Discussion of VAS and Initial Results from Legacy Core and Cuttings Samples from Iniskin Unit Wells for Hilcorp on 11.11.2020

Supplied by Advanced Hydrocarbon Stratigraphy (AHS)

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Technology Development

AHS Background

- AHS founded in the 1994 by Michael P. Smith (MPS) (PhD, U. of Hawaii 1981) after working at Amoco research for 10 years
- Technology that MPS developed at Amoco in 1985 fluid inclusion stratigraphy (FIS) (Gen 1), coupled with his experience, was instrumental in the exploration and development multiple Amoco assets[1]
- In 1999 AHS's technique/technology, fluid inclusion volatiles (FIV) (Gen 2), was sold to ExxonMobil, MPS worked as a consultant on the technology till 2009 for ExxonMobil Upstream Research Company; FIV continues to be extensively used by ExxonMobil as first analysis method on exploration wells[2]
- AHS "re-founded" in 2010 after expiration of non-compete clause from the 1999 sale
- Current technology, rock volatiles stratigraphy/volatiles analysis service (VAS) (Gen 3) began development in 2011 and reached maturation in 2015, though improvements continue to be made, technology focuses on present day fluids and gas entrained in cuttings and/or core, not historical fluids and gas as is the case in fluid inclusions

1. Smith, M. P. FINDING AND EVALUATING ROCK SPECIMENS HAVING CLASSES OF FLUID INCLUSIONS FOR OIL AND GAS EXPLORATION. US Pat # 5241859, 1993.
1. Smith, M. P. OBTAINING COLLECTIVE FLUID INCLUSION VOLATEES FOR INCLUSION COMPOSITION MAPPING OF EARTH'S SUBSURFACE. US Pat # 5416024, 1995.
1. Smith, M. P. APPARATUS FOR ANALYZING FLUID INCLUSIONS. US Pat # 4,960,567, 1990.
1. Smith, M. P. INCLUSION COMPOSITION MAPPING OF EARTH'S SUBSURFACE USING COLLECTIVE FLUID INCLUSION VOLATILE COMPOSITIONS. US Pat # 5,328,849, 1992.
2. Becker, S. P. Fluid Inclusion Tools in Petroleum Systems Analysis. In *Pan-American Current Research on Fluid Inclusions, PACROFI 14*; Houston, 2018; pp 25–26.

Novel Gentle Extraction and Cryo-Trap Mass Spec. Analysis

What are Measured

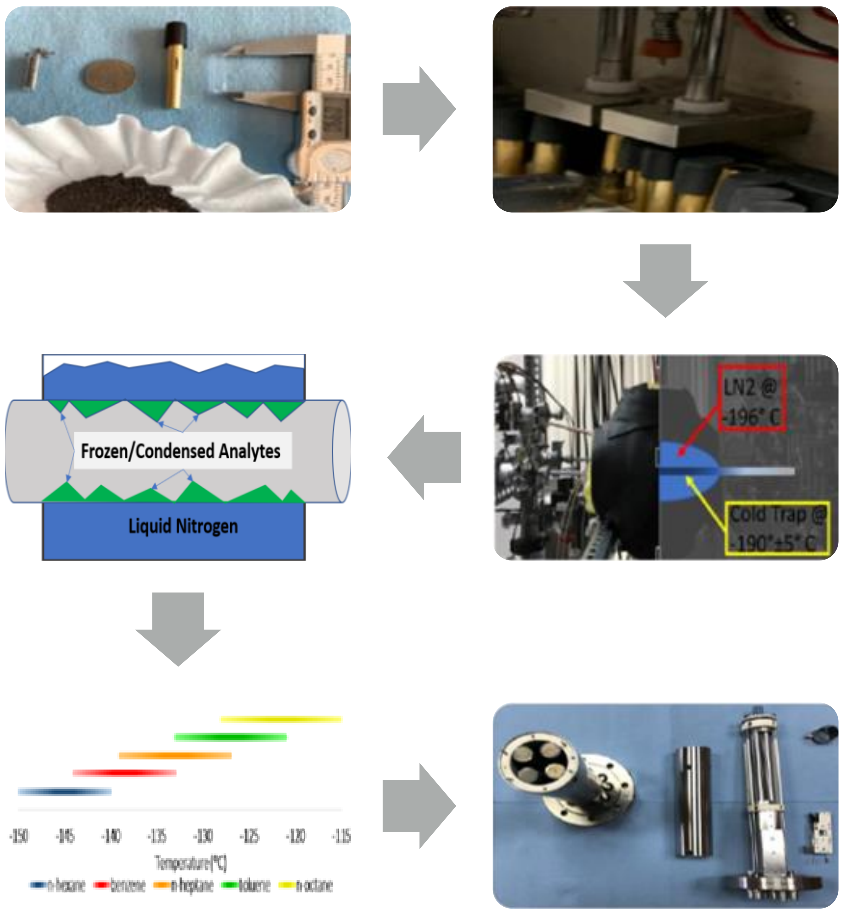
- C1-C4 Gases
- C5-C10 Paraffins
- C6-C10 Naphthenes
- C6-C8 Aromatics
- Helium

- Water
- Carbon Dioxide
- Hydrogen Sulfide
- Carbon Disulfide
- Carbonyl Sulfide
- Formic Acid
- Acetic Acid
- Methyl Ethyl Ketone

- Argon
- Molecular Oxygen
- Molecular Nitrogen
- Ethene
- 2-Trans-Butene

- 32 species directly measured under three different conditions
- Permeability indices for most species
- Mechanical strength byproduct measurement
- Over 120 possible data points per sample
- Isomers, isotopes, and/or additional species are possible

How are they Measured



- Analyzed by 20 and 2 mbar vacuum extractions

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Sampling and Sample Considerations

VAS Samples/Sample Collection

- Analysis works on cuttings regardless of the mud system from water-based mud, oil-based mud, and air drilled wells
- Cuttings from PDC bits, rock bits, and even cable tools can be used
- Core, side wall core, outcrop samples, and muds can be utilized
- Samples can either be collected and sealed on site (sealed at well) or prepared in the lab (washed and dried) allowing different types of analysis
- Ideal sampling: collect cuttings directly from flow line before entering the possum belly or going over the shaker table, sampling density 10 ft in verticals and curves, every 30 ft in laterals
- VAS works on historical samples (can be several decades old) provided that the samples have not been chemically, vacuum, and/or heat treated

Sample consumable kit with cuttings

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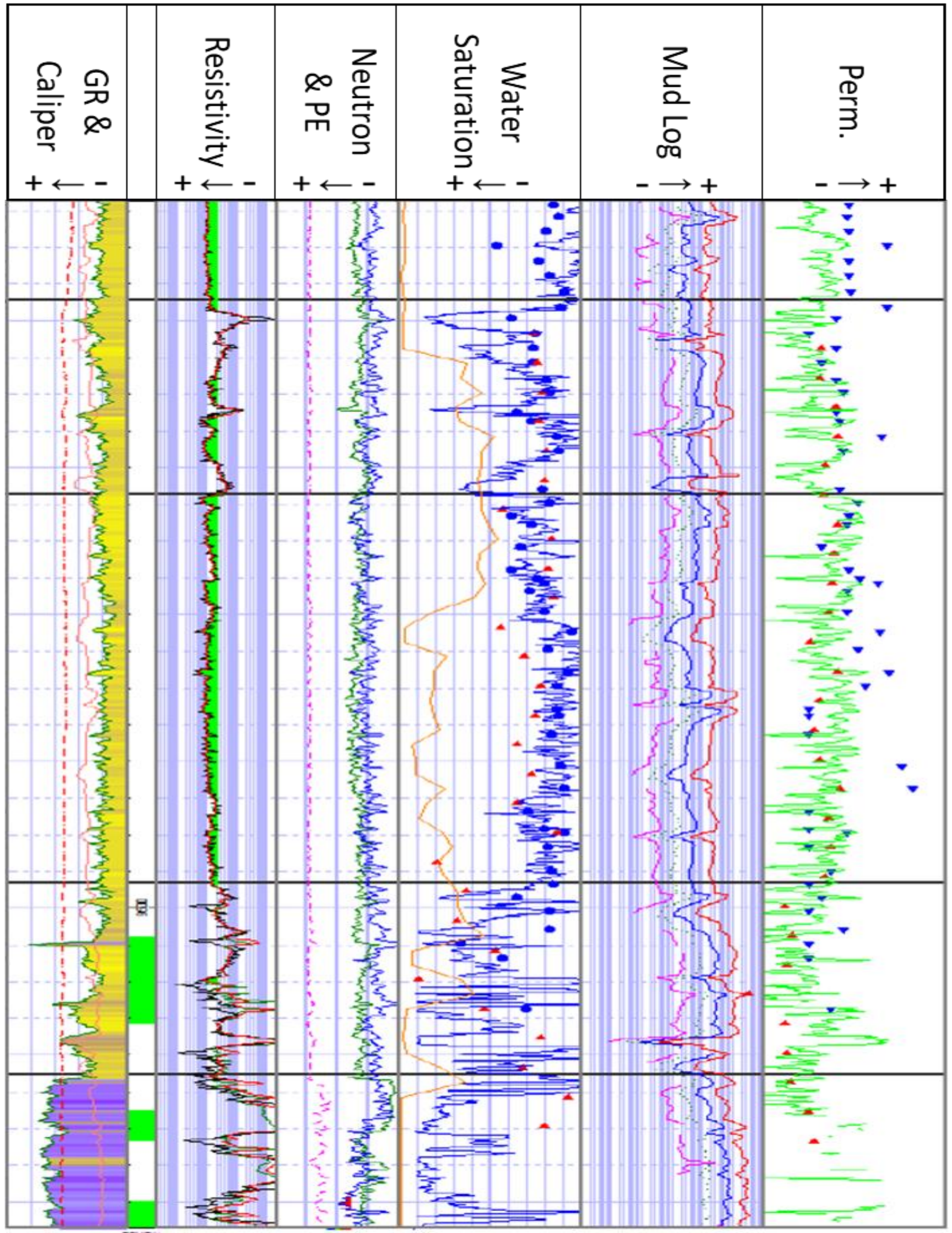
Permeability and Sw (Delaware Basin, NM)

