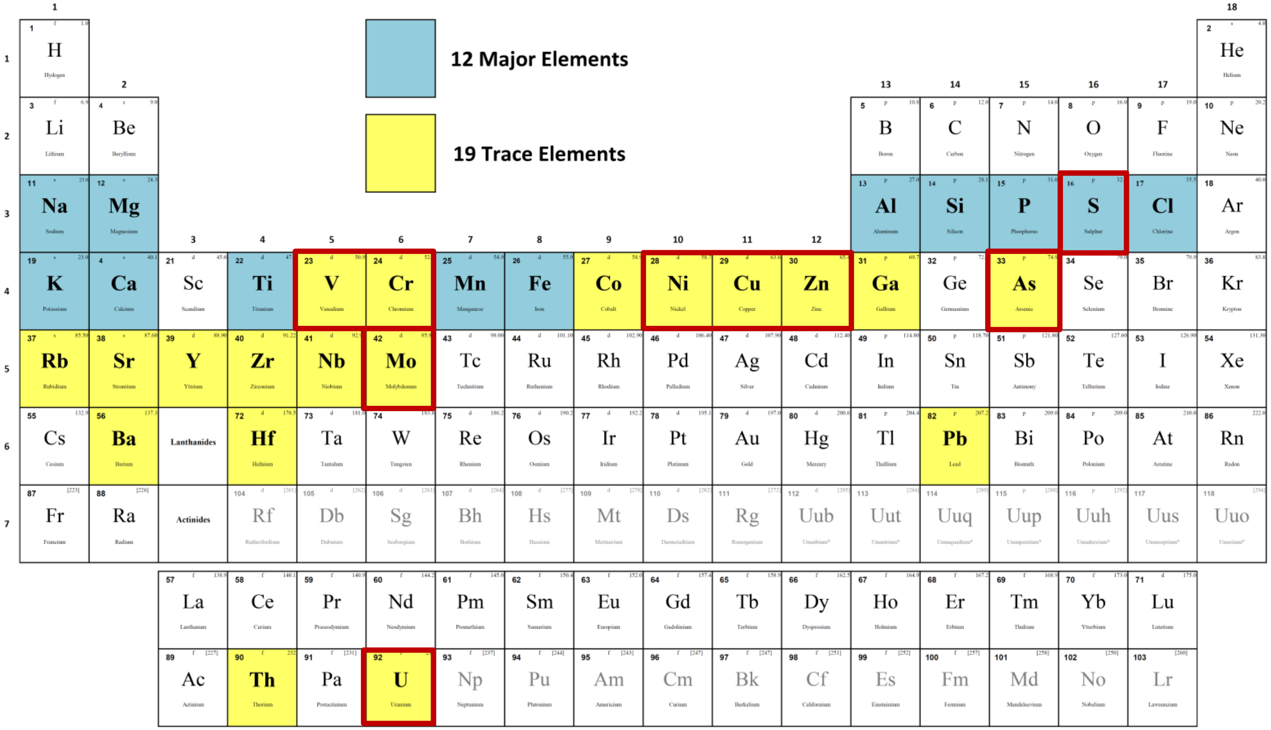
Data Acquisition

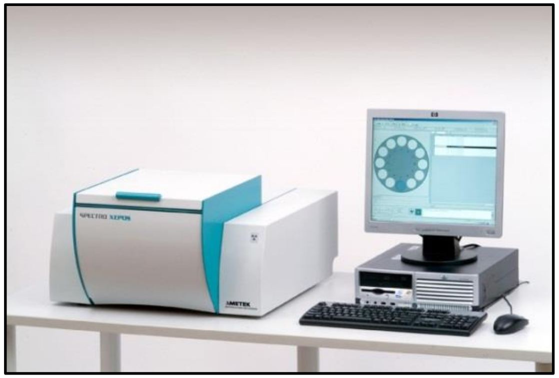
XRF - Direct Measurement of Major and Trace Elements

Redox-sensitive Trace Elements – Organic proxies

V, Cr, Ni, Cu, Zn, As, Mo, U
(S)

Most Useful
V, Ni, Mo, U





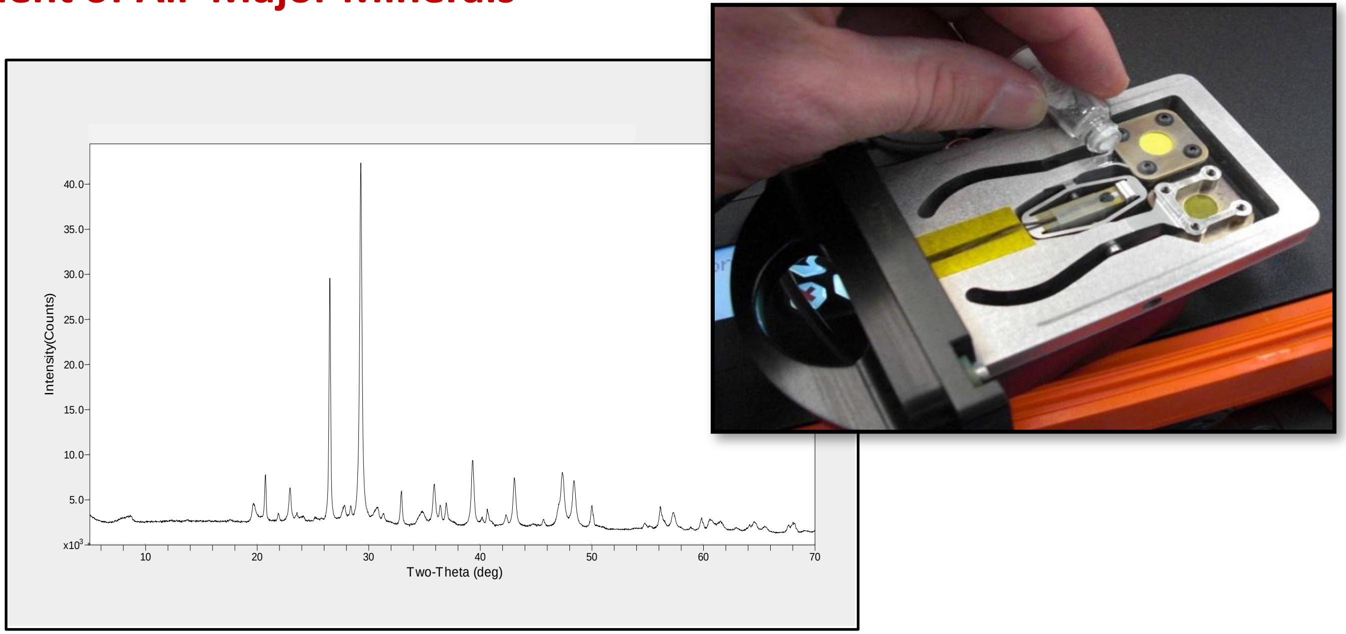
Tabletop ED-XRF

- *Up to 32 elements quantitatively in shales and shaley lithologies*
- *20-25 elements quantitatively in clean sandstones and carbonates*

Data Acquisition

XRD - Direct Measurement of All Major Minerals

- Quartz
- Opal-CT
- K-Feldspar
- Plagioclase
- Total Clay
- Calcite
- Dolomite
- Siderite
- Pyrite
- Anhydrite
- Apatite
- Halite



Customized Brittleness Index

Mineral Distribution & Rock Fabric

$$BI = (\alpha\beta M_1 + \alpha\beta M_2 + \ldots) / (\alpha\beta M_1 + \alpha\beta M_2 + \alpha\beta M_3 + \ldots)$$

Brittle Components

Brittle + Ductile Components (includes organic matter)

Where,

M_n = key mineral (either ductile or brittle)

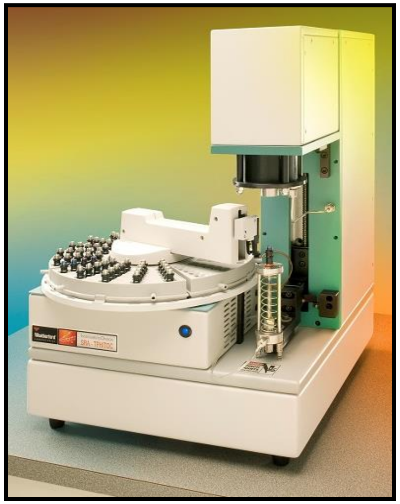
α = mineral-specific coefficient that accounts for mechanical properties

