

Virtually Eliminate Dry or Sub-Economic Wells in Over-Pressured and Normal-Pressured Fields: Jonah Field and Anadarko Basin Case Studies*

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Abstract

In the Jonah field in the Green River Basin in Wyoming it was realized, through the drilling of multiple sub-economic wells, that over-pressured zones were critical to gas storativity, porosity preservation, and field economics while normal pressured areas were sub-economic. The question became how to differentiate prospective over-pressured areas from sub-economic areas. An ultrasensitive surface hydrocarbon survey was employed to map areas of elevated hydrocarbon richness, enhanced porosity, and over-pressured zones. A direct correlation was found between the survey hydrocarbon probability values and OGIP (original gas in place) times reservoir pressure. The difference in geochemical signatures at over-pressured versus normal-pressured wells was related to intensity and not composition. Thus, the ultrasensitive hydrocarbon survey was able to map the areas of over-pressure versus normal-pressure, which was useful in mapping field prospectivity. The Anadarko basin, in western Oklahoma, contains numerous charged horizons (oil and gas) throughout the Paleozoic section, including carbonate, sand and shale intervals. Of particular interest are over-pressured Pennsylvanian Red Fork Channel sands. This geochemical survey technique was utilized to differentiate and map Red Fork fluvio-deltaic sands. Analysis of the survey samples showed strong correlation between effective reservoir porosity, net pay thickness, and the surface geochemical expression. A plot of phi-h versus surface probability values resulted in an r² value of 0.87. The data correctly differentiated dry wells, sub-economic wells, and productive wells. Twenty-two wells were drilled on positive post-survey hydrocarbon anomalies. Twenty-one wells were commercial and one was dry. Of eight wells drilled on dry survey anomalies, five were plugged and abandoned, and one was sub-economic. Thus, the two case studies show that ultrasensitive hydrocarbon surveys can be used effectively to define field sweet spots and optimize field production.

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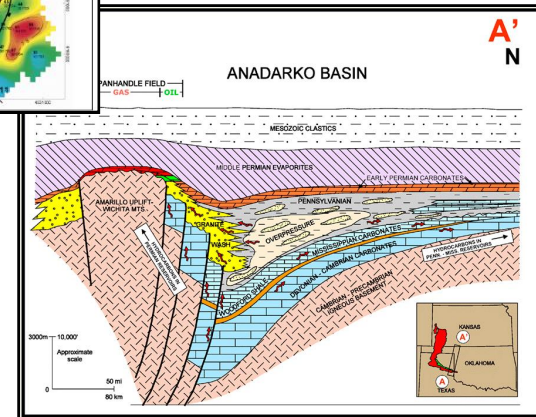
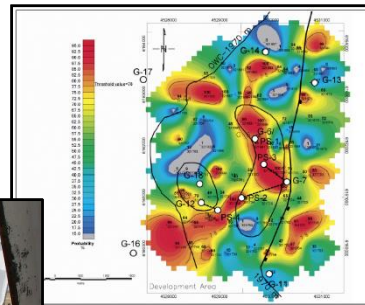
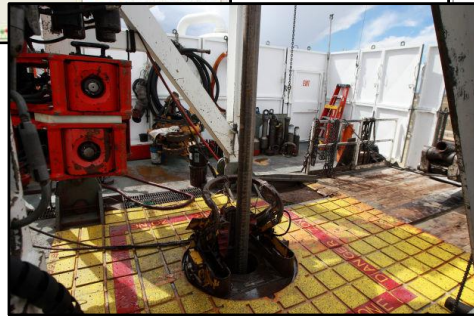
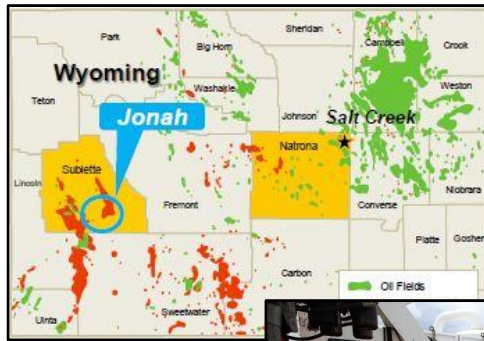
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by Rick Schrynmeeckers
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Seismic Data . What's in the Can

Seismic interpretation is the foundation of traditional exploration

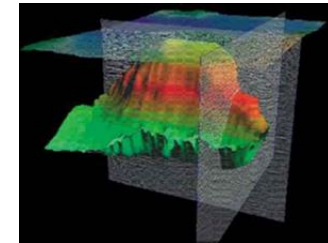
- " Finds structures that could trap oil or gas
- " Cannot provide reliable information on trap content*
- " A fundamental weakness of traditional exploration

Seismic images are somewhat akin to providing cans without labels

- " Who knows what's in the can?
- " Result is many dry or marginal wells being drilled

* Schlumberger *Oilfield Review* Summer 2009 %Basin and Petroleum System Modeling

3D Seismic Image



What's in the Can?

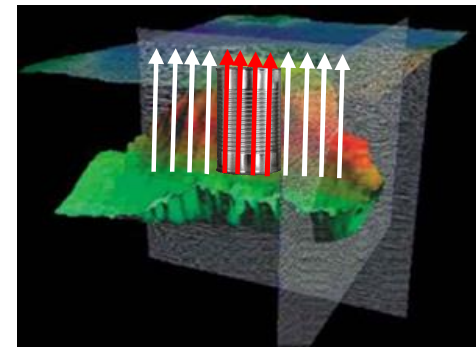
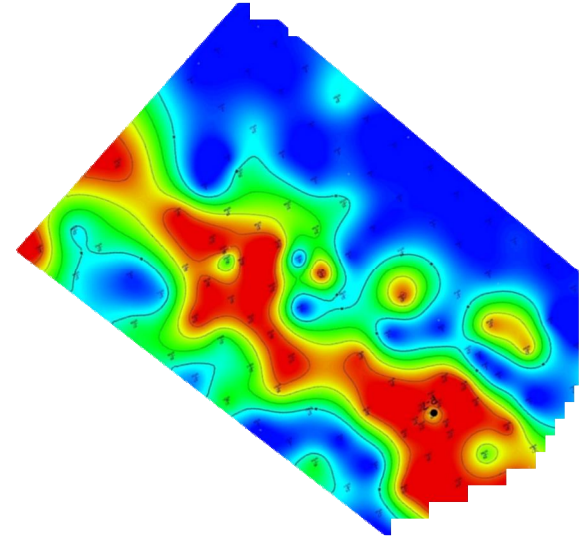


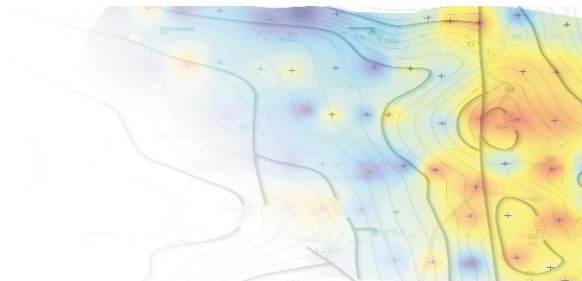
Surface Hydrocarbon Mapping

The Amplified Geochemical Imaging surface survey tells you:

- “ Is the can empty? Should you drill there?
- “ Does it have hydrocarbons?
- “ If so, what kind of hydrocarbons?
- “ Do you have multiple petroleum systems?
- “ What are the boundaries of potential accumulations?

