Baker Hughes Volatiles Analysis Services (VAS)

Supplied Through Advanced Hydrocarbon Stratigraphy (AHS)

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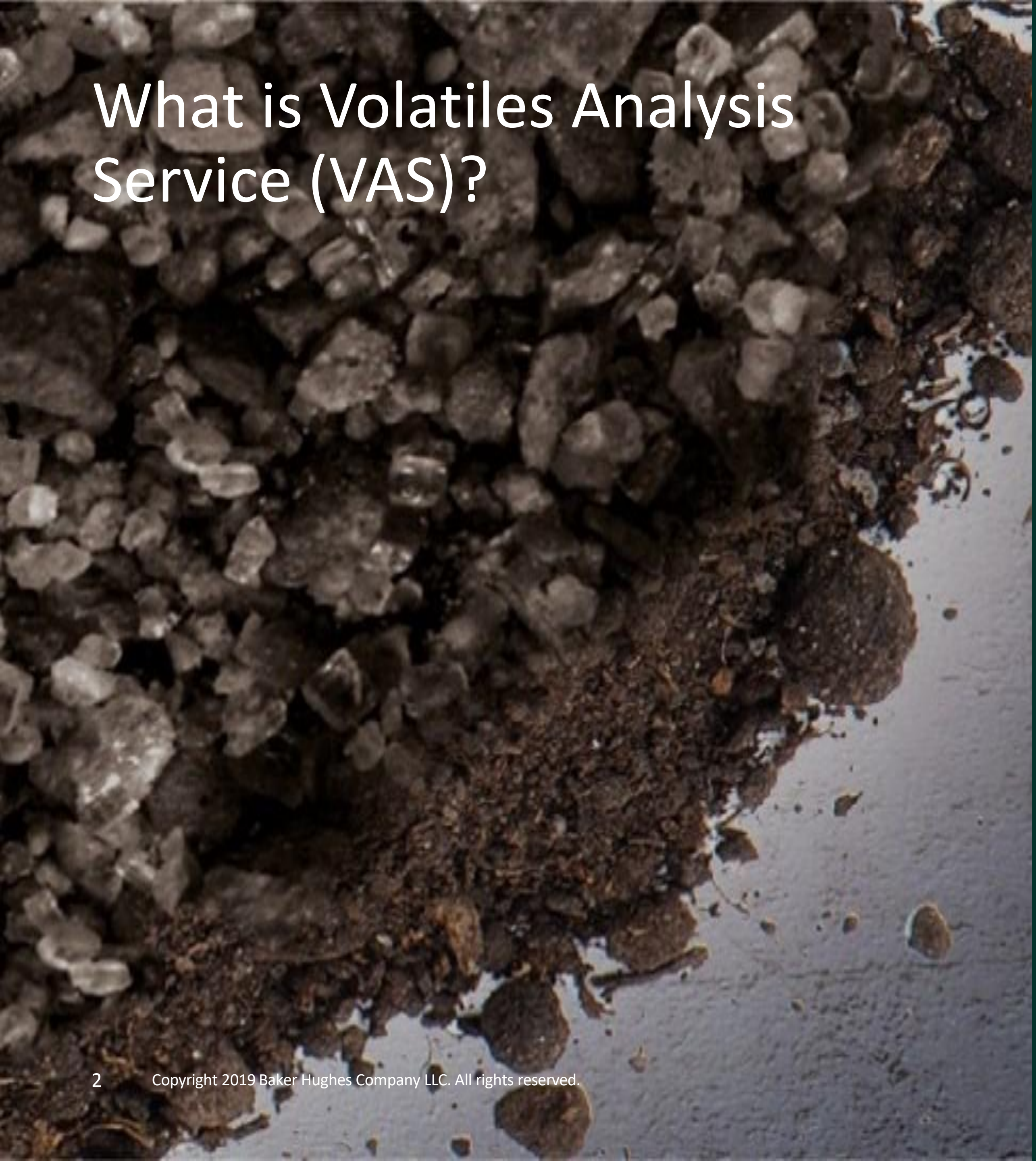
What is Volatiles Analysis Service (VAS)?



A partnership between Baker Hughes and Advanced Hydrocarbon Stratigraphy (AHS) that delivers a service providing insightful petroleum system-related measurements from drill cuttings or core

Measurements enable operators to characterize the reservoir around laterals, identify landing zones or pay proximity, interpret geological or migration occurrences (i.e. faults/fractures, oil migration) and provide estimations on ultimate recovery per well (EUR).

Samples are recovered from the well and sent to laboratories in Tulsa or Houston for the service. Sample preparation and interpretation can be done in as little as 24 hours depending on clients need and urgency.

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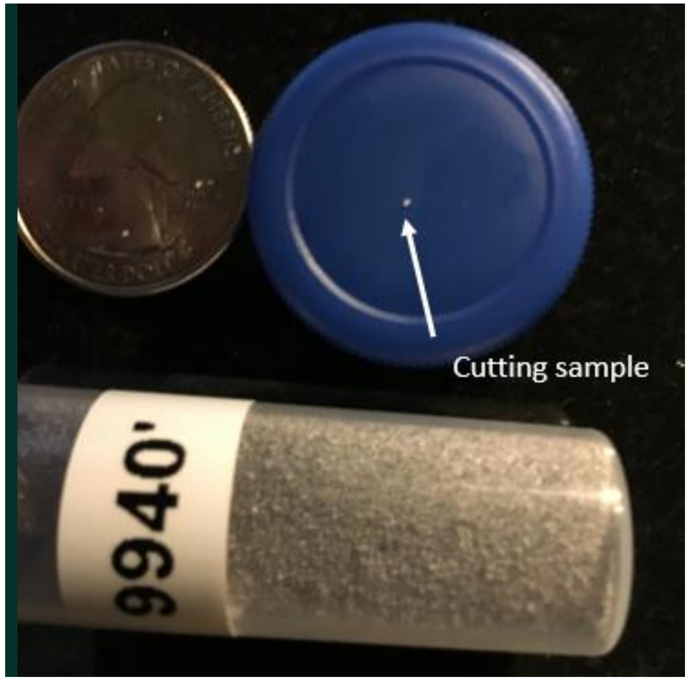
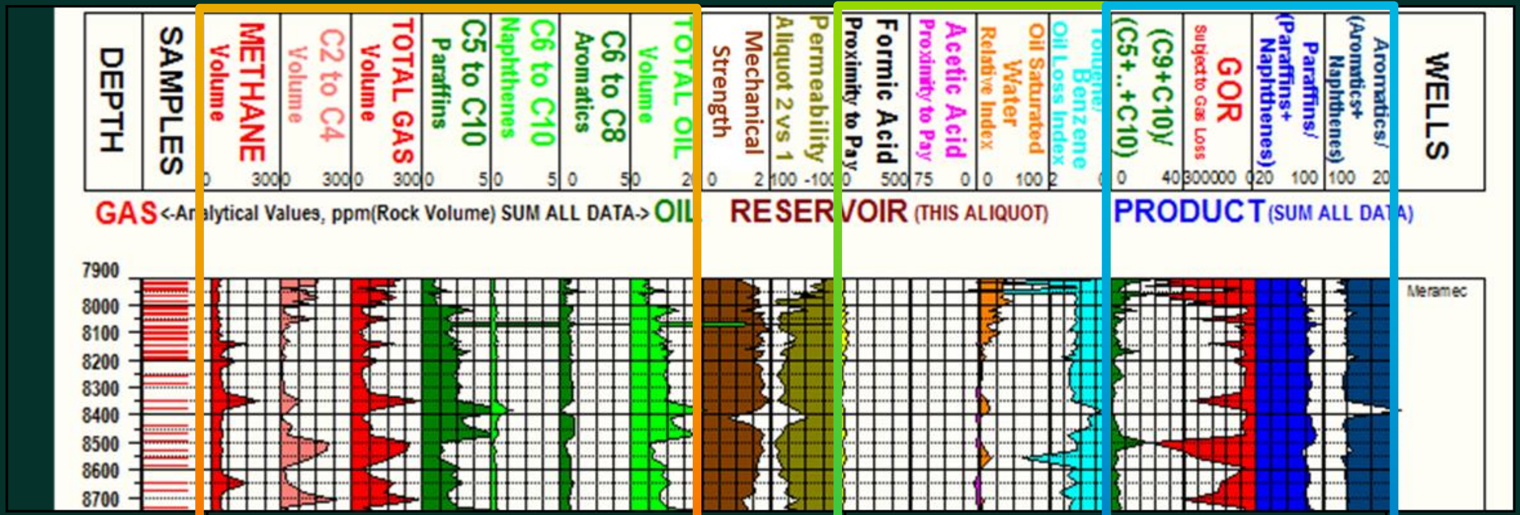
What can a Sample Tell You?



- PDC cuttings, sub-millimeter in size
- Gently caught
- Washed and dried then loaded or
- Sealed at well immediately after gently caught, and washed. Usually sealed less than a minute after the cuttings are caught.
- WBM or OBM
- New wells and old wells
- Rock bit cuttings, mud, SWC and whole core.



C1-C10, Total Gas/Oil	Frac & Perm	Prospect Evaluation	HC Analysis
HC Detection, Reservoir Quality, Oil Migration, Oil-Water and Oil-Gas Contacts ID: faults, fractures, rock types, etc.	VAS Exclusive	Sw, Proximity to Pay, Organic Acids, Oil Migration	Pay Zone Mapping, product quality

EUR from sealed at well samples in tight rocks

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Examples of Work Done with Sealed at Well Cuttings

These are cuttings that are collected directly from the flowline, quickly rinsed with water, and hermetically sealed. This sample type allows for evaluating the hydrocarbons in place, especially in the tight rocks that characterize unconventional plays.

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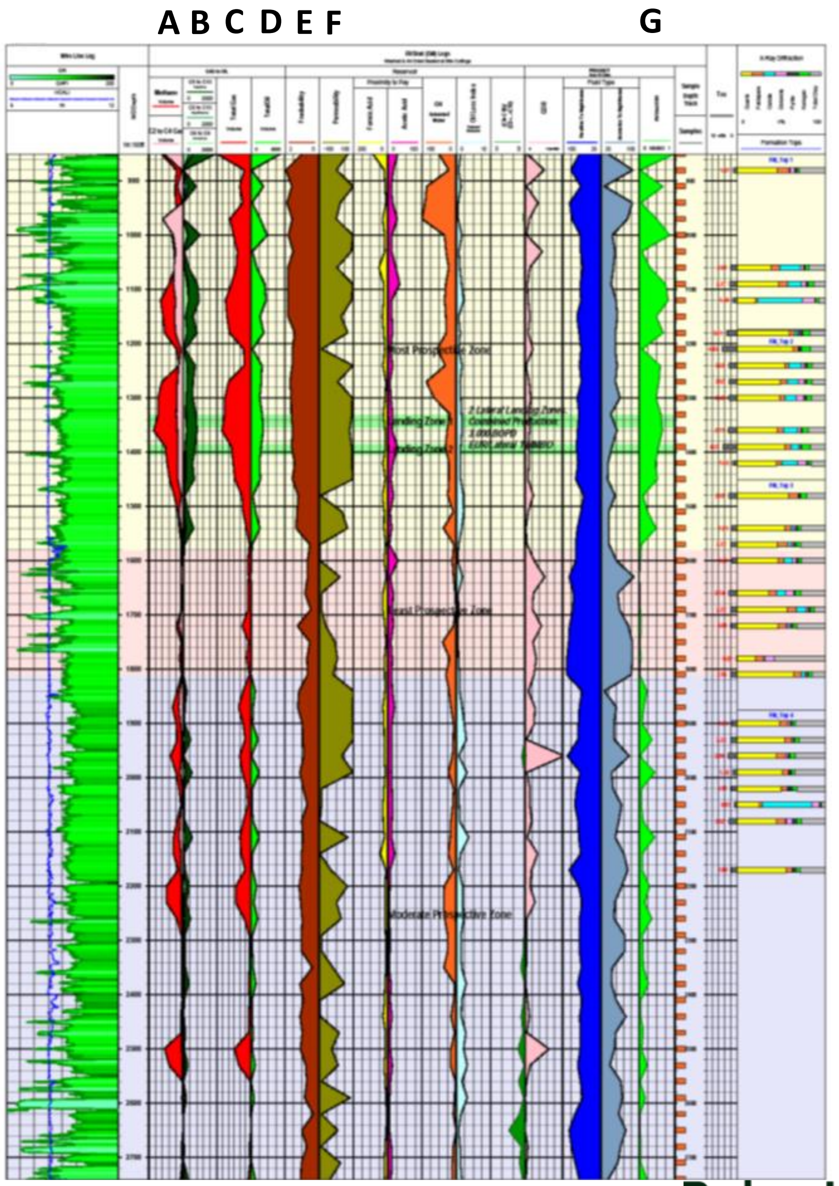
Landing Laterals: Midland Basin (TX)

Landing Zone Recommendation and EUR Prediction

- This is work from a pilot well that was drilled in the Midland basin using sealed at well samples
- Because samples were sealed at well and were tight rocks AHS was able to predict the EUR at different depths
- AHS delivered data before well was logged and cased and picked the landing zones for two laterals
- Provided direct insight into the hydrocarbon content of the three zones examined and recommended landing laterals in the shallow yellow zone, green demarks landing positions
- Lateral locations were recommended based on hydrocarbon content (**A**, **B**, **C**, and **D**, red tracks are gas and green tracks are liquids), rock properties (**E**, mechanical strength and **F**, permeability index), and predicted EUR (**G**).