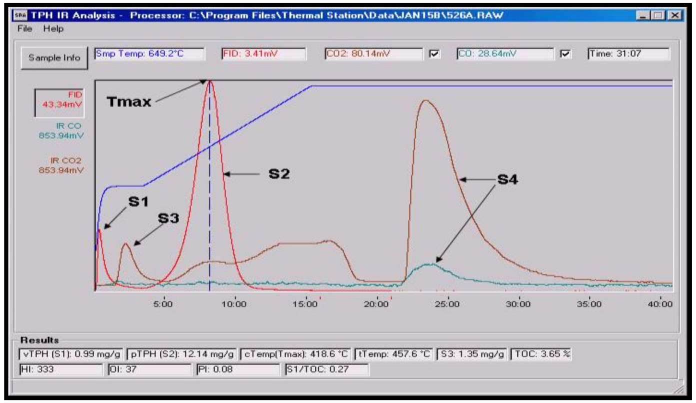
β = mineral-specific coefficient that accounts for distribution and rock fabric

Data Acquisition

Programmed Pyrolysis Instrument provides

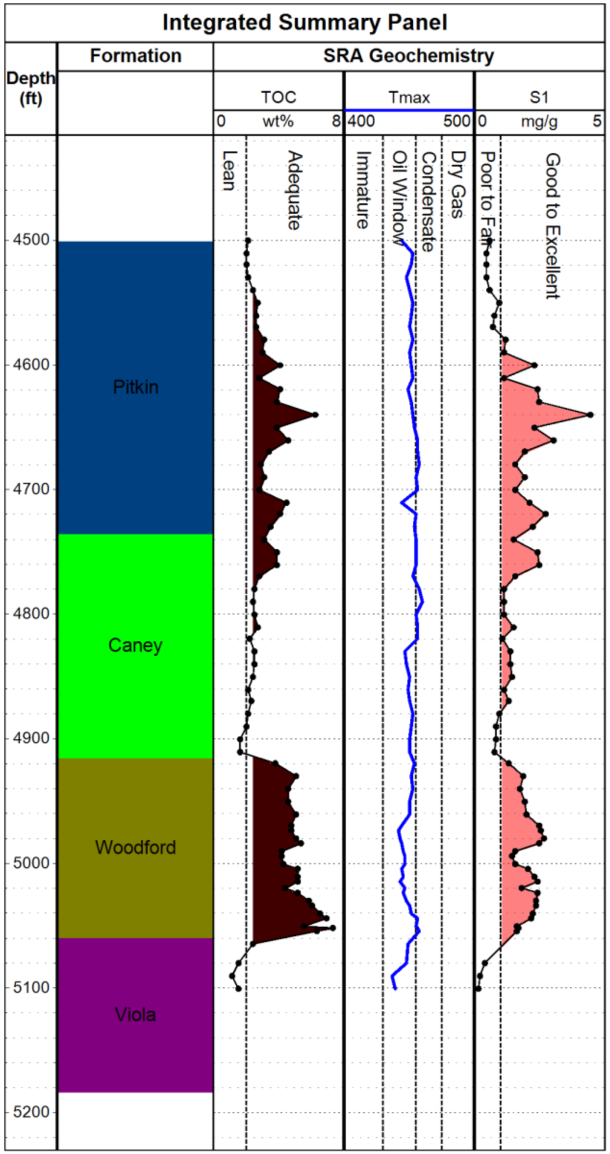
- Free Hydrocarbon (Gas/Oil) Content – S_1
- Remaining Hydrocarbon Generation Potential – S_2
- Organic CO2- S_3
- Residual Carbon – S_4
- Organic richness – TOC
- Thermal Maturity – T_{max}





Smp Temp: 649.2°C
FID: 3.41mV
CO2: 80.14mV ☑
CO: 28.64mV ☑
Time: 31:07

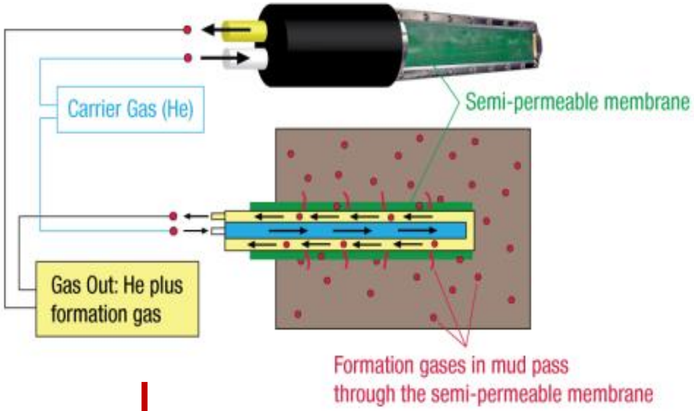
Results
vTPH (S1): 0.99 mg/g
pTPH (S2): 12.14 mg/g
cTemp(Tmax): 418.6 °C
tTemp: 457.6 °C
S3: 1.35 mg/g
TOC: 3.65 %
HI: 333
OI: 37
PI: 0.08
S1/TOC: 0.27



Data Acquisition

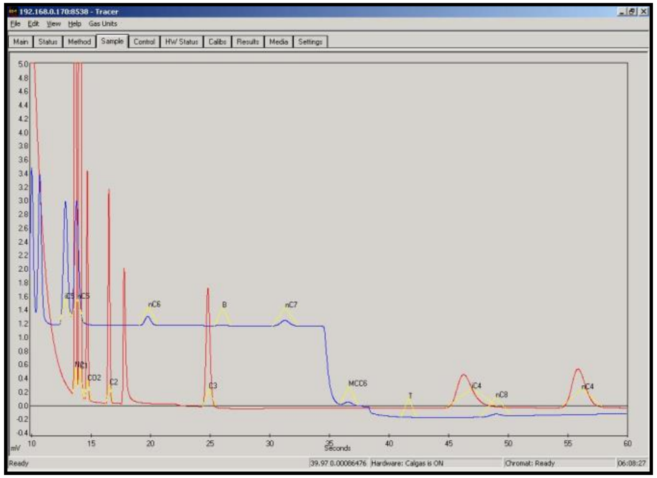
Advanced Gas Detection System

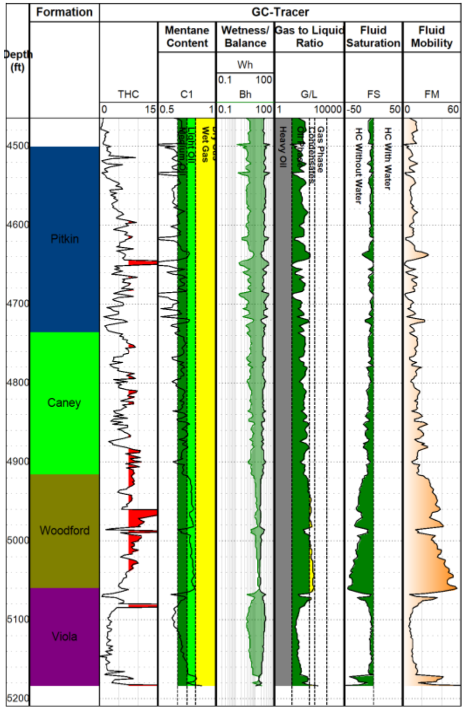
- Semi-permeable membrane gas extraction system that utilizes TCD gas chromatography
- Measures **C_1-C_8**, benzene, toluene, N_2, CO_2,
- Measurement every 55 seconds
- Measures gas in drilling mud, not gas in air
- 1 ppm resolution
- GAS IN and GAS OUT quality control



