

Predicting Channel Sand Wells in the Anadarko Basin with a 90% Accuracy*

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Abstract

Ultrasensitive hydrocarbon mapping can be used in conjunction with seismic programs to dramatically de-risk exploration and reduce costs while improving production. This is particularly true in channel sand fields where seismic resolution may not be sufficient to map sinuous sand beds. Additionally, ultrasensitive hydrocarbon mapping can identify phase for the charged sands, which cannot be elucidated by seismic data. The surface surveys took place in southwestern Custer County and southeastern Roger Mills County of western Oklahoma, along the axis of the Anadarko Basin. The purpose of the survey was to map over pressured gas condensate from the Pennsylvanian Red Fork channel sands at a depth of ~14,000'. One of the difficulties of the project was that the Anadarko Basin includes numerous charged horizons throughout the Paleozoic section. Consequently, passive sorbers were placed at the surface around strong producing wells and around dry wells to provide end member hydrocarbon signatures of interest. Additional samples were placed in grid patterns across five townships covering 120 mi². The end member signatures were used to generate a probability contour map to identify the location of the winding channel sands. The contour map was then used, in conjunction with seismic data, to identify high prospectivity drilling locations.

Thirty post-survey wells were drilled based on the ultrasensitive geochemical results.

- 22 wells were drilled on positive geochemical anomalies for Red Fork gas condensate, with 21 commercial discoveries and 1 dry well (i.e. 95% accuracy),
- 8 wells were drilled on negative anomalies (no hydrocarbons), with 5 P&A'd and three gas discoveries (one failed to pay completion cost)
- The ultrasensitive hydrocarbon mapping correctly predicted 27 of 30 wells (i.e. 90% accuracy) drilled post-survey.
- The ultrasensitive probability factors were also plotted verses porosity*net pay (phi-h). The plot shows a strong correlation (i.e. $r^2 = 0.87$) between effective reservoir porosity (θ), net pay thickness (h), and the surface geochemical expression. The data shows dry wells and sub-economic wells with a probability factor ranging from ~50% - 60% while wells with the highest phi-h exhibited the highest probability factor (i.e. 80% - 90%). Thus, the graph demonstrates the ability of the ultrasensitive geochemical data to identify and map areas of higher porosity and net pay thickness (i.e. Sweet Spots).

- There was also a strong correlation with the survey probability factors and production. Field production increased proportionally with surface survey probability values. The graph also identifies a potential completion problem. A well reporting only 300 MCFPD had an elevated probability factor (i.e. ~73%) and an elevated phi-h, suggesting possible additional behind-pipe pay.

Summary:

- With multiple hydrocarbon signatures the ultrasensitive geochemical data was still able to distinguish Red Fork gas condensate charge from other petroleum systems in the area (e.g. Granite Wash, Cleveland sands),
- The survey was able to map Sweet Spots (i.e. areas of higher production) with better hydrocarbon richness, porosity, and net-pay over 5 townships.
- The field production history and post-survey wells validated the survey results,
- The survey identified depletion affects,
- The survey optimized production in areas where seismic resolution was insufficient to do so.

Selected References

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2017 AAPG Mid-Continent Section Meeting

Predicting Channel Sand Wells in the Anadarko Basin with a 90% Accuracy

October 3, 2017

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Objectives

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

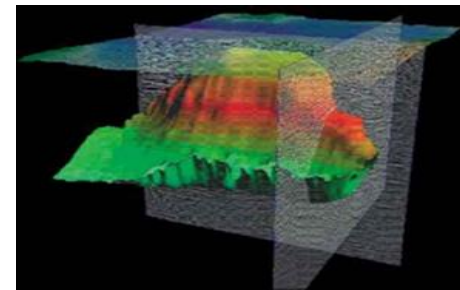
Typically does not have the resolution to map channel sands

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

3D Seismic Image



What's in the Can?



Derisking Exploration Requires Data Integration

Geology: Provides a regional stratigraphic and structural framework

Petrophysics: Supplies baseline rock property data from both logs and cores

Geophysics: Provides a means to extend the petrophysical rock property data away from the well bore

