Evaluating Shale Play Opportunities, Optimizing Your Own Operations*

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Abstract

The ongoing downturn in oil and gas prices, combined with high costs and steep decline curves, has dealt a death blow to many parts of what were once prospering shale plays. Companies have had to take write-downs, and many have put their properties on the selling block. The fact that there is a great deal of inventory turnover in today's U.S. shale plays means that there are significant opportunities for operators who know how to identify sweet spots and to utilize technologies to economically produce.

If you are an operator in a shale play that has converted itself into an uneconomic money sink, there is no doubt that you have already instituted cost-cutting / cost-postponing measures, such as drilling horizontals without completing. You have also become much more efficient with your frac jobs, and you are conducting geological fracs rather than geometrical. In addition, you have improved your produced water efficiencies and are geosteering with better precision.

But, it's not enough. Your costs are still high, and your wells are not uniformly productive. So, what next? Do you put it all on the selling block and try to sell as quickly as possible to stop the hemorrhaging? If you do, you are in a "going out of business" mode, and you are not really going to get much for your fire sale, unless you happen upon a miracle and are able

to leverage what you clear in a highly efficient producing property that does not have any unwelcome surprises lurking in the leases. Or, do you keep drilling and completing, but utilizing new technologies to optimize your production, knowing that you are rolling the dice and it is quite possible that your gambles will not pay off, at least in this iteration, as you are still somewhere in the learning curve.

Alternatively, you may optimize your operations to the best of your ability, with a view to grooming your properties for a sale, or you may implement a strategy that will, over time, result in profitability.

Regardless of the strategy you employ, there are a few considerations to keep in mind.

1. *Heterogeneity comes in many different forms.* Know your reservoir and your lithologies. You may have fine-grained sand interbeds, or you may have more mudstone or marly facies. Understanding the nature of the heterogeneity (lithology, fracture density, pore architecture, diagenetic alteration / overgrowths) really do matter.
2. *Fluid migration pathways matter more than you may think*. While it is easy to think of all shales as essentially self-sourcing ("my source rock is now my reservoir"), that is not actually the case in all shales, and depending on the fracture networks and the pore architecture, you may have differentially enriched sediments which constitute excellent sweet spots. Understanding the source, direction, and geochemistry of the reservoir fluids (including gases) will help you pinpoint the sweet spots.
3. *Connectivity, but for how long?* Knowing how long your induced fractures will stay open, and which proppants seem to live up to their promise can make the difference between a well you would like to purchase, or one you would like to run from.
4. *Frac Interference, Thief Zones, and other signs of over-muscling the frac design.* The conventional wisdom suggests that the bigger the frac the better, and the more rock you "rubble-ize", the better. But, some reservoirs exhibit behavior that deviates (dramatically) from conventional wisdom. Sometimes it is not easy to determine what exactly transpired, but if there is frac interference or thief zones, it is an indication that there are ways to move the hydrocarbons, and that there is a certain level of responsiveness to stimulation. So, these areas bear reconsideration, particularly if there is high TOC. It is important to keep in mind that recovery rates can hover around 10%; this means that there is definitely oil in place.
5. *Geochemistry can give you an edge.* Whether you are looking at kerogen typing or isotopes, which can help you with gas / oil fingerprinting, the more geochemical information you have, the better you can determine where to drill, and also the kinds of fluids to use in drilling and completion.

6. *The stress regimes and pore pressure are potential solutions to "cliff-dive" decline curves.* Understanding the stress regimes, pore pressure, and also the orientation of fractures, along with migration pathways, can help you fine-tune your completions in order to maintain flow and reduce the rapid declines. High IPs can be exhilarating, but it is not so thrilling when the rates basically drive off a cliff and are flat all too soon. A more tempered approach may be the solution.

There are additional points to consider when evaluating acquisitions or grooming your properties for optimization or sale.

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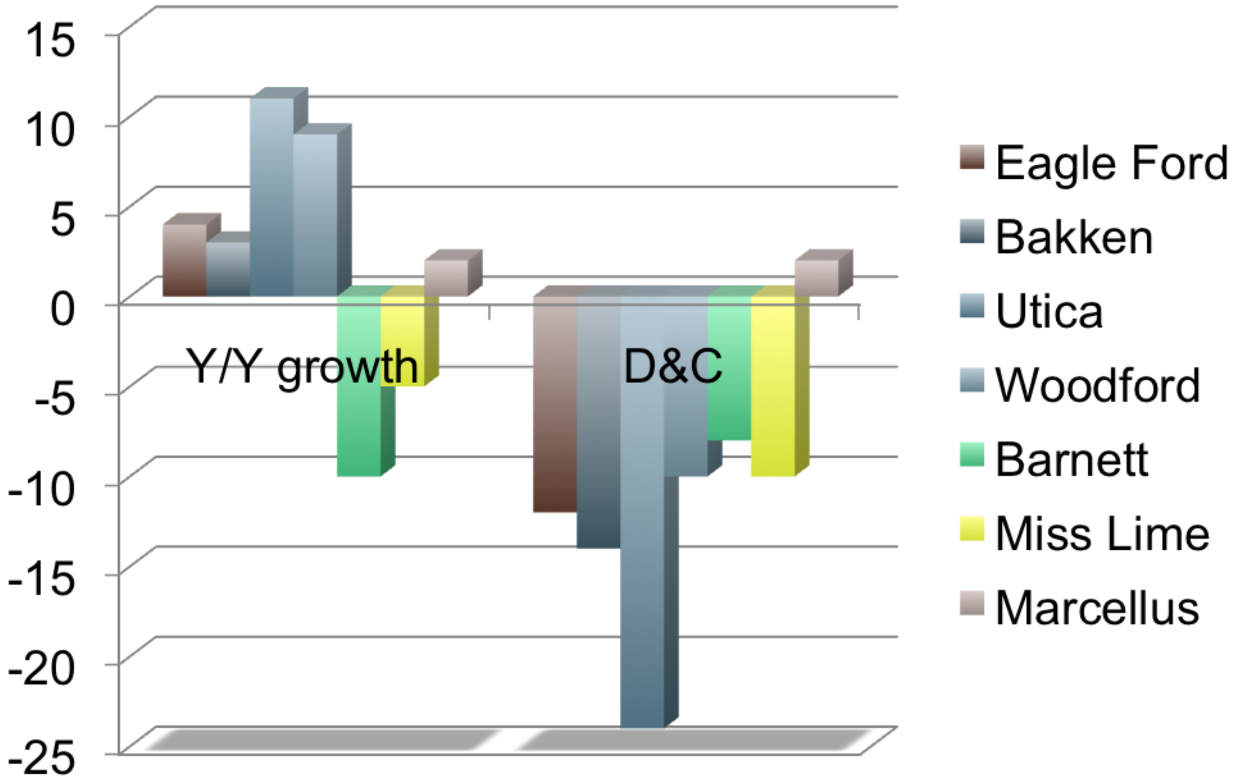
U.S. Unconventionals Outlook: 2016

- Overall production expected to increase 4% in 2016
- Spending levels projected to drop an additional 9%
- Shale play growth in 2016
  - Permian Delaware Basin
    - EOG Resources
    - Devon Energy
    - Concho Resources
  - Utica growth due to delayed completions
  - Woodford growth due to Continental Resources
    - SCOOP
    - Cana
- Shale play decreases by 10% in other large plays: Bakken, Eagle Ford, Permian Midland

Source: Oil and Gas Financial Journal, November 2015

Projected 2016 North American Shale Production Growth and Drilling and Completion



Sweet Spots in Shale Plays

Liquids-Rich Shales:

- Maturity is the key determinant (vitrinite reflectance of more than 0.85% in marine facies and more than 0.9% in continental facies have sufficient hydrocarbon-generating capacity)
- Should have favorable migration pathway
- Favorable conditions for natural fracturing (macro- and micro-fissures)
- Favorable pore pressures
- Organic porosity development

Types of Sweet Spots

Geologic:

- Good source rocks
- Good reservoir thickness
- Natural fractures
- Formation energy
- Pore pressure
- Local structure
- Connectivity of pores
- Pore architecture

Engineering:

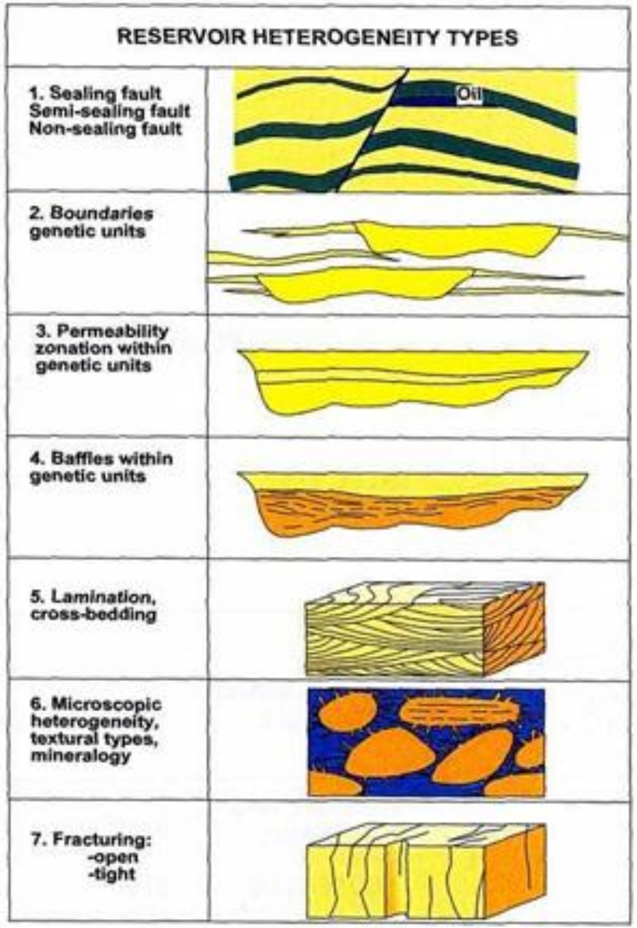
- Good fracability
- Anisotropy of crustal stress
- Pore pressure
- Pore conductivity
- Less relative heterogeneity

Economic:

- Large resource scale
- Good oil quality
- Accessible
- Amenable to pad drilling
- Not too deep

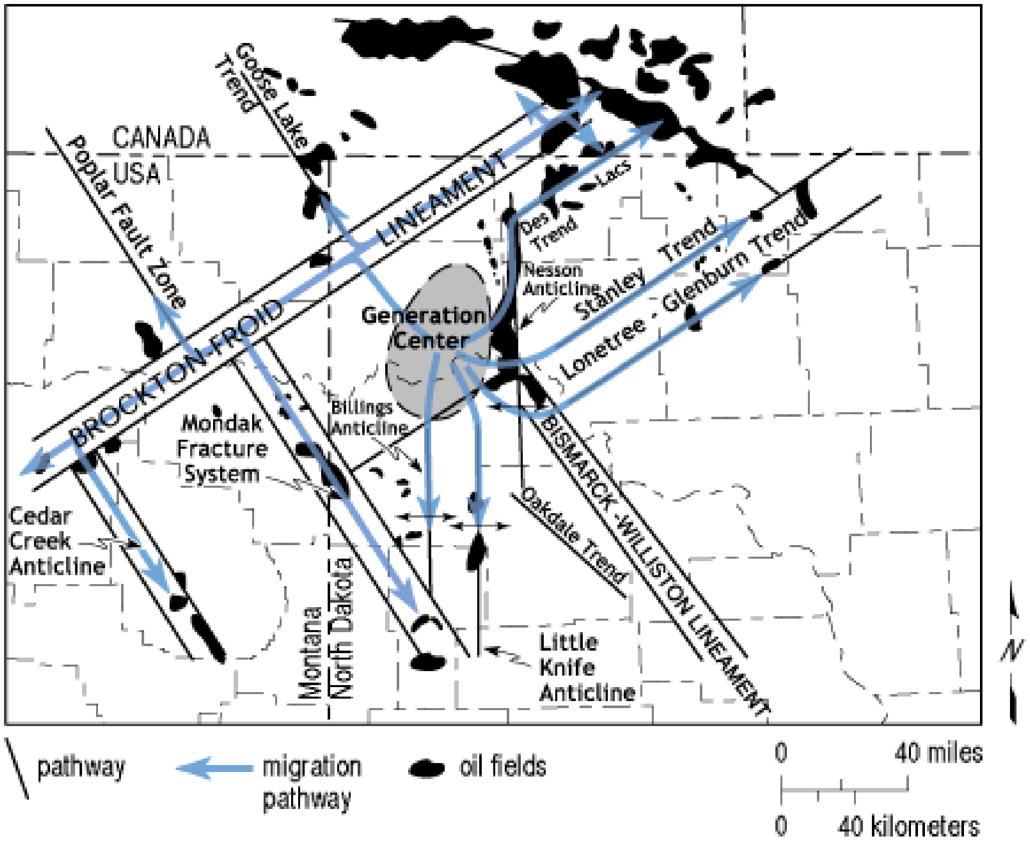
The Many Faces of Heterogeneity

- Lithofacies changes
- Structure
- Fracture networks
- Pore architecture
- Reservoir fluid
- Diagenesis
    - Overgrowths
    - Chert
    - Dolomite
    - Crystal faces
    - Dissolution