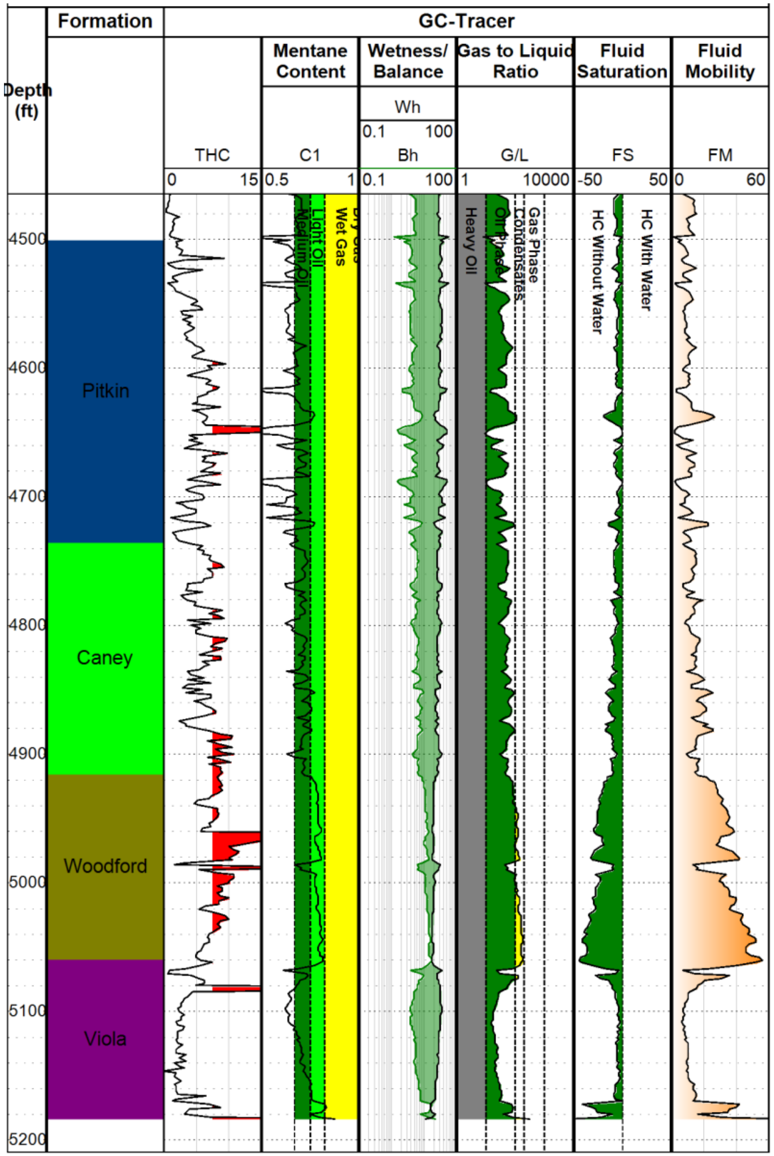
Thermal Conductivity Detector (TCD)

Gas Chromatograph Chart





Mud gas data is not formulaic !



Total Hydrocarbon – Summation of all HC compounds.

Methane content (C1%) -
Increasing indicates lighter HC.

Wetness (Wh) and Balance (Bh)-
Hydrocarbons in oil phase results in higher Wh and lower Bh.
Hydrocarbons in gas phase result in lower Wh and higher Bh.

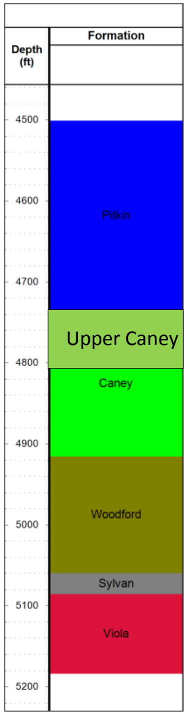
Gas to Liquid Ratio – It's a ratio of (C1 – C4) and (C5-C8).
G/L ratio identifies "gas" from "oil".

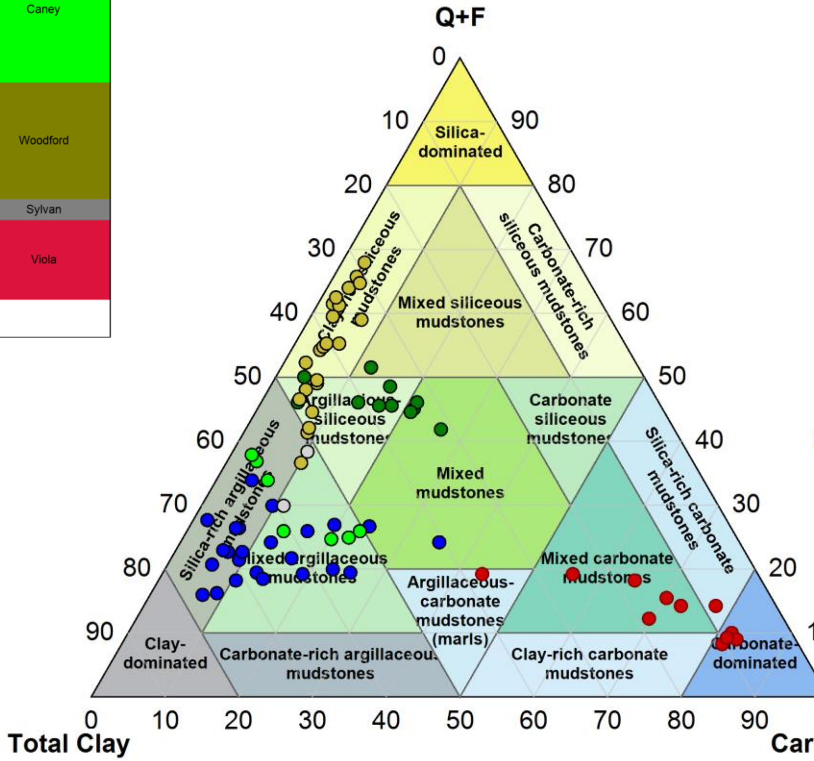
Fluid Saturation (FS)-
Positive deflection indicates water saturation or tight intervals.
Negative deflection indicates hydrocarbon saturation

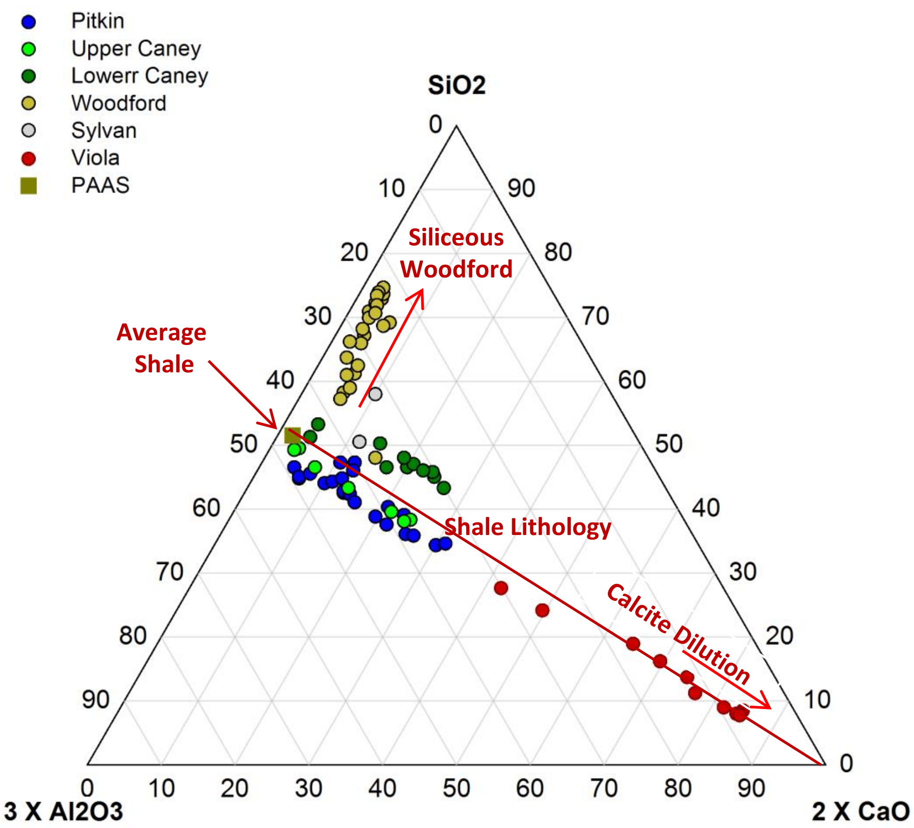
Fluid Mobility (FM)-
FM ∝ density of fluid
FM ∝ relative permeability of the rock.

Lithology and Formation changes

Mix of lithotpyes ranging from carbonate dominated Viola Lime, Shaly Caney and Pitkin, and siliceous Woodford.