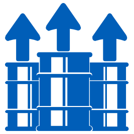


Delivered Value for Client

- Operational recommendations within client's time constraints:
  - Pay zones identification
  - Landing zones identification
  - Completion recommendations

- Data integration with petrophysics

2 laterals landed in best VAS zone. AHS predicted an EUR of 800 MBbls per lateral. Well came in with combined production of 3000 bbls/day, each lateral's production based EUR is 1 MMBbls



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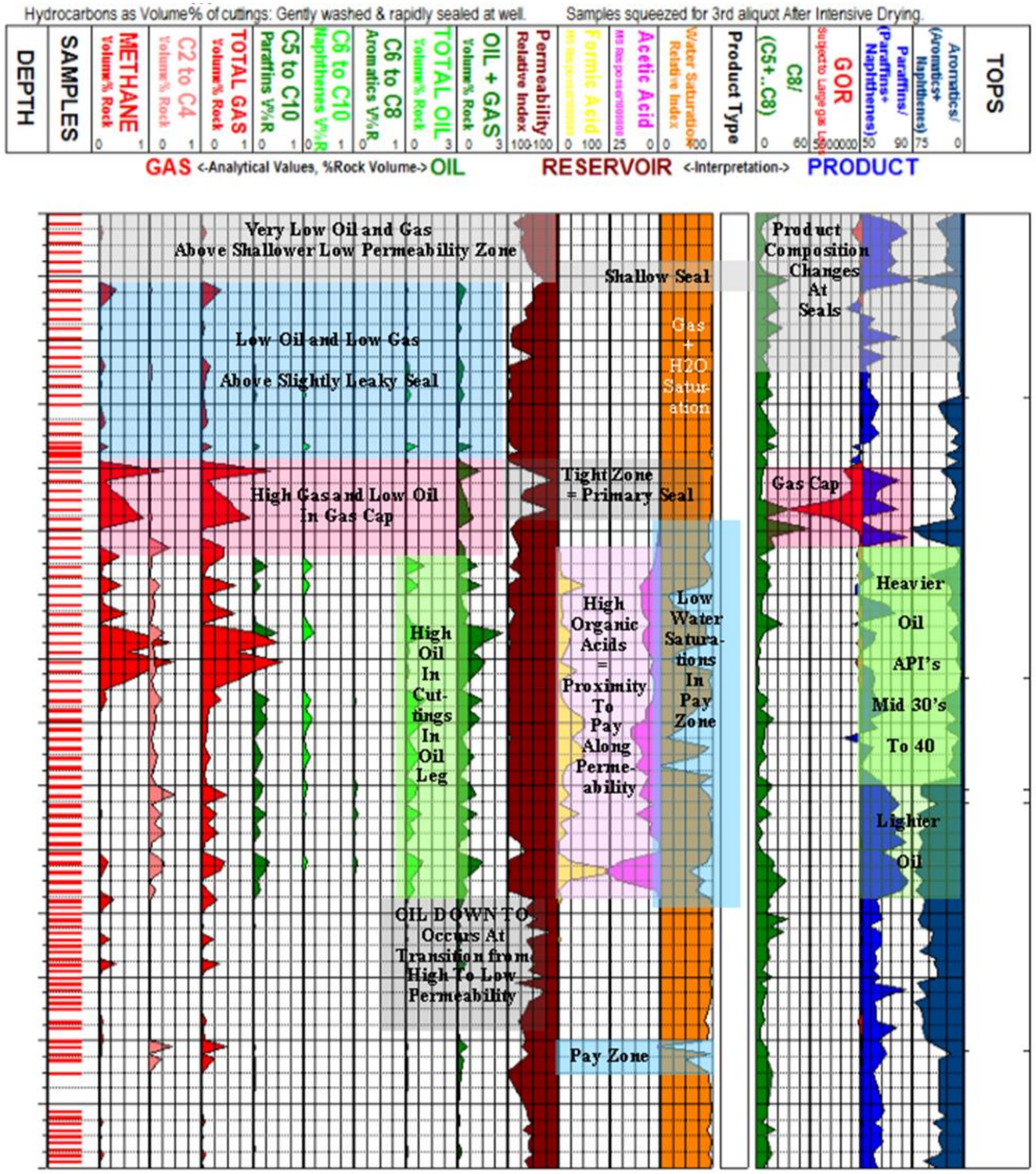
Bypassed Pay Recognition: Delaware Basin (NM)

Bypassed Pay Identification

- Using sealed at well samples two bypassed pay zones were identified

- Largest bypassed pay zone identified actually contained two oils, one that generated in place and one that had migrated

- In addition to identifying pay, seals, seal quality, gas cap, and oil quality were identified/assessed



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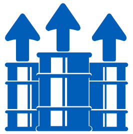
Delivered Value for Client

- Operational recommendations within client’s time constraints:
  - Missed pay identification
  - Proximity to pay indicators
  - Completion recommendations

- Data integration with petrophysics

Identified 600ft of shallow hydrocarbon zone (2 different oils) , client had targeted deeper unconventional reservoir and went back after VAS analysis to perforate shallower section.



Evaluating HC Content and Structure in Structurally Complex Gas Well: Appalachian Basin (PA)

Customer Challenge

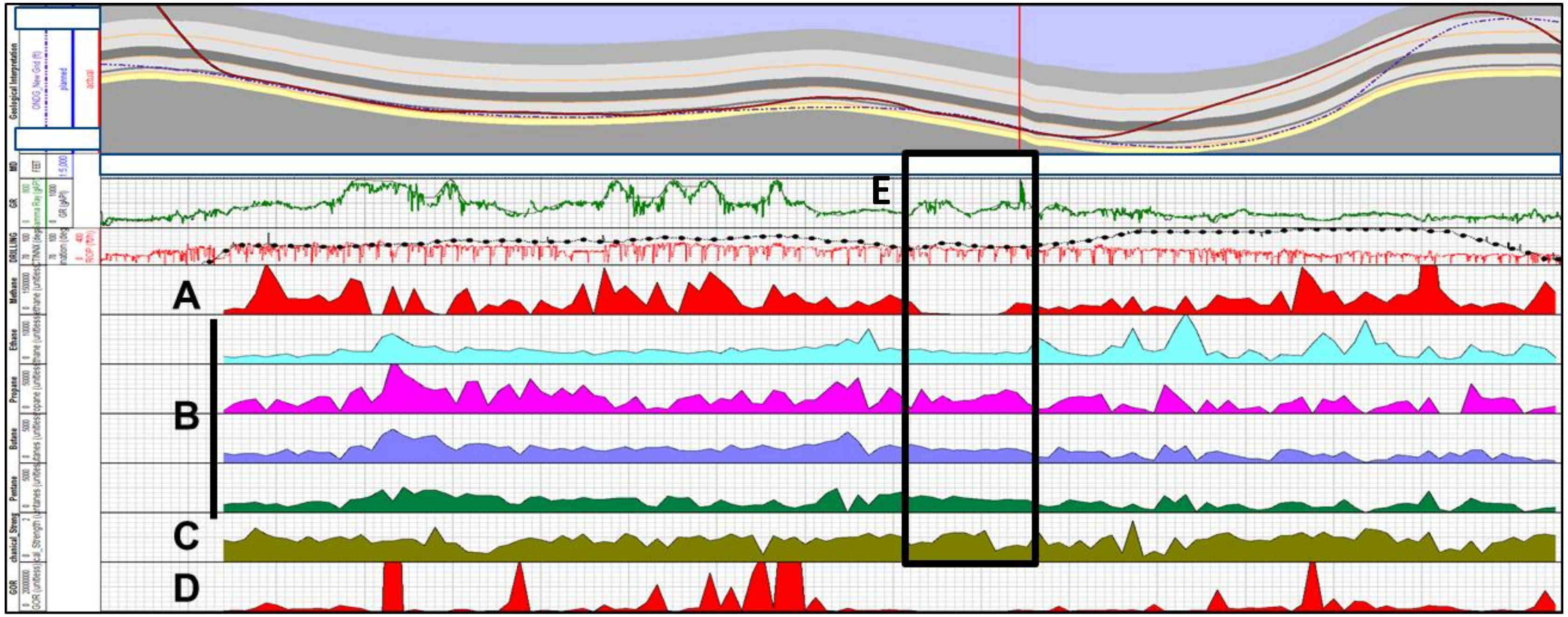
- Customer is seeking to gain an understanding of hydrocarbon composition and structural features in a structurally complex portion of their acreage
- Seeking to identify structural features such as fractures that may impact the completion and performance of the well

Solution

- Customer utilized VAS on sealed at well cuttings to evaluate the gas composition across the length of the lateral
- Chemical signatures in the VAS data can be used to assist or even ID structural features such as faults and fracture swarms

Key

- Bottom seven tracks come from VAS analysis. In descending order: Methane, Ethane, Propane, Butanes, Pentanes (all in units of nanoMoles), mechanical strength (unitless), and GOR



Outcomes and Value Delivery

- Mapped HC composition across length of lateral
- The similar trends in C2-C5 hydrocarbons (ethane, propane, butanes, and pentanes) distributions and the dissimilarity to the distribution of methane suggests that the pore throat size is ≤ ethane providing key insights into petrophysics and possible production (**A**+**B**)
- Disproportionally high GOR responses, showing gas composition similar to what is produced by offset wells, are possible fracture indicators and can be used to map probable fracture swarms (**A**+**B**+**D**)
- Weak mechanical strength and a loss of methane several hundred feet before a possible fault offers further evidence of the fault; fault appears to be a conductive pathway out for the methane, but other molecules are too large to escape the rock (**A**+**B**+**C**+**E**)

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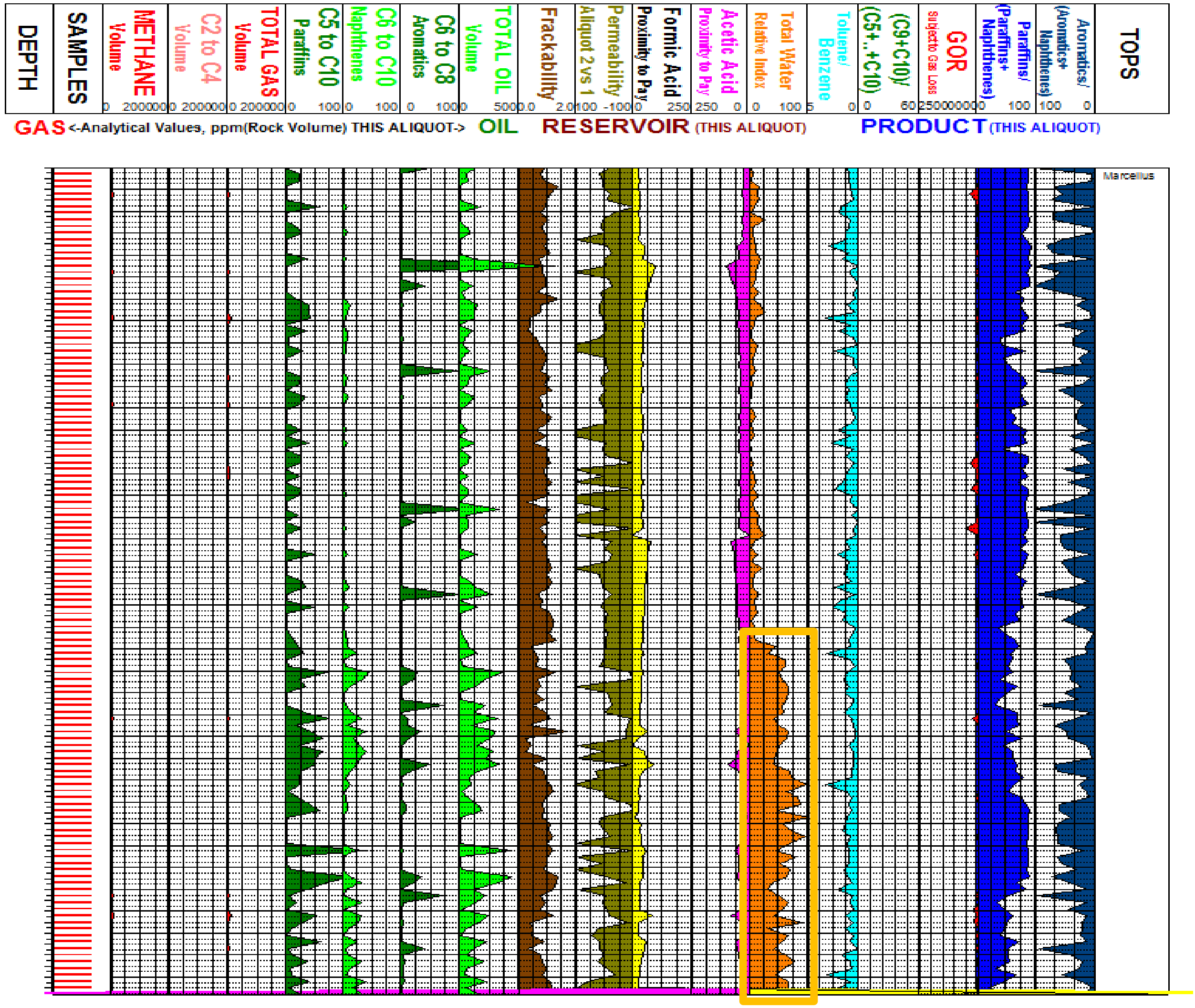
Evaluating HC Content and Structure in Structurally Complex Gas Well: Marcellus (PA)

Toe side of fault also has increased water content



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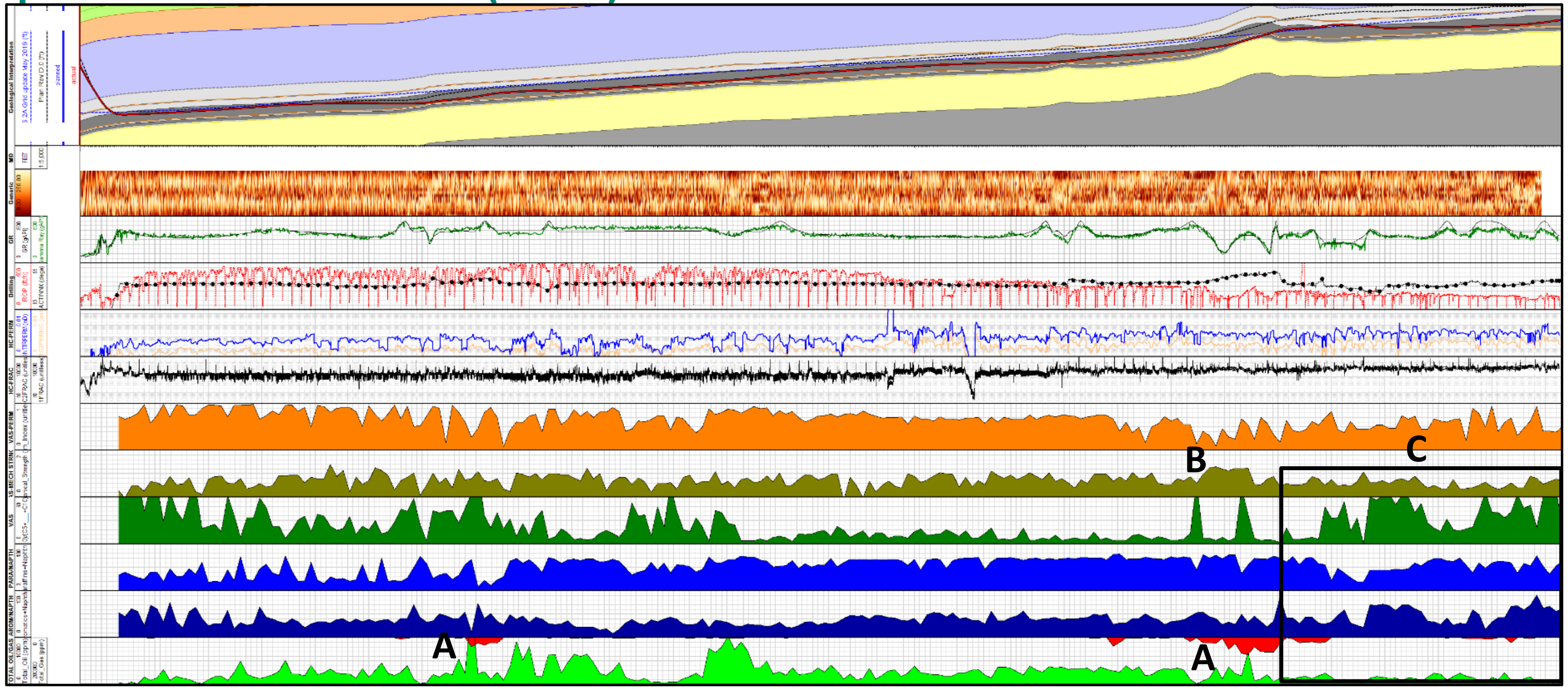
Evaluating HC Content and Structure in Structurally Simple Wet Gas/Condensate Well: Appalachian Basin (WV)