Migration Pathways

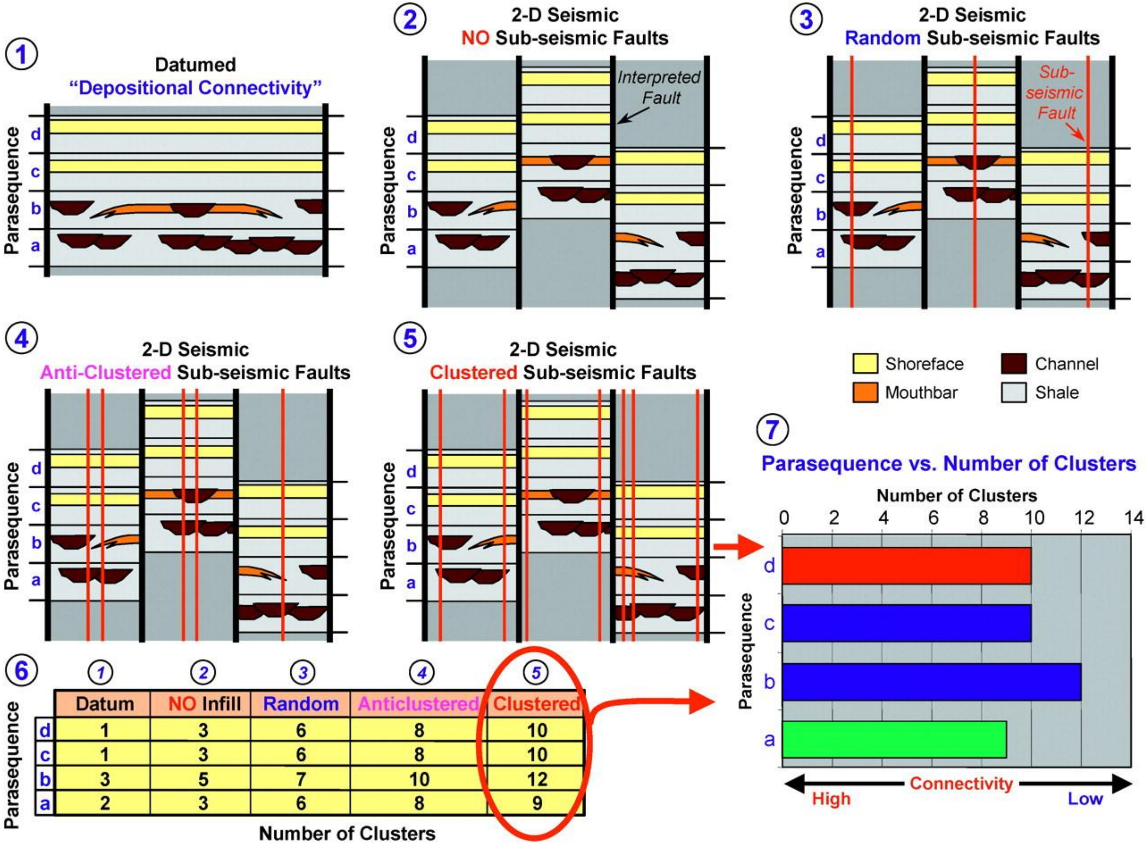
- •Source
- •Direction of flow from the “kitchen”
- •Tectonic history
- •Basement structure
- •Fracture networks
- •Geochemistry of the reservoir fluids (including gases)



Migration pathways in the Williston Basin
http://www.kgs.ku.edu/Current/2004/Gerhard/06_petrol.html

Connectivity

- Different types of connectivity
- Important to know which kind …



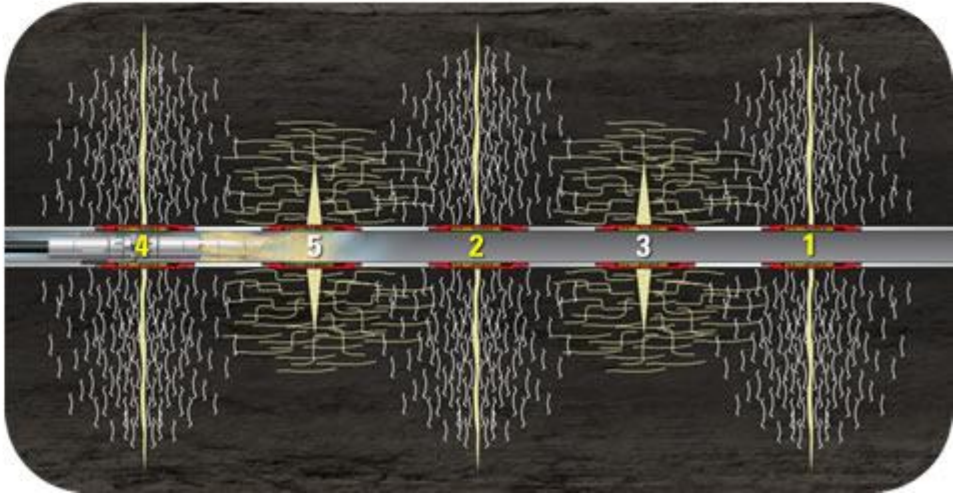
Parasequence	Datum	NO Infill	Random	Anticlustered	Clustered
d	1	3	6	8	10
c	1	3	6	8	10
b	3	5	7	10	12
a	2	3	6	8	9

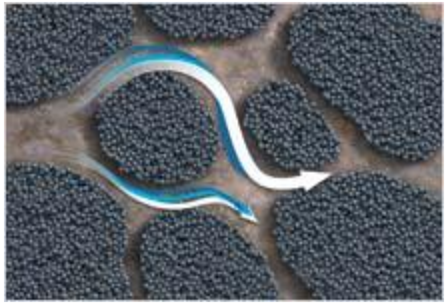
Number of Clusters

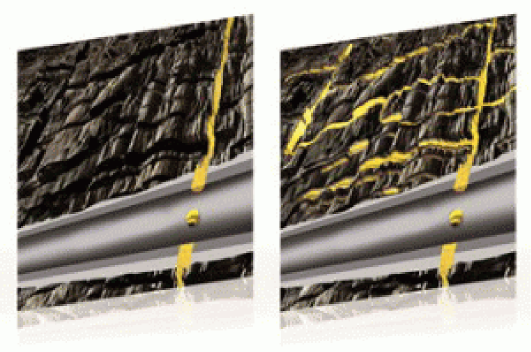
http://pg.lyellcollection.org/content/12/2/127/F6.large.jpg

Frac Interference

- Good planning of fractures
- Re-fracing



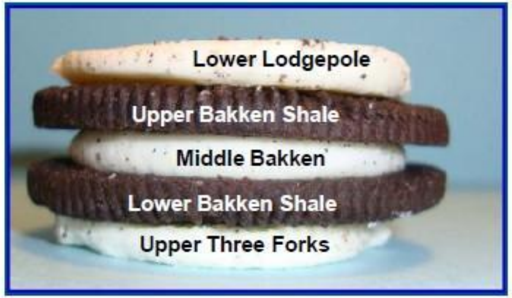


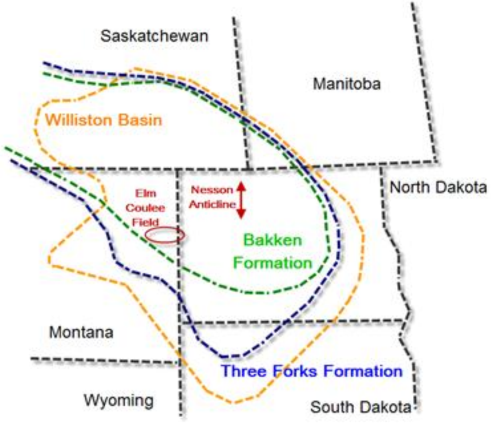


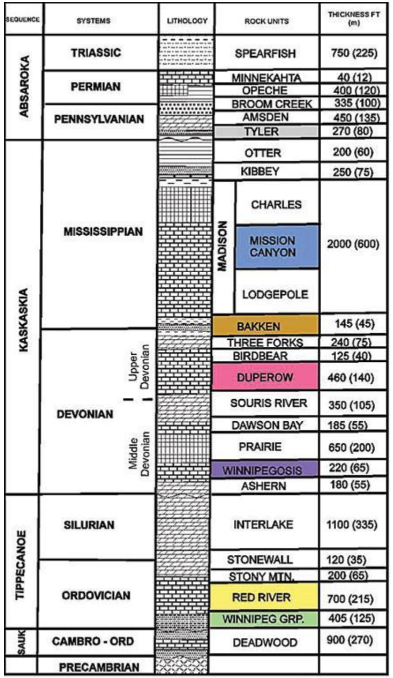
Stress-induced Complexity in Brittle Rock

http://www.halliburton.com/public/pe/contents/Overview/images/stress_induced_complexity.jpg