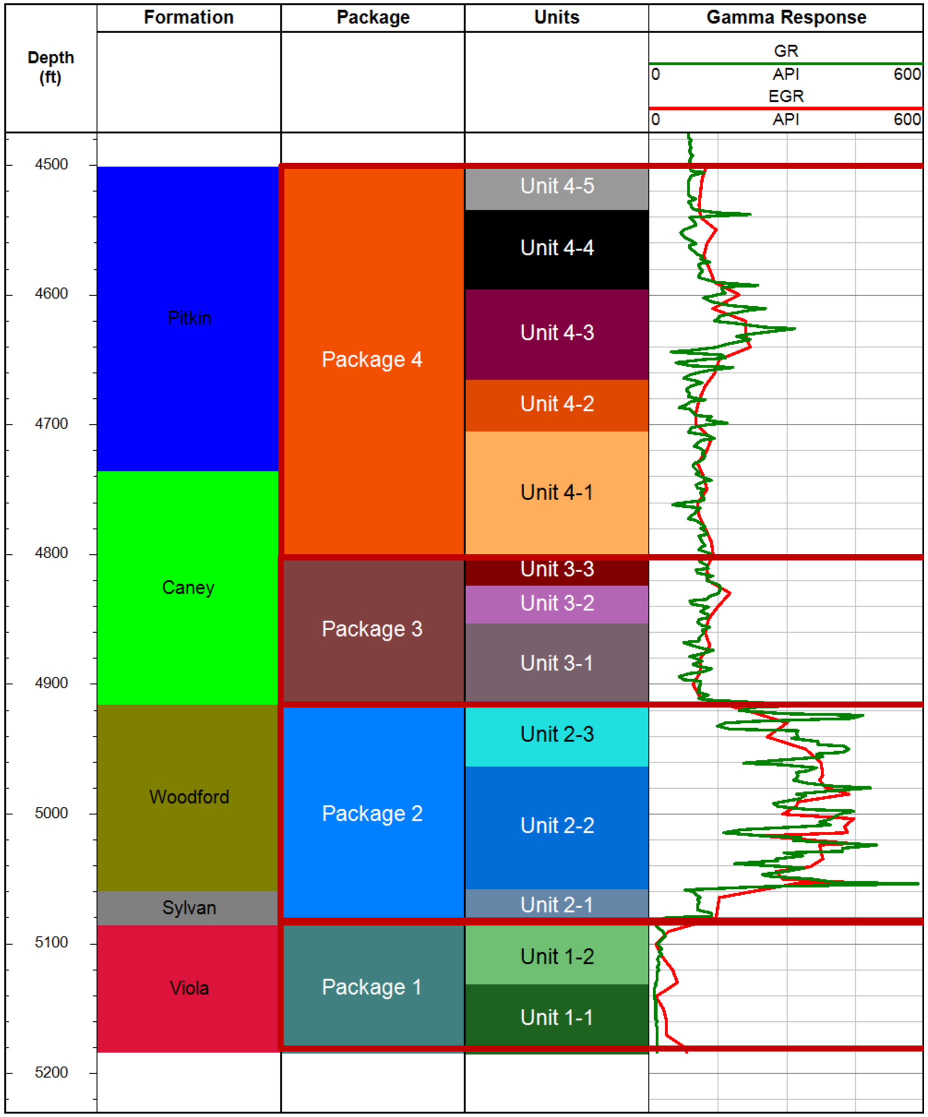


Chemostratigraphy

Techniques of Chemostratigraphy was applied to delineate:

4 Chemostratigraphic Packages

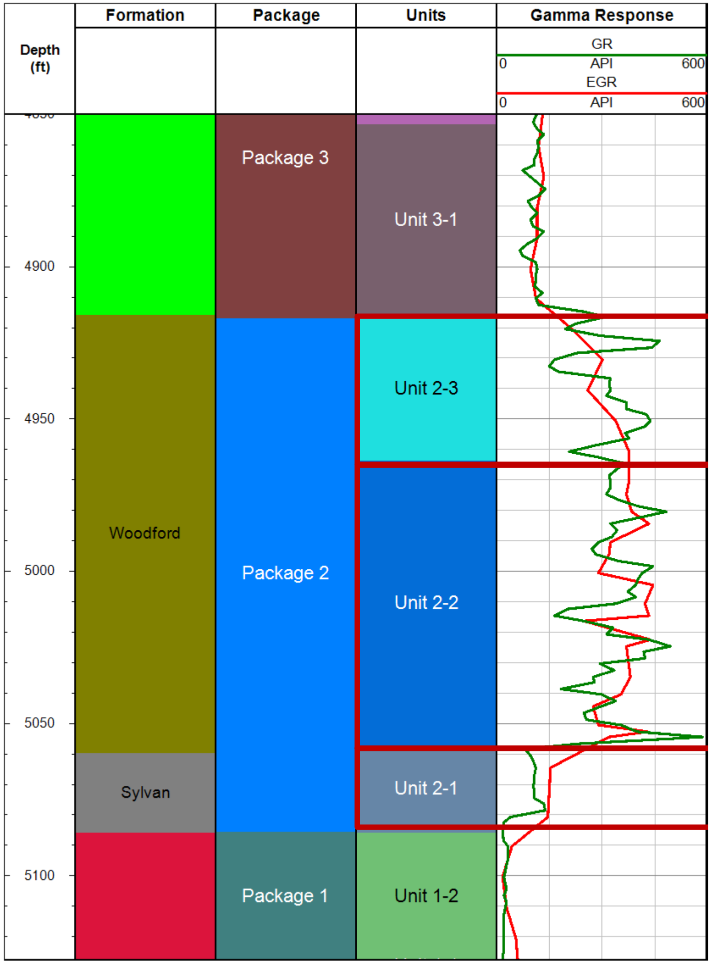
13 Chemostratigraphic Units



Chemostratigraphy – Woodford Shale

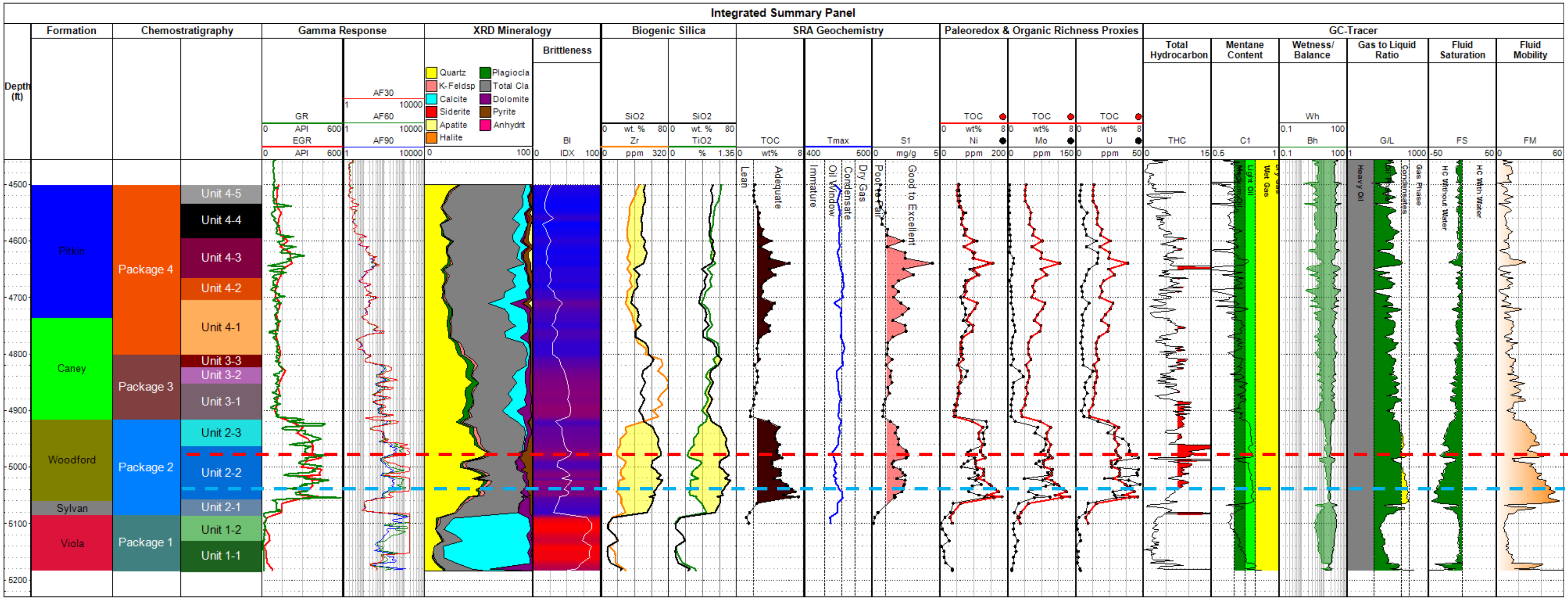
Techniques of Chemostratigraphy was applied to delineate:

Package 2 (Woodford and Sylvan) further divided into 3 Chemostratigraphic Units

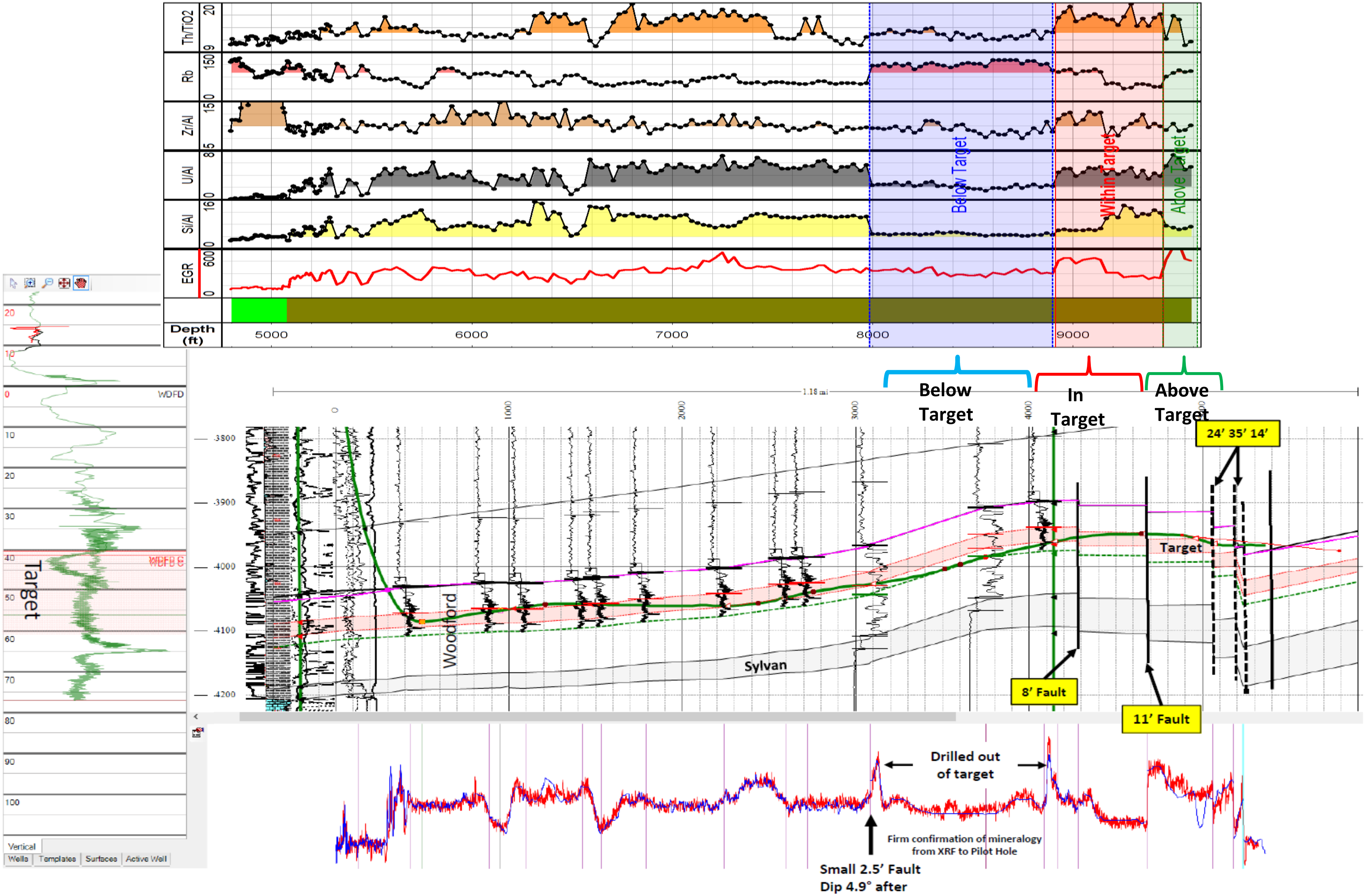


Integrated Summary Panel

- Identification of higher organics target intervals
- Brittle Rocks reacts better to hydraulic fracturing.



Elemental Geomonitoring Of The Lateral



Below Target

In Target

Above Target

24' 35' 14'