Seismic data can't answer these important questions

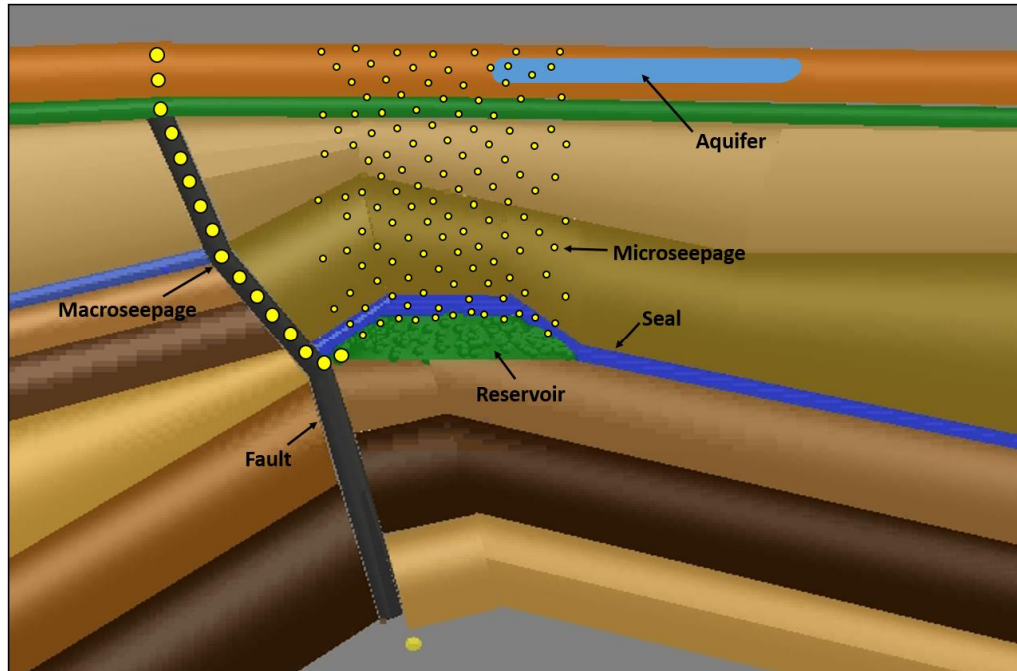




The Science Behind the Technology

Vertical Migration

Vertical migration of microseepage



**Microseepage
signal affected by:**

- ” Pressure (P)
- Porosity (θ)
- Net Pay (h)

Macroseepage:

- ” Detectable in visible amounts
- ” Pathway follows discontinuities
- ” Offset from source/reservoir

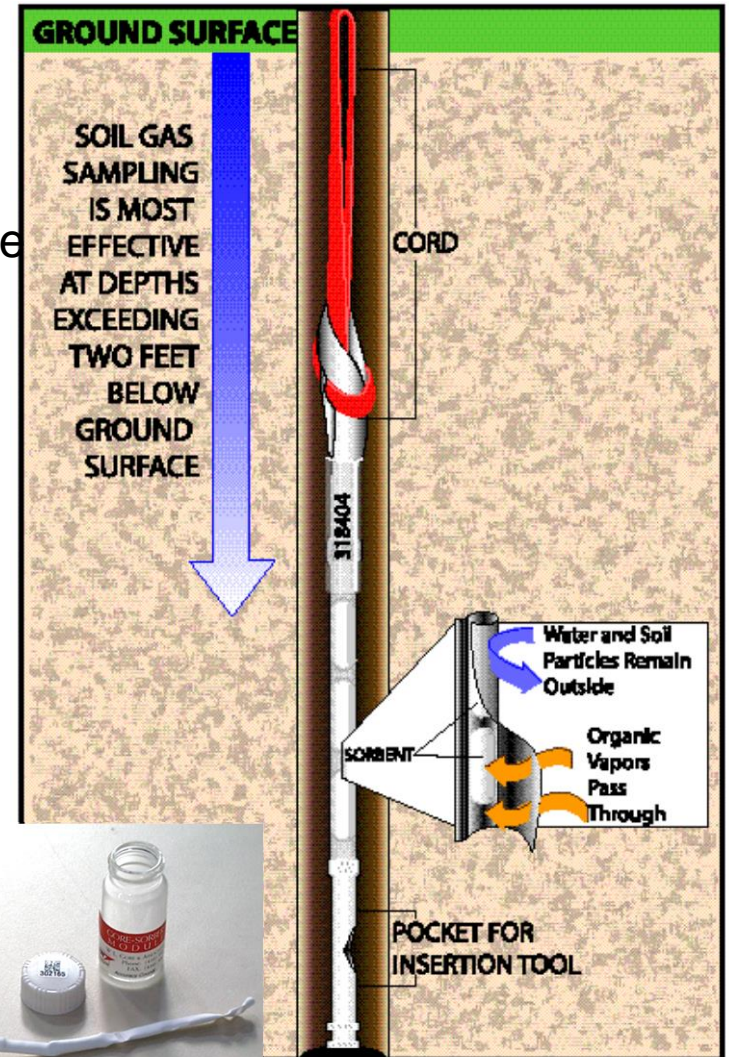
VS

Microseepage:

- ” Detectable in analytical amounts
- ” Pathway is nearly vertical
- ” Overlie source/reservoir

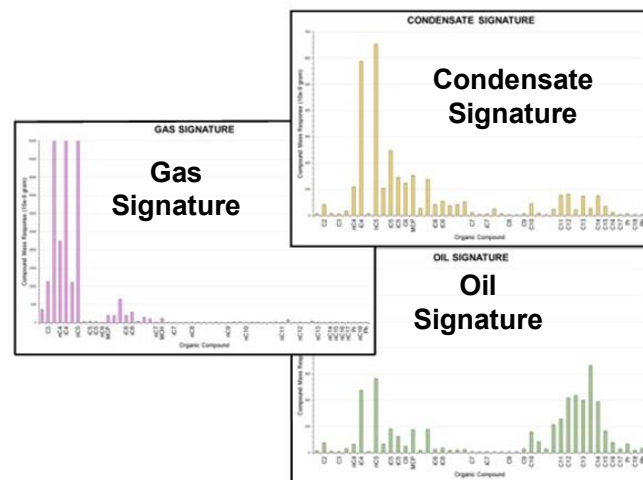
Modules

- “ Patented, passive, sorbent-based
 - . Chemically-inert, waterproof, vapor permeable
 - . Direct detection of organic compounds
 - . Sample integrity protected
- “ Engineered sorbents
 - . Consistent sampling medium
 - . Minimal water vapor uptake
- “ Time-integrated sampling
 - . Minimize near-surface variability
 - . Maximize sensitivity (up to C20)
 - . Avoids variables inherent in instantaneous sampling
- “ Duplicate samples