Vacuum Extraction at Two Pressures Allows for Meaningful Relative Index Measurements of Sw and Perm

- Postmortem analysis of well targeting the Bone Springs
- Lateral failed to produce meaningful quantities of HCs, produced large quantities of water
- Operator paid ~750K to assess well (logs and side wall cores)
- AHS assessed well (with 30 legacy samples) two orders of magnitude less, correctly assessed normalized Sw and Perm. compared to traditional methods (red dots [VAS] vs continuous lines [petrophysics] and blue dots [side wall cores])
- Similar Sw and/or Perm. comparisons have been proven correct in:
  - STACK
  - Powder River
  - North Slope AK



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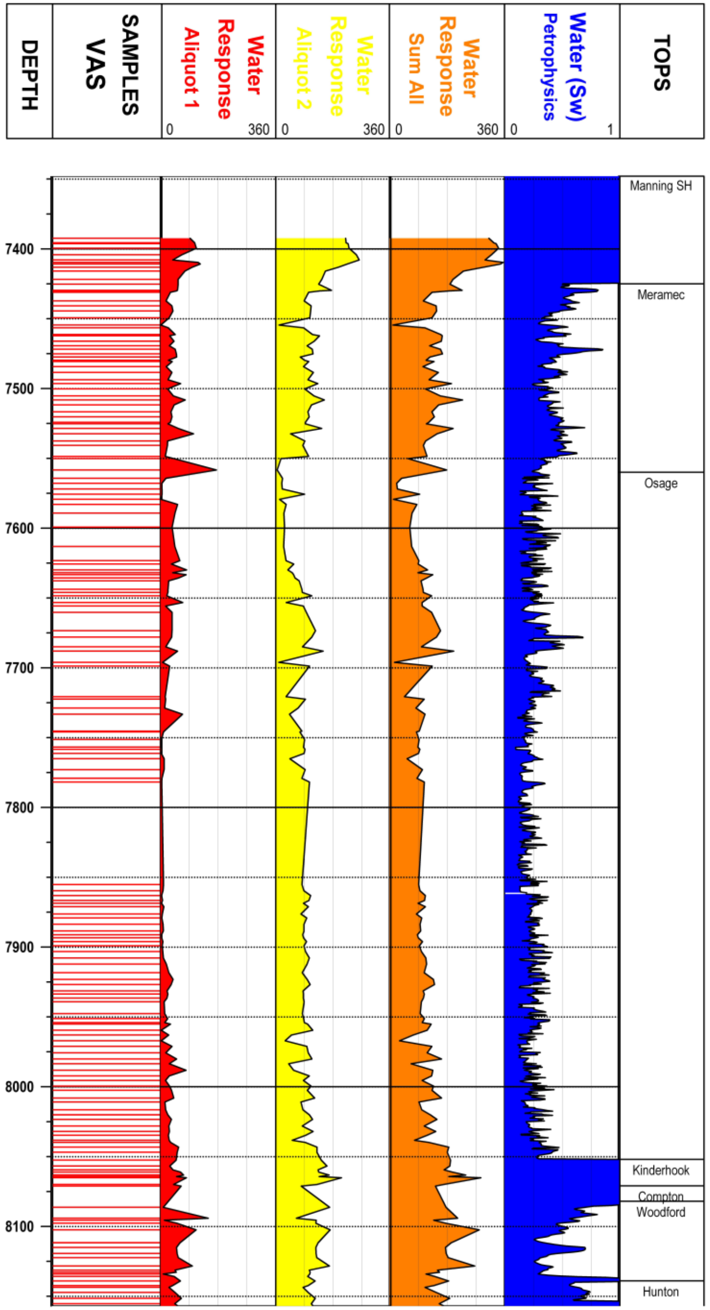
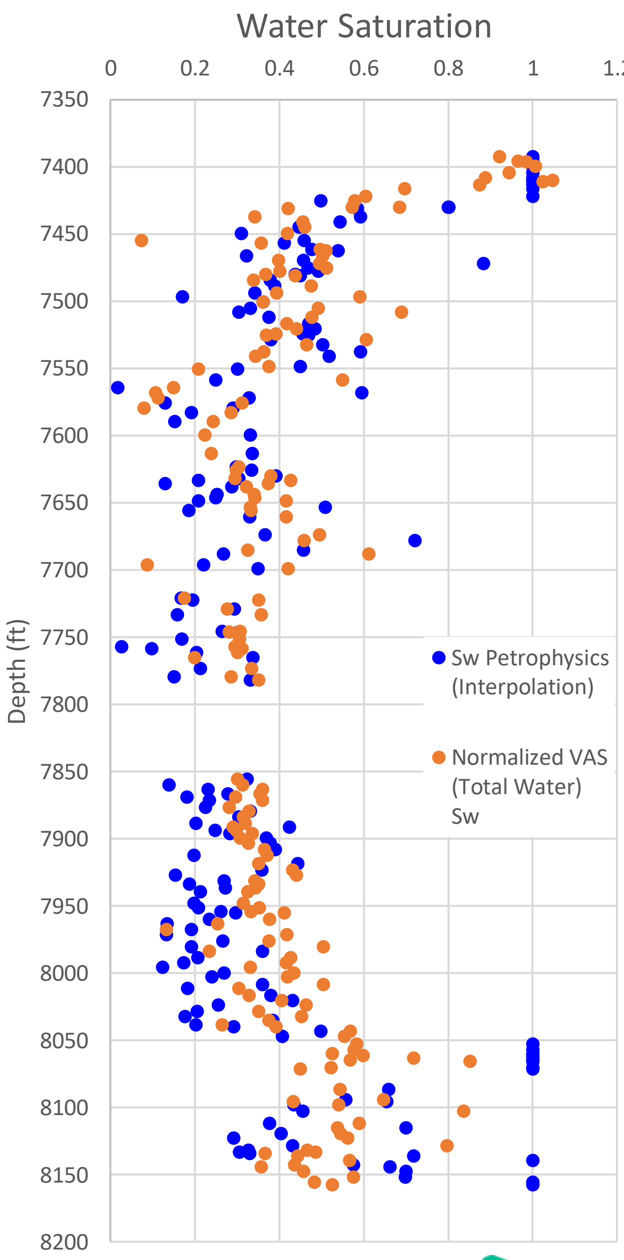
Smith, M.; Smith, C. Advanced Geochemical Analysis of Volatiles Present in Drill Cuttings to Drive Decisions from Single Well Completions to Acreage / Basin Assessments : Examples from the Permian , STACK , and SCOOP. In URTeC Conference Paper; Austin, 2020. https://doi.org/10.15530/urtec-2020-3035.

Advanced Water Saturation Analysis (STACK, OK)

The sum of the directly measured water correlates to the Sw determined from petrophysics

- The sum of the water from both extractions when normalized matches the point by point Sw
- Water extracted at 20 mbar correlates to “macro” porosity water (water in pore spaces >4 nm)
- Water extracted at 2 mbar correlates to “micro” porosity water (water in pore spaces from ~1.5 - 4 nm)
- Relationship begins to breakdown below the Osage where the petrophysicist did not have a model, though trends are consistant





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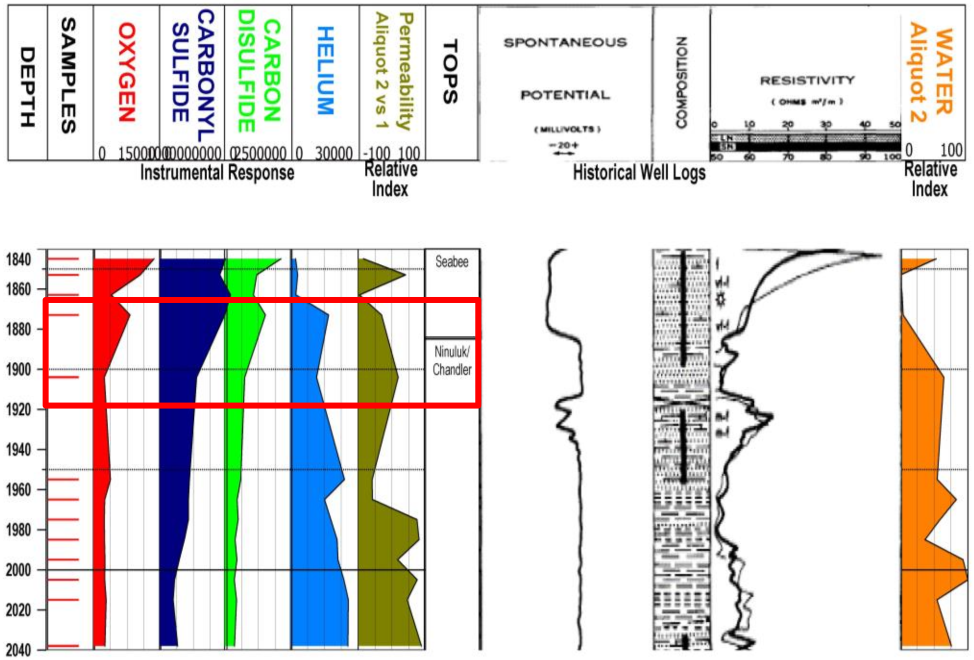
Square Lake 1: Identifying the Unconformity

Selected VAS and Historical Data



Nonhydrocarbon volatiles pick out unconformity

Core Images of Section of Interest

Image provided courtesy of State of Alaska's Geological Materials Center

Collins, F. R. USGS 305-H, 1959

Smith, C. M. Baker Hughes Volatiles Analysis Services (VAS): Square Lake Test Well 1; Supplied by Advanced Hydrocarbon Stratigraphy. In *Alaska Geological Society Invited Talk*; Alaska Geological Society and Alaska Geological Materials Center: Anchorage, 2020