8' Fault

11' Fault

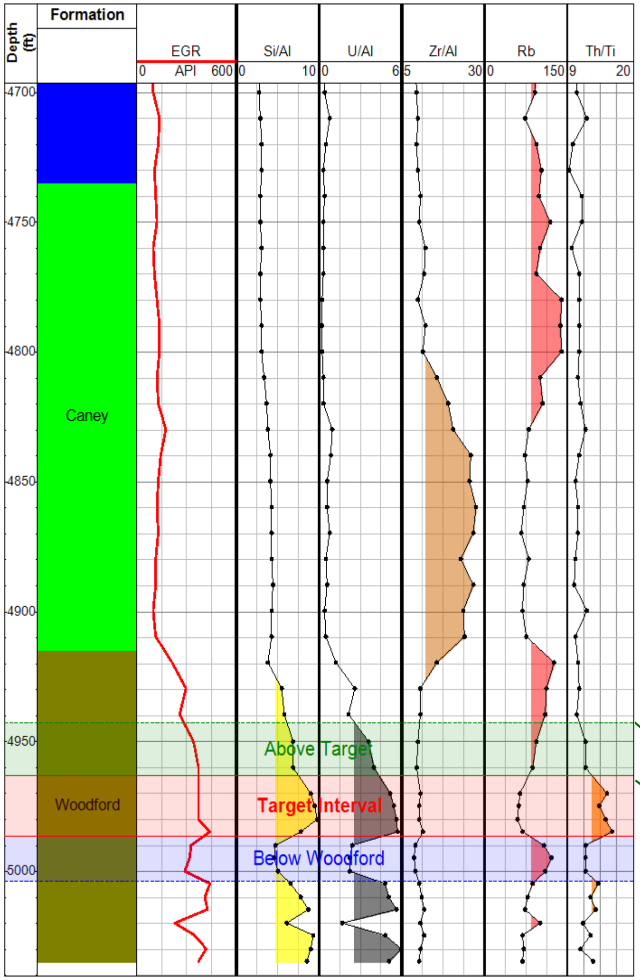
Drilled out of target

Firm confirmation of mineralogy from XRF to Pilot Hole

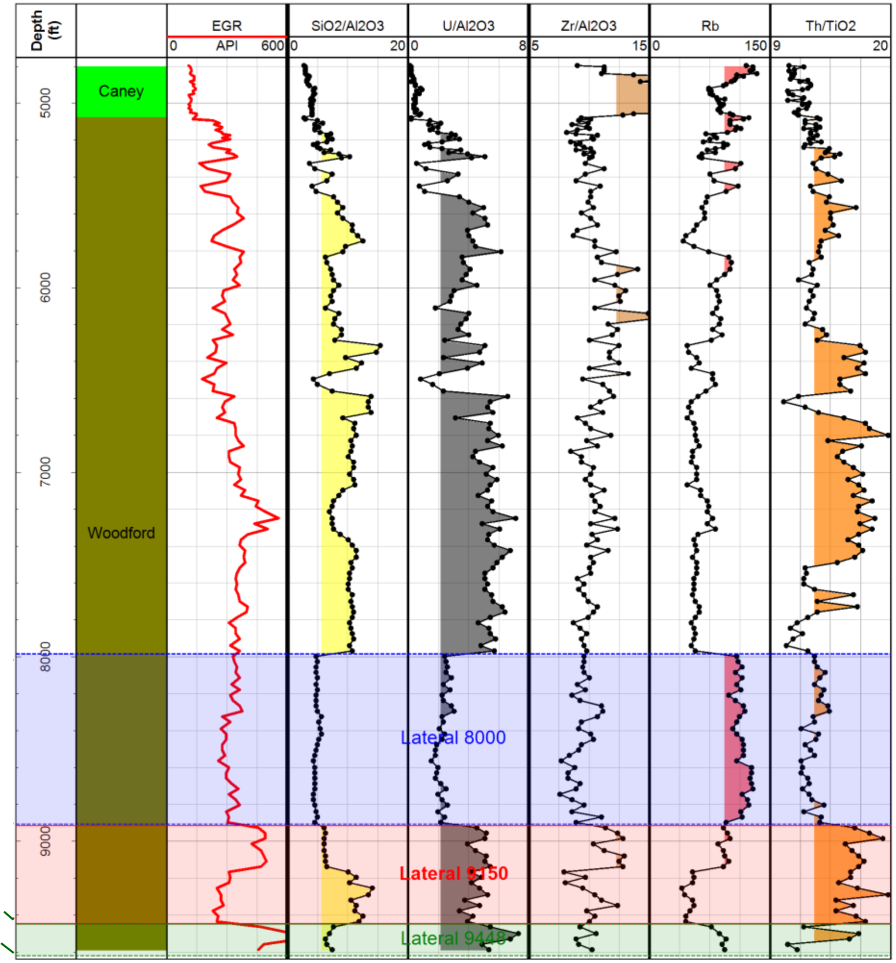
Small 2.5' Fault Dip 4.9° after

Elemental Geomonitoring Of The Lateral

Pilot Hole Woodford Target Chemostratigraphy

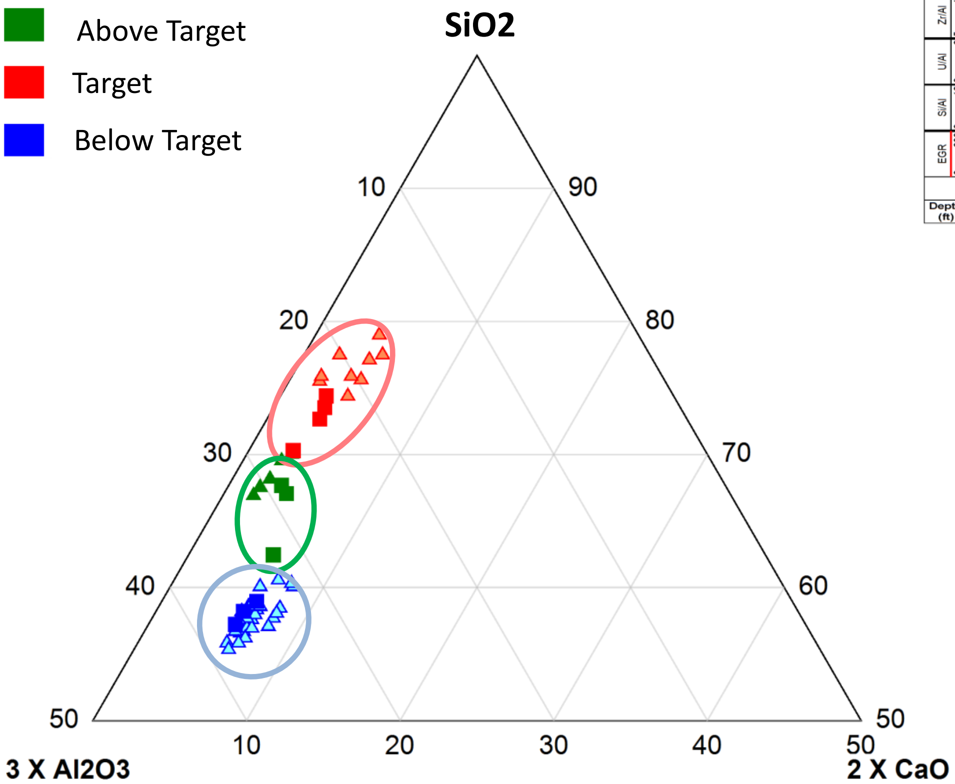


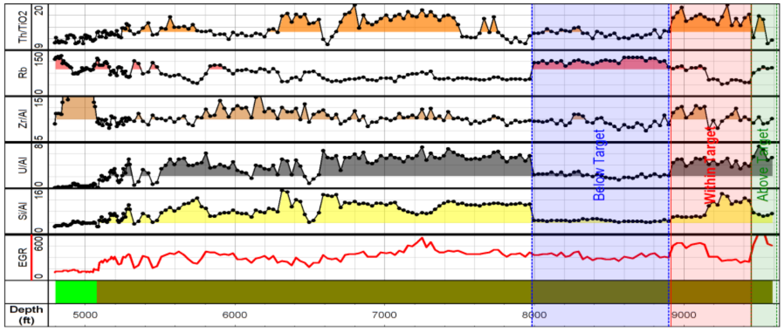
Lateral Well Chemostratigraphy



Elemental Geomonitoring Of The Lateral

Elemental signature of the target and the bounding beds.





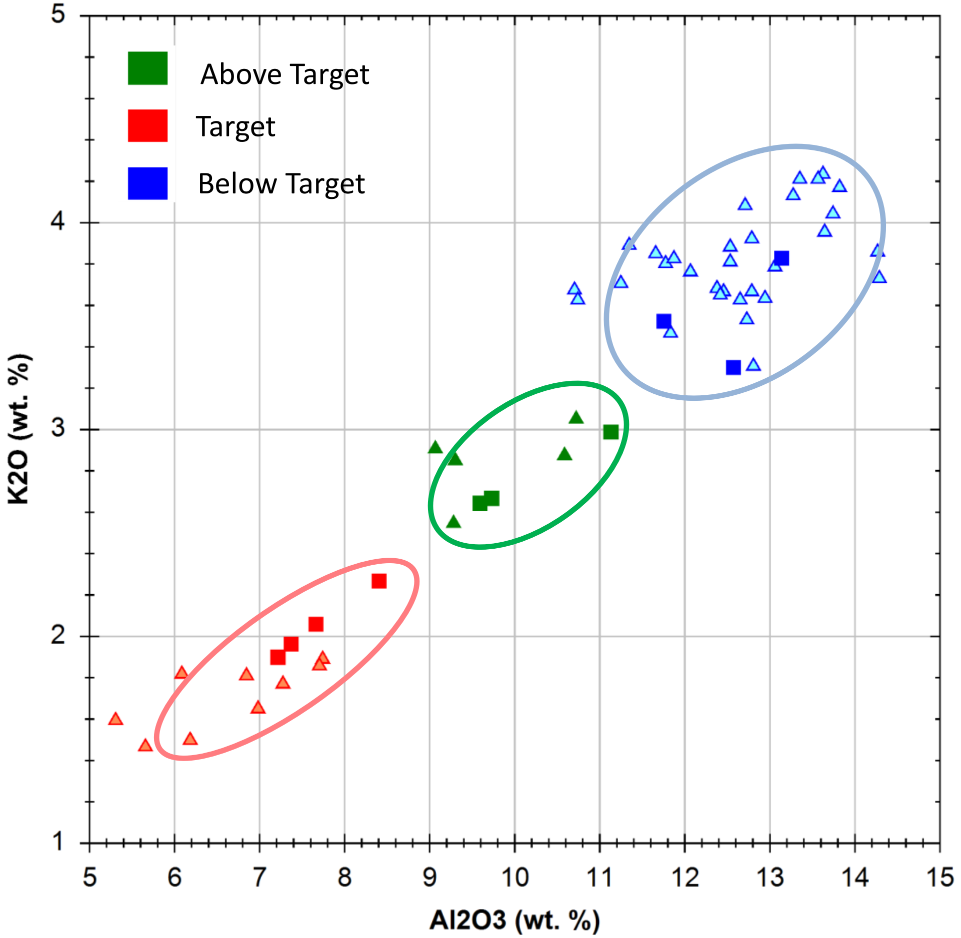
Wellbore below the Target Interval.

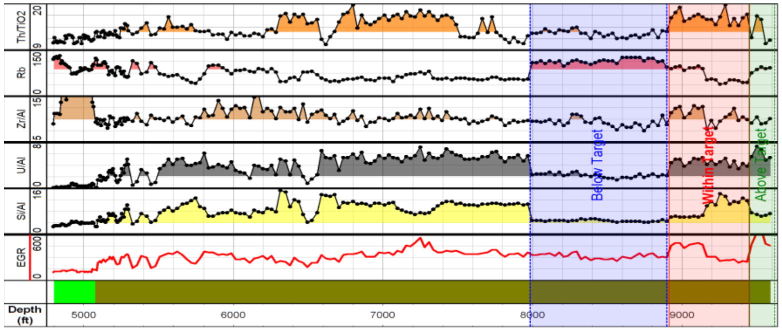
Wellbore within the Target Interval.

Wellbore above the Target Interval.

Elemental Geomonitoring Of The Lateral

Elemental signature of the target and the bounding beds.