Analytical Compound List: C₂ - C₂₀

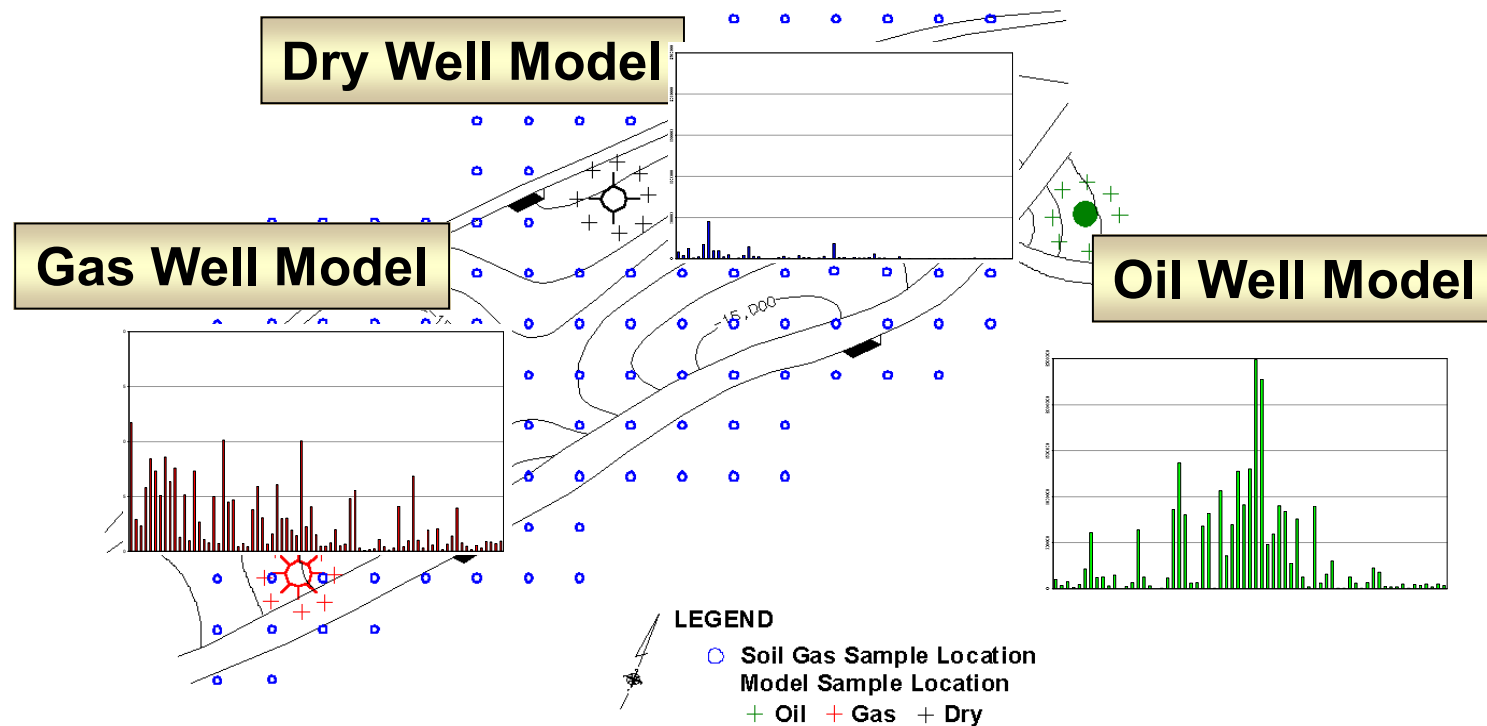
Typical Petroleum Constituents Hydrocarbon number in ()			
Normal Alkanes	Iso-alkanes	Cyclic Alkanes	Aromatics and PAH*
Ethane (2) Propane (3) Butane (4) Pentane (5) Hexane (6) Heptane (7) Octane (8) Nonane (9) Decane (10) Undecane (11) Dodecane (12) Tridecane (13) Tetradecane (14) Pentadecane (15) Hexadecane (16) Heptadecane (17) Octadecane (18)	2-Methylbutane (5) 2-Methylpentane (6) 3-Methylpentane (6) 2,4-Dimethylpentane (7) 2-Methylhexane (7) 3-Methylhexane (7) 2,5-Dimethylhexane (8) 3-Methylheptane (8) 2,6-Dimethylheptane (9) Pristane (19) Phytane (20)	Cyclopentane (5) Methylcyclopentane (6) Cyclohexane (6) cis-1,3-Dimethylcyclopentane (7) trans-1,3-Dimethylcyclopentane (7) trans-1,2-Dimethylcyclopentane (7) Methylcyclohexane (7) Cycloheptane (7) cis-1,3/1,4-Dimethylcyclohexane (8) cis-1,2-Dimethylcyclohexane (8) trans-1,3/1,4-Dimethylcyclohexane (8) trans-1,2-Dimethylcyclohexane (8) Ethylcyclohexane (8) Cyclooctane (8) Propylcyclohexane (9)	Benzene (6) Toluene (7) Ethylbenzene (8) m,p-Xylenes (8) o-Xylene (8) Propylbenzene (9) 1-Ethyl-2/3-methylbenzene (9) 1,3,5-Trimethylbenzene (9) 1-Ethyl-4-methylbenzene (9) 1,2,4-Trimethylbenzene (9) Indane (9) Indene (9) Butylbenzene (10) 1,2,4,5-Tetramethylbenzene (10) Naphthalene (10) 2-Methylnaphthalene (11) Acenaphthylene (12)
Byproduct / Alteration and Other Compounds			
Alkenes	Aldehydes	Biogenic	NSO* and Other Compounds
Ethene (2) Propene (3) 1-Butene (4) 1-Pentene (5) 1-Hexene (6) 1-Heptene (7) 1-Octene (8) 1-Nonene (9) 1-Decene (10) 1-Undecene (11)	Octanal (8) Nonanal (9) Decanal (10)	alpha-Pinene beta-Pinene Camphor Caryophyllene	Furan 2-Methylfuran Carbon Disulfide Benzofuran Benzothiazole Carbonyl Sulfide Dimethylsulfide Dimethyldisulfide

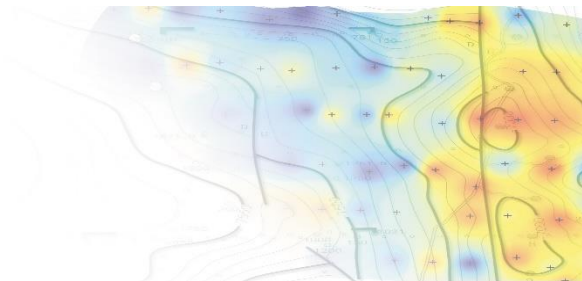


Example Fingerprints

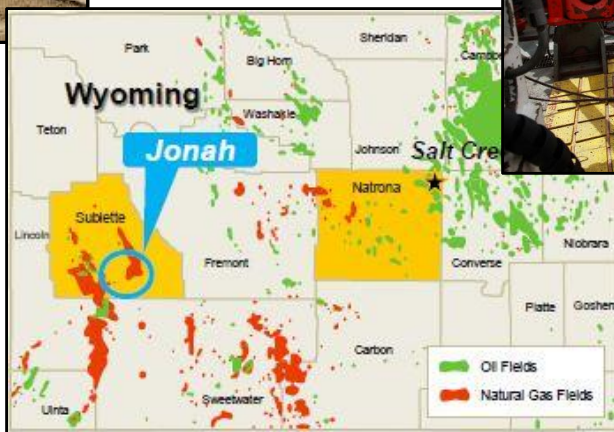
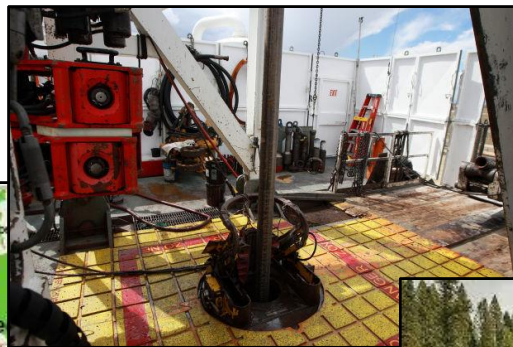
Surveys Design

Model development..