Geomechanics: Describes the stress state both locally and regionally

Engineering: Delineates the results of drilling, completion, and production

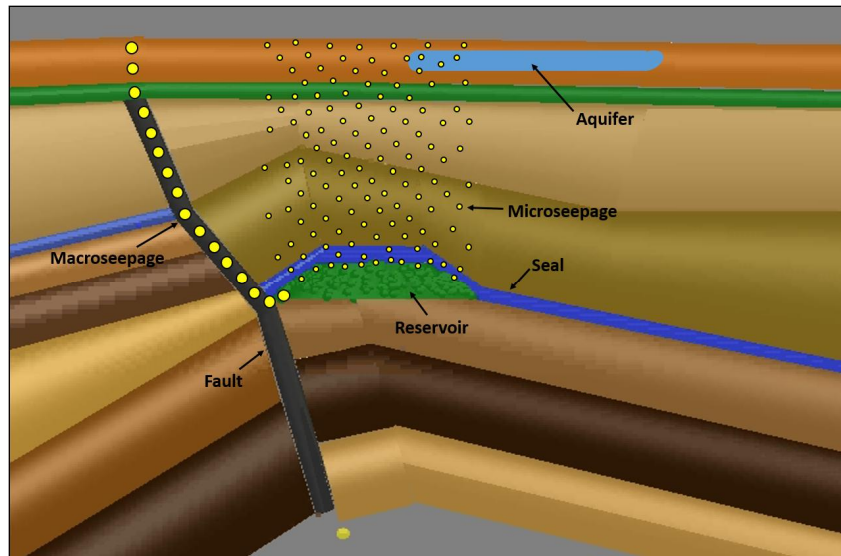
from "Making Connections: Eagleford, Meet Marcellus", by Louise S. Durham in the October 2012 issue of AAPG EXPLORER

But one very important data group is missing.

Hydrocarbon richness

Hydrocarbon Movement Mechanisms

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

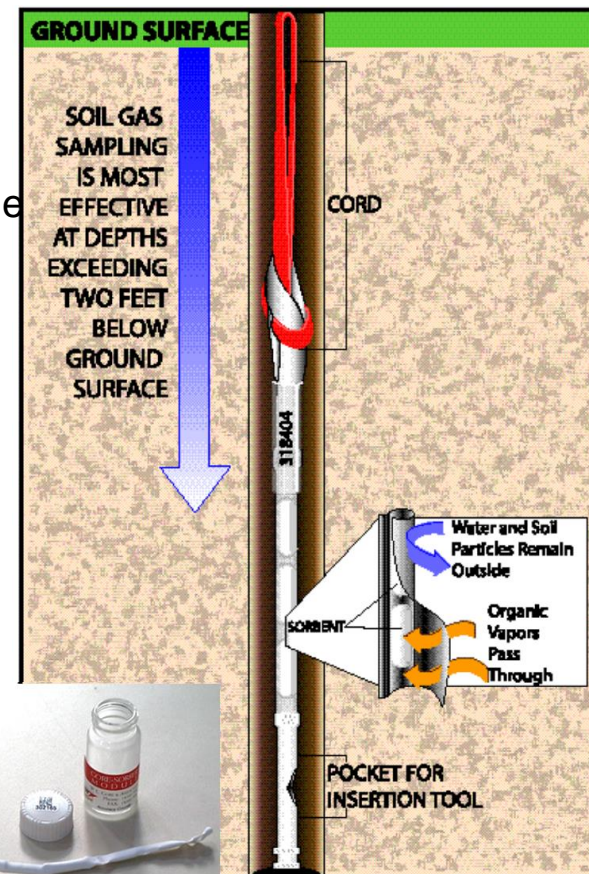
VS

Microseepage:

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

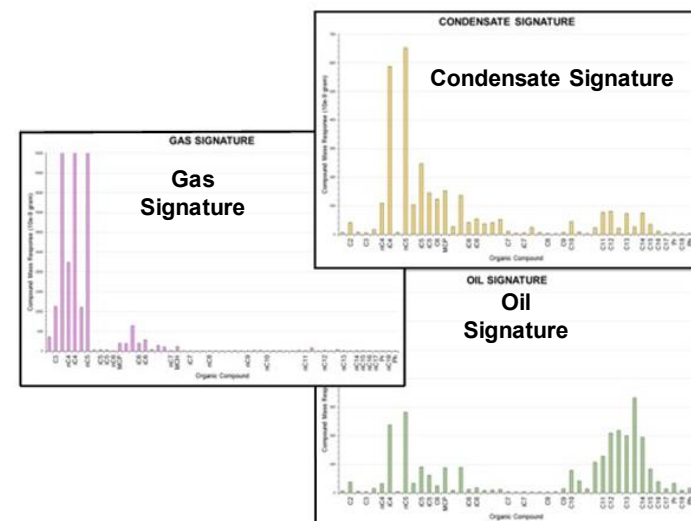
Hydrocarbon Capture Mechanism

- “ 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



Hydrocarbon 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

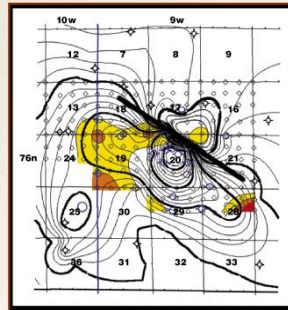
Hydrocarbon Microseepage Speed

Keota Dome Iowa – 300 m

ETHANE ANOMALIES AT KEOTA DOME, IOWA

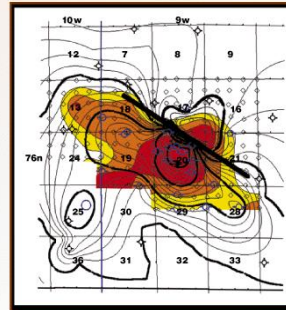
Keota Dome gas storage field, Washington County, Iowa