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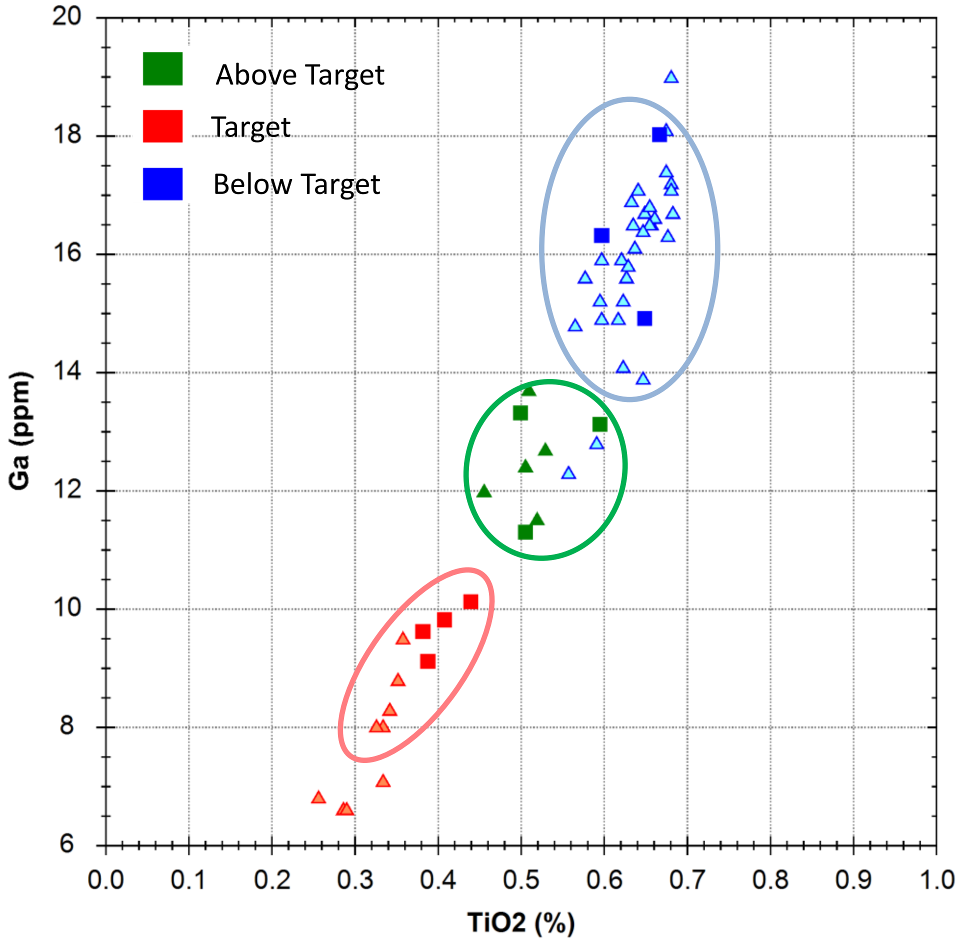

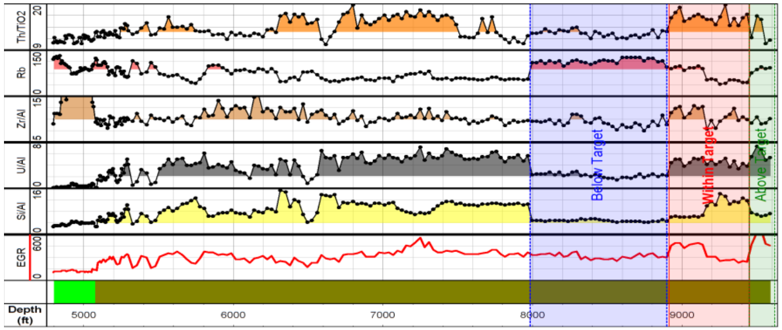

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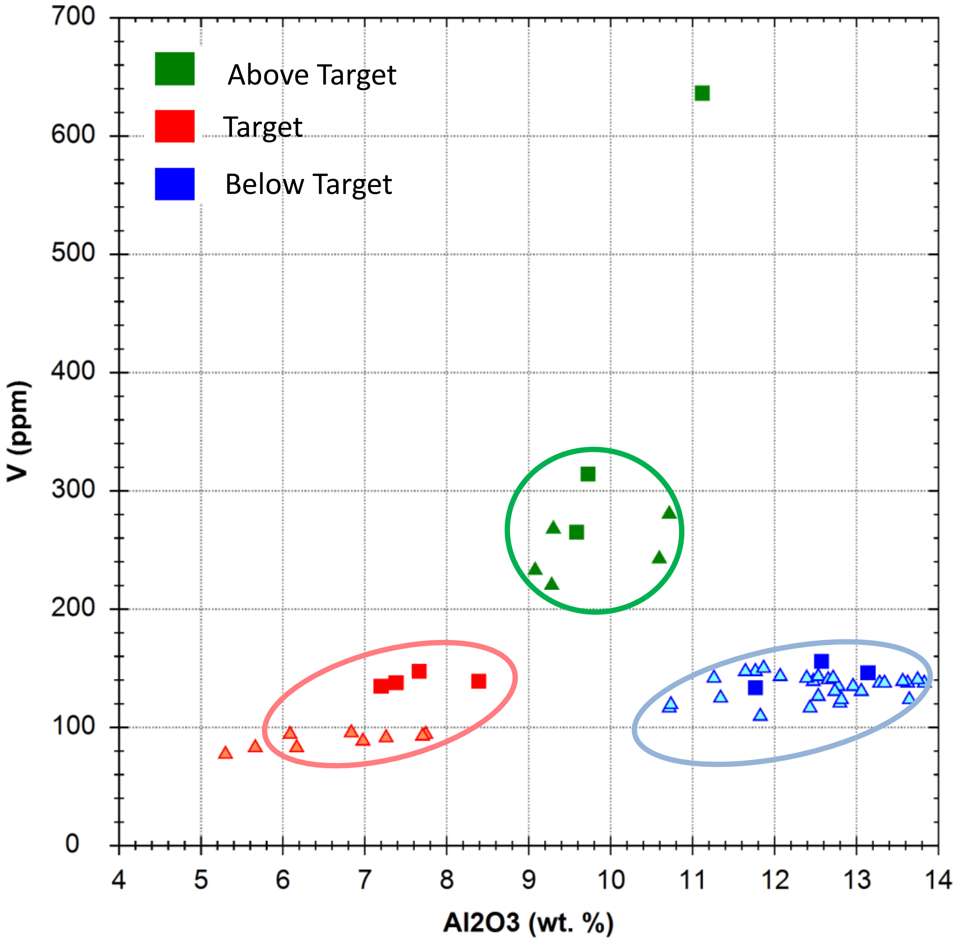
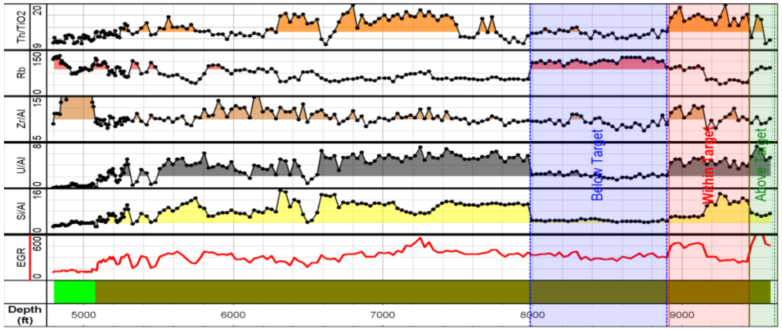




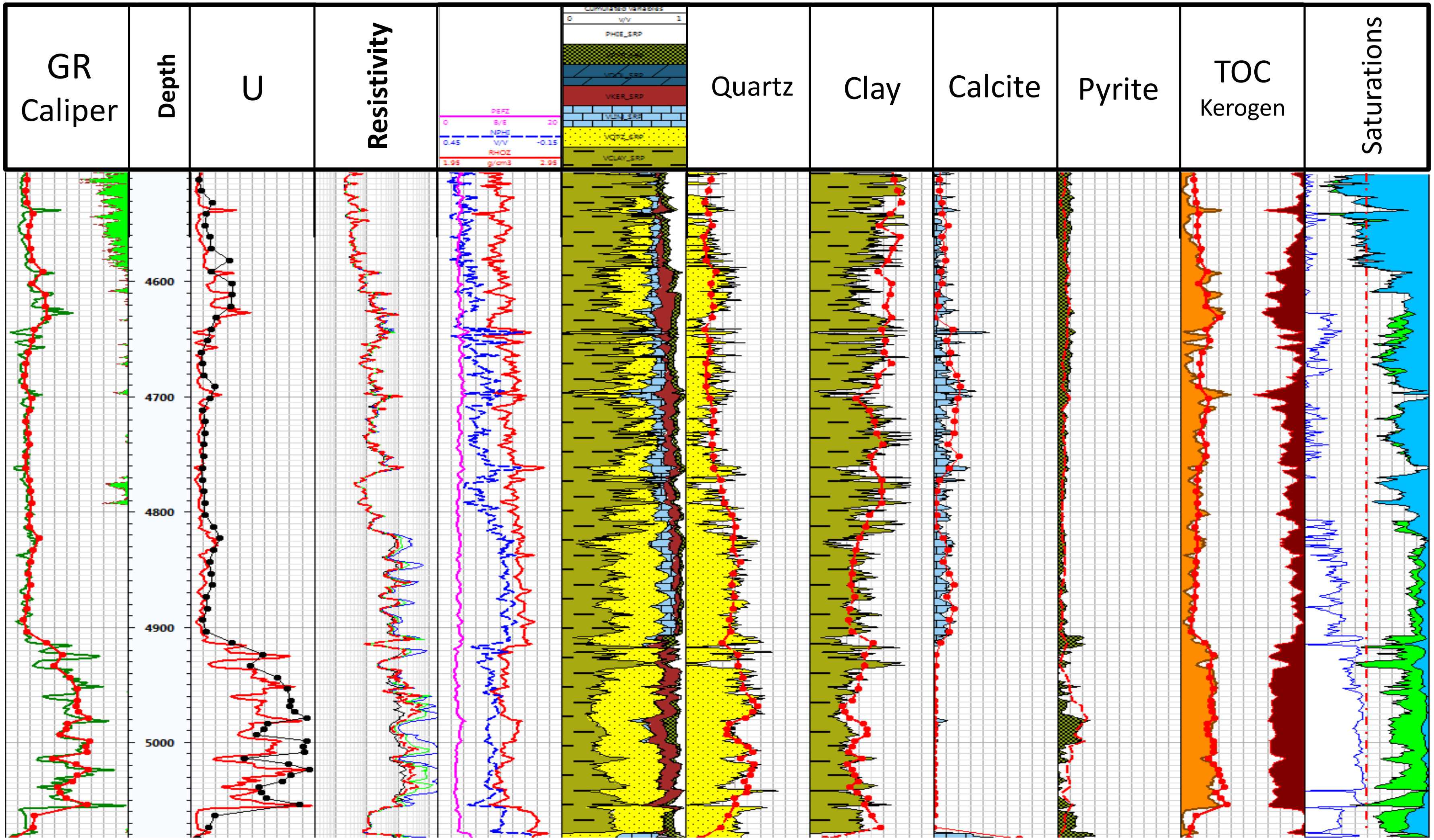
Wellbore below the Target Interval.