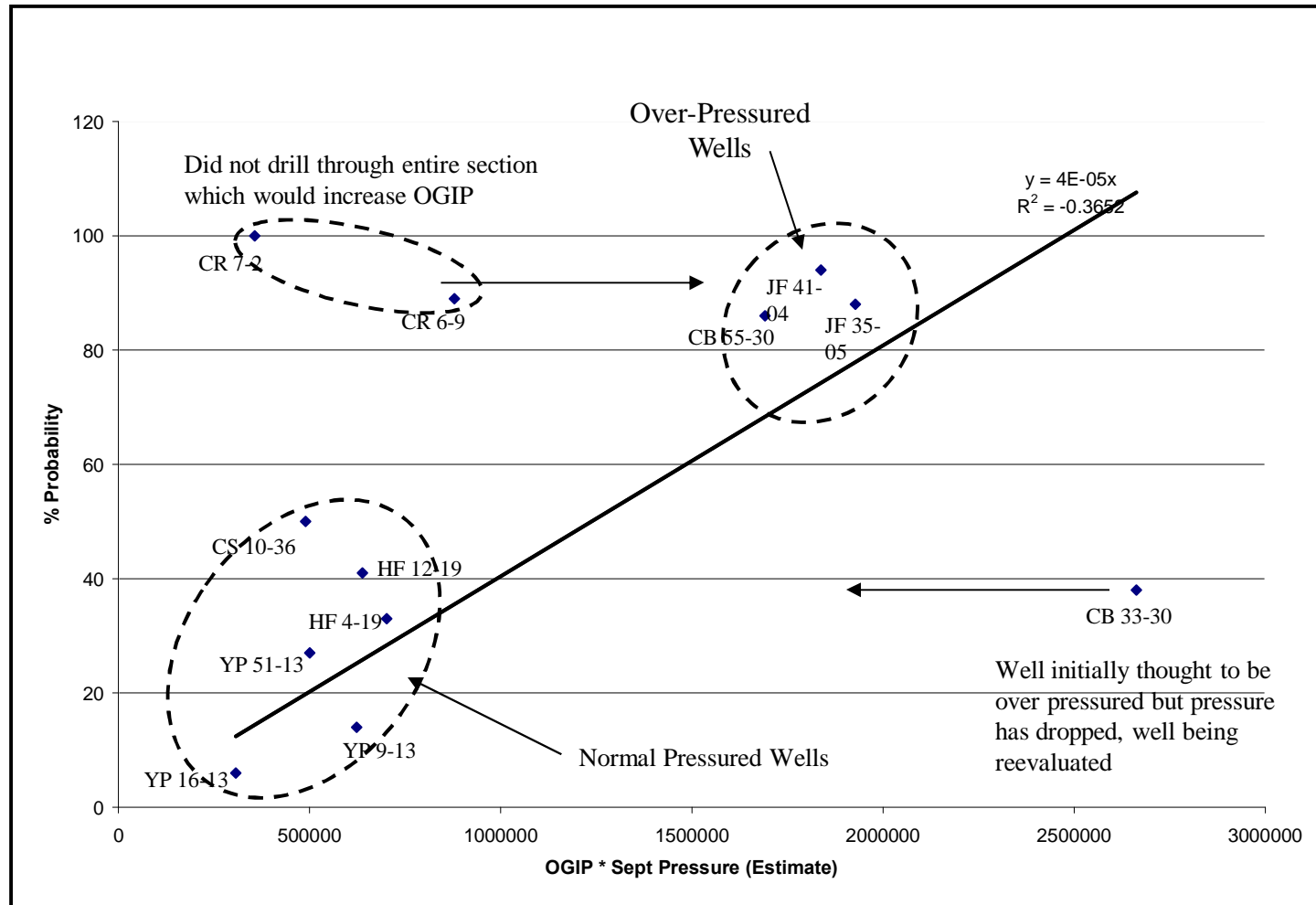


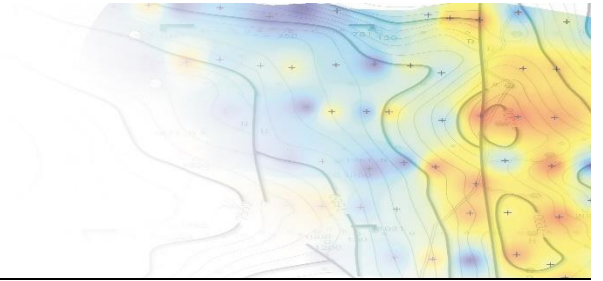


The Jonah Field Case Study

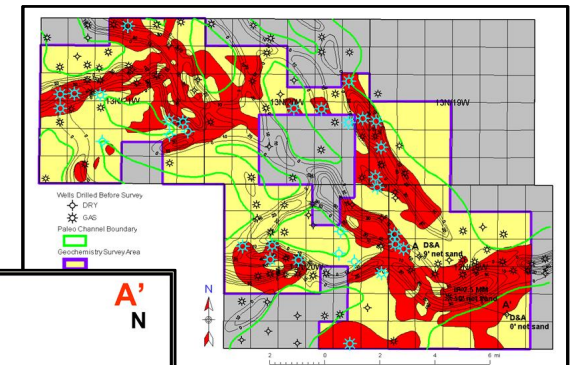
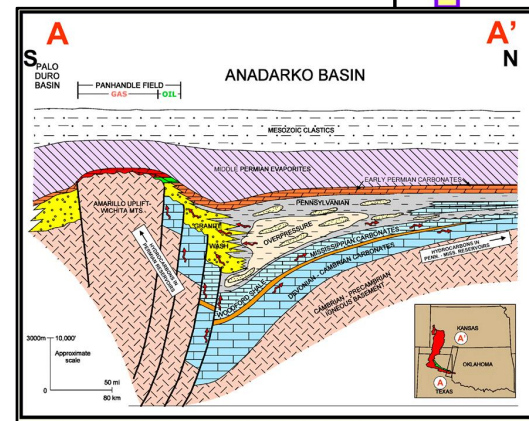
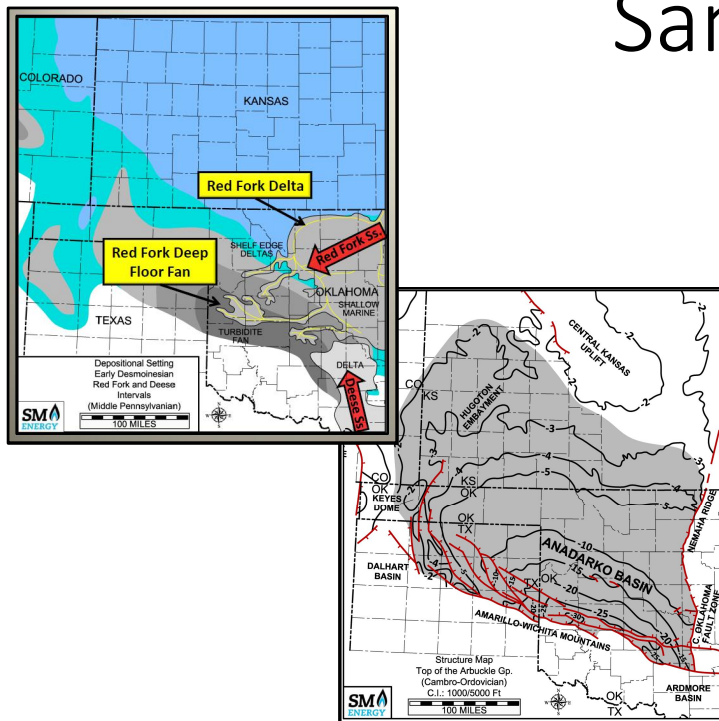


Jonah Field Survey Results





The Anadarko Basin Channel Sand Project



Survey Information



Study Objectives

- “ Surface geochemical sample acquisition from a series of surveys located in southwestern Custer County and southeastern Roger Mills County of western Oklahoma, along the axis of Anadarko Basin deep
- “ Exploration target: gas from Pennsylvanian Red Fork sands at moderate depth (~14,000q)
- “ Distinguish gas condensate signature from other charged sections, and map Red Fork sand channel reservoirs