Customer Challenge

- Customer is seeking to gain an understanding of hydrocarbon composition and structural features in a structurally simple portion of their acreage
- Seeking to identify structural features such as fractures that may impact the completion and performance of the well

Solution

- Customer utilized VAS on sealed at well cuttings to evaluate the HC composition across the length of the lateral
- Chemical signatures in the VAS data can be used to assist or even ID structural features such as faults and fracture swarms
- VAS identifies HC composition changes that occur at different stratigraphic positions

Key

- Bottom six tracks come from VAS analysis. In descending order: Permeability Index (unitless), mechanical strength, C9+C10/(C5+…+C10), Paraffins/Paraffins+Naphthenes, Aromatics/Aromatics+Napthenes (%), and gas volume (red) and liquids volume (green) in ppm

Outcomes and Value Delivery

- Mapped HC composition across length of lateral
- Gas zones are observed when borehole crosses close to or through the underlying limestone (**A**); rock here is tight to gas, elsewhere the rock is highly permeable to C1-3 HCs which have left the rock during transport
- Region where borehole crosses the limestone has the highest mechanical strength in the well; stage placed there will likely need to be treated differently, stages should not be placed that cross the transitions of this zone (**B**)
- Different packet of chemistry in terms of the quantity and types of liquids identified along the lateral, especially pronounced in toe of well despite being in a similar stratigraphic position as earlier in the lateral (**C**)

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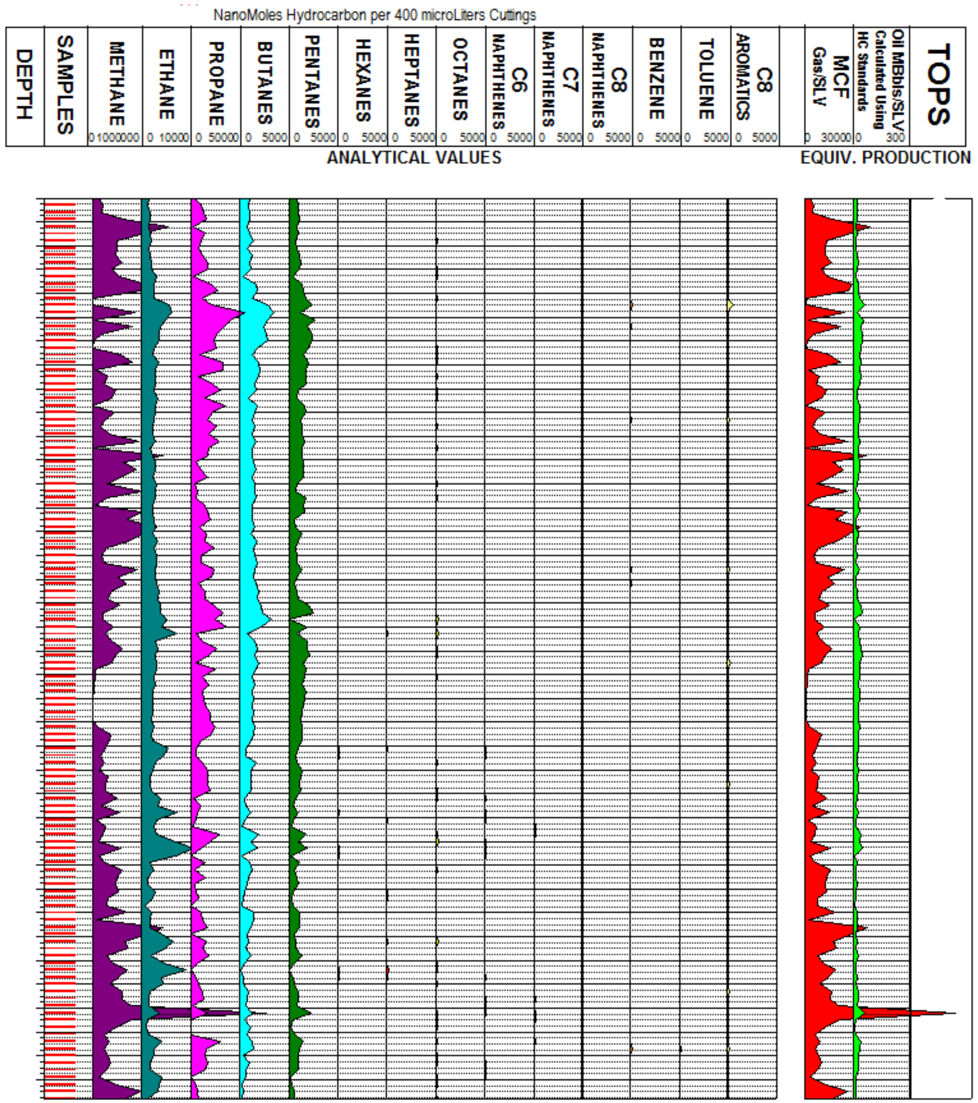
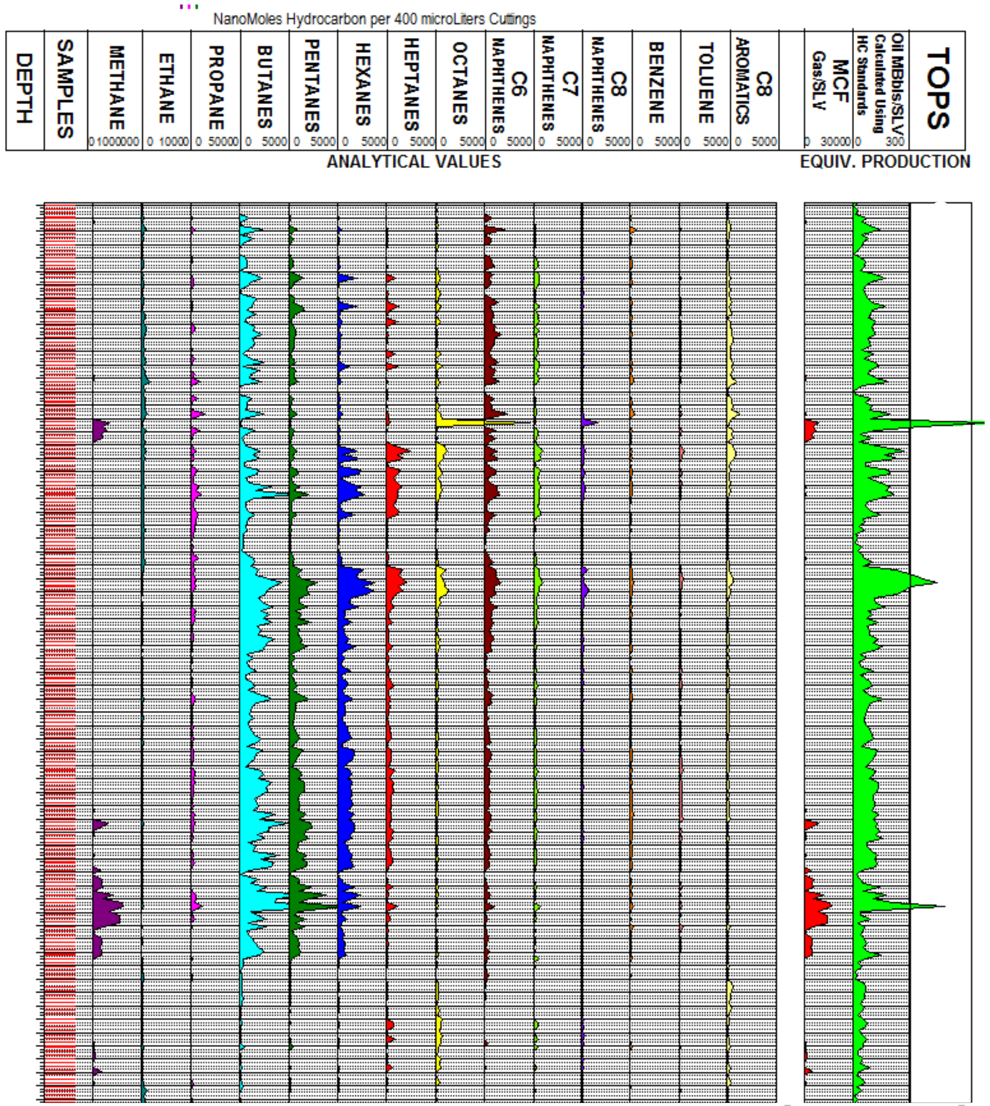
Comparison of Hydrocarbon Logs

PA Well



WV Well



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Examples of Work Done with Washed and Dried Cuttings

This sample type allows for evaluating what chemistries have been left behind after the volatiles have been gently removed at STP. Higher responses indicate tighter rocks; lower responses indicate rocks with better reservoir quality. Other signatures that inform on oil quality, oil migration, oil-water contacts, etc. remain. This sample type is used for our Sw measurement. All legacy materials are treated as this sample type.

Acreage Assessment, Well Design, and Completion Design: STACK (OK)

Faults as HC Migration Paths and Well Placement

- VAS identified chemistries of interest relevant both to the completion of individuals wells and assessment of the petroleum system, specifically the role of faults, for a client on their acreage using washed and dried samples.

- The assessment of the petroleum system and, the faults specifically, from multiple legacy wells, allowed for suggesting optimized well placement, lateral trajectory, and completion of new wells in the client's acreage

- VAS was also used to identify a pay zone signature that correlated directly to EUR from production allowing for the mapping of "Predicted Preferred Reservoir Zones"

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Fault Feeds Oil Into Reservoir

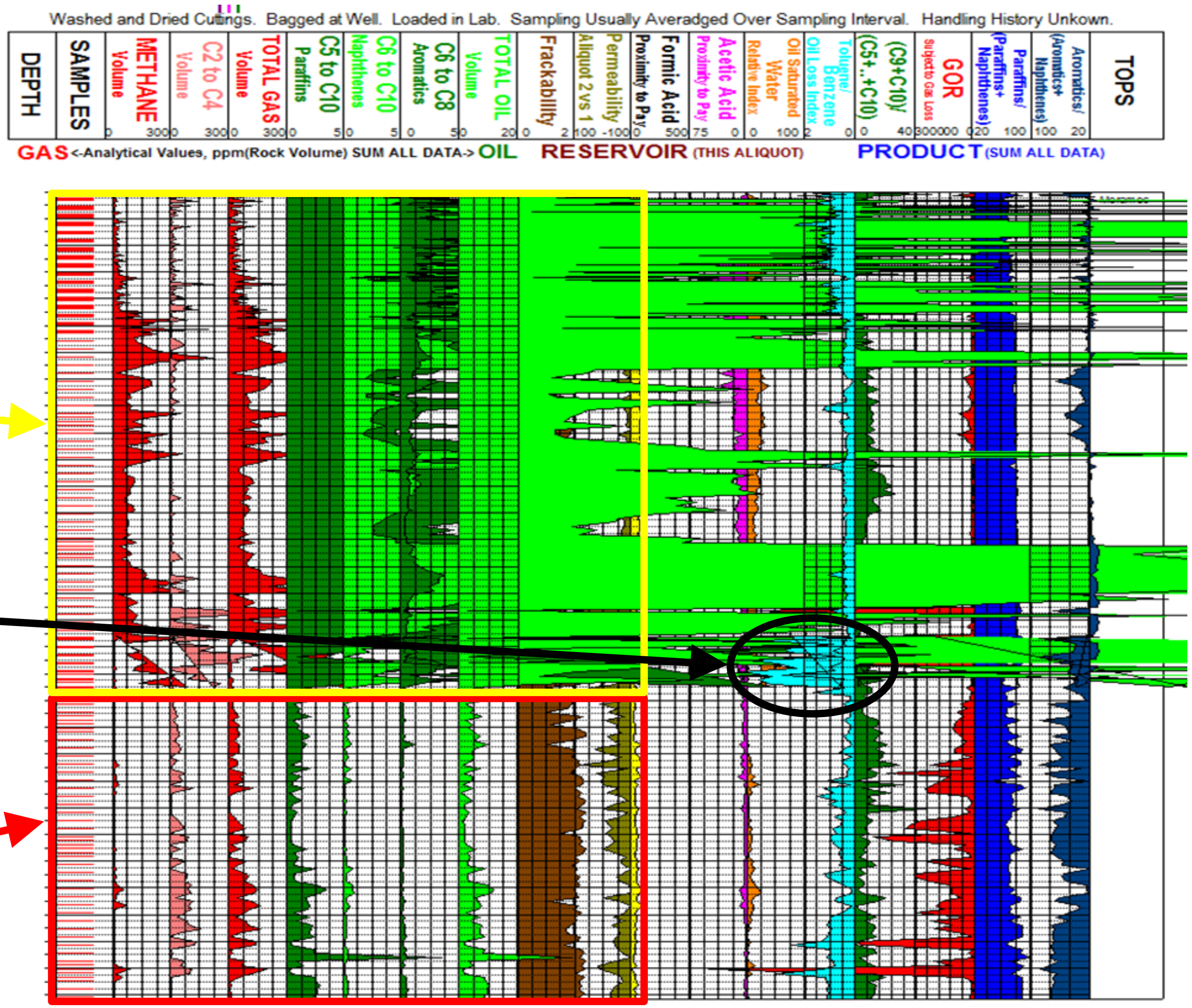
Lateral is drilled through a fault. Fault is migrating oil and charging the upper fault block in the toe of the well. Brines migrating along fault invade the lower fault block in the heel and causing cementation.

Tighter Rocks Retain Oil and Gas from Cuttings Through Drilling and Transport to the Surface

High Toluene/Benzene Ratio at Fault = Zone of Active Oil Migration

Predicted Preferred Reservoir Zones

High Porosity High Permeability Rocks Can Lose Oil During Drilling , Transport, and Sample Prep



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Faults Feed Reservoirs and Create Porosity

Not all faults in the STACK present the same way and have the same effects. Signatures like acetic acid allow evaluation of what formation(s) that fault is communicating with.