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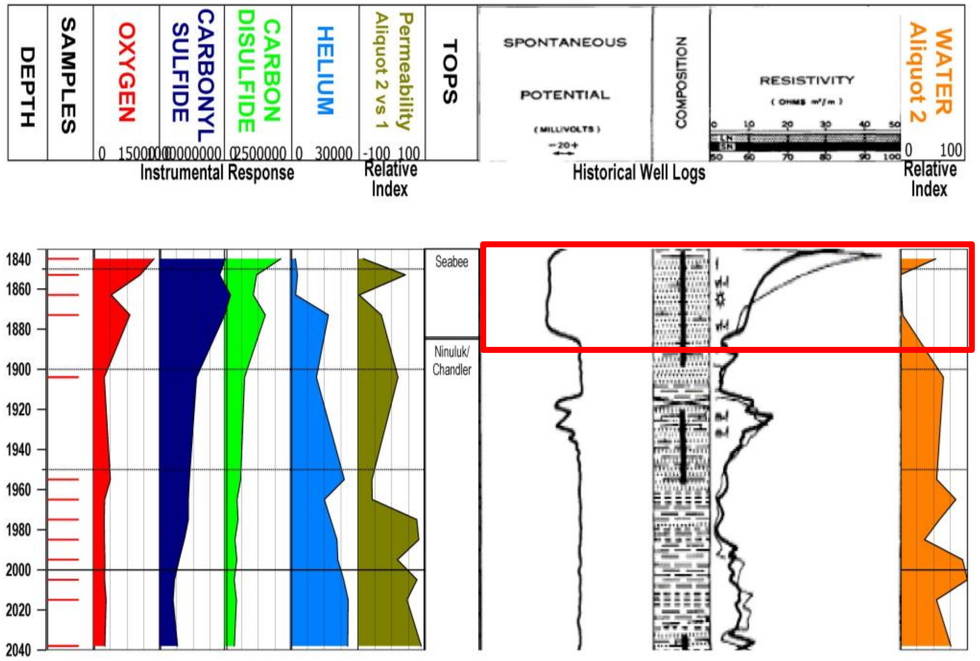

Low Water Saturation Identifies Gas Pay Zone

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**

Collins, F. R. USGS 305-H, 1959

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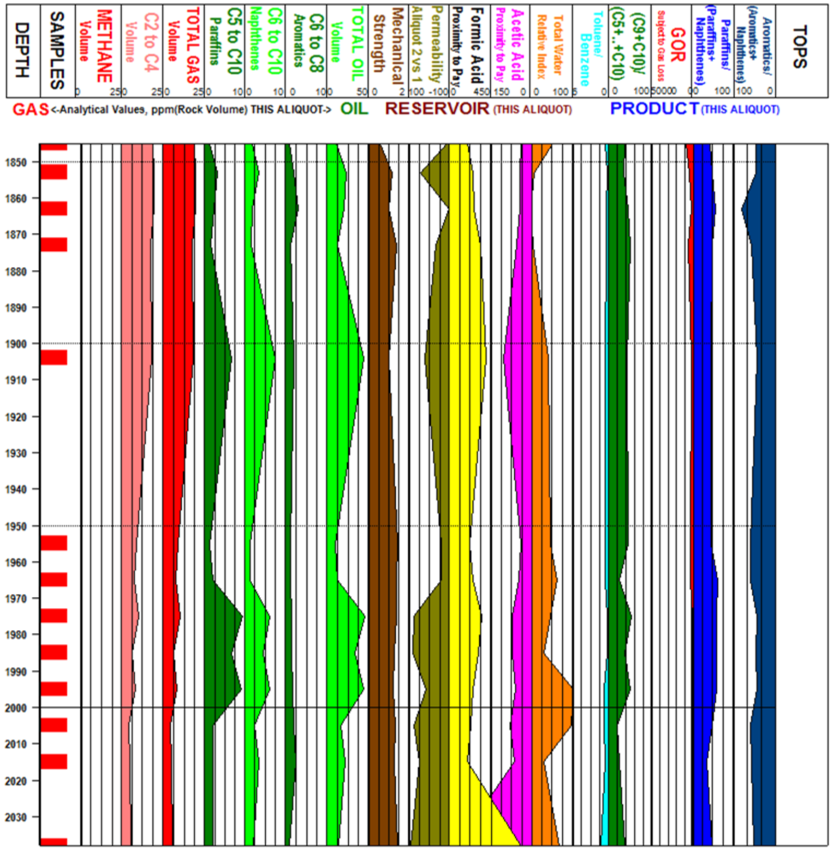
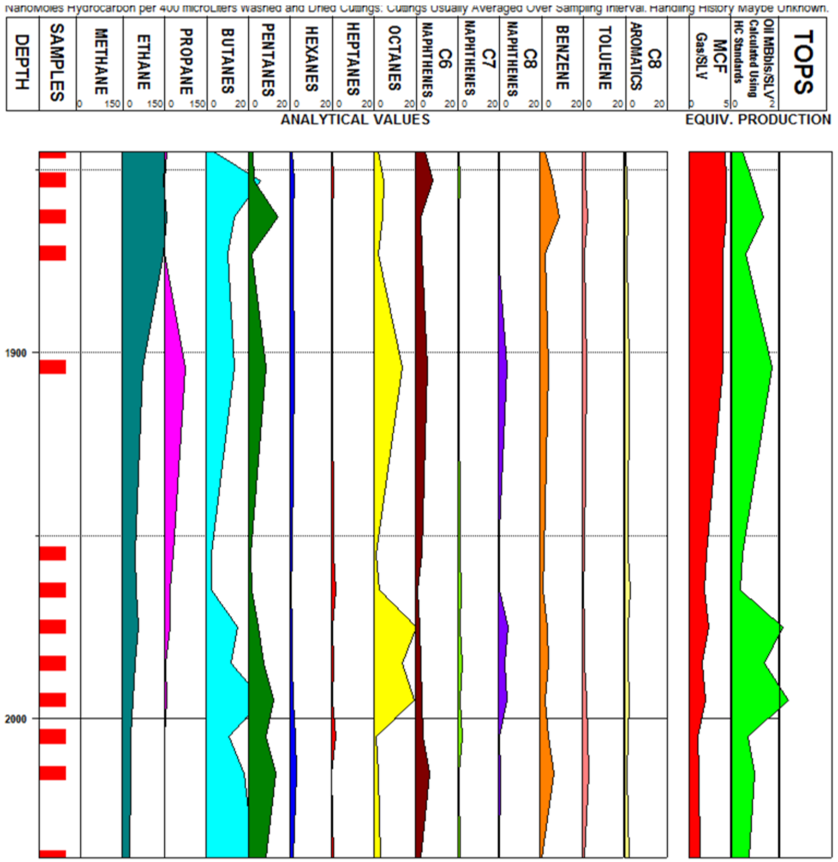
Square Lake 1: Presence of Liquid Hydrocarbons

Rock Properties Log



Hydrocarbon Log



Liquids are detected in the samples as is evidence of biological activity, inconsistent with only dry gas migration and provides evidence of past oil migration in this section of the well

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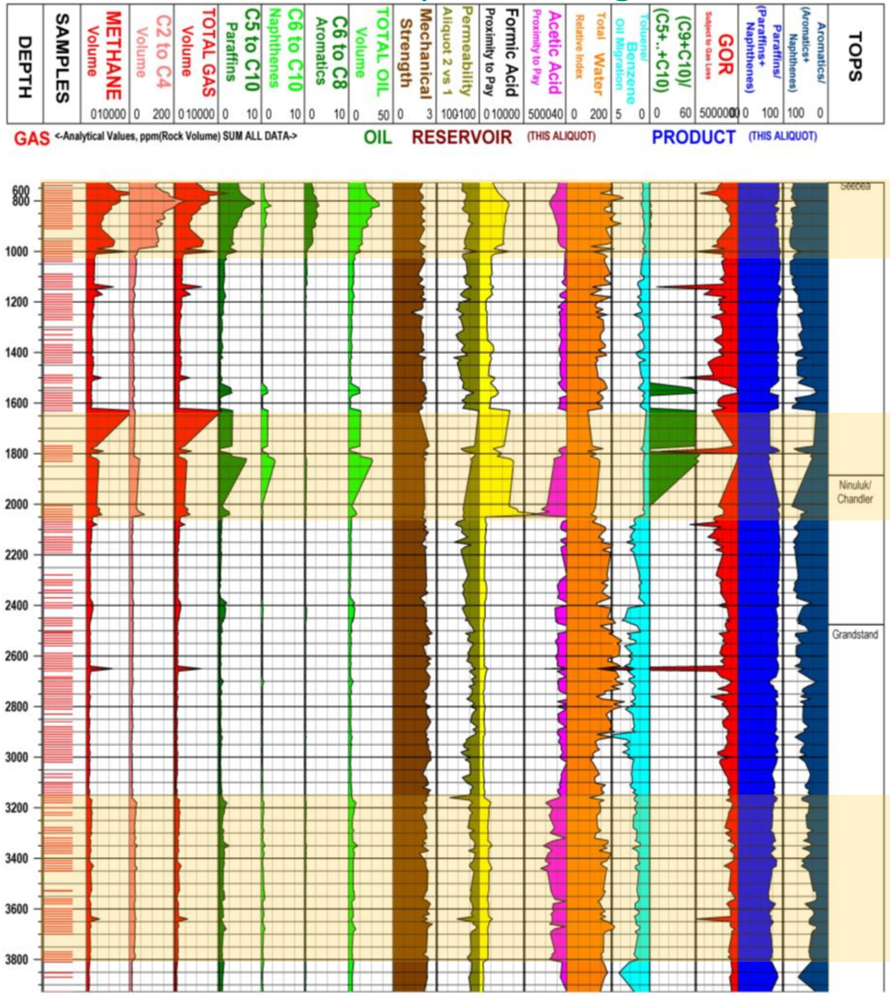
Personal Communications w/ David Houseknecht (USGS) Oct 2019