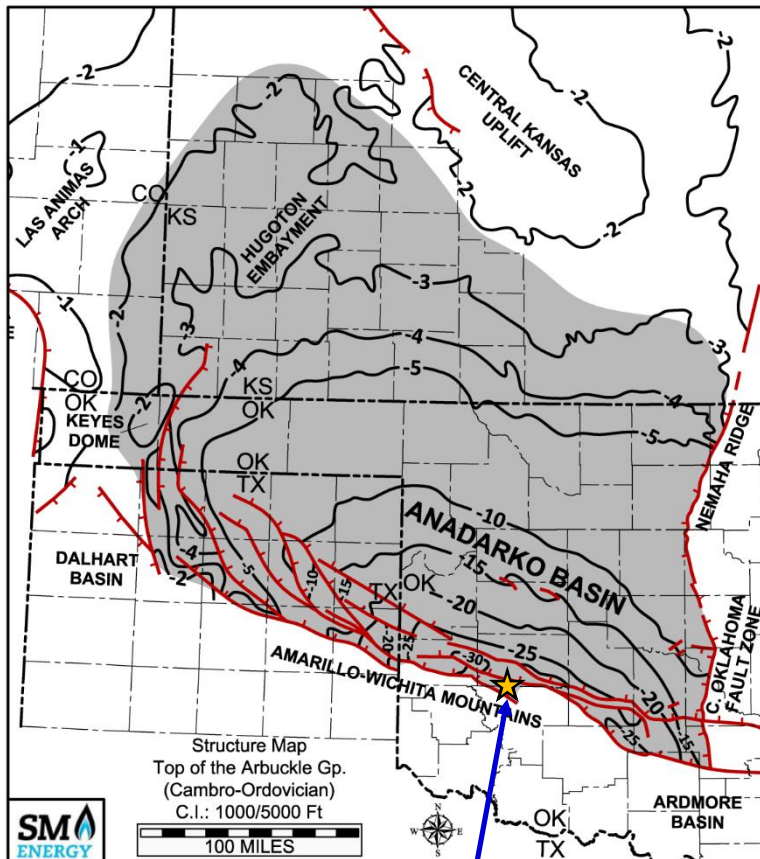
Survey Design

- “ Scope of work: nine geochemical surveys conducted over three years; number of samples: >2,500
- “ Sample resolution: 600q. 800qgrid (reconnaissance) with select 200q. 400qgrid (infill), over 120 mi² area

Key Points

- “ Basin is ~24,000qdeep in vicinity of geochemical surveys: appreciable section below target depth
- “ Anadarko Basin includes numerous charged horizons (oil and gas) throughout the Paleozoic section, including carbonate, sand and shale intervals (e.g., Upper Devonian Woodford Shale)
- “ Charged Pennsylvanian Granite Wash and Missourian series Cleveland Sand plays are located in the same area
- “ Red Fork gas sands are over-pressured, favoring surface geochemical signature strength

Basin Depth



Survey area

Depth structure of the Anadarko Basin to Top Arbuckle Group (undivided Cambro-Ordovician). Basin deep is along the southern edge of the basin, approaching ~40,000ft to basement.

Six generalized petroleum systems in the basin:

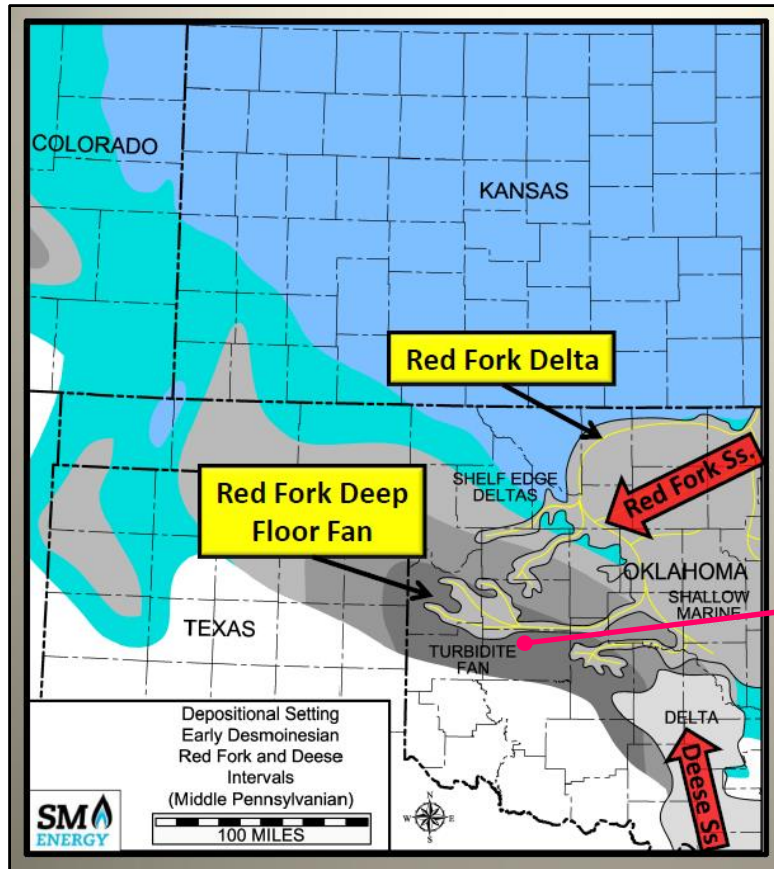
- " Permian carbonates and granite wash
- " Pennsylvanian fluvio-deltaic sands, marine sands and limestone (including Red Fork sand)
- " Mississippian carbonates and Upper Devonian shale and chert
- " Siluro-Devonian carbonates (Hunton Group)
- " Middle / Upper Ordovician sandstones and limestones (Simpson & Viola groups)
- " Cambro-Ordovician carbonates (Arbuckle Group)

Survey target is the Red Fork of the Desmoinesian series (middle Pennsylvanian).

Depth to Red Fork gas targets in the area: ~14,000'.

From Mitchell (2012) presentation. Map adapted from Davis and Northcutt (1989).