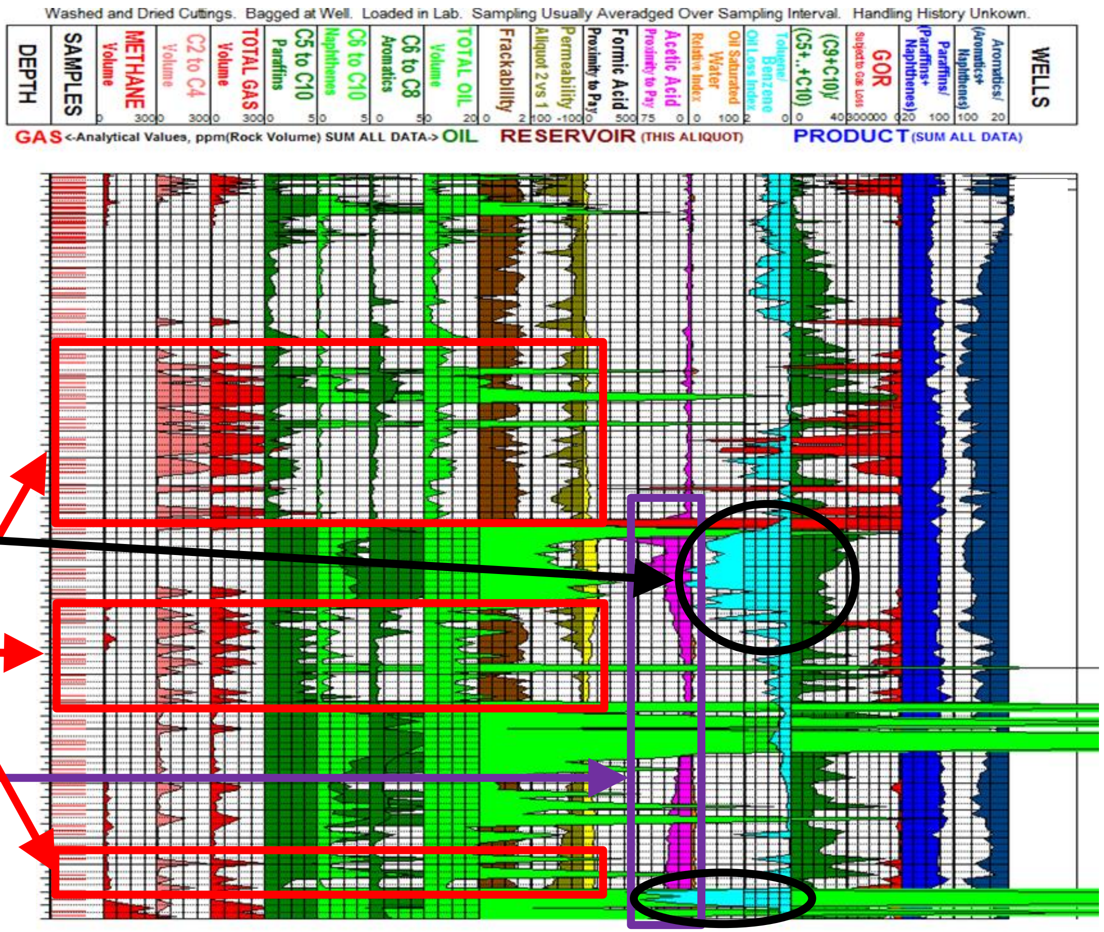
Lateral Drilled through a Fault

High Toluene/Benzene =
Oil Migration along Fault

AHS Predicted Preferred Reservoir Zones Surrounding Fault

High Acetic Acid Toe Side of Fault

Small Fault Feeding Small Reservoir



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Reservoirs May be Filled by Nearby Fault

After using legacy cuttings to map oil migrating faults, charged upper fault blocks, and offsets, client began drilling laterals parallel to identified oil migrating faults in charged upper fault block

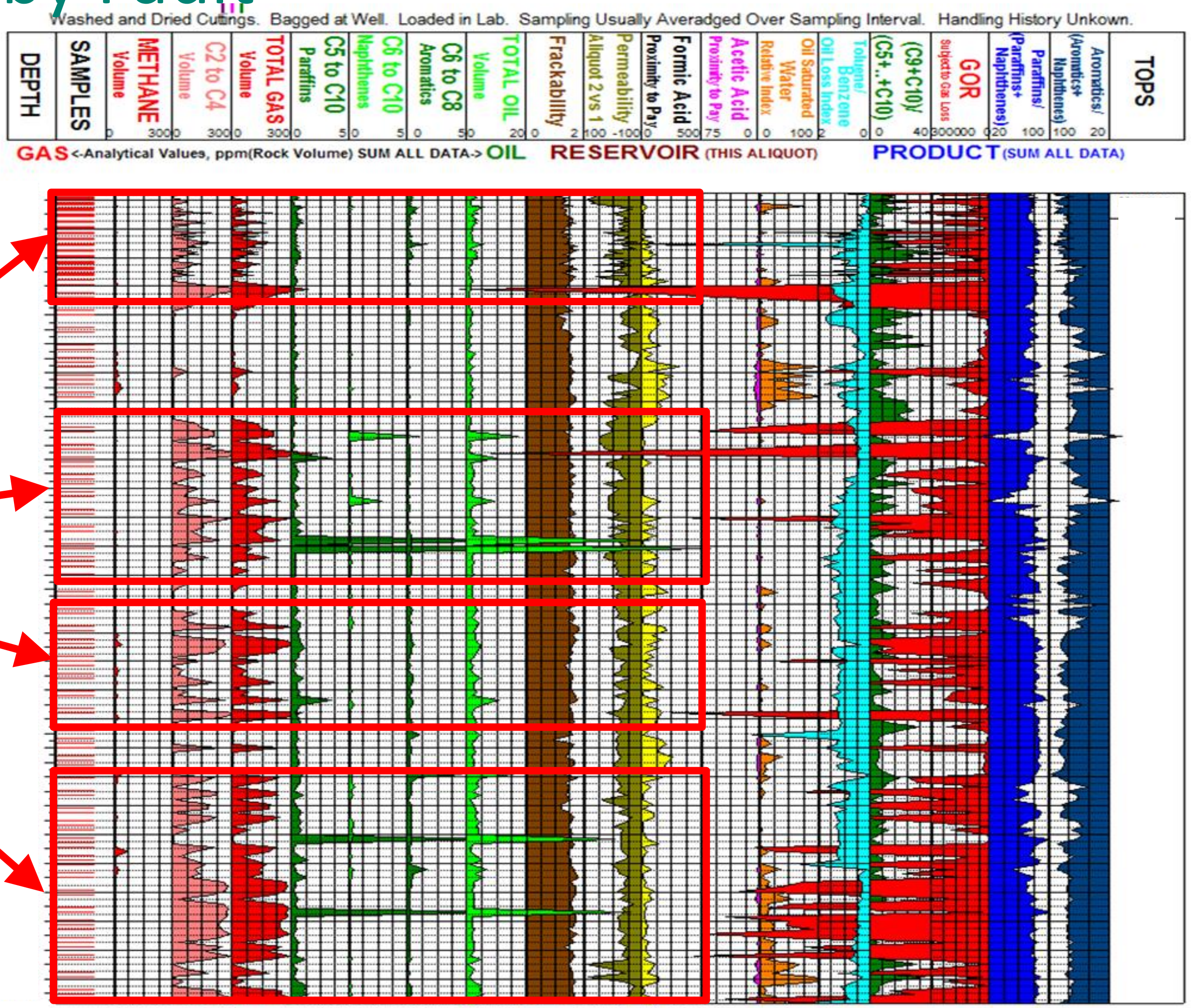
High Performing Well

Lateral Drilled Along N-S Fault

Predicted
Preferred Reservoir Zones

Nearby Parallel Fault
May be Filling Reservoirs the
Entire Length of Lateral

High Porosity High Permeability Rocks Can Lose Oil
During Drilling, Transport, and Sample Prep



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Delivered Value for Client

VAS is the only tool used by low-cost operators e.g. in the STACK that provides significant insights into the fluid chemistry of the well

- Operational recommendations within Ops time constraints:
  - Pay zone identification
  - Proximity to pay indicators
  - Completion recommendations

- Acreage and Basin Assessment:
  - Petroleum system evaluation and reporting
  - Acreage high-grading
  - Well placement Recommendations

- Sweet spot identification

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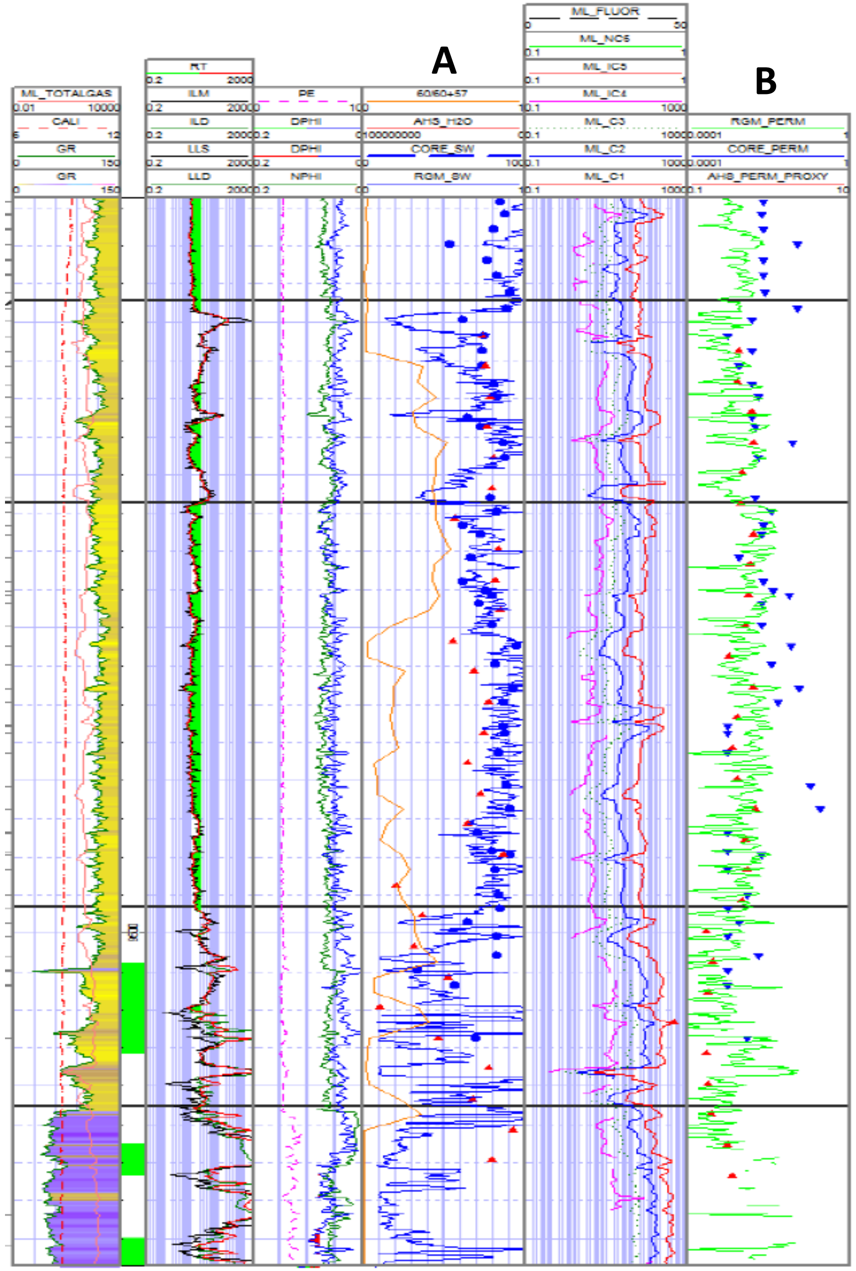
VAS – Permeability and Water Saturation (Delaware Basin, NM)

VAS extracts volatiles gently at two different vacuum pressures (aliquots), 2 and 20 mbar, allowing for meaningful relative index measurements of Sw (water measured at 2 mbar) and permeability (ratio of response at different pressures) from cuttings

- Technology competition involving major operator in the Permian
- Lateral landed off this vertical pilot failed to produce meaningful quantities of HCs, landed in the water leg
- Operator paid ~750K to assess well as a postmortem (Sidewall core, wireline logs, and petrophysical work up)
- AHS won technology competition, assessed well (with 30 legacy samples) for two orders of magnitude less cost, correctly evaluated Sw and permeability from cuttings



Key: **A**) Sw track, blue continuous line is from logs, blue dots are from sidewall core, red dots are from VAS. **B**) permeability track, green continuous line is from logs, blue dots are from side wall core, red dots are from VAS

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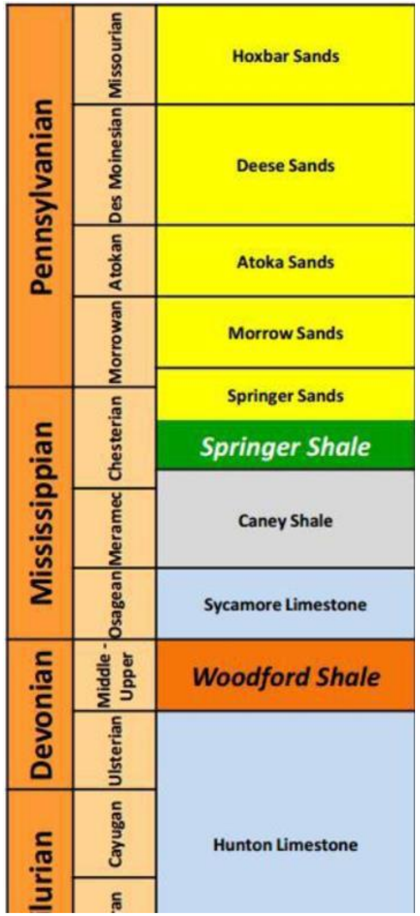
Evaluating an Under Preforming Hoxbar Lateral (SCOOP): Atkinson 1-21H

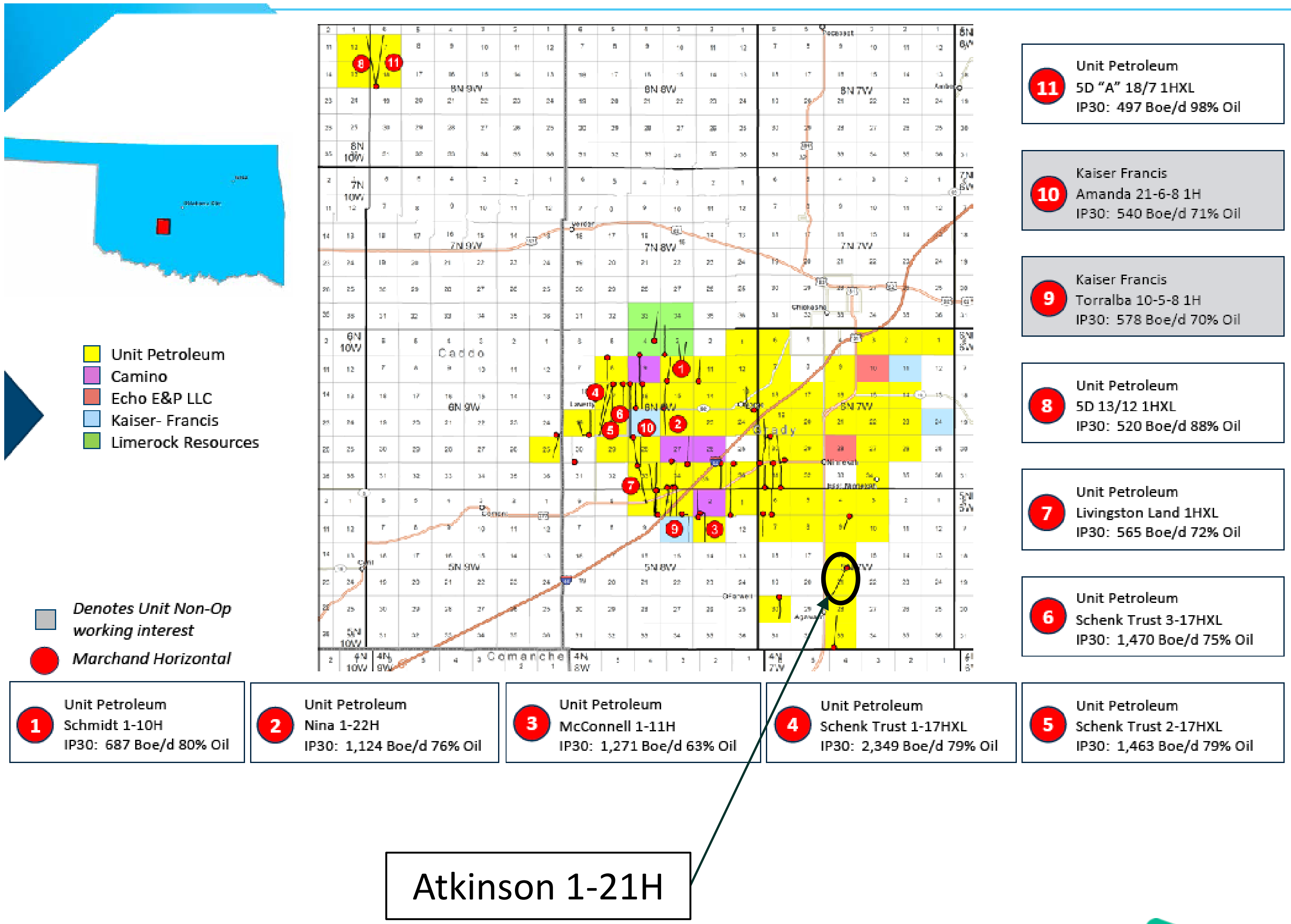
The Hoxbar Sands are a tight sandstone target present in the Anadarko Basin in OK (SCOOP).