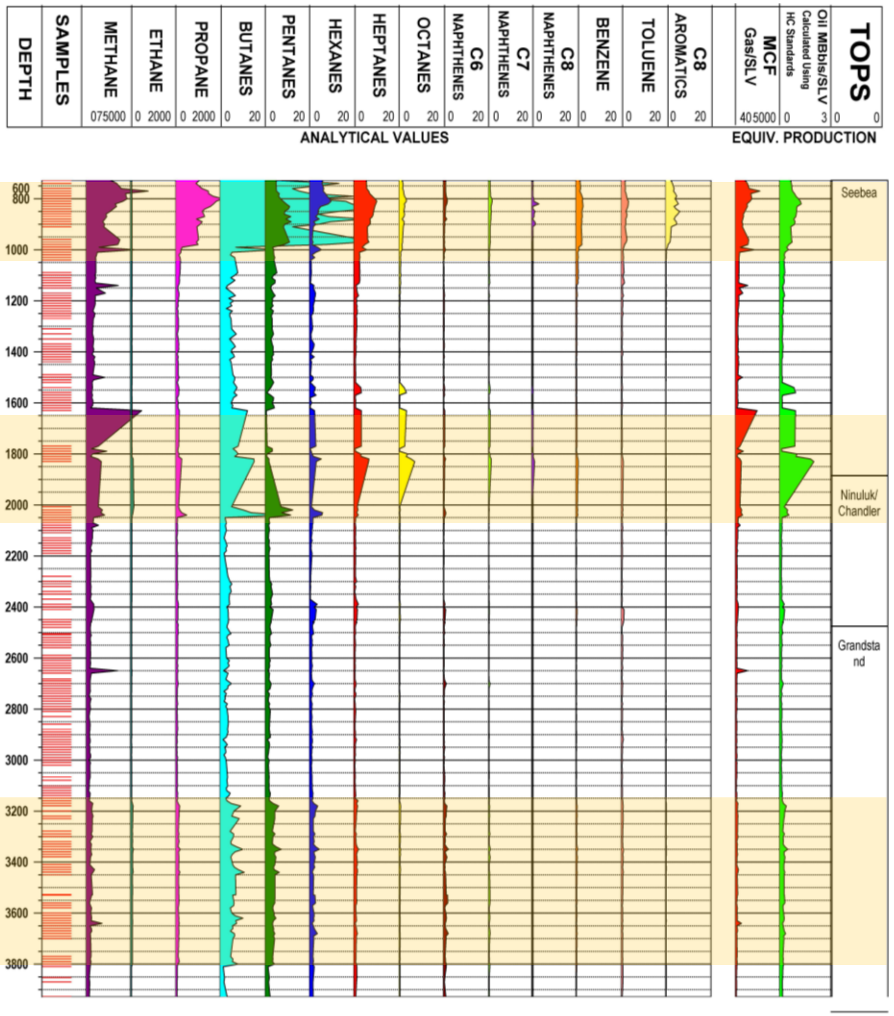
Square Lake 1: Identifying Oil in 67-Year-Old North Slope Cuttings

- Examined well from top to TD
- Well has since been tied to gas migration but not oil migration, two gas zones
- VAS identified liquids in well, including in the gas zones, suggesting liquids migration
- Three distinct hydrocarbon compositions are observed likely not in communication:
  - Shallow: Aromatic rich/Naphthene poor (hydrate/permafrost associated)
  - Middle: Biodegraded with C9/C10 HCs (Hue sourced)
  - Deep: lighter liquid, minimal C8-10 species and aromatics, lower GOR (GRZ sourced)
- Complex migration story in Deep section of the well

Rock Properties Log



Hydrocarbon Log



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Previous Work for Hilcorp AK;

Analysis of MPS S-203 Ugnu Well

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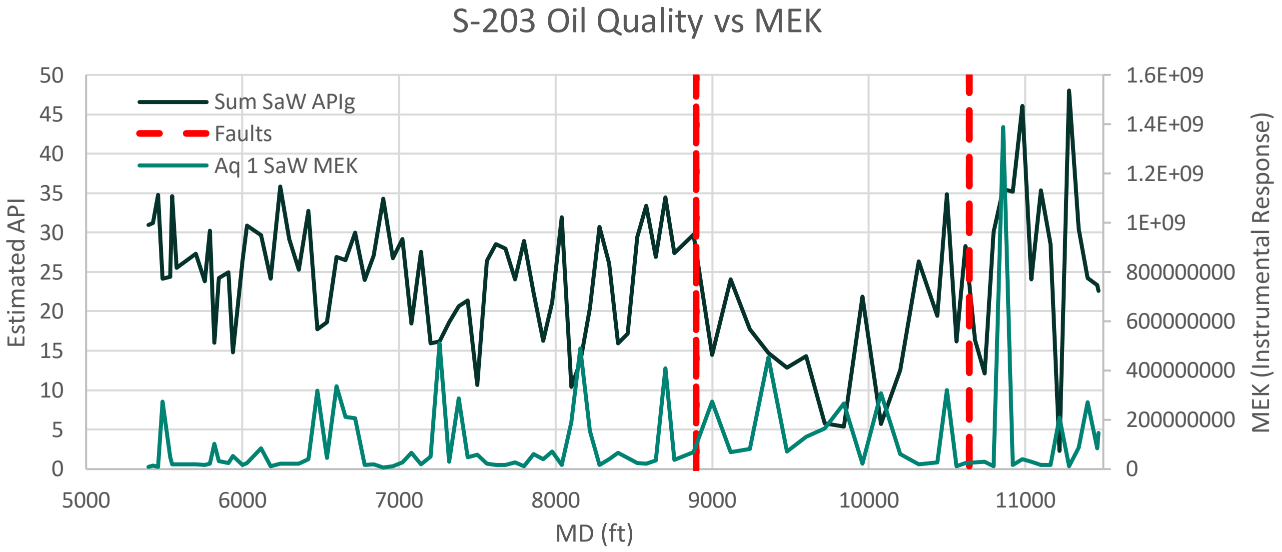
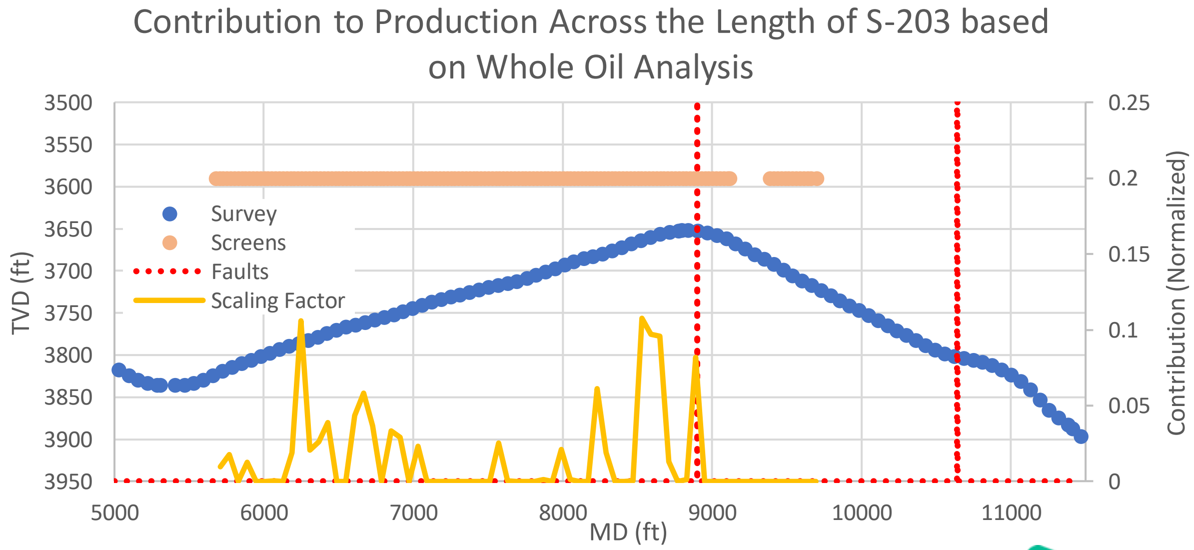
Hilcorp Milne Point S-203: Mapping Oil Quality and Production



- VAS was used on S-203 to evaluate changes in oil quality in the Ugnu across three fault blocks
- Middle fault block contains oil of significantly lower quality
- Strong correlation between low oil quality and methyl ethyl ketone (MEK), aerobic biodegradation product of butane
- Concentration of MEK in middle fault block ~2 times greater than first fault block
- Water may be migrating along faults

- A whole oil sample from production was analyzed
- Chemical signatures from oil sample were compared to S-203 sealed at well cuttings to model contribution to production across the length of the competed borehole (Scaling Factor)
- Model predicts no production in middle fault block; ~40% of the length of the completed lateral contributes to production