Bakken: Improved Efficiencies





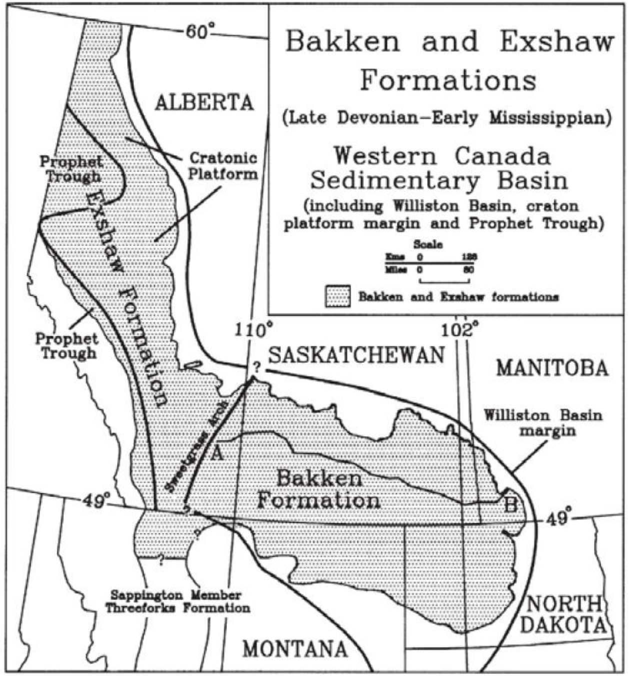


Modified from LeFever 1992; Anna, 2009

Oasis Petroleum:
Core slickwater well costs from $10.6 MM to $7.4 MM
Drilling days: from 24 in 2014 to 16 in 2-15
35% reduction in operation costs
Strong hedge position ($53 - $74/bbl)
Increasing mix of high-intensity wells in core: (high-volume proppant, plug & perf, 150-220k bbls fluid)
Continental Resources:
Average EUR up 45% from 2014
60% of wells drilled on 660-880’ interwell spacing within zone
30% reduction in current well costs
faster drilling (3-mile lateral in 6.4 days)

Bakken and Three Forks: Sweet Spots

Exhibit 2: Distribution of Bakken and Exshaw Formations



Source: Mark Smith and Marc Bustin, "Late Devonian and Early Mississippian Bakken and Exshaw black shale source rocks, Western Canadian Sedimentary Basin: A sequence interpretation," *AAPG Bulletin*, July 2000.

Exshaw / Big Valley Play area:

Basement structure matters

Detailed basement structure map

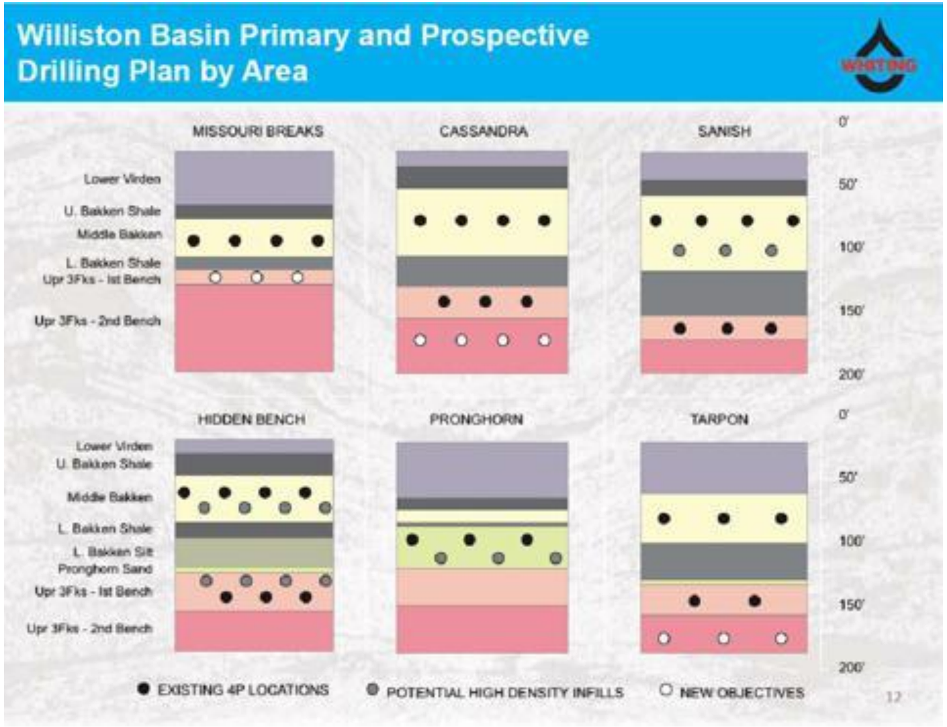
Use magnetic data

Fields located along faulted edges of major pull-apart basin that developed between the Nesson anticline and the faulted edges of the Superior Craton

More brittle and fractured shale packages developed along the active edges of basement faults

(Berger and Mushayandevu, 2014)

Pronghorn & Lewis & Clark Fields: Sweet Spots



Sanish / Pronghorn member:

Whiting discovery

Sweet spots in the Bakken

- source rock quality & maturity
- reservoir matrix quality & saturation
- fractures, pressures, etc.

Angular unconformity on top of Three Forks

Provenance variations - key to success

Pronghorn member isopach

IPs as high as 3611 BOEPD

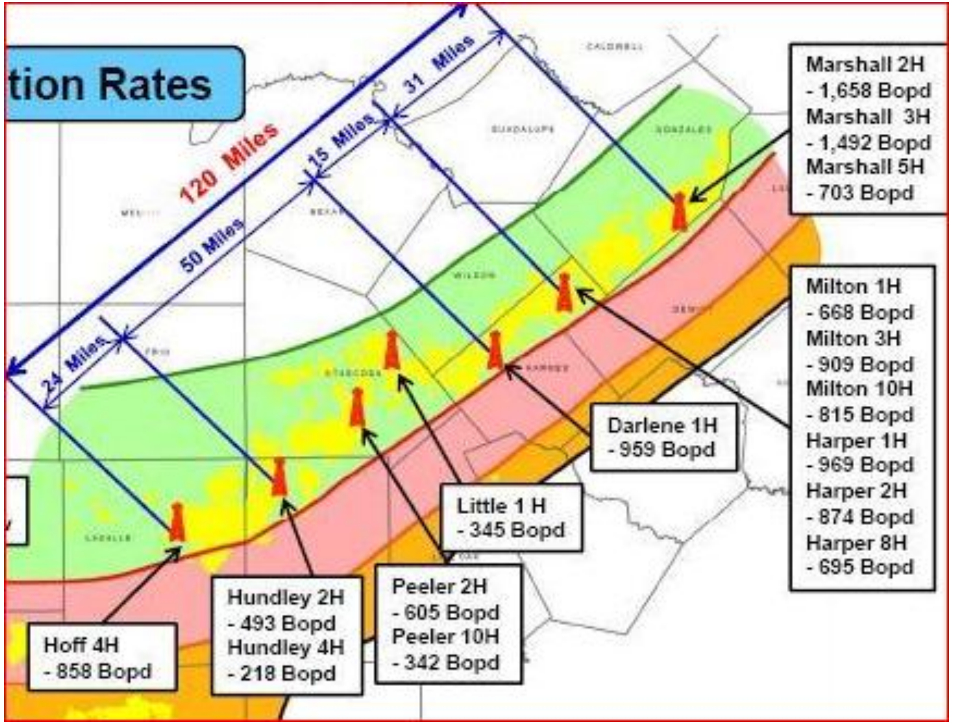
Whiting - 80 wells

Array fracing / Downspacing

(Skinner, et al., 2015)

http://www.searchanddiscovery.com/documents/2015/110176skinner/ndx_skinner.pdf

Eagle Ford: Recent Trends



DeWitt County

Improved efficiencies in drilling and completion:

Example: Devon

9 sub-plays, all have different economics

The Karnes Trough has one of the lowest breakevens in the Lower 48 ($42/bbl)

DeWitt County delivers best-in-class results for operators such as Devon (2015)

90-day Eagle Ford Wellhead IPs average 440 BOED

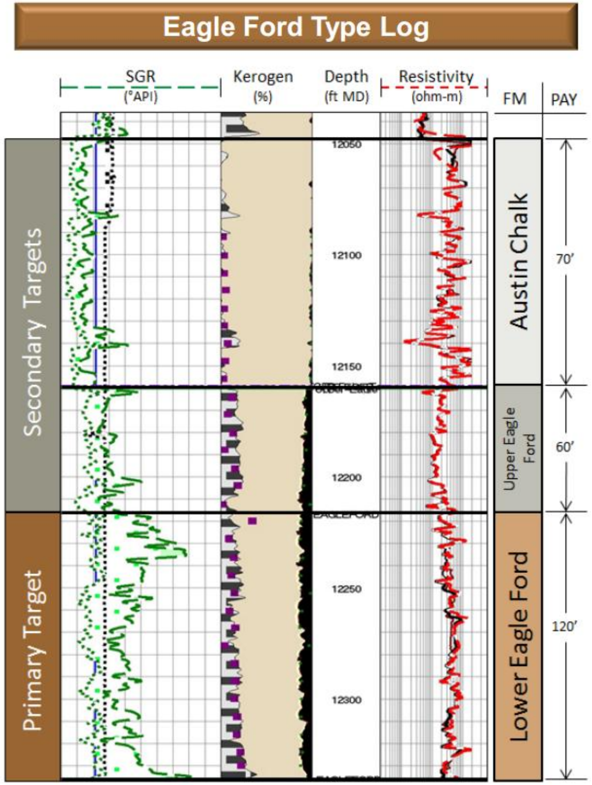
50% drilling efficiency improvement in 2015

25% complete cost savings, driven by lower pressure-pumping rates and recent design enhancements

Future: staggered lateral development, completion of wells drilled but not completed

Eagle Ford: Sweet Spot Factors

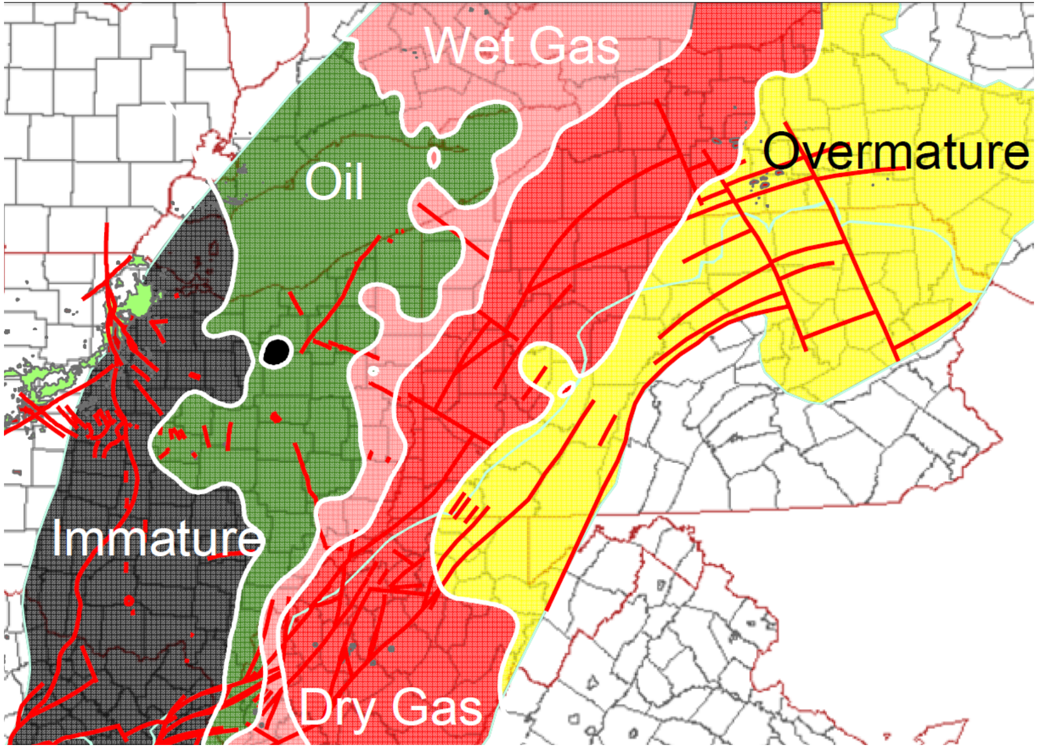
Operators
Abraxas
Anadarko
BHP Billiton
Cabot
Devon
Laredo
Lewis
Marathon
Matador
Murphy
Newfield
Pioneer
Plains
Rosetta
Shell
Statoil
Swift



Integrate Petrophysical and Geophysical Analysis

- Image logs
- TOC
- Reservoir thickness
- Inversion & acoustic impedance to determine "net" thickness prediction with higher porosity
- Seismic attributes
- History matching

Marcellus: Updates

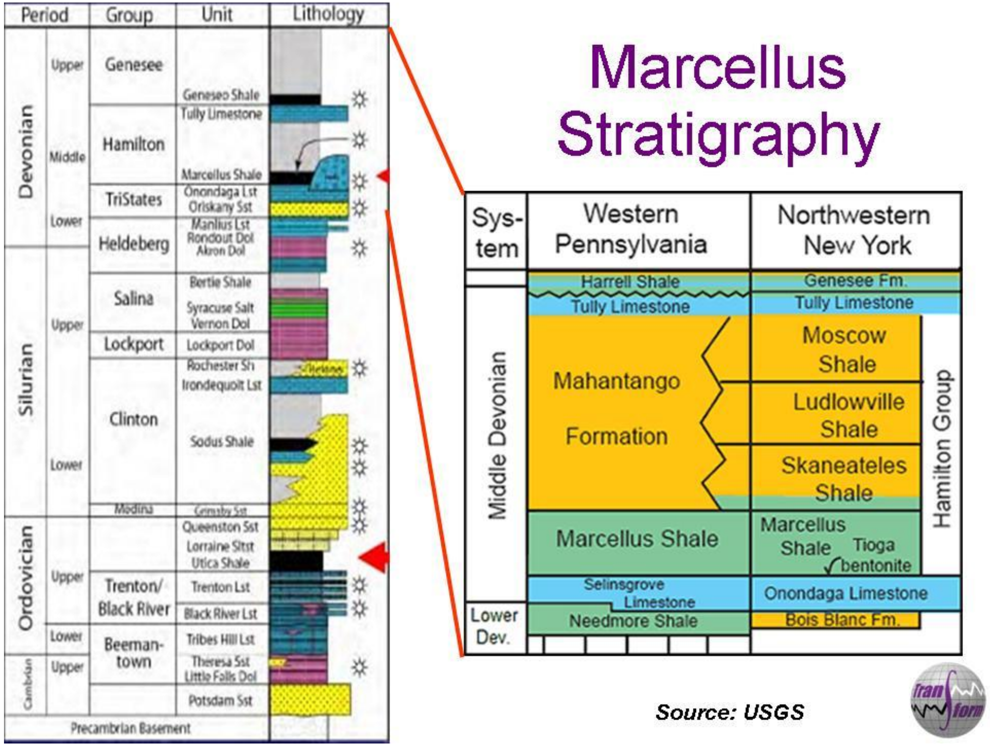


Understanding the Reasons

- Liquids-rich play
- Thermal maturity patterns
- Oriskany Structure / major fold trends (NE -- high amplitude folding)
- Regional Pressure Trends
- Shale gross thickness - favored preservation of organic matter
- Rome trough and cross-strike faulting
- Natural Fracture - Increase to the East
- Natural Gas Liquids rich portion of the SW Core areas -- large pore sizes and high concentration of organics (high organic porosity)

http://www.searchanddiscovery.com/pdfz/documents/2015/110183zagorski/ndx_zagorski.pdf.html