Paleo-depositional Model

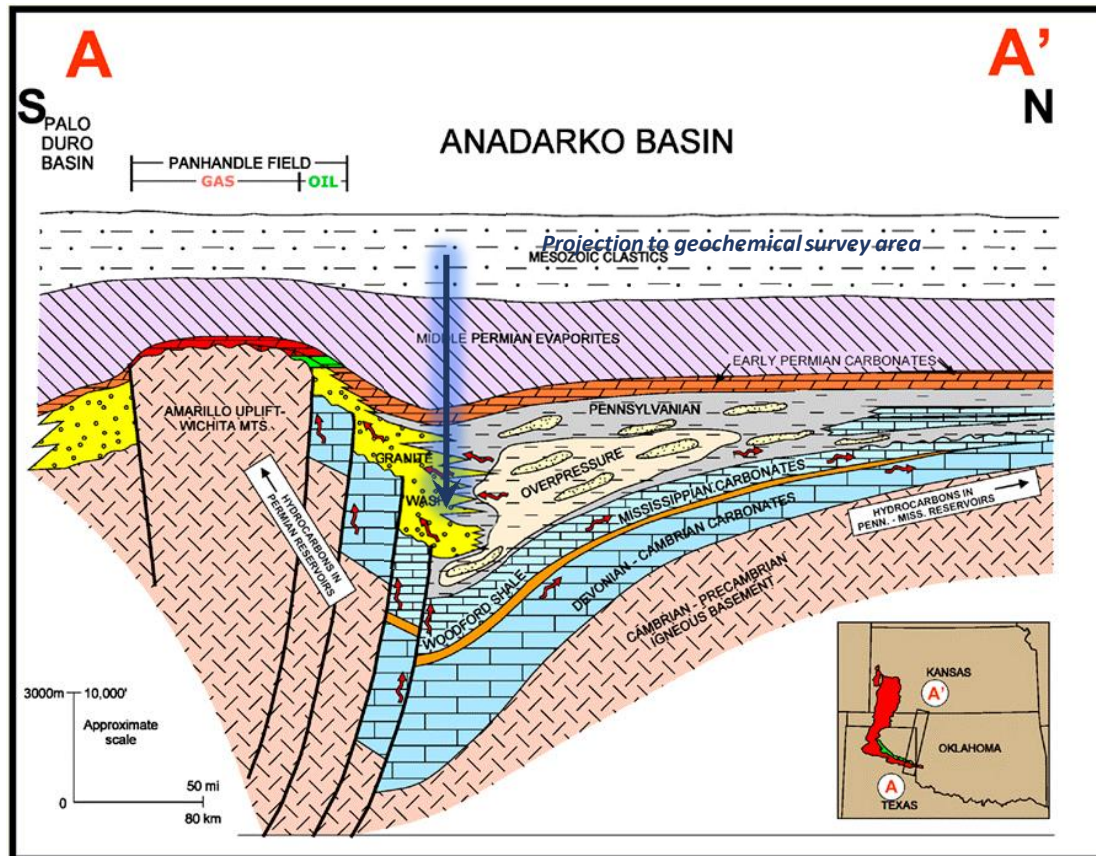


Middle Pennsylvanian Red Fork sand system in Oklahoma consists of deltaic complex to the north, with significant oil and gas production, and deep water turbidite fans and channels to the west, with over-pressured gas production from numerous fields across Roger Mills and Custer counties.

Location of geochemical surveys, in main deep water turbidite system

From Mitchell (2012) presentation. Map adapted from Adler, et al. (1971), and Andrews (1997).

Cross-section Through the Basin



Cross-section of basin from S to N, showing depth of Paleozoic section and primary petroleum production targets (Granite Wash, Mississippian limestones, Woodford Shale), as well as Red Fork sand packages in shales of the Pennsylvanian.
















The discerning factor for the Red Fork interval is over-pressured gas sands, which results in distinct surface signature of hydrocarbons (relative to other hydrostatically charged sections).

Note the presence of Permian evaporites over deeper charged sections. Microseepage is not impeded by such lithologies, even with very thick sequences involved.

From article by John Fierstien in Drilling Info magazine, 9 December 2014. Figure modified after Sorenson (2005).

Stratigraphic Column

Pennsylvanian section in western Oklahoma.

STRATIGRAPHIC CHART			
SYS.	SERIES	GROUP	UNIT
PENNSYLVANIAN	VIRGILIAN	Shawnee/Cisco	 Shawnee Wash Heebner Sh
		Douglas/Cisco	Haskell Sh  Tonkawa Ss
	MISSOURIAN	Lansing/Hoxbar	 Cottage Grove Wash
		Kansas City/Hoxbar	 Hoxbar Wash/Shale  Hogshooter Wash  Checkerboard Wash  Cleveland Wash
	DESMOINESIAN	Marmaton	 Marmaton Wash
		Cherokee	 Upper Skinner Shale  Upper Skinner Wash Lower Skinner Shale (Pink Ls Marker)  Lower Skinner Wash  Red Fork Ss & Sh
	ATOKAN	Atoka	 Atoka Wash 13 Finger Ls
	MORROWAN	Morrow	 Upper Morrow Squawbelly Ls  L. Morrow (Primrose)

ANADARKO BASIN - MOUNTAIN FRONT - OKLAHOMA

The Desmoinesian series is divided into Marmaton and Cherokee groups, with Red Fork sands and shales comprising the lower interval of the Cherokee.

Petroleum is prevalent throughout the section in various sand and granite wash expression sequences.

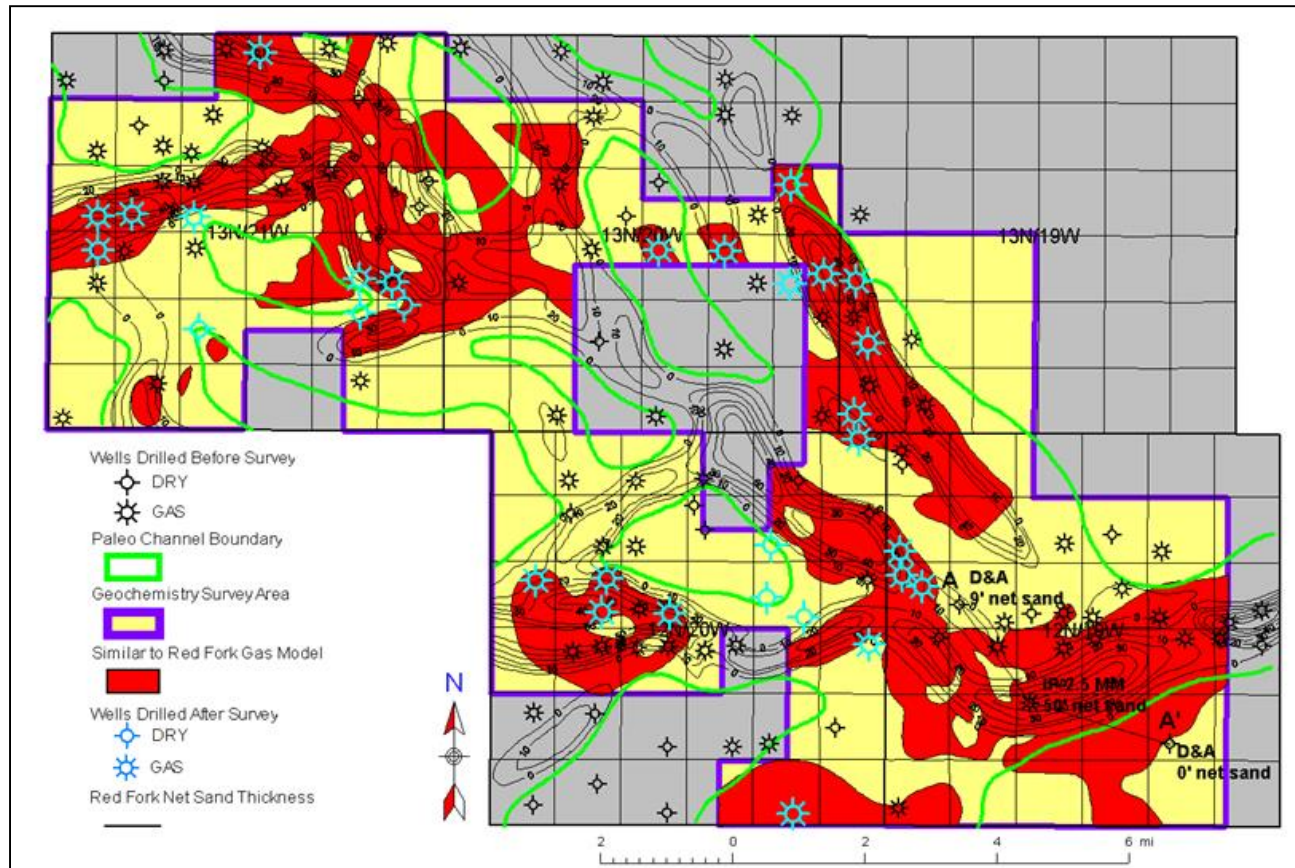
Surface petroleum microseepage signatures correlate with reservoir porosity, net thickness and pressure (at least hydrostatic). Depth to pay does not factor in the microseepage signature, nor does overlying lithology (i.e., all rock sequences are extensively micro-fractured).