July 1988



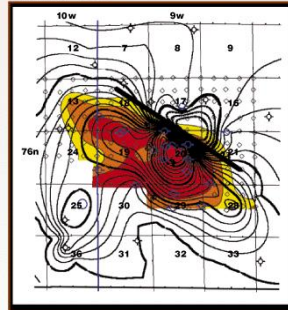
Beginning of
Charge - July

October 1988



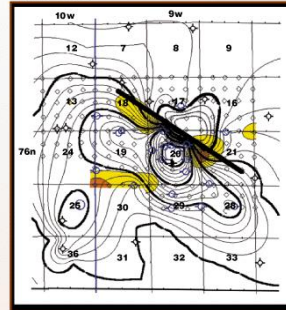
Continued Charge –
October

January 1989



Full Charge / Beginning of
draw down - January

April 1989



After Draw down - April

Shows percent C₂ (ethane) data through time. Contour interval .5 ppm. Structure on top of St. Peter sandstone. Data in 12%, 15%, and 18% C₂ intervals. Gas storage wells in blue. Oil wells in black. Source: Released with permission from CST Oil & Gas Corp. and Exeter Oil & Gas.

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Project 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 signature from other charged sections, and map Red Fork sand channel reservoirs

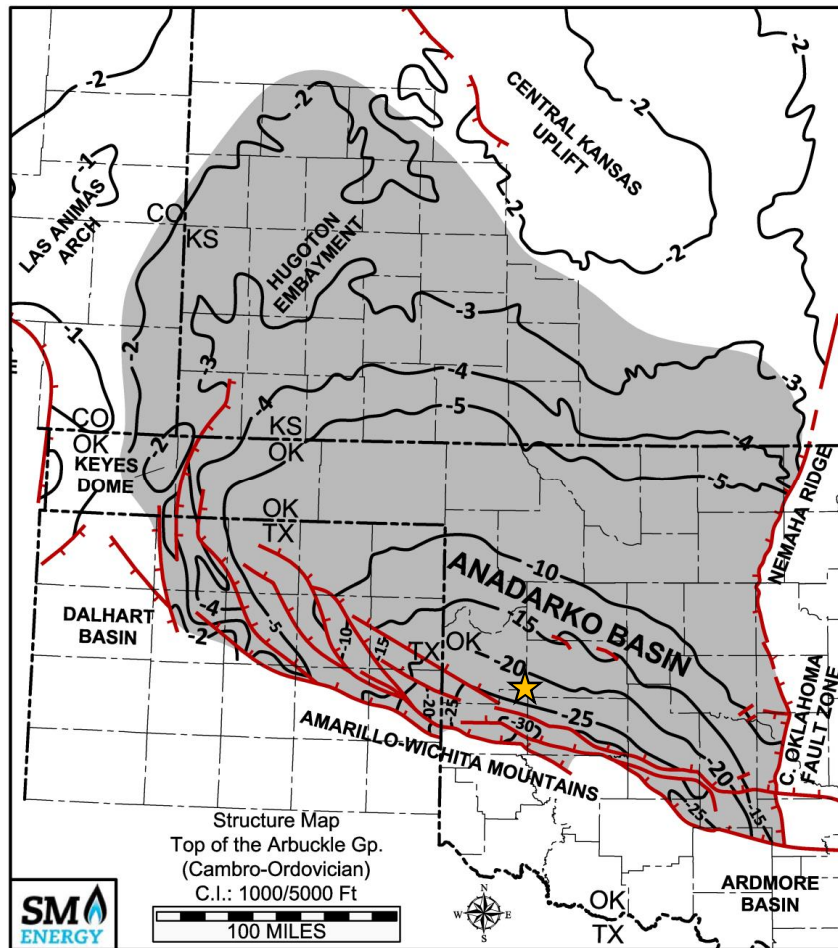
Survey Design

- “ 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)
- “ Pennsylvanian Granite Wash and Missourian series Cleveland Sand plays are located nearby to the south (next townships)
- “ Red Fork gas sands are over-pressured, favoring surface geochemical signature strength