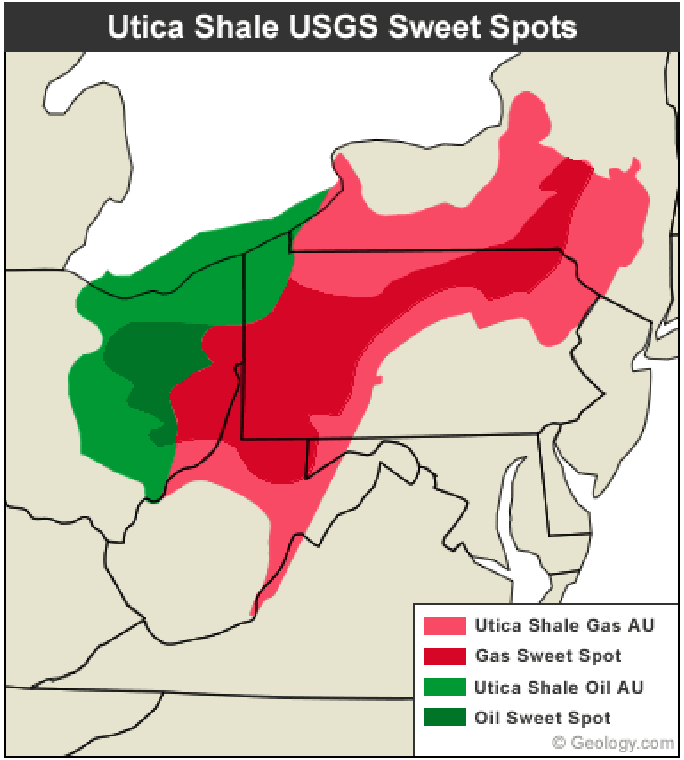
Marcellus: Sweet Spot Factors



Integrated Information

- Fracture networks
- Pore pressure
- Thermal maturity patterns
- Basin structure
- Structural history
- Geochemistry
- Microseismic

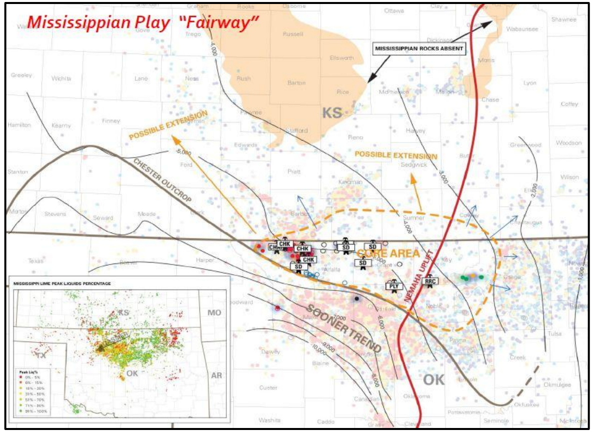
Utica: Sweet Spot Factors

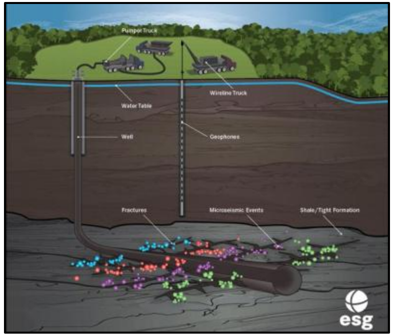


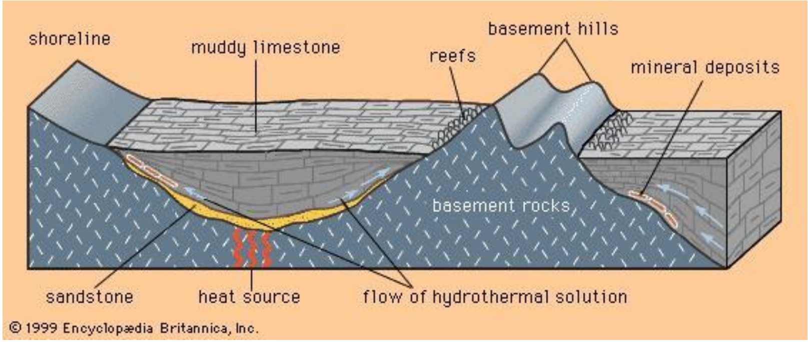
Integrate Petrophysical and Geophysical Analysis

- Paleotopography
- Unconformities
- Mineralogy / XRD
- Isotopes and Geochemical Fingerprinting
- Resistivity variations
- Faulting
- Airborne EM resistivity measurements to find correlative attributes in “predictive analytics” (geostatistics)

Mississippian Lime: Sweet Spot Factors



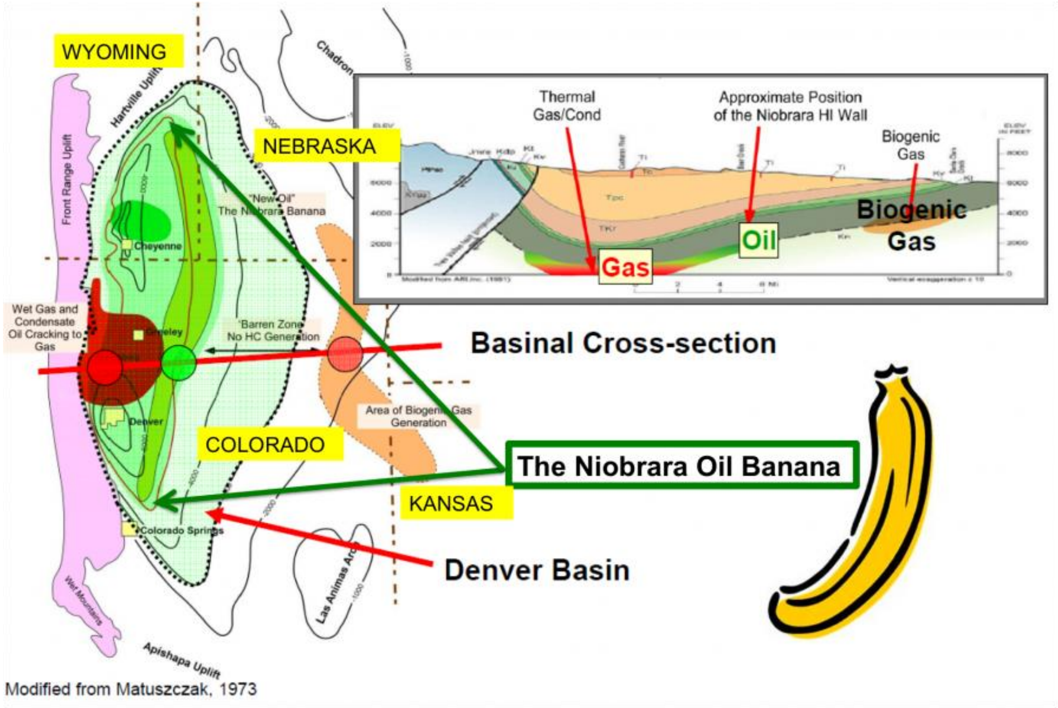




Multi-pronged approach

- Lithofacies variations
- Heat flow over time (Mississippi Valley type of structure)
- Understanding the timing of deep-seated tectonic movement
- Determine where the migration pathways existed – use isotopes for "fingerprinting"
- Fracture networks (natural and induced)
- History matching
- 3D seismic
- Fluid flows / diagenetic alteration patterns