The discerning factor for the Red Fork interval is over-pressured gas sands, which results in distinct surface signature of hydrocarbons (relative to other hydrostatically charged sections). Presumably Red Fork sand channels and deep water turbidite fans (proximal and distal facies) are encased in shales, and pressure-sealed from surrounding sections. Granite wash sequences are presumably not isolated, and its charged sections are at hydrostatic pressure.

Stratigraphic sequence from Mitchell (2015) presentation.

Survey Probability Map

Geochemical Model Result



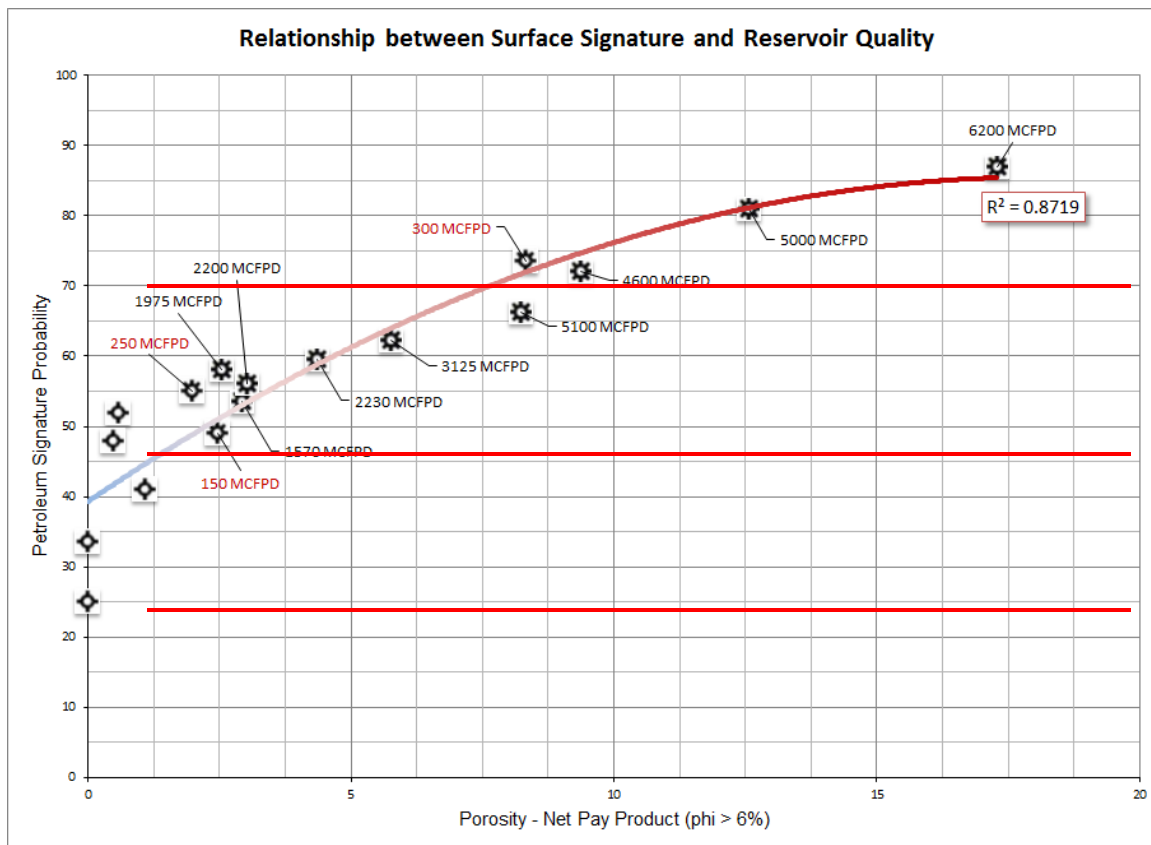
Red Fork gas signature probability map, expressing the fit between sample and gas calibration fingerprints. Anomalies in red color.

Red Fork sand channel isopach is integrated with anomaly map, showing very good fit. Confirms the $[\phi h]$ relationship discussed in an earlier slide. Also implies minimal effect from other charged sections.

Note the post-survey wells (blue symbols): the geochemical model is highly predictive. Areas of anomaly outside of channel boundaries are thin sand overplays (non-commercial).

Plot of Surface Probability Factors vs Phi-h

Surface Geochemical Signal



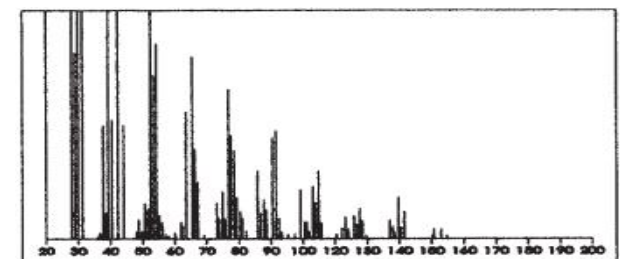
Plot shows strong correlation between effective reservoir porosity (ϕ), net pay thickness (h), and surface geochemical expression.

Reservoir pressure (P) is also a factor, assumed to be constant since specific data is lacking for the time of the survey.

Gas show wells illustrate interesting points:

- “ Sub-commercial charge is detectable at the surface with this high-sensitivity method;
- “ One well (300 MCFPD well) suggests additional behind-pipe pay, with lower production amount for the calculated surface signature (pressure depletion would have lowered the signature).

Plot from Potter et al. (1996).



C_2 C_3 C_4 fragment from saturated hydrocarbon (example: butyl fragment)
 C_6 C_7 C_8 fragment from aromatic hydrocarbon (example: benzene fragment)

Project Results

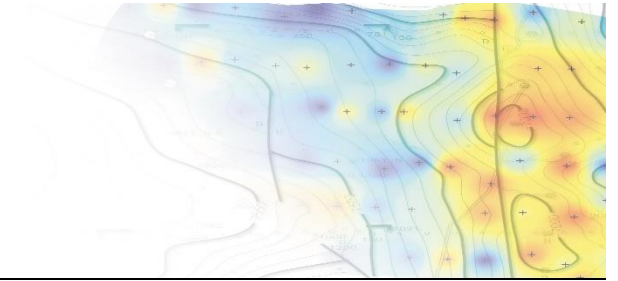


Good calibration well site data was obtained:

- “ The AGI data showed clear distinction from Red Fork condensate wells and dry wells
- “ The AGI data was also able distinguish Red Fork condensate charge from other petroleum systems in the area (e.g. Granite Wash, Cleveland sands);
- “ Calibration signature for Red Fork gas features C_2 - C_6 saturated hydrocarbons (alkanes)
- “ Effective geochemical model to map the Red Fork signature over large portions of five townships

Geochemical results were confirmed by post-survey wells

- “ 30 wells were drilled post-survey for which AGI has information:
 - 22 wells drilled in geochemical anomalies for Red Fork gas, with 21 commercial discoveries and 1 dry
 - 8 wells drilled out of anomaly (no hydrocarbons), with 5 P&A and three gas discoveries (one failed to pay completion cost)