They are charged by the Woodford Shale.

Major Hoxbar operator, Unit Petroleum, drilled Atkinson 1-21H, which under performed compared to offset laterals.

Legacy cuttings were acquired from the OK Geo. Survey and submitted to VAS.





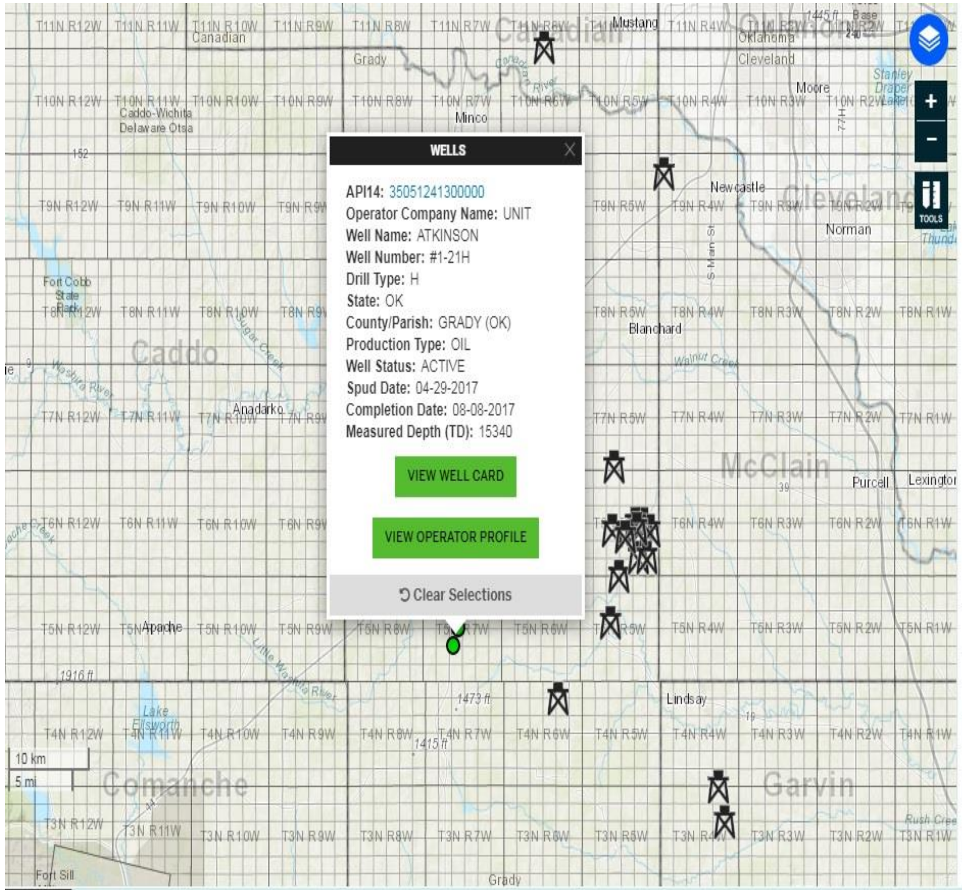
Seyedolali, A. (Oklahoma Geological Survey) "The Hoxbar Project", 2019
Unit Petroleum, "SOHOT-Low Cost, High ROR Oil Play", 2019

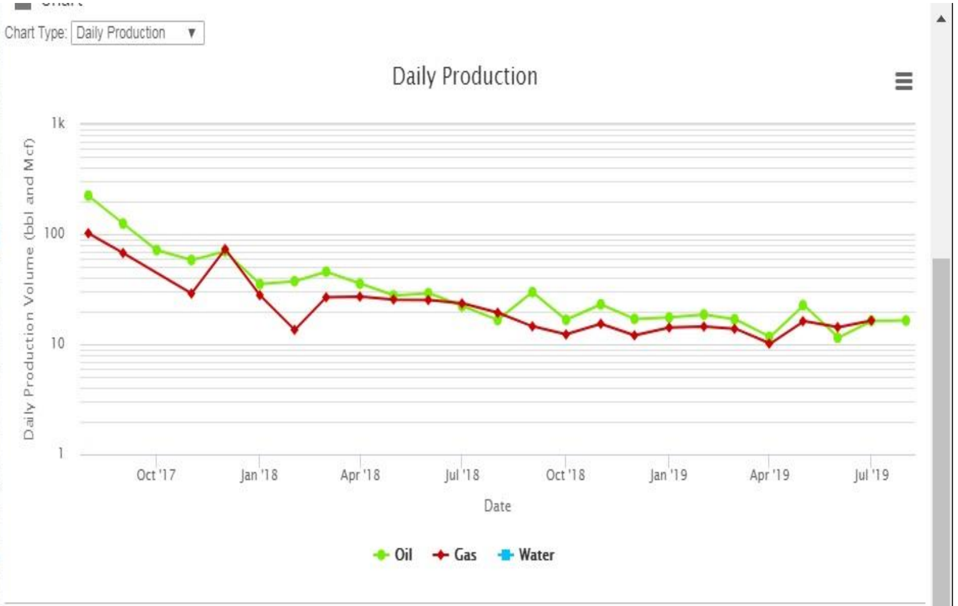
Hoxbar Atkinson 1-21H Evaluation

Production data shows offsets have an IP30 of approx. 500 to 1500+ bbl/d production.

IP30 of Atkinson 1-21H was approx. 2-6 times less than these offset wells.

Goal of study was to use legacy cuttings to evaluate why the lateral was underperforming.





Production

Date	Monthly Oil (bbl)	Monthly Gas (Mcf)	Monthly Water (bbl)	Avg Daily Oil (bbl)	Avg Daily Gas (Mcf)	Avg Daily Water (bbl)	Wells	Days
08-2017	6,921	3,151	0	223	102	0	1	
09-2017	3,740	2,022	0	125	67.4	0	1	
10-2017	2,218	0	0	71.55	0	0	1	
11-2017	1,744	866	0	58.13	28.87	0	1	
12-2017	2,156	2,265	0	69.55	73.06	0	1	
01-2018	1,090	864	0	35.16	27.87	0	1	
02-2018	1,045	378	0	37.32	13.5	0	1	

TABLE

LEASES | PRODUCTION | WELLS | PERMITS | RIGS | LANDTRAC LEASE | LANDTRAC UNIT | APPLICATIONS & ORDERS | COMPANY ACREAGE | DEALS FOR SALE | TRANSACTIONS | SHAPEFILES

Active Filters: API10 = 3505124130 | Data Filters

API14	Well Name	Well Number	Lease Name	Operator Alias (Legacy)	Operator Company Name	Operator (Reported)	Operator Ticker	Field	County/Parish	DI Basin	DI Play	DI Subplay	DI Landi	DI Lan	Target Form	Producing Re	Elevation	Elevation	Ground Elev	Measured Dept
35051241300000	ATKINSON	#1-21H	ATKINSON	UNIT PETR	UNIT	UNIT PETROLEUM C...	UNT	HARNESS NW	GRADY (OK)	ANADARKO	SCOOP				HOXBAR	HOXBAR	1296	KB	1266	15340

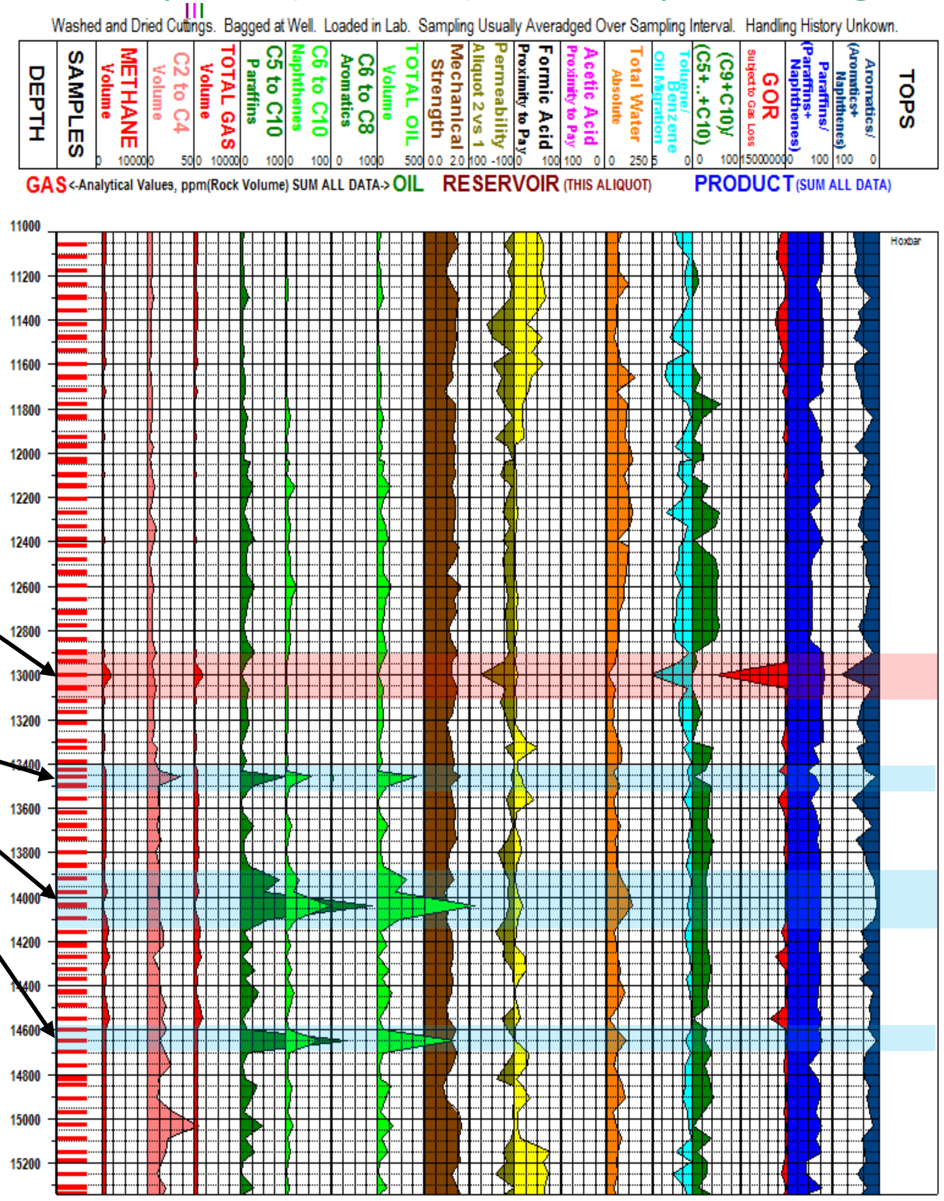
Drillinginfo.com, accessed Oct 2019

Hoxbar Atkinson 1-21H Evaluation

Rock Properties Log reveals several structural features along borehole

- Well was drilled heel down/toe up
- Discreate gas zone is observed, coupled with well trajectory this suggests there is a “seal” that compartmentalizes the well here
- Discrete disproportionate high oil or gas responses in VAS data can be used to pick out oil or gas filled fracture swarms; there is evidence of three fracture swarms in the last half of the lateral

Aliquot 1 (20 mbar) Rock Properties Log



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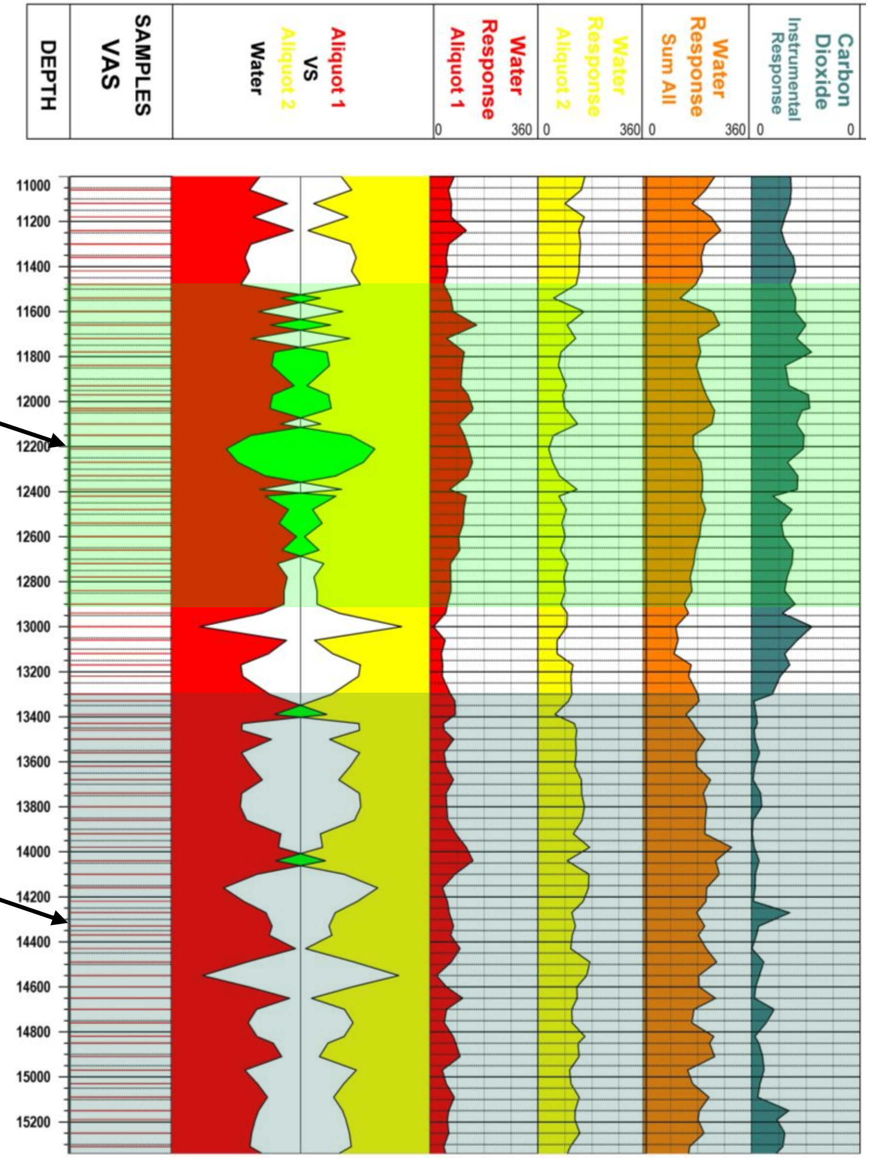
Hoxbar Atkinson 1-21H Evaluation

Comparison of water measured at each aliquot, water crossover and CO_2

- VAS data where Aliquot 1 water exceeds Aliquot 2 water has been shown to empirically correlate with pay zones; appears to suggest that 1/3 of the lateral is in pay

- Notable depletion of CO_2 in the half of the lateral approaching the toe. Lack of CO_2, suggests a loss of oil pressure which would subsequently result in the loss of CO_2 from solution. This suggest the last half of the lateral is not in pay.