Numerous Petroleum Systems



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

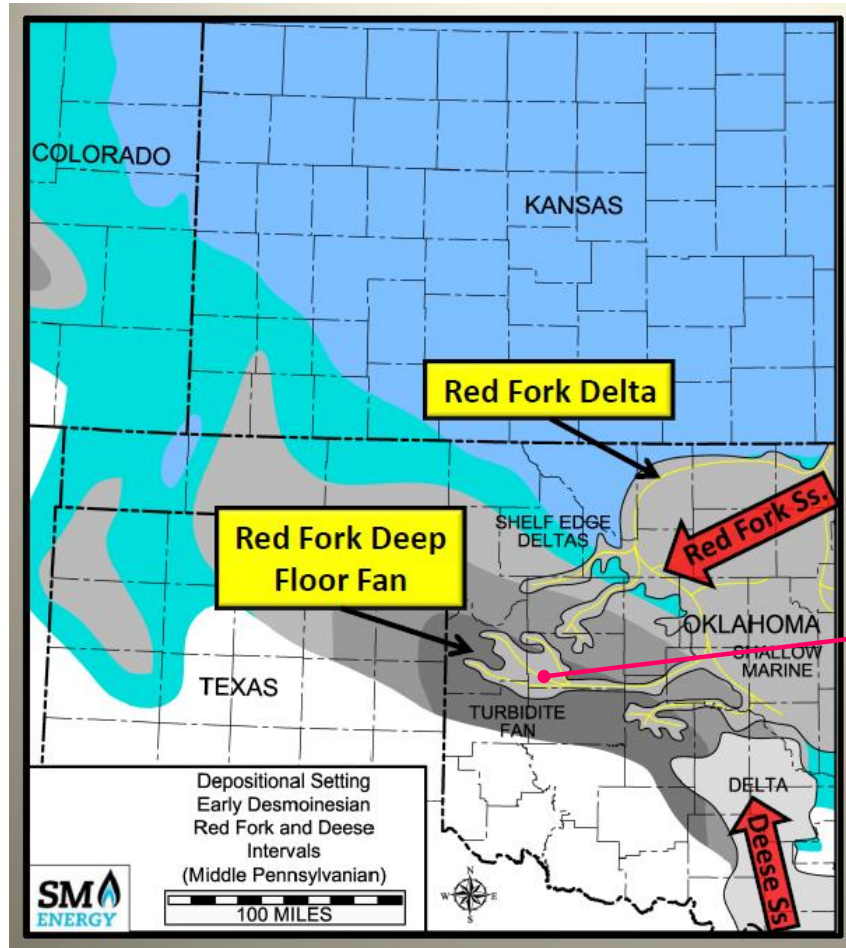
Six generalized petroleum systems in the basin:

- " 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)

Location of geochemical surveys in Custer and Roger Mills counties indicated by orange star. Survey target is the Red Fork of the Desmoinesian series (middle Pennsylvanian). Depth to Red Fork gas targets in the area: ~14,000q