Niobrara: Sweet Spot Factors

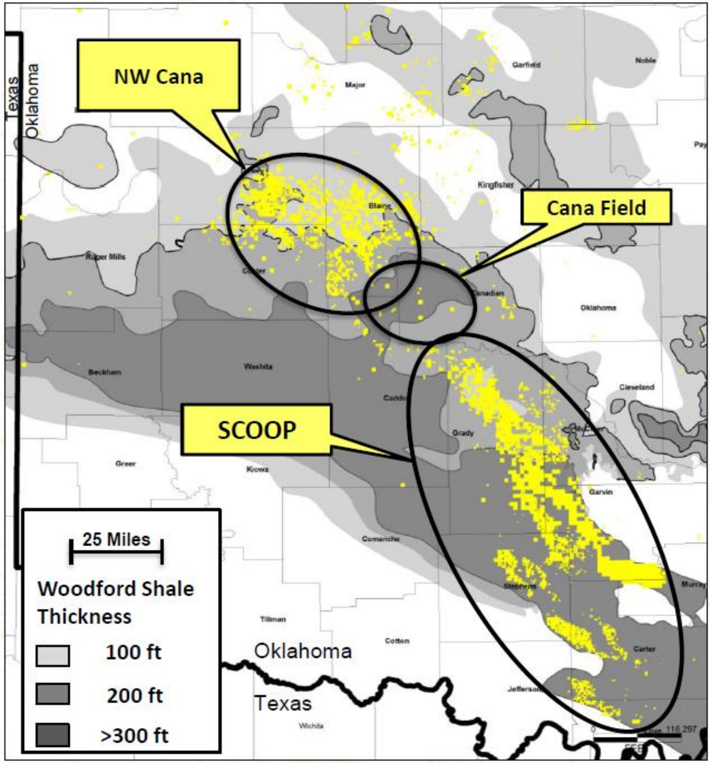


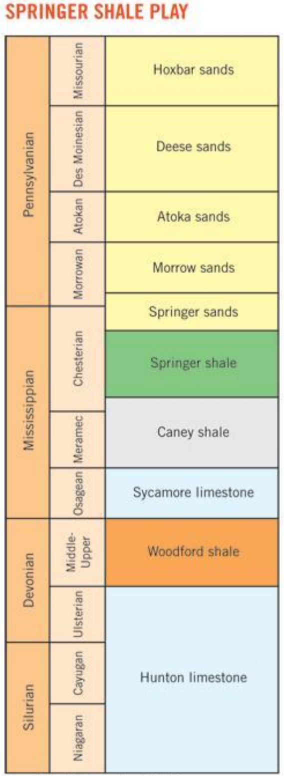
The Niobrara has very low porosity and permeability, and is self-sourced. Producibility factors:

- Thermal Maturation: 0.60 – 1.35 % Ro – Vitrinite Reflectance
- Natural fracturing along basement faults (surface lineaments)
- Wrench fault-triggered fracturing
- Volumetric changes due to salt movement / dissolution
- Oil “banana” (shape of the oil zone)
- 3D seismic
- Satellite images (remote sensing of surface lineaments, etc.)

- http://www.niobraranews.net/niobrara-exploration-controls/

Woodford Shale: Sweet Spot Factors





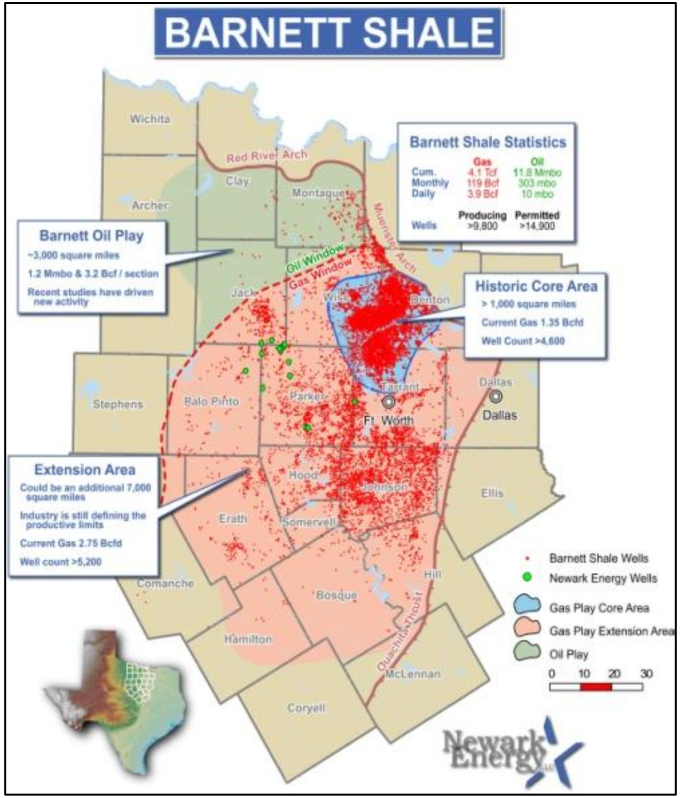
Source: Continental Resources Inc., Sept. 2014

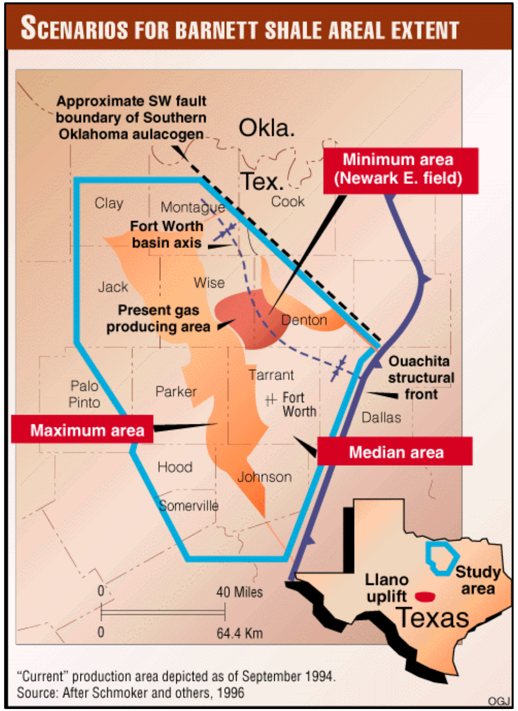
Workflows Should Include the Following

- Natural fractures
- High fracability index (relatively low ductility)
- Heat flow / thermal maturation
- Areas of relative lack of faulting / structure (so the oil stayed in place rather than migrating out)
- Good TOC levels
- 3D seismic to determine
- High levels of organic porosity
- Good pore pressure

- http://www.slb.com/~/media/Files/resources/oilfield_review/ors13/win13/02_sweet_spot.pdf