Water Comparison and CO_2 Logs



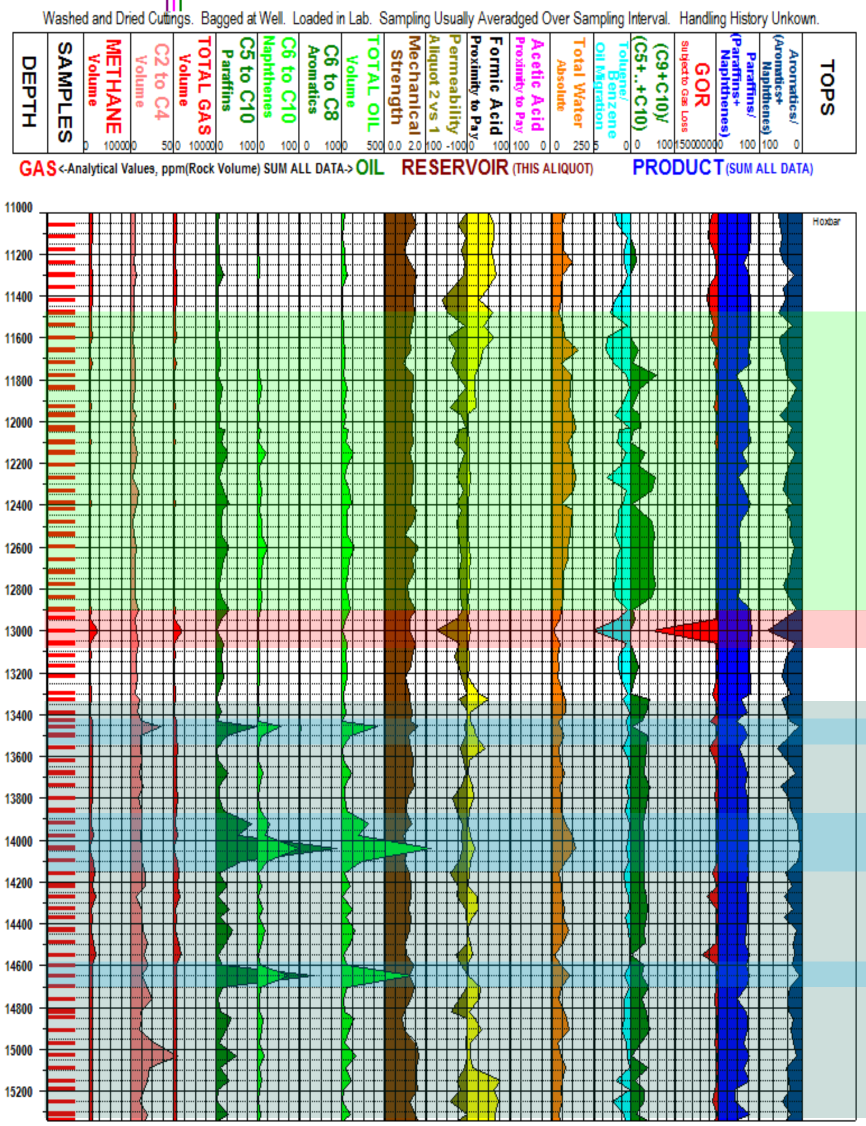
Hoxbar Atkinson 1-21H Evaluation

Combining both VAS logs an explanation as to why the lateral underperforms emerges

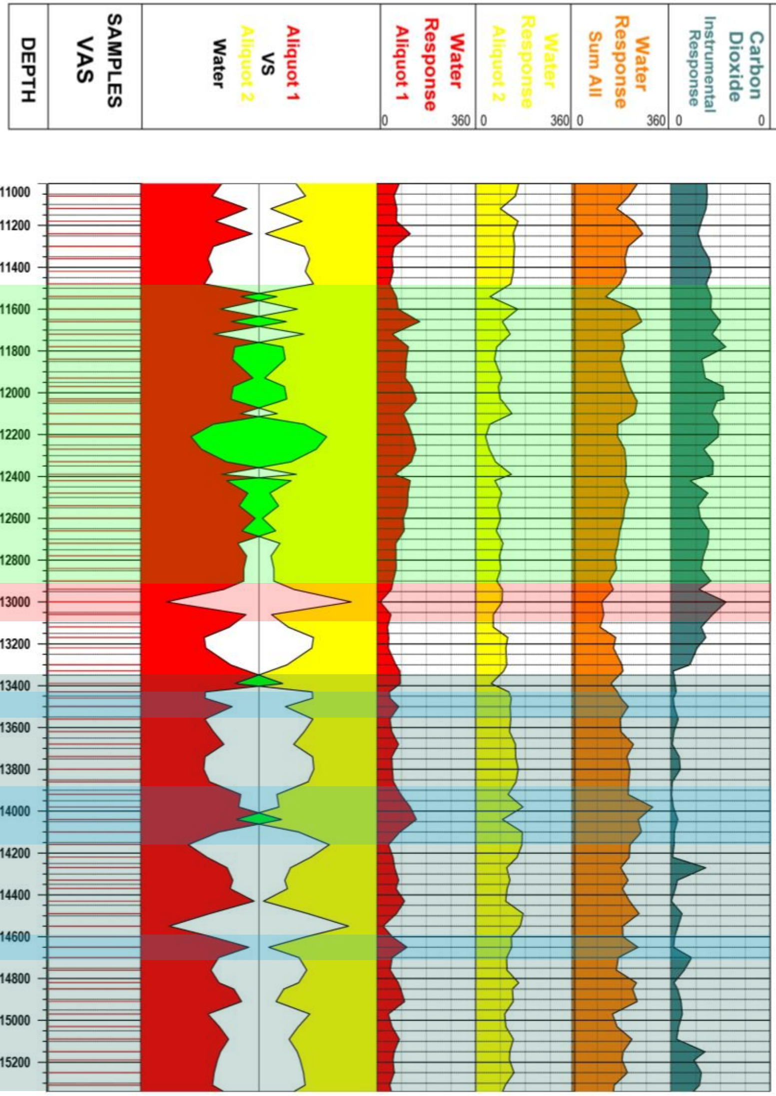
- The roughly the first third of the lateral is in charged reservoir and encounters a seal around 13000 ft MD; seal is evidenced by discrete gas cap
- In the adjoining compartment, last half of the lateral, there is a notable lack of CO_2. This could be from a loss of pressure, due to the loss of oil, which allowed the CO_2 to come out of solution
- The presence of multiple fracture swarms suggests a mechanism of loss for the oil; it has been locally drained via these fractures

VAS analysis allows a simple completion strategy to be suggested that would have resulted in equivalent production and drastic cost reduction. Only complete the well to the gas zone; do not complete the unproductive last half of the lateral

Aliquot 1 (20 mbar) Rock Properties Log



Water Comparison and CO_2 Logs



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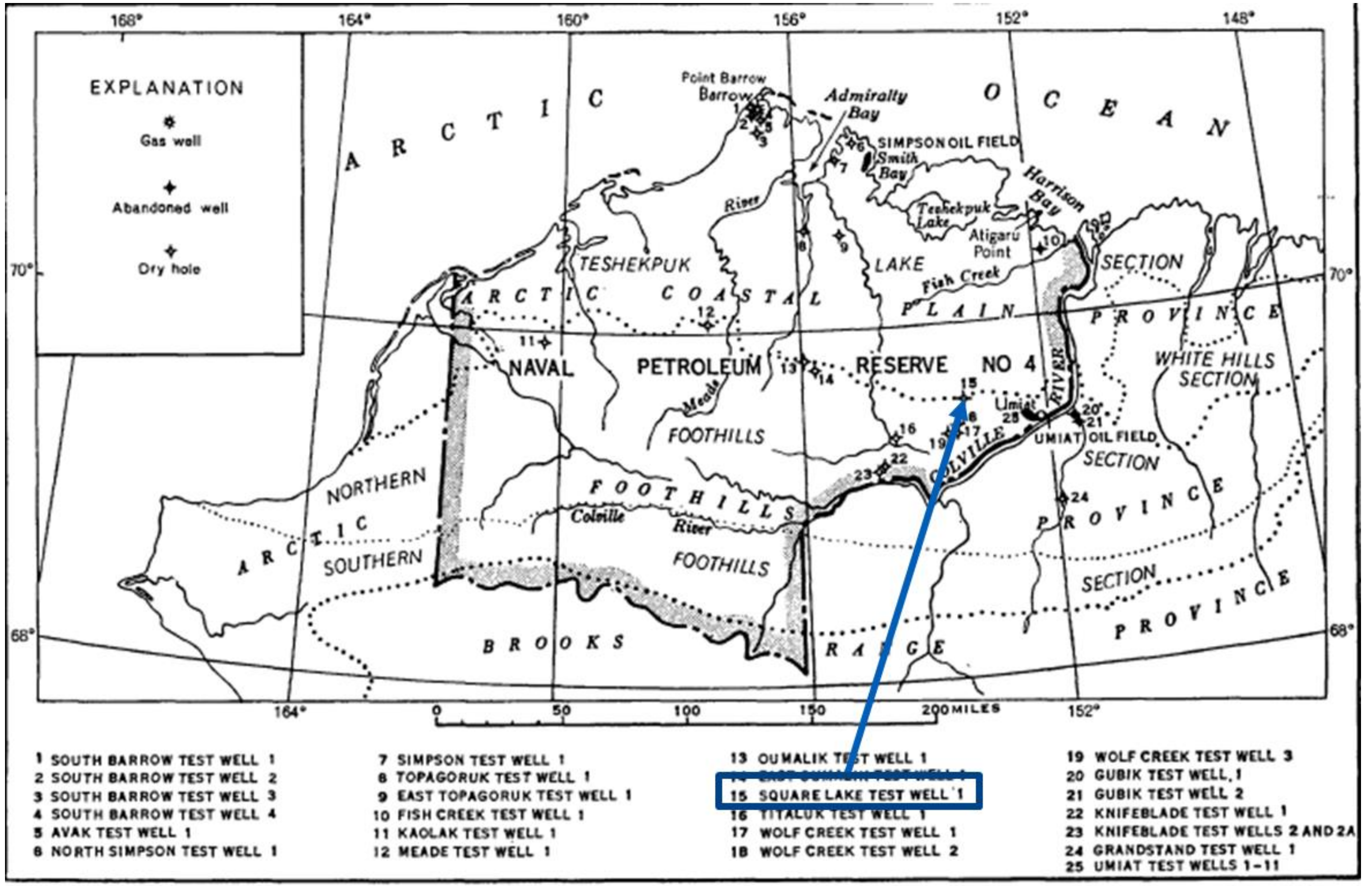
North Slope Alaska Legacy Cutting Analysis

Extracting Relevant Chemical Information from 60+ Year Old Samples?

- Goal of pilot was to determine if viable chemical information existed in cuttings from 1952 and if changes across an unconformity could be detected.
- Washed and dried cuttings housed by the GMC from Square Lake 1 well were analyzed using VAS.
- A total of 13 samples covering 190 ft of core were studied.
- End goal of project was to incorporate VAS data into existing legacy data sets.



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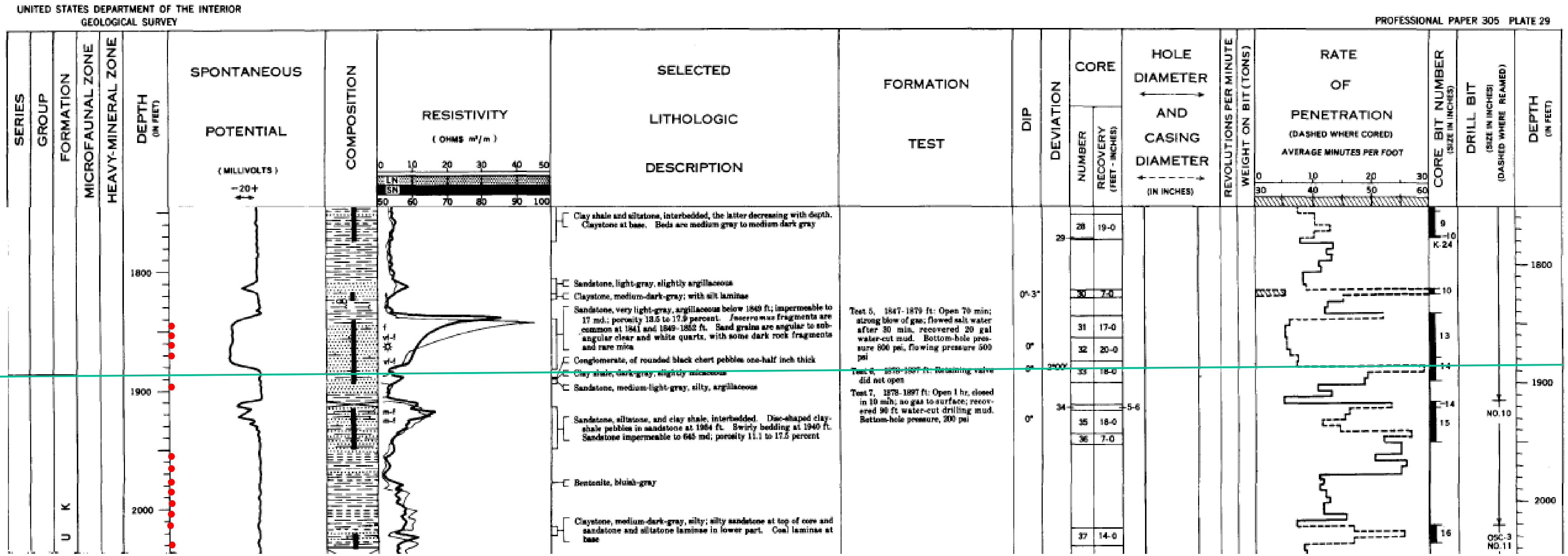
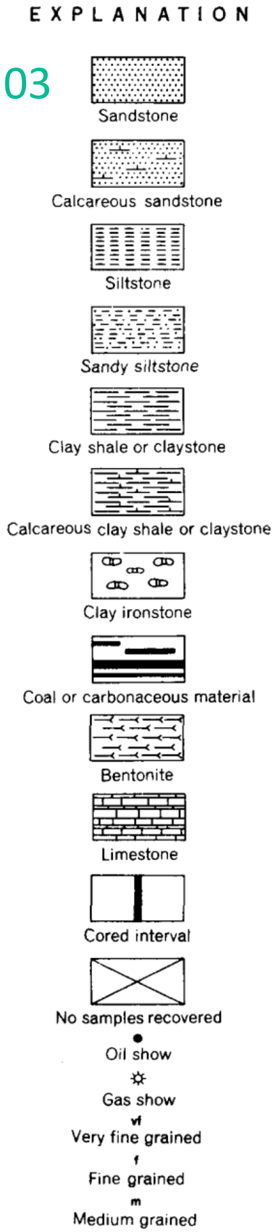
USGS 305-H

Square Lake 1 Historical Data

03





VAS Cutting Sample Locations

Historical well logs and descriptions from Square Lake 1. The 190 ft of core submitted include the contact between the lower Seabee and upper Ninuluk/Chandler (undifferentiated) formations; contact is ~1885 ft. The unconformity occurs at ~1886 ft (green line).