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

Paleo-depositional Model

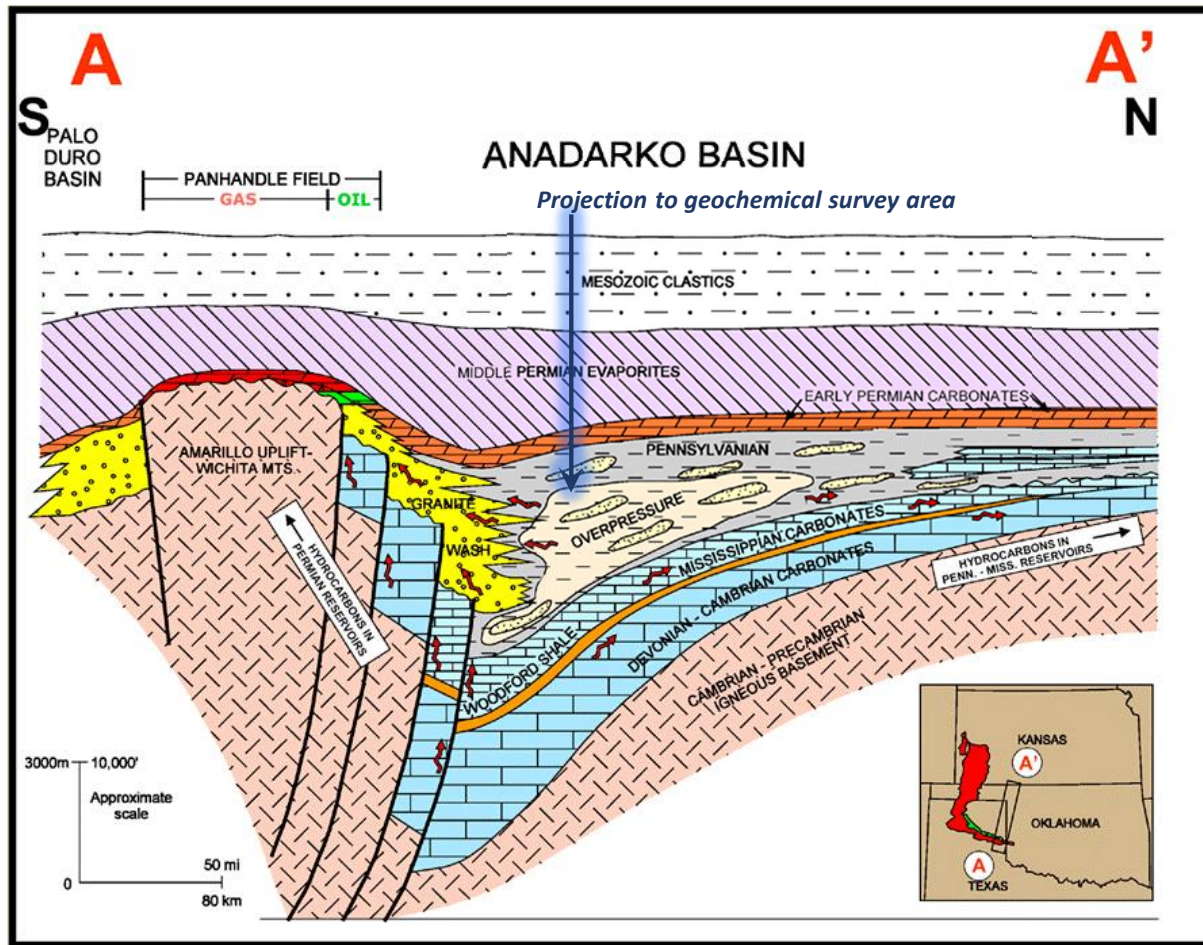


Middle Pennsylvanian Red Fork sand system in Oklahoma consists of deltaic complex to the north, with significant oil and gas production, and deep water turbidite fans and channels to the west, with over-pressured gas production from numerous fields across Roger Mills and Custer counties.

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).

Stratigraphy of Target Section

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

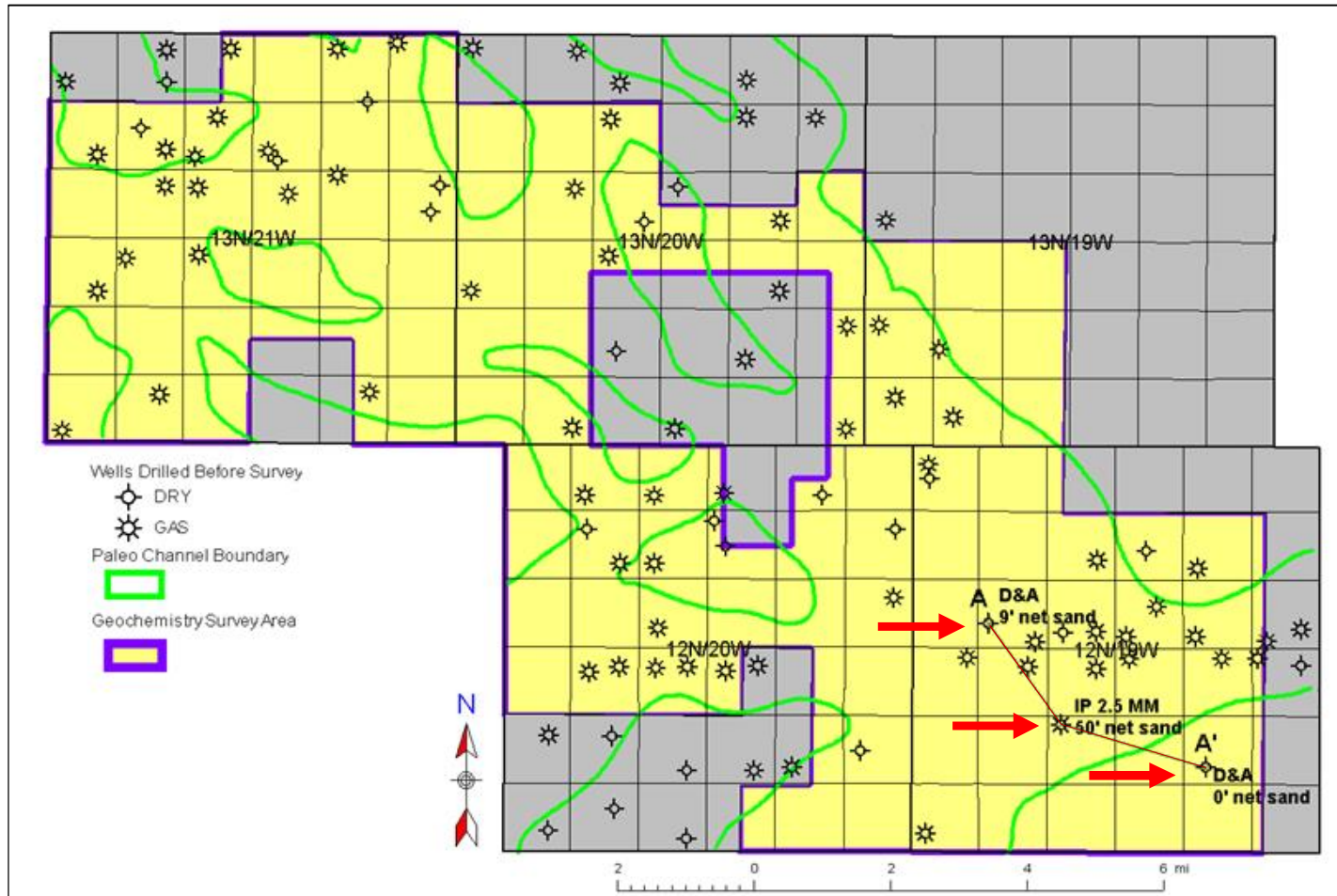
Pennsylvanian section in western Oklahoma. The Desmoinesian series is divided into Marmaton and Cherokee groups, with Red Fork sands and shales comprising the lower interval of the Cherokee. Petroleum expression is prevalent throughout the section in various sand and granite wash sequences.