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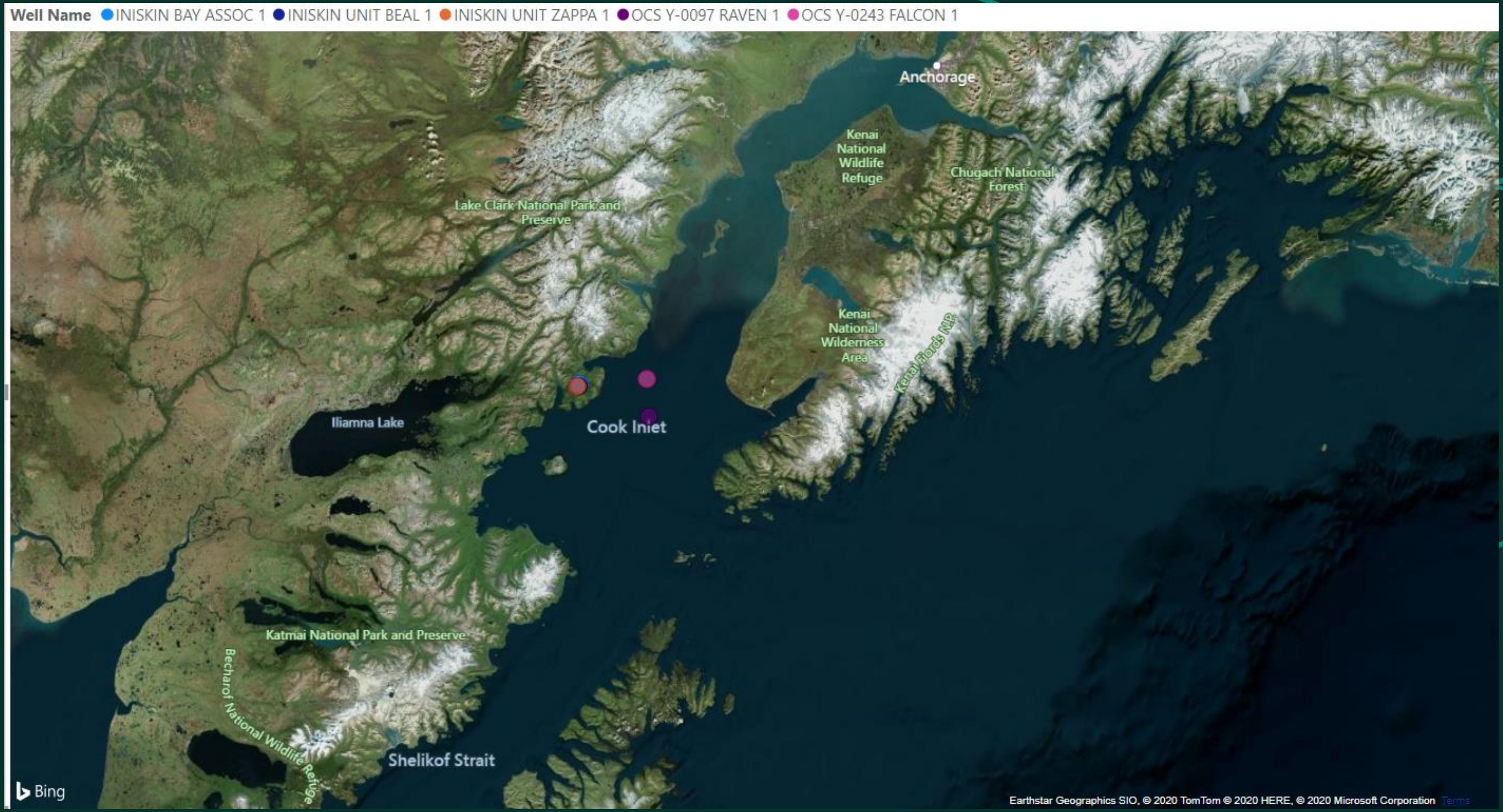
Cook Inlet Study Area



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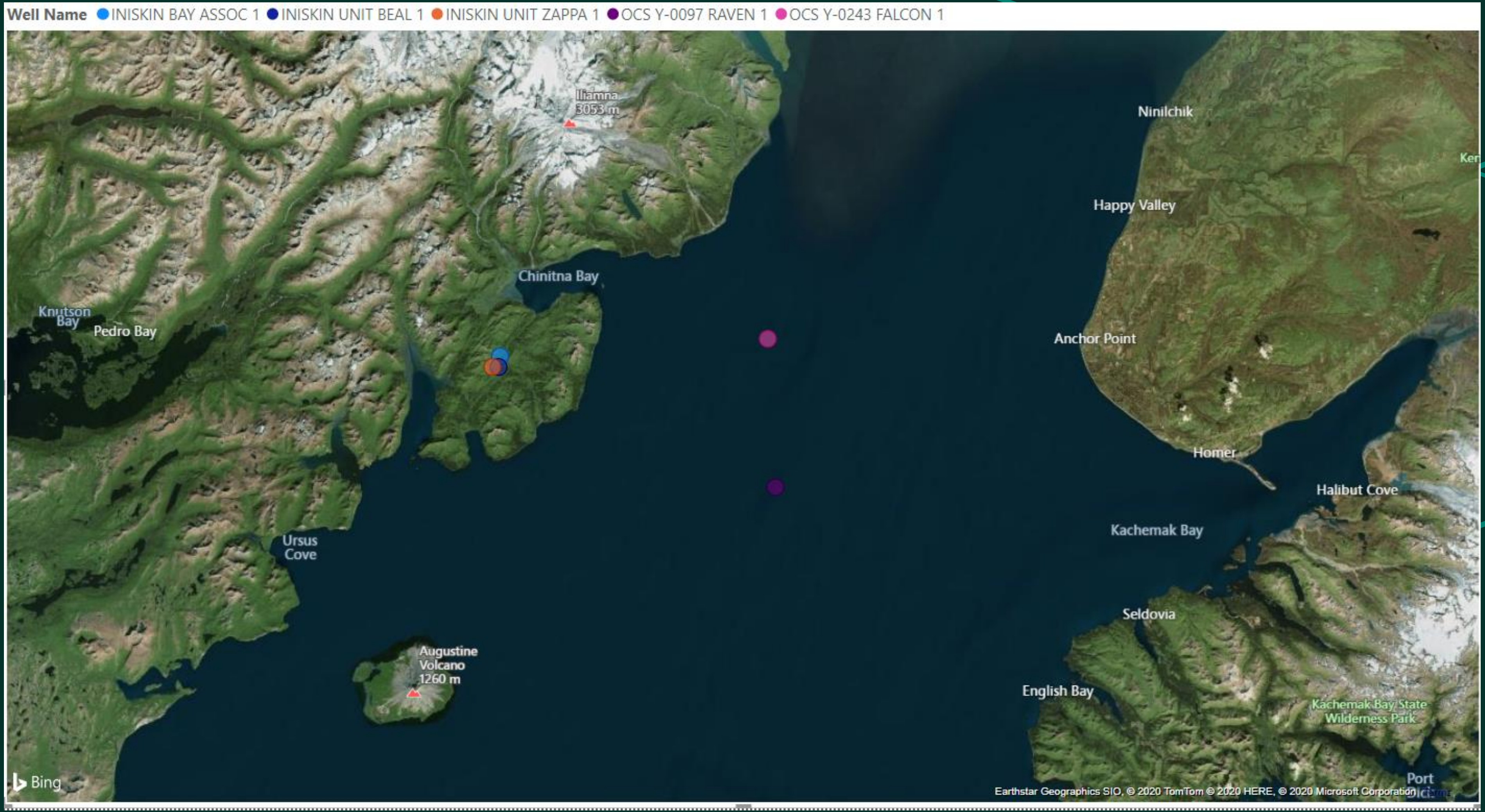
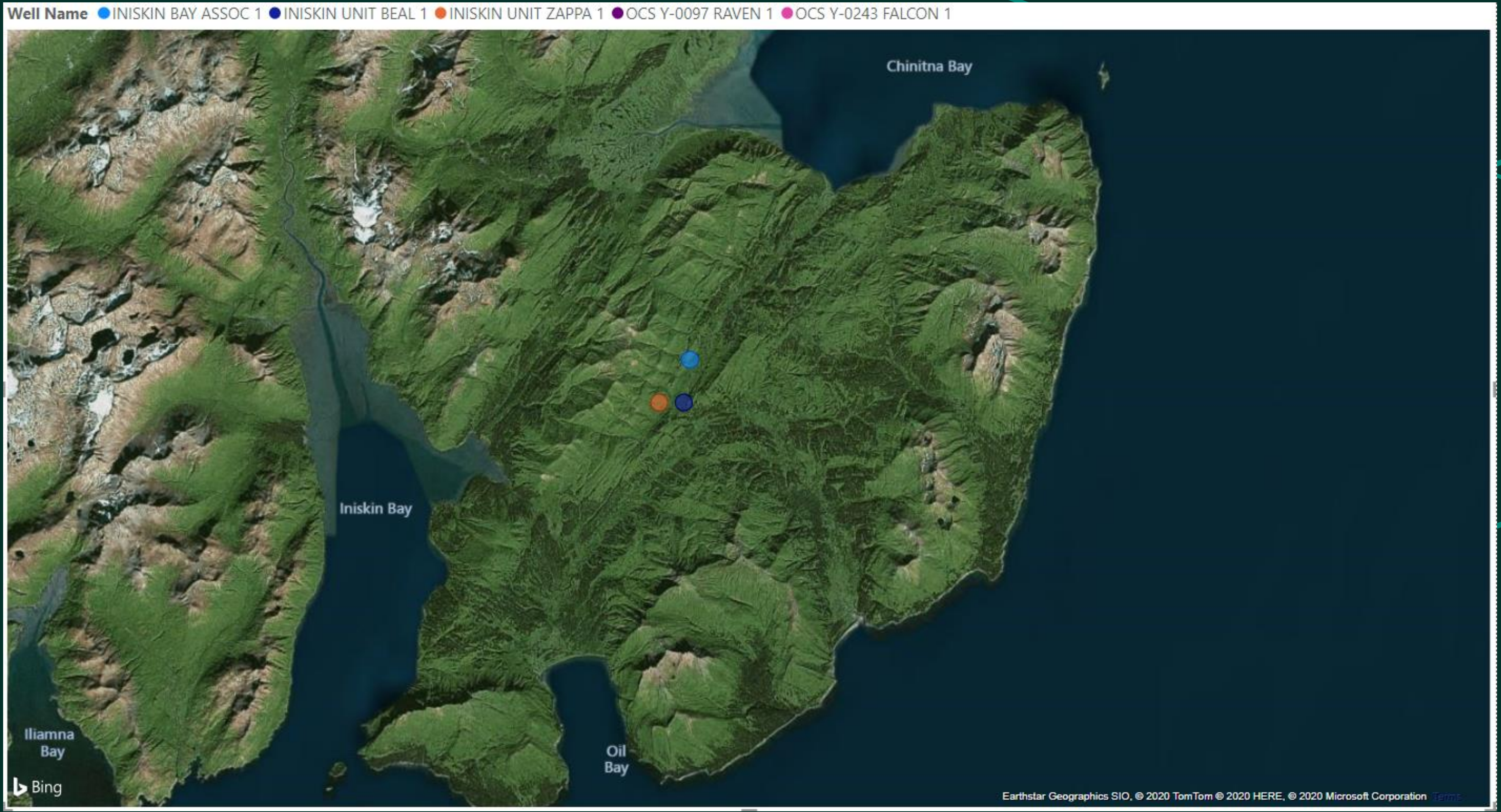