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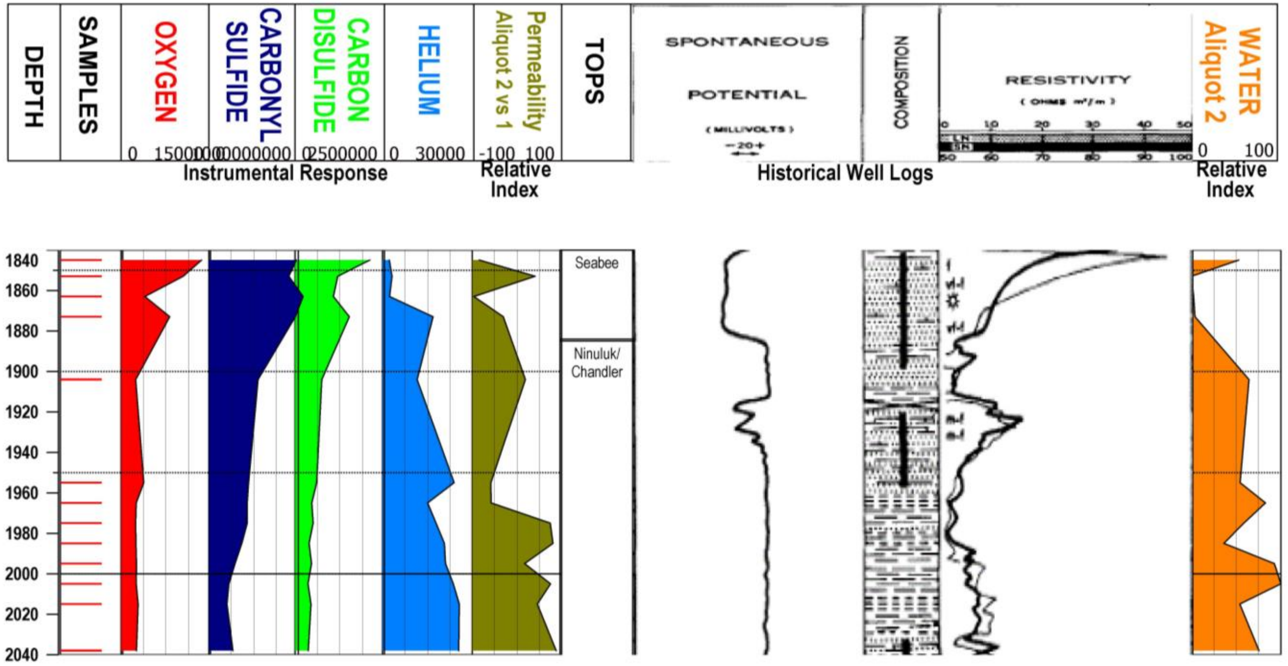
USGS 305-H

Relating VAS to Historical Data: Unconformity and Permeability

Comparison of VAS Data to Historical Data

- VAS molecular oxygen (O_2), carbonyl sulfide (COS), and carbon disulfide (CS_2) show a notable change in their apparent trends between the sampled positions at 1873 ft and 1904 ft; unconformity occurs at ~1886. This is likely due to atmospheric conditions at the time of deposition.
- The O_2 and CS_2 tracks show an anomaly at 1863 ft; an abrupt change in the behavior of the helium data occurs at the same depth. A decrease in permeability is also observed at this position suggesting a partial obstruction/seal to the vertical migration/diffusion of helium.
- From historical core plugs, air permeabilities of <1 mD (1854 ft) and 17 mD (1873 ft) were reported. These values roughly correspond with the observed permeability trend described by VAS; relatively permeable rock at 1873 ft and tight rock at 1863 ft followed by good permeability rock at 1853 ft.

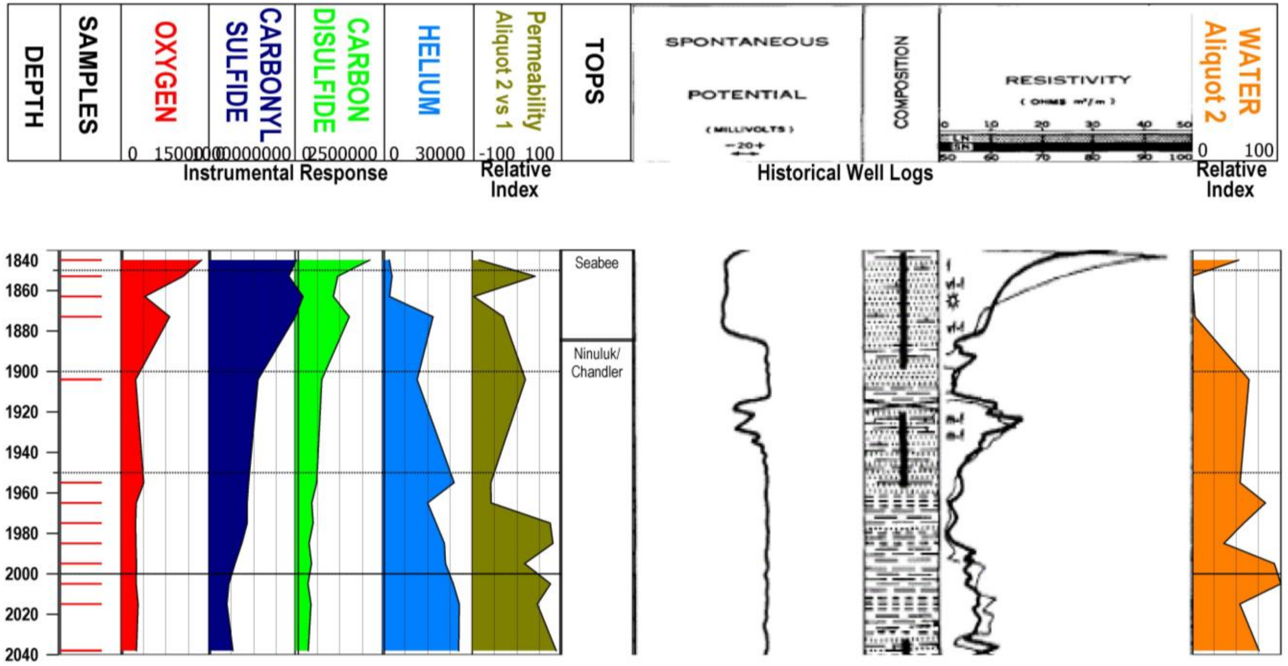


USGS 305-H

Relating VAS to Historical Data: Water Saturation

Comparison of VAS Data to Historical data

- The aliquot 2 VAS water measurements, which correlates to Sw, decreases towards the top of the section.
- SP and resistivity historical well logs both suggest low water saturations from ~1840-1880 ft. Description also notes a gas show about these depths at ~1865 ft.
- Historical formation tests at 1847-1879 ft produced gas and some water. A subsequent formation test from 1878-1897 ft produced only water.
- **VAS is picking out a gas saturated zone based on water extracted from 60+ year old cuttings**



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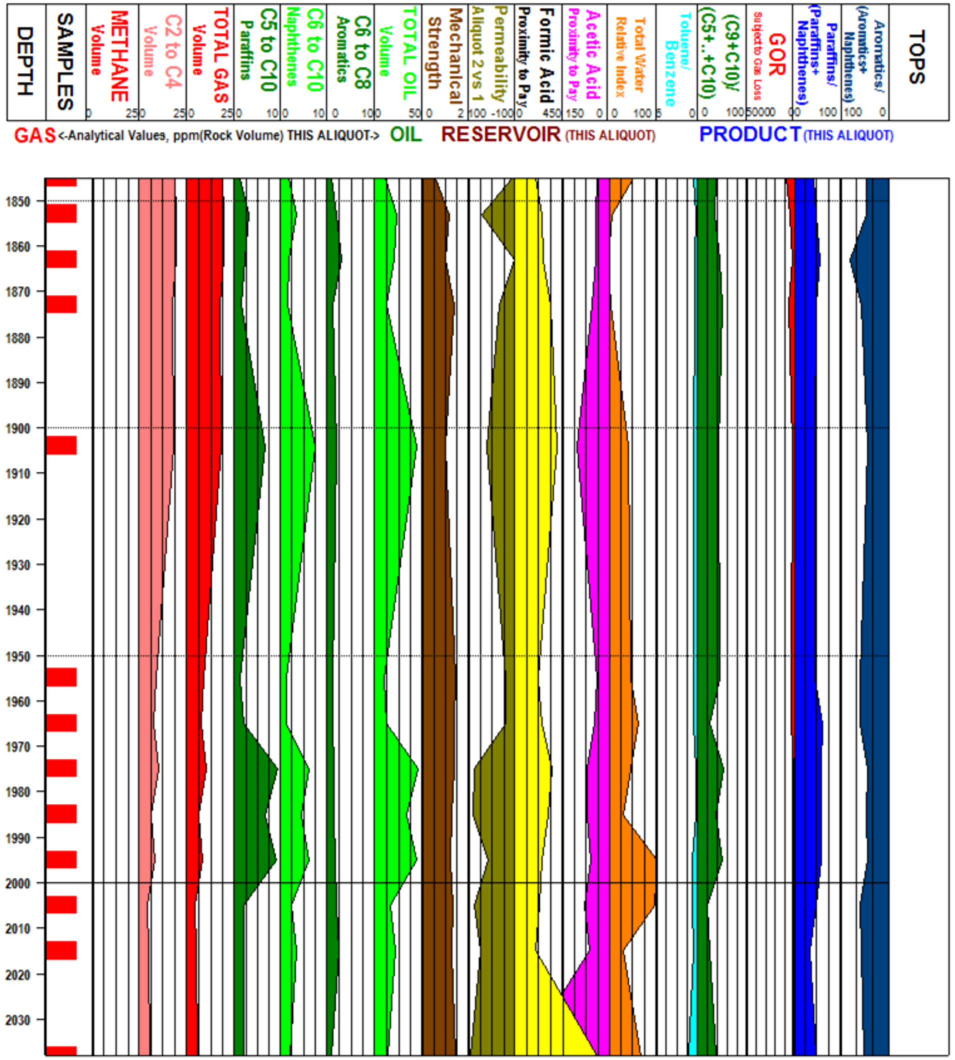
USGS 305-H

Using VAS to Gain New Insights with Legacy Materials

Previous models for the region tied this section of Square Lake 1 have evaluated that gas migration occurred, but not oil migration. VAS not only demonstrates gas migration but also demonstrates oil migration.

- All samples analyzed contained oil. In washed and dried samples from conventional plays, this indicates vertical migration that did not encounter effective seals. (Seals appear as discontinuities in the liquid hydrocarbon data)
- The chemical signatures extracted from the VAS analysis also inform on the quality/nature of the migrated oil and associated processes:
  - Low paraffinic content/high aromatic content and high C9+C10/C5+…+C10 ratio suggest migration of a relatively heavy oil
  - Low paraffinic content/high aromatic content suggest notable biodegradation of resource has occurred; paraffins are the first target of biodegradation processes, aromatics are the last
  - Relatively high organic acid shows offer further evidence of biodegradation of resource; in colder formations (<80°C) these are byproducts of biodegradation

Evidence of previously unknown oil migration is being used to reconsider petroleum system model for this portion of Alaska; study being expanded to additional legacy wells in consultation with local subject matter experts



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Example of Work Associated with Legacy Core Analysis

VAS has been used to evaluate cores in various states including sampled fresh at wellsite, preserved storage, and slabbed legacy core. Legacy core materials are analyzed in a manner similar to the washed and dried cuttings. One major difference between the analysis of washed and dried cuttings and legacy core materials is that the sum of both aliquots correlates to the Sw. Our current hypothesis is that different mechanisms occur in cuttings and core in relation to the retention of representative water, with the core maintaining much of its original porosity compared to the cuttings; this allows for a level of differentiation between "macroporosity" and "microporosity" water.

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Analysis of Unpreserved Core to Evaluate Oil Migration, Water Saturations, and Pay Zones in the STACK (OK)

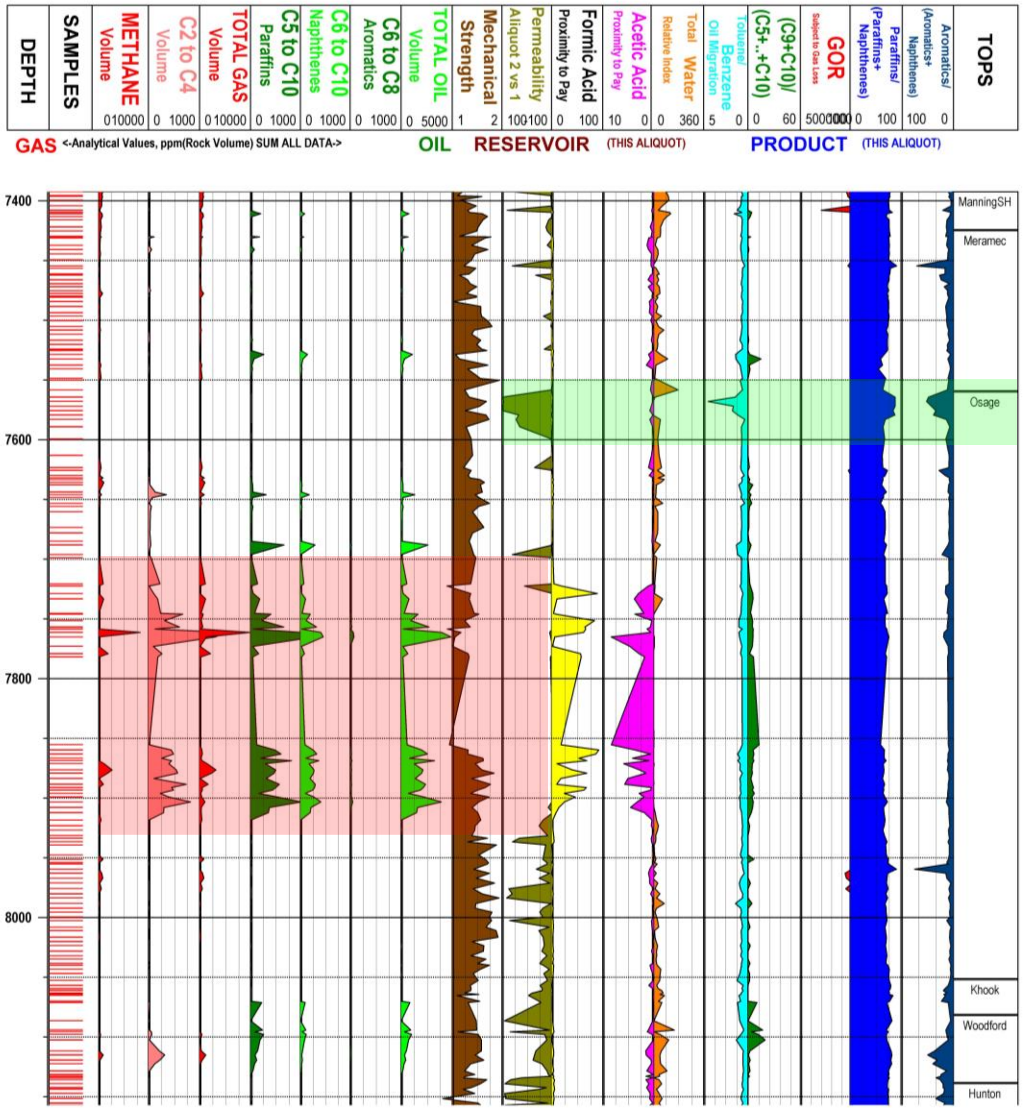
Evaluation of Unpreserved Legacy Core

- Thin sections from a 6+ year old unpreserved core were taken at 173 depths; VAS was run using core chips associated with resulting thin sections
- High sampling density of the core allows for observation of discrete events along the length of the core such as oil migration at formation contacts and in high permeability and/or low "macroporosity" water zones
- Analysis of water data demonstrates a strong empirical correlation to Sw from petrophysics from operator; aliquot 1 (20 mbar) water release appears to be linked to "macroporosity" water while aliquot 2 (2 mbar) water appears to be linked to "microporosity" water
- Water analysis provides additional insights into potential pay zones