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.

Well Control in Geochemical Survey Area



Geochemical survey covers portions of five townships. Numerous wells existed prior to the series of surveys conducted over three years. Red Fork sand channels are mapped by well control, as shown by green outline (client interpretation).

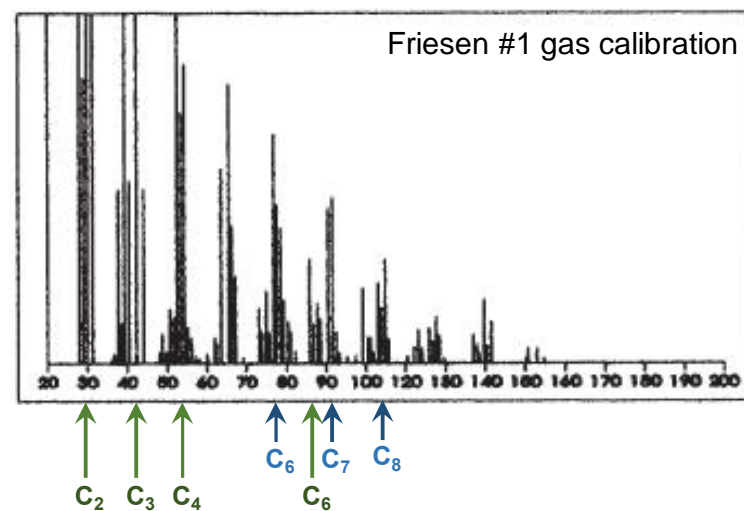
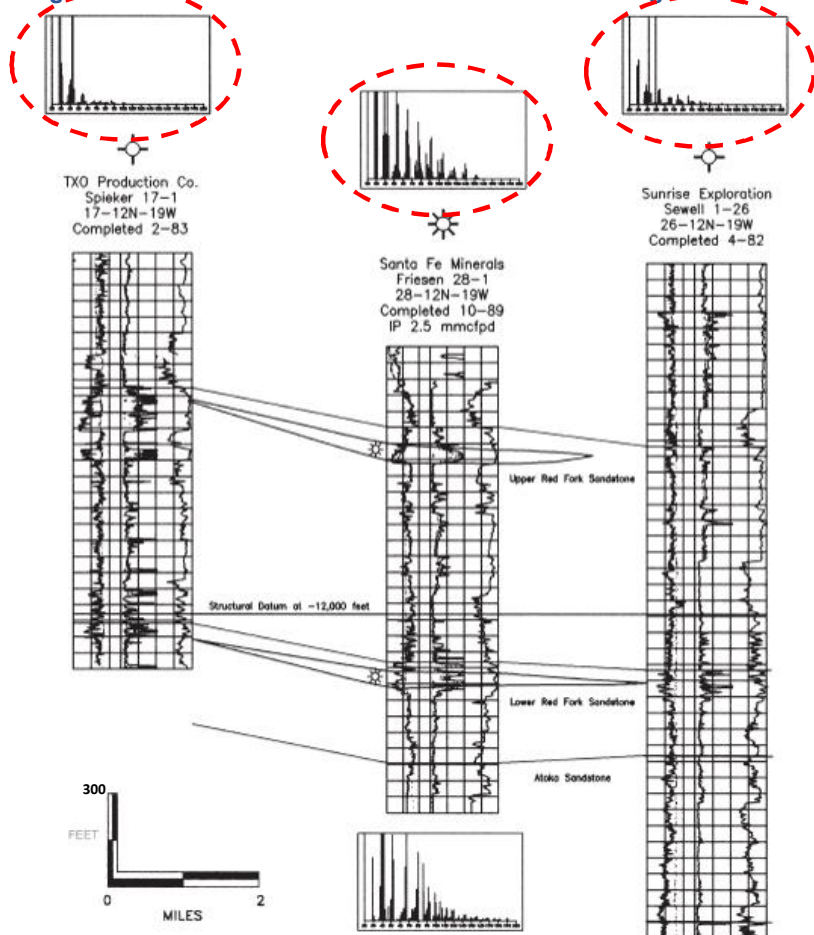
Geochemical calibration acquired near three wells in southeast corner of survey area (indicated by A – A' transect). The two dry wells were drilled at least 6 years prior to survey; gas producer was in process during the initial surveys.