Cook Inlet Study Area, Wells of Interest



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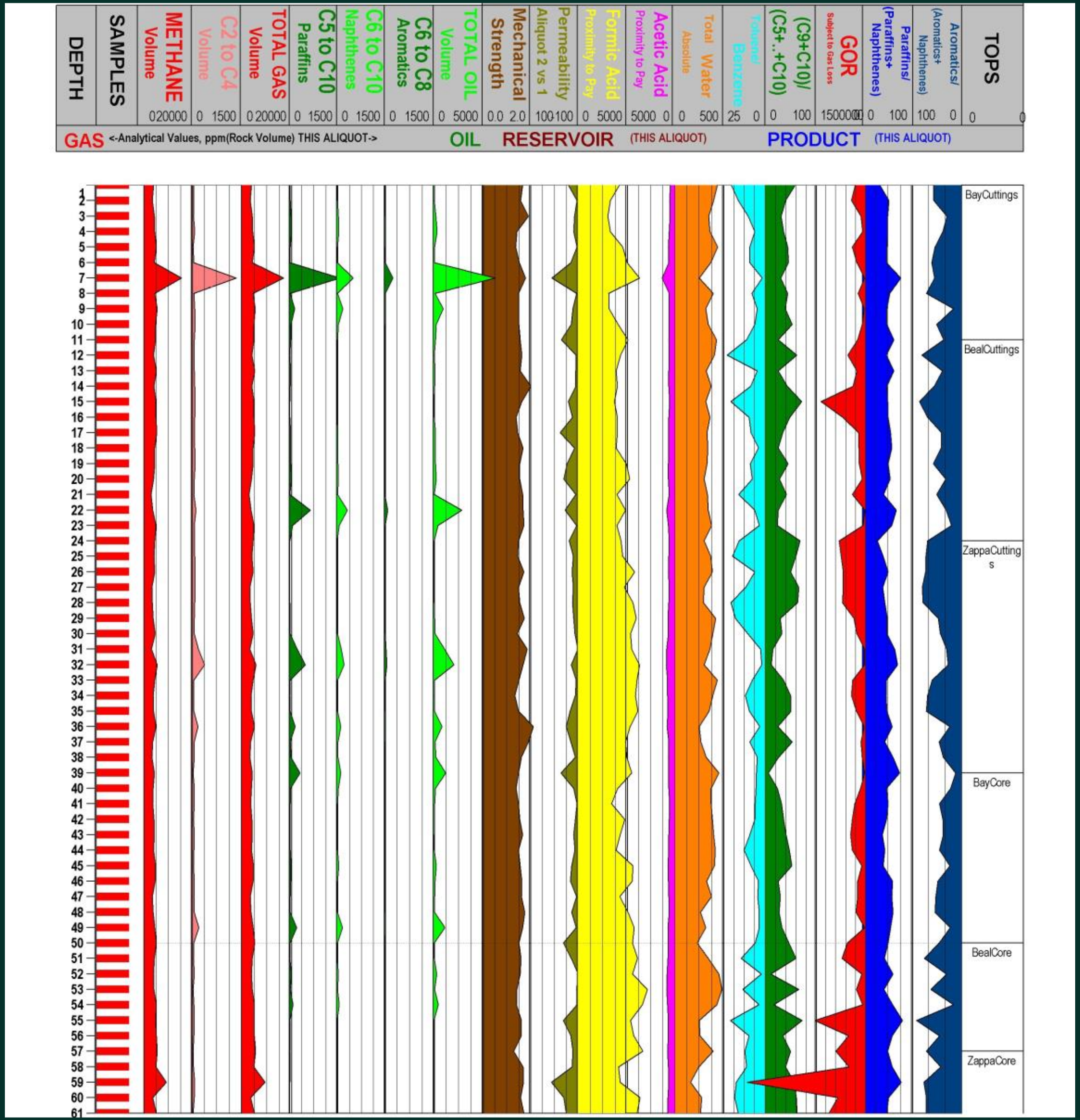
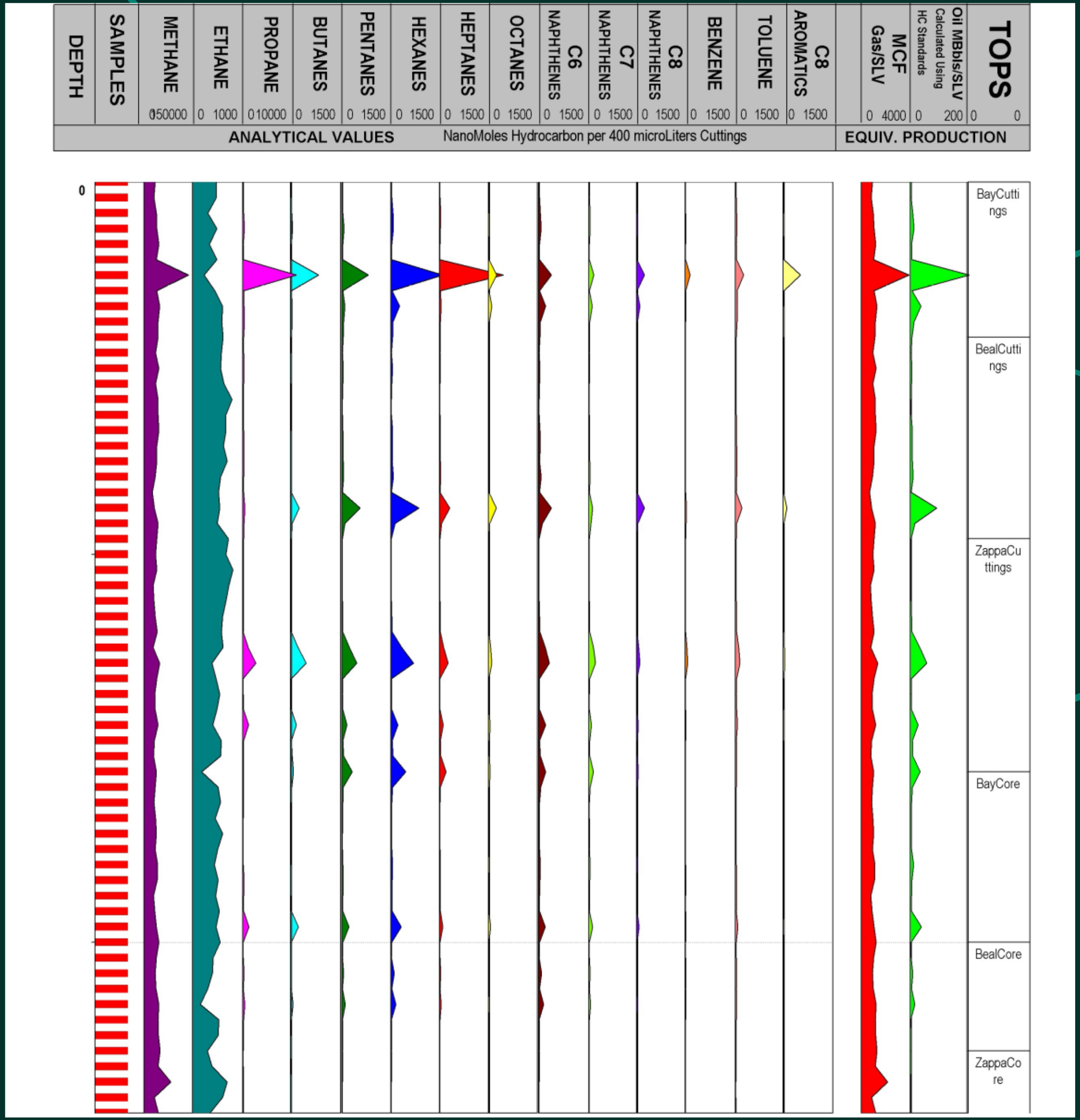
61 samples, a combination of cuttings and core chips from the three wells in the study area were submitted for VAS analysis as lab loaded samples