Lithuania Field Development Case Study



Lithuania Project Information

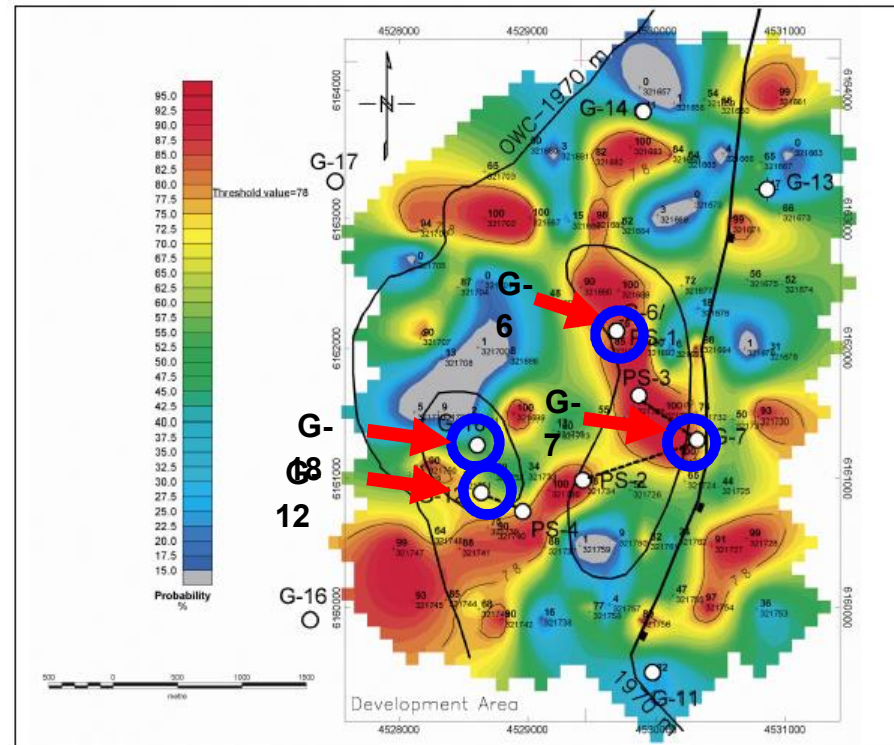
Survey information

- “ Located in the Baltic Syncline petroleum province
- “ Target was an onshore marine Cambrian sandstone
- “ Producing horizon 2,000 meters deep
- “ 150 samples were located in a grid over 20 km²

Pre-survey Field Production

Production Test Data (BOPD)	
Wells drilled before the AGI survey	
G6/PS1	160
G7	120
G11	Dry
G12	-----
G13	Dry
G14	3
G18	120

403

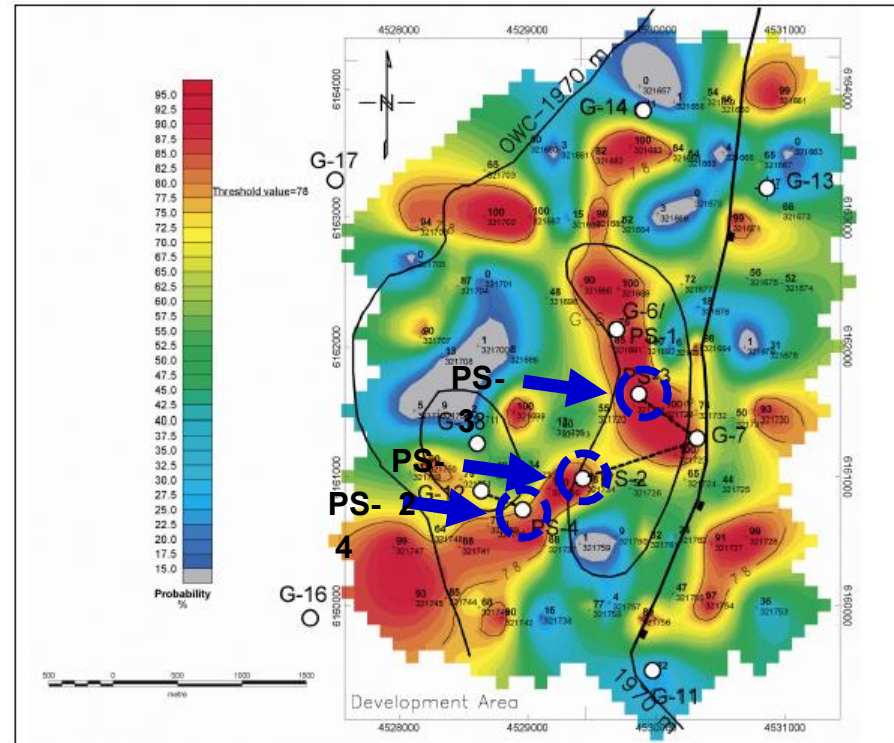


Post-survey Field Production

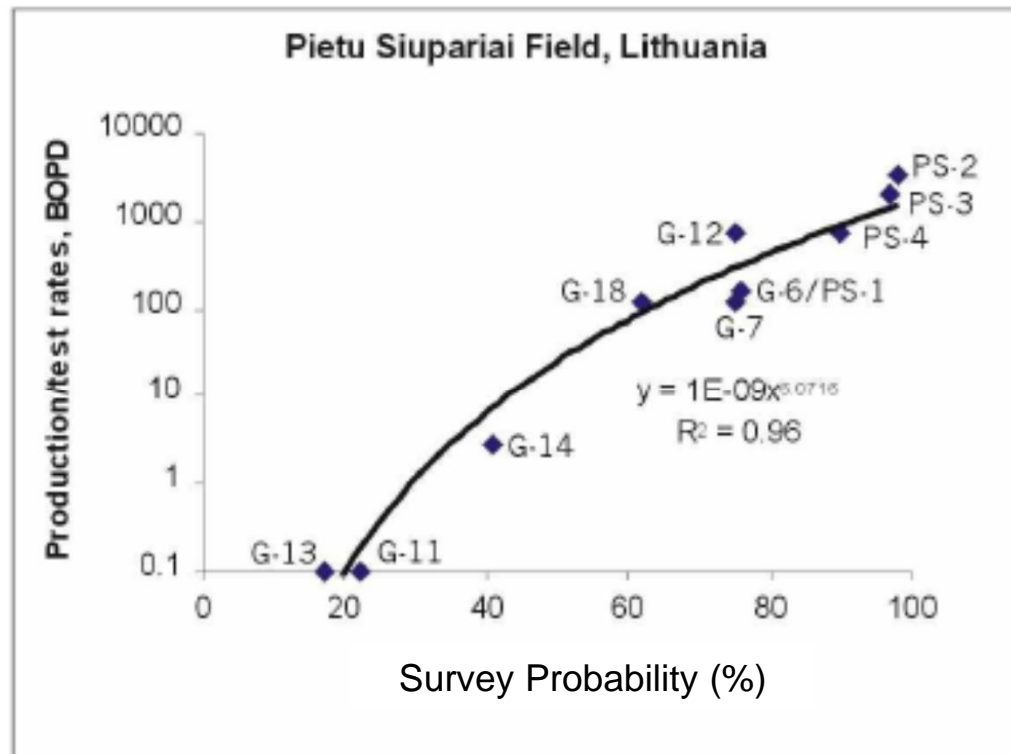
Lithuania Development Case Study

Production Test Data (BOPD)	
Wells drilled after the AGI survey	
PS-2	3,350
PS-3	2,020
PS-4	760

6,130



Probability vs Production



Production Test Data (BOPD)			
Wells drilled before the AGI survey		Wells drilled after the AGI survey	
G6/PS1	160	PS-2	3,350
G7	120	PS-3	2,020
G11	Dry	PS-4	760
G12	-----		
G13	Dry		
G14	3		
G18	120		
	403		6,130

Production increased 16-fold

“Reservoir sweet spots identified with surface geochemistry – an example from the Cambrian Pietu Siupariai oil field, Lithuania.”

Authors: T. Haselton and P. Willumsen

Conclusions

- “ Optimum field production (i.e. Profitability) is directly related to defining optimum reservoir characteristics (i.e. pressure, porosity, net pay, & hydrocarbon richness)
- “ Ultrasensitive hydrocarbon mapping is driven by the microseepage mechanism which results from pressure, porosity, net pay, & hydrocarbon richness
- “ These case studies have shown that ultrasensitive hydrocarbon surveys can be used effectively to define field sweet spots and optimize field production with little well control and help to maximize operator production and, thus, profitability.

Thank You!