Geochemical Calibration

Background calibration

Positive calibration

Background calibration

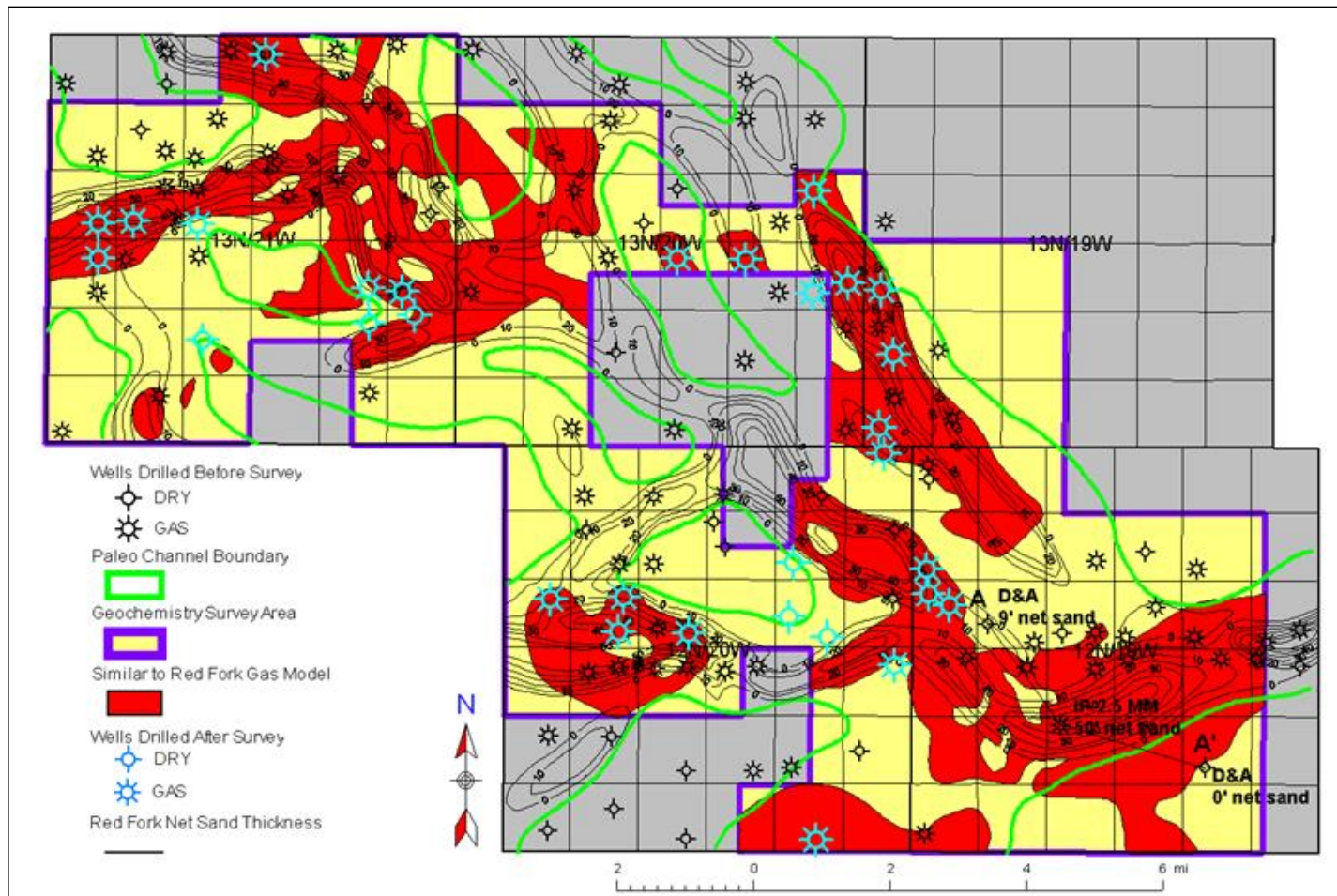


C₄ fragment from saturated hydrocarbon
(example: butyl fragment)

C₆ fragment from aromatic hydrocarbon
(example: benzene fragment)

Positive hydrocarbon signature acquired near the Friesen #1, showing mainly light saturates C₂ – C₆, with aromatics. Plot shows mass spectral fingerprint, measured in ion abundance versus mass-to-charge of ion fragments along x-axis.