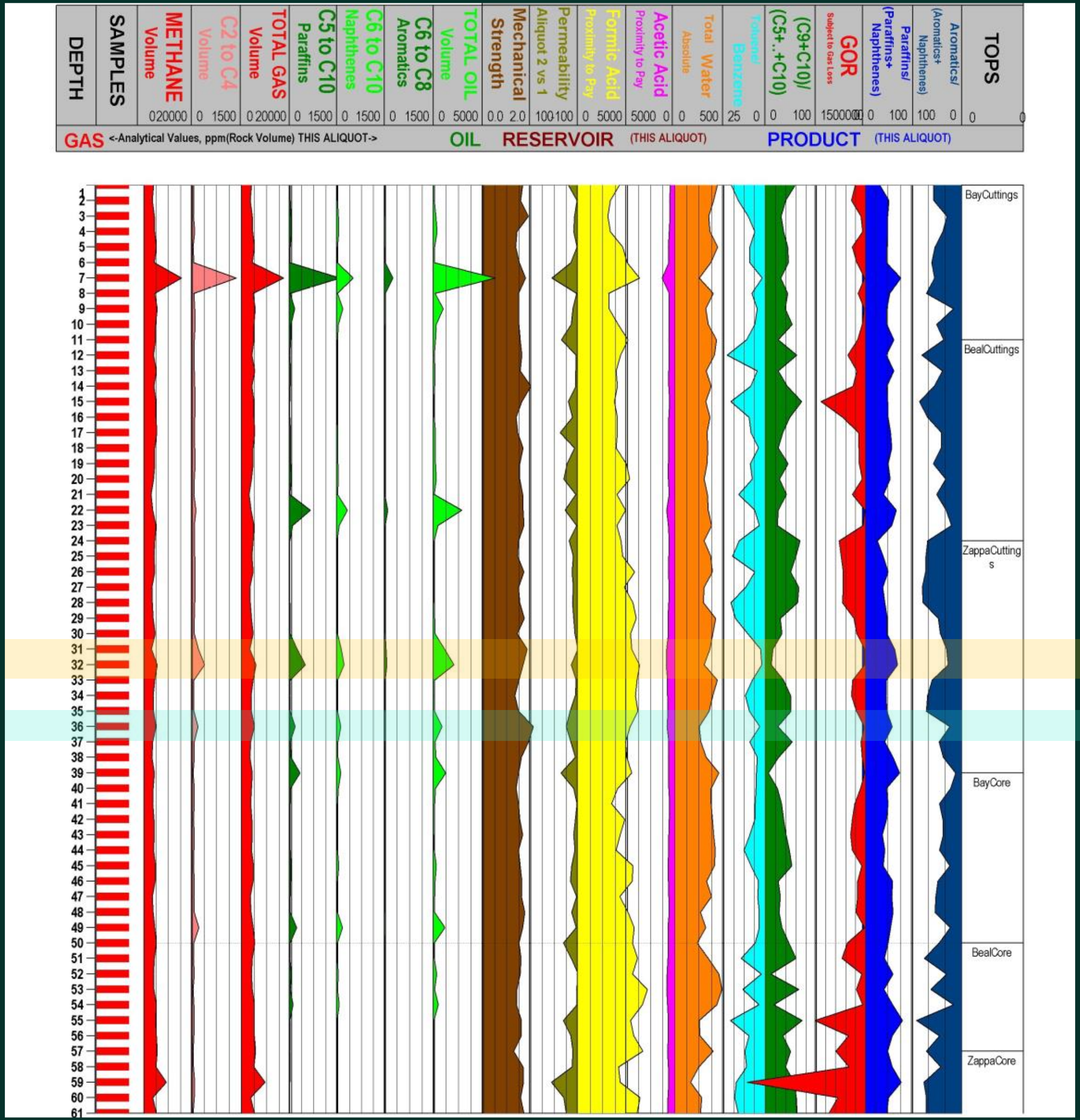
Historical well reports on file with the GMC/AOGCC were reviewed for some additional context given the point analysis nature of the work

Historically wells are known to have a gas/gas condensate resource (clear liquids) and a green high gravity oil

IBA 1 completed 1939, Beal in 1955, and Zappa in 1959


DEPTH
SAMPLES
METHANE Volume
C2 to C4 Volume
TOTAL GAS Volume
C5 to C10 Paraffins
C6 to C10 Naphthenes
C6 to C8 Aromatics
TOTAL OIL Volume
Mechanical Strength
Permeability Aliquot 2 vs 1
Formic Acid Proximity to Pay
Acetic Acid Proximity to Pay
Total Water Absolute
Toluene/Benzene
(C9+C10)/(C5+..+C10)
GOR
Paraffins/(Paraffins+Naphthenes)
Aromatics/(Aromatics+Naphthenes)
TOPS
GAS <-Analytical Values, ppm(Rock Volume) THIS ALIQUOT->
OIL
RESERVOIR
(THIS ALIQUOT)
PRODUCT
(THIS ALIQUOT)
BayCuttings
BealCuttings
ZappaCuttings
BayCore
BealCore
ZappaCore


DEPTH
SAMPLES
METHANE
ETHANE
PROPANE
BUTANES
PENTANES
HEXANES
HEPTANES
OCTANES
C6 NAPHTHENES
C7 NAPHTHENES
C8 NAPHTHENES
BENZENE
TOLUENE
C8 AROMATICS
MCF Gas/SLV
Oil MBbls/SLV Calculated Using HC Standards
TOPS
ANALYTICAL VALUES
NanoMoles Hydrocarbon per 400 microLiters Cuttings
EQUIV. PRODUCTION
BayCuttings
BealCuttings
ZappaCuttings
BayCore
BealCore
ZappaCore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TOPS
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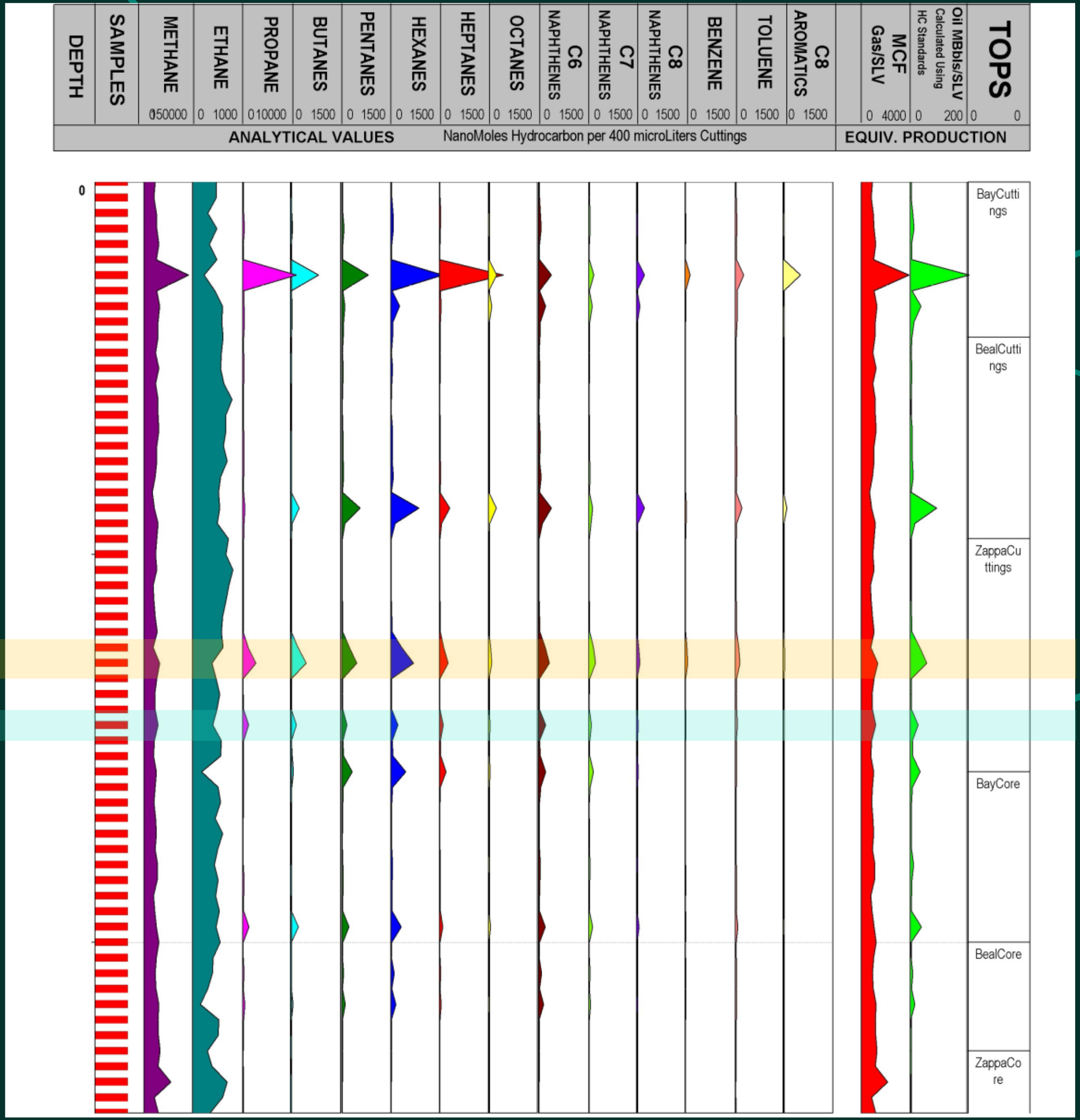
OIL
RESERVOIR (THIS ALIQUOT)
PRODUCT (THIS ALIQUOT)
BayCuttings
BealCuttings
ZappaCuttings
BayCore
BealCore
ZappaCore


DEPTH
SAMPLES
METHANE
ETHANE
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ANALYTICAL VALUES
NanoMoles Hydrocarbon per 400 microLiters Cuttings
EQUIV. PRODUCTION
BayCuttings
BealCuttings
ZappaCuttings
BayCore
BealCore
ZappaCore

Samples in Zappa well indicated in orange are tight samples that appear to have retained significant quantities of apparently unfractionated resource in the cemented calcite (5520 and 5900)

Sample in Zappa well indicated in blue is silt stone with fine pyrite and this specific depth, compared to the surrounding ones on the lithology log, stringers of light green-gray claystone. There is some potential evidence that this depth may be either slightly fractionated or is from a different resource than the shallower samples.