Wellbore within the Target Interval.

Wellbore above the Target Interval.

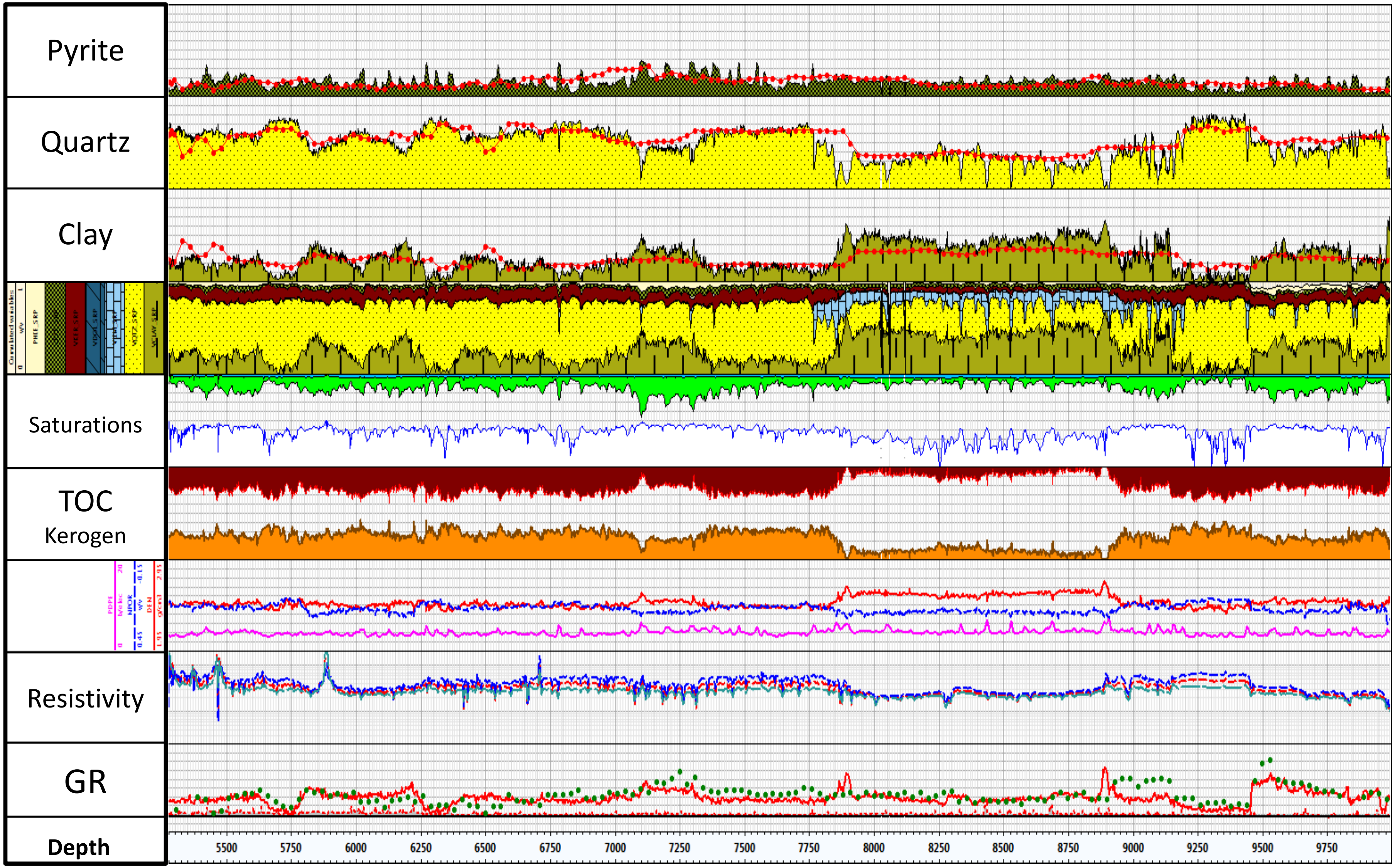
Post-Well Integration

Integration with Open hole logs in the Vertical



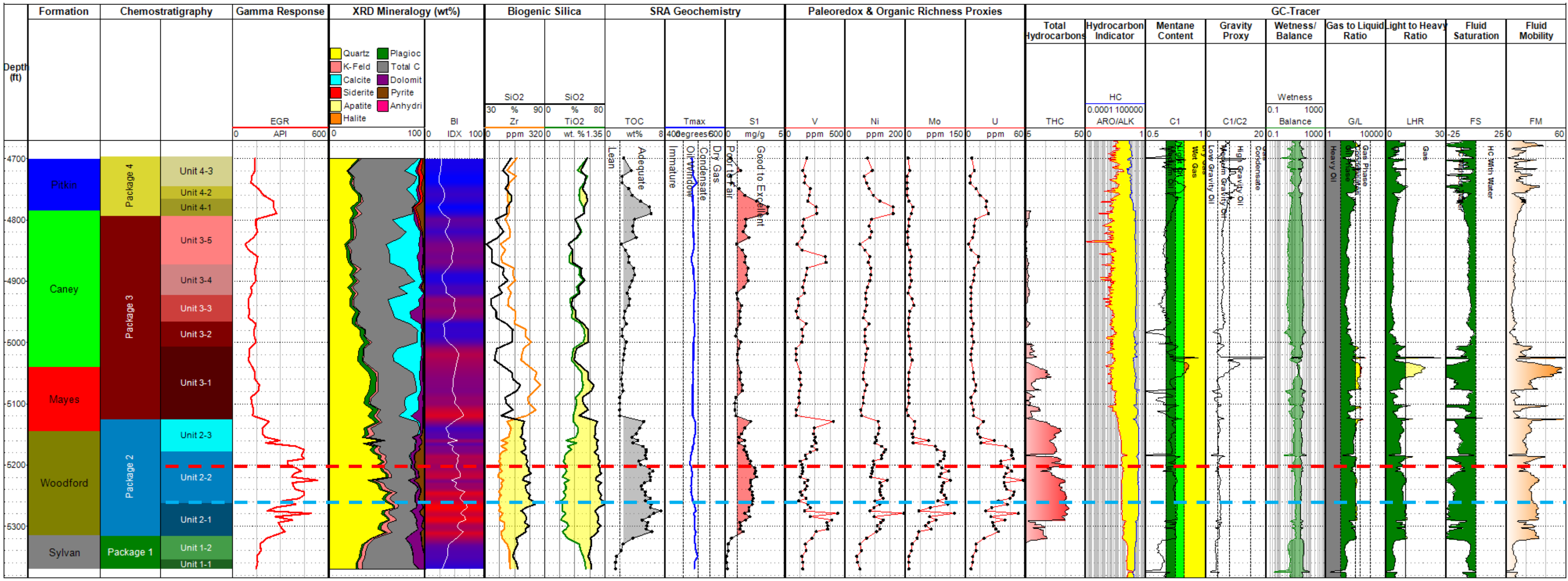
Post-Well Integration

Integration with Open hole logs in the Lateral



FE Solution For Future Drilling

- Identical Geochemical signature observed in nearby well.



We knew what to look for in the next well !

Acknowledgements

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TPX

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Questions ?