Geochemical Model Result

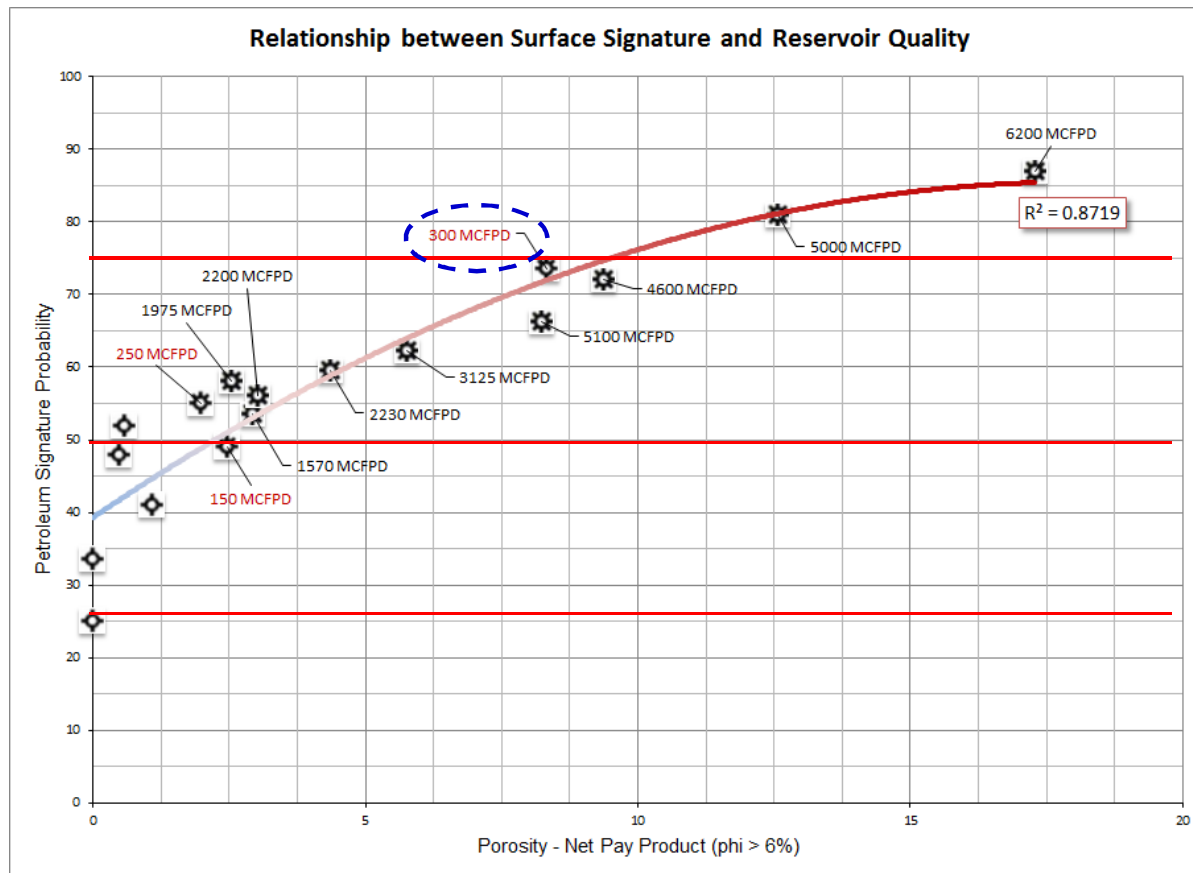


Red Fork gas signature probability map, expressing the fit between sample and gas calibration fingerprints. Anomalies in red color.

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 over-splays (non-commercial).

Surface Geochemical Signal



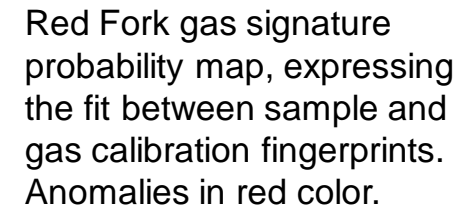
Analysis of surface geochemical samples collected at well sites in the Anadarko Basin, including Red Fork gas production (from ~14,000q and non-commercial wells).

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



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 over-splays (non-commercial).

Project Results

Geochemical results were confirmed by post-survey wells

30 wells were drilled post-survey for which AGI has information:

- “ 22 wells drilled in positive geochemical anomalies for Red Fork gas, with 21 commercial discoveries and 1 dry **(21 of 22 - 95% accuracy)**.
- “ 8 wells drilled out of anomaly (no hydrocarbons), with 5 P&A, one failed to pay completion costs and one gas discovery **(6 of 8 - 75% accuracy)**.
- “ **The AGI ultrasensitive hydrocarbon mapping data correctly predicted 27 (90%) of 30 wells drilled post-survey in the narrow Red Forks channel sands.**

Project Summary



- “ With multiple hydrocarbon signatures the AGI data was still able to distinguish Red Fork condensate charge from other petroleum systems in the area (e.g. Granite Wash, Cleveland sands),
- “ The survey was **able to map Sweet Spots (i.e. areas of higher production)** with better hydrocarbon richness, porosity, and net-pay over 5 townships.
- “ The field production history and post-survey wells validated the survey results,
- “ The survey identified depletion affects,
- “ **The survey optimized production in areas where seismic resolution was insufficient to do so.**

Thank You!