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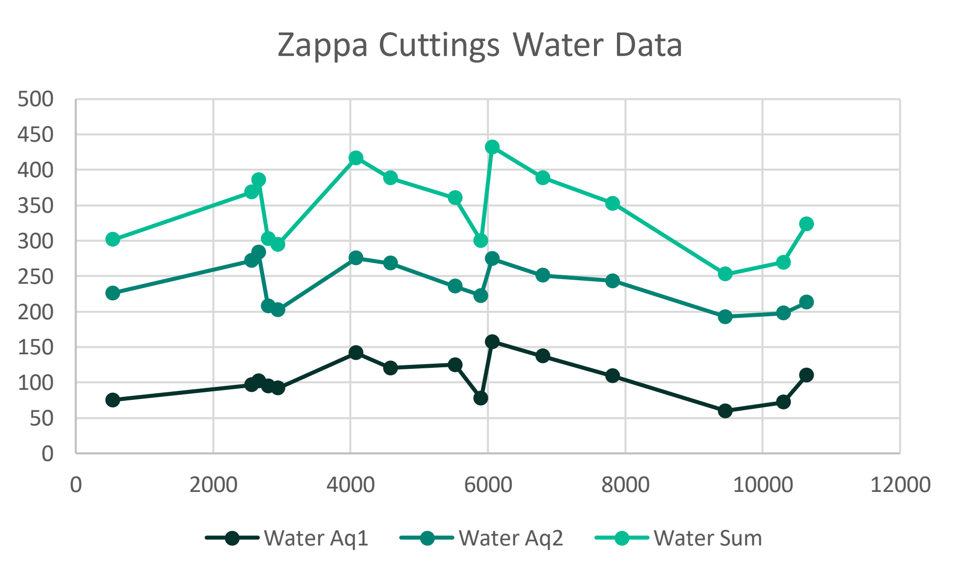

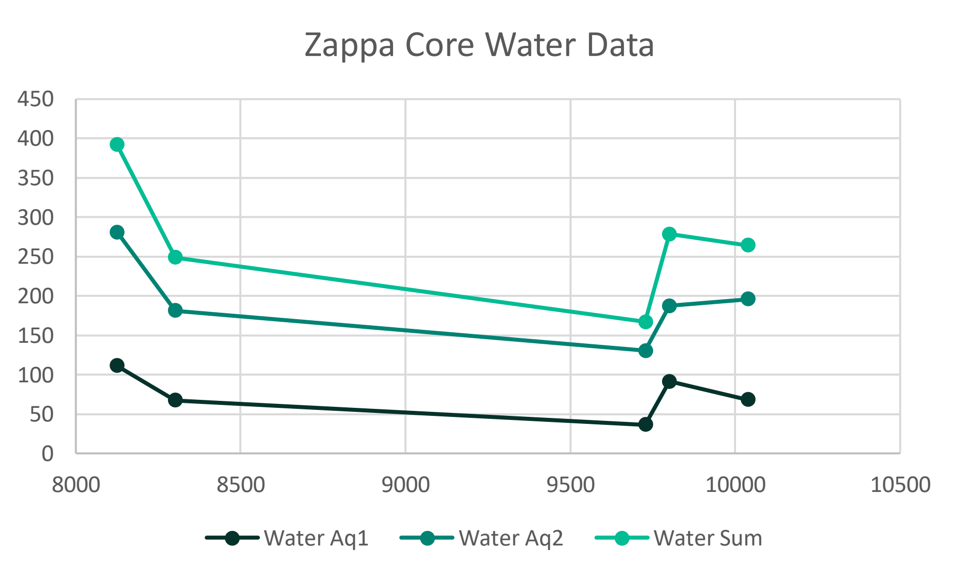

Water data can be used to understand volumes of water present in the rock and where in the rock the water is present. Aliquot 1 water responds like "bulk" water and is likely water associated with larger pore spaces with diameters down to approx. 4 nm and larger. The Aliquot 2 water is "tight" water and is likely water tightly bound to surfaces and rocks (like water bound to clay) and in smaller pores with diameters of approximately 1.5 nm to 4 nm.

Zappa Cuttings

Depth	oil mbbl slv 100 feet drainage radius 4500 foot lateral	mcf gas slv 100 feet drainage radius 4500 foot lateral	C1/C5	C1/C3	Paraffin C#	Liquids C#	% Aro	% Para	% Naph	Psuedo B	Toluene/Benzene	Puesdo A
540	1.263049	997.1227623	24165.51	555.3487	8.626378129	8.20518	25.65849	47.21405	27.12746	5.862045624	15.53807	0.234041
2560	1.249131	906.4253586	17977.51	454.1808	8.393050531	7.898194	31.8397	46.44898	21.71132	5.468548131	19.32268	0.213871
2660	1.505197	1005.752097	9245.836	369.515	7.916847535	7.569063	34.18402	45.92916	19.88682	5.343051385	6.112553	0.456073
2800	1.041147	700.9109125	21249.78	275.177	8.564080462	7.992512	35.57116	45.89918	18.52967	6.862531222	11.58518	0.406323
2940	1.09513	766.5977977	17593.22	263.3329	8.453042421	7.926408	35.16186	46.87896	17.95918	6.085768192	20.34968	0.217402
4080	2.448354	844.875865	3867.328	492.3338	7.410431085	7.200634	23.75275	44.79477	31.45247	2.685811977	17.76798	0.100935
4580	3.911033	1005.718334	2684.434	1167.073	7.394913679	7.275875	19.35729	47.64968	32.99303	2.43491568	10.17552	0.10616
5520	30.7902	715.0185644	125.1235	26.27493	6.509221746	6.690492	11.30056	58.86728	29.83217	0.827141775	2.580351	0.113691
5900	55.97486	1290.56043	106.0561	18.22237	6.333993663	6.540317	8.693749	64.83384	26.47242	0.526320103	2.042861	0.090433
6060	2.596866	996.8044425	5015.804	1264.833	7.47960162	7.319141	30.61511	41.40431	27.98058	4.281871078	7.652928	0.26939
6800	1.955215	824.461595	5854.361	1206.491	7.912694978	7.6267	31.22643	45.68446	23.08911	5.129624911	11.8046	0.231204
7820	3.155084	865.5436572	3954.47	687.0447	7.882150017	7.630606	31.91888	45.77845	22.30267	5.314373393	9.29902	0.267894
9460	25.98502	1118.977975	294.6439	37.70379	6.957484924	6.98514	8.348744	59.13073	32.52053	0.545365422	3.065769	0.083744
10300	5.924427	783.4067674	1937.255	604.466	8.028520572	7.874439	14.342	56.20828	29.44972	1.723375675	8.9477	0.088839
10640	7.14255	716.4319416	746.4744	266.3566	7.015276524	7.061299	13.39216	58.08163	28.52621	0.914078058	4.672092	0.097086

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Zappa Core

Depth	oil mbbl slv 100 feet drainage radius 4500 foot lateral	mcf gas slv 100 feet drainage radius 4500 foot lateral	C1/C5	C1/C3	Paraffin C#	Liquids C#	% Aro	% Para	% Naph	Psuedo B	Toluene/Benzene	Puesdo A
8125	1.36783	1227.814	12078.06	1198.117	7.865835	7.592199	32.81148	46.38428	20.80424	6.131909	12.06301	0.199884
8302	2.198119	1078.866	4888.283	2601.623	7.531086	7.460591	12.90662	61.95146	25.14191	1.158313	11.00331	0.048351
9728	0.584449	2082.506	68902.78	1571.032	8.227693	7.877074	25.96896	65.83662	8.194428	3.00409	17.21619	0.084313
9800	0.948968	783.3	17999.32	520.516	8.360909	7.996481	25.14684	57.02881	17.82435	2.747011	18.12305	0.128634
10039	1.018346	1118.873	25407.32	2023.099	8.440843	8.031012	26.10956	55.0907	18.79973	3.792723	15.90039	0.183867

Calculations

All values were calculated with the sum all data

C1/C5 ratio of methane to pentanes
C#= (number of carbons * moles of compound +….. For all the molecules in the class or combination of classes)/sum of all moles considered)
Pseudo B (similar to Thompson B parameter) =toluene/heptanes
Pseudo A (similar to Thompson A parameter)=benzene/hexanes

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Thoughts/Summary:

C1/5 values close to 100 and less than 1000 are empirically what oil in legacy materials looks like. It is worth noting that these values are occurring in the high oil volume response samples. Other signatures such as the Toluene/Benzene are similar to what would be observed in produced crude, these values are typically 3 or less. Enhanced toluene/benzene ratios greater than 3 could come from one of three scenarios, liquids migration conduit, evaporative fractionation, and/or water washing. Normally, we would interpret this enhanced signature as liquids migration but given other signatures here this appears to likely be an effect from evaporative fractionation (less volatile toluene is left behind while the more volatile benzene continues in the gas). This explanation seems likely given the pseudo B and to a lesser extent pseudo A parameters suggest evaporative fractionation in the low response samples compared to the high response samples in Zappa. The same workup of the data from the other wells revealed a similar trends. Higher C1/C5 ratios indicate the presence of either water or gas (there is not enough contrast to make a call with the water data available directly), based on the historical documents this is likely indicative of gas. The distribution of the C#s and the family compositions also suggest extensive fractionation in the low response samples, with the heavier/less volatile species being left behind during gas migration. With the distribution of samples here it is difficult to say anything more than this in terms of how the fractionation may have happened and where the resource may ultimately be located.

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Notes:
It can be reasonably asked are these fractionation effects due to the age of the samples vs representing subsurface effects/distributions. It does not appear that this is the case. First, this effect of enhanced toluene to benzene is not a common effect in our overview of legacy samples of a similar age in AK, see Square Lake 1 (it has been observed in Fish Creek 1, though this is consistent with the Torok in this region containing thin sandstones and siltstone beds that are thought to function as migration conduits). Second, when examining the Zappa well cuttings the ratio of C3/C4 does not show any notable patterns of C3 loss compared to C4 as a function of total oil response. An enhancement of C4 relative to C3 would likely be encountered if fractionation were occurring due to evaporative processes as a function of the age of the unpreserved samples.

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