Oil Migration and Tight Rock Observed at 20 mbar

Oil Migration is observed at formation contacts and occurs in zone of high permeability (Aliquot 1 Data)

- High permeability detected at contact of Osage and Meramec in the upper Osage; attributed to proto-karst development from subaerial exposure which results in the formation of soils; the soils generate organic acids causing carbonate dissolution
- High toluene/benzene ratio indicating oil migration at contact occurring in high permeability zone
- Migration signal correlates to area of low water measured in aliquot 1
- Zone of high gas/oil response indicates tight rocks associated with a chert section



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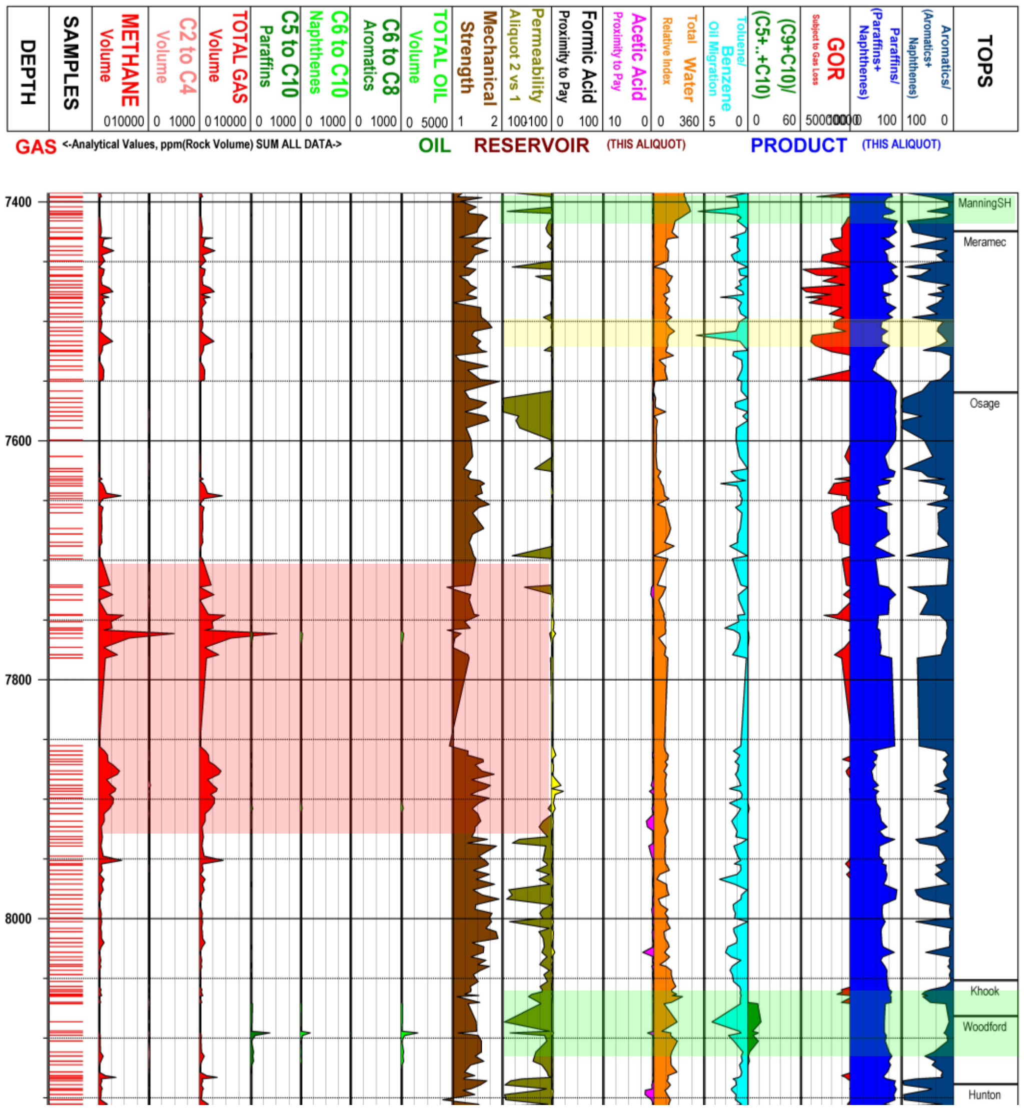
Oil Migration and Tight Rock Observed at 2 mbar

Oil Migration is observed at formation contacts and occurs in zones of high permeability (Aliquot 2 Data)

- High toluene/benzene ratio at contact of Woodford and Kinderhook indicating oil migration out of source rock; occurs at zone of high permeability
- Evidence oil migration in Manning in discrete high permeability zone located in lower Manning near contact with Meramec
- Evidence of oil migration in Meramec
- Each oil migration signature corresponds to low water responses in the aliquot 1 data; “macroporosity” water is minimally present in migration pathways
- Chert section has a higher methane response under higher vacuum conditions of aliquot 2 than observed in aliquot 1; indicates very tight methane filled pore network unavailable to larger hydrocarbons (duel porosity/permeability system)



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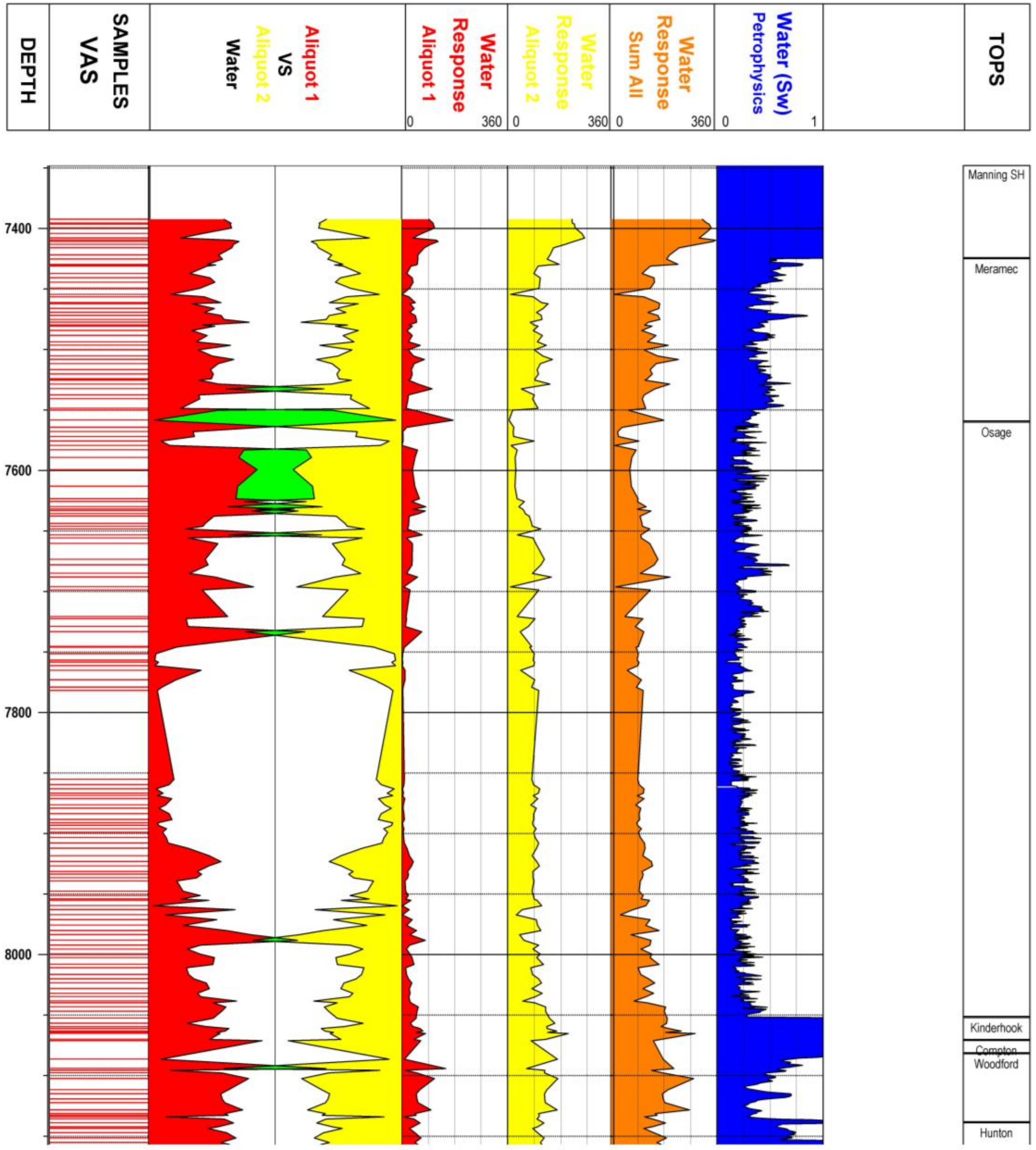
VAS Water Data vs Sw from Petrophysics

The correlation of VAS to Sw from petrophysics on core is most apparent by summing the released water measured at each vacuum pressure (2 mbar and 20 mbar). Given the theoretical understanding of how water organizes in tight spaces vs. "bulk" environments we believe that this process effectively separates "bulk" water existing in macro pore spaces from "tight" water existing in nanometer to sub-micrometer pore spaces; i.e. "macroporosity" vs "microporosity" water. For "bulk" water the boiling point at 20 mbar is approx. 16°C; this water is readily volatilized and removed at the first vacuum pressure. The combination of capillary forces at the sub-micrometer scale and water organizing into an ice like phase at the nanometer scale can increase the boiling point of water in excess of 350°C as a function of pore diameter (at 1 atmosphere/1013 mbar); under the 2 mbar vacuum water in pores with a diameter of approx. 1.5 nm or greater reaches its boiling point at room temperature and can be volatilized and removed.

- Depths where aliquot 1 water exceeds aliquot 2 water have been shown to empirically correlate with pay zones; in this case it suggests that the observed oil migration at the Meramec/Osage contact has charged reservoirs in the lower Meramec and upper Osage
- A neighboring well was drilled by operator in the indicated Osage zone with AHS assistance and using VAS, EUR based on production predicted to be 300+ MBbls



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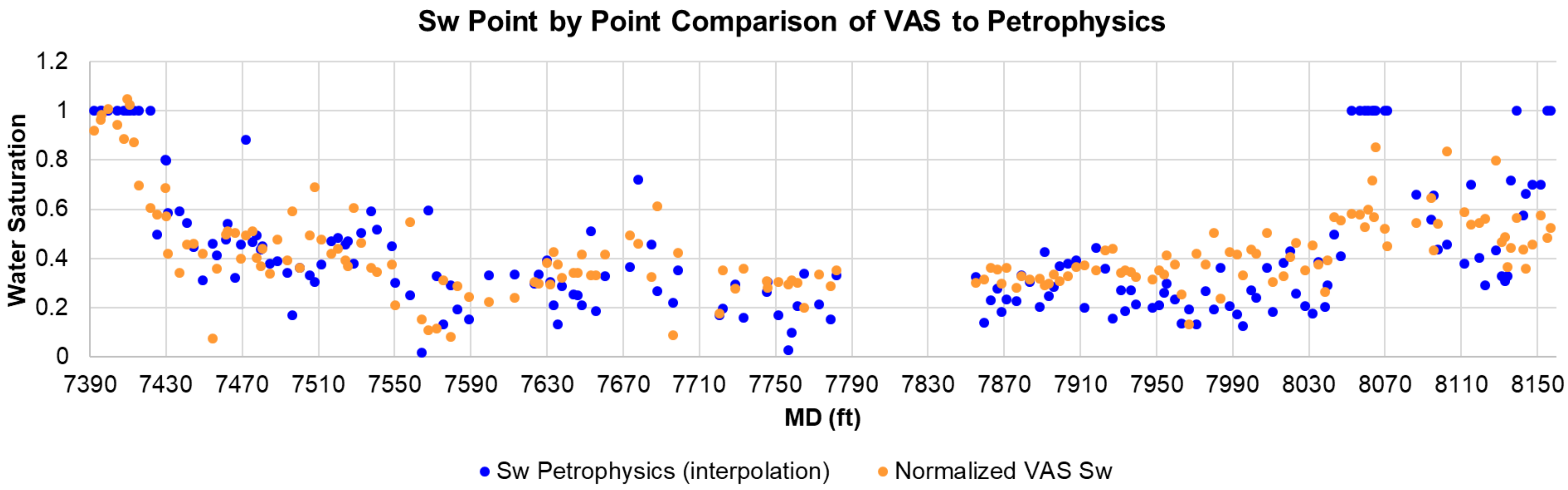
Direct Comparison of Individual Data Points; VAS vs Sw



Sw data were interpolated to depths where VAS data were collected with VAS data being linearly rescaled to enable comparison. Sw in the formations below the Osage (Kinderhook, Compton, Woodford, and Hunton) was calculated using the Osage model and may explain some of the observed divergence here

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Volatiles Analysis Services (VAS)

Pay Identification and HC Characterization:

- Unconventional (pilots & laterals)
- Conventional (old and new)
- Estimated ultimate recovery (EUR)
- API predictions
- Thermal maturity
- Proximity to pay
- HC migration pathways
- Drilling mud analysis (C1-C10)
- Oil based muds and PDC bits acceptable

Rock Type and Properties Prediction:

- Clastics, carbonates
- Rock properties
- Sw estimation
- Reservoir compartmentalization
- Fault and Fracture identification
- Permeability, Dual porosity
- Seal(s) identification
- Mechanical strength and fracability

Reporting and Expert Consultation:

- Volatile well logs:
  - HC's and rock properties interpretation
- Operational recommendations within Ops time constraints:
  - Pay and missed pay identification
  - Landing zones identification
  - Proximity to pay indicators
  - Completion recommendations
- Geochemical properties mapping
- Petroleum system evaluation
- Acreage high-grading
- Sweet spot identification

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