Barnett Shale: Sweet Spot Factors

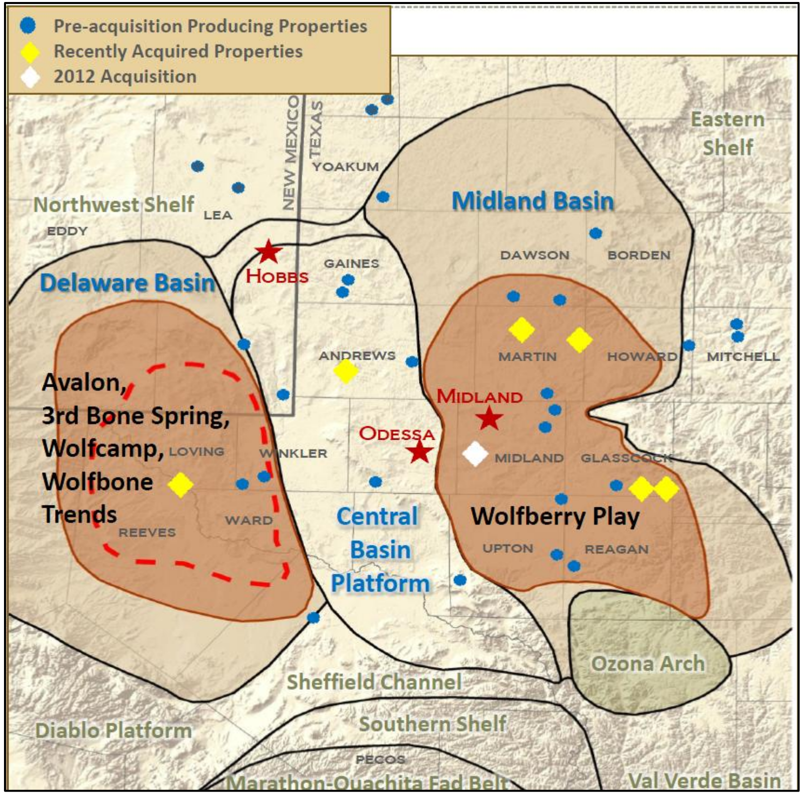




Multiple factors

- Away from main faults
- Water zone / boundary
- Pore pressure good due to organic porosity development
- Excellent conductivity with respect to pore throats and pore architecture
- Fracable, and effective completion strategies
- 3D seismic anomalies
- Storage in well developed pores and fracture networks
- Microseismic indicates fracture networks
- Seismic attributes / fracability - high levels of anisotropy indicating stress fields

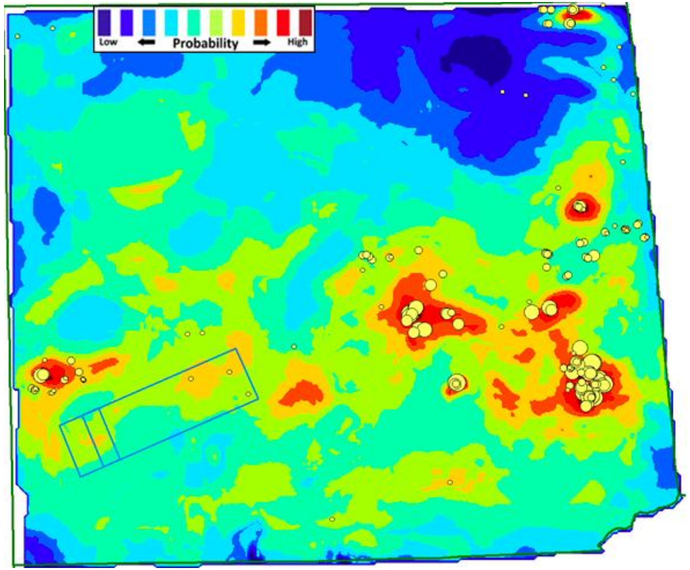
Permian Basin Shales: Sweet Spot Factors



Production Sweet Spots

- Slow-to-fast S-wave velocity ratio derived from AVOAZ inversion
- Anisotropy related to production sweet spots
- High kerogen content / TOC
- Organic porosity
- Microcracks / microfissures
- Self-sourcing (sufficient thermal maturation)
- Fracture detection with seismic frequency attributes
- Dividing the basin into time slices / understand the basin depositional history
- Explore on the margins (not in the basin center)
- Understand the direction of the sediment gravity flows (SGFs) into the basin

Data Mining: New Directions in Geostatistics



- Neutron porosity: a good indication of maturity
- High resistivity: potential indicator of hydrocarbons
- Calculate TOC (using the Schmoker model)
- Calculate difference between maximum and minimum horizontal stresses (the larger the difference the better)
- Calculate Young's modulus (degree of shale deformation)
- Calculate Poisson's ratio (brittleness)

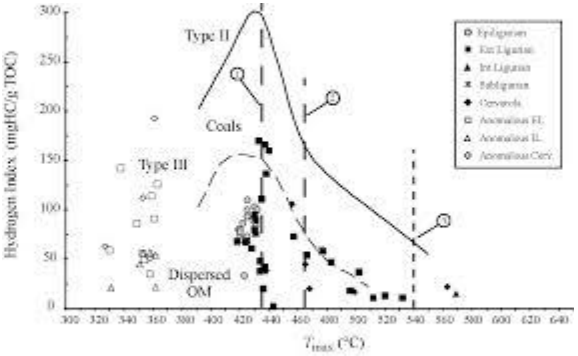
- *Bring it all together*

http://blog.neosgeo.com/2012/05/20/detecting-sweet-spots-in-a-shale-reservoir-marcellus-example/

Leila Aliouane, Sid-Ali Ouadfeul, Sweet Spots Discrimination in Shale Gas Reservoirs Using Seismic and Well-logs Data. A Case Study from the Worth Basin in the Barnett Shale, Energy Procedia, Volume 59, 2014, Pages 22-27.

Tools and Techniques

Pyrolysis and TOC – Tmax



Overview: *Interpretation of pyrolysis and TOC data using the compiled graphical plots is a suitable tool for geosteering while drilling for tight oil targets because it provides a means for predicting sweet spots and also delineating formation tops.*

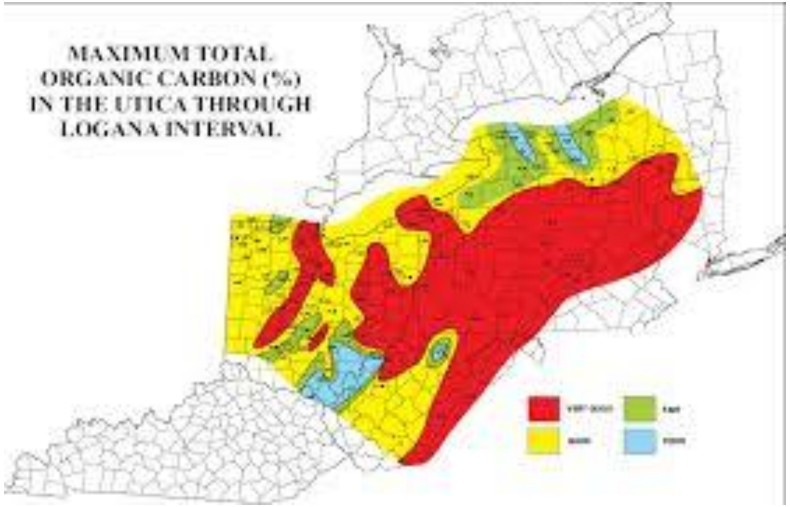
The pyrolysis data comprised of S1, S2, S3 and Tmax. TOC is the organic carbon content of the rock.

Drawbacks: Requires core analysis; cores may not be available.

Satinder Chopra, et al. (2014) Shale Gas Reservoir Characterization Workflows
http://www.searchanddiscovery.com/pdfz/documents/2014/41266chopra/ndx_chopra.pdf.html

Maende, Albert. (2013) Pyrolysis and TOC Identification of Tight Oil Sweet Spots. UrTEC 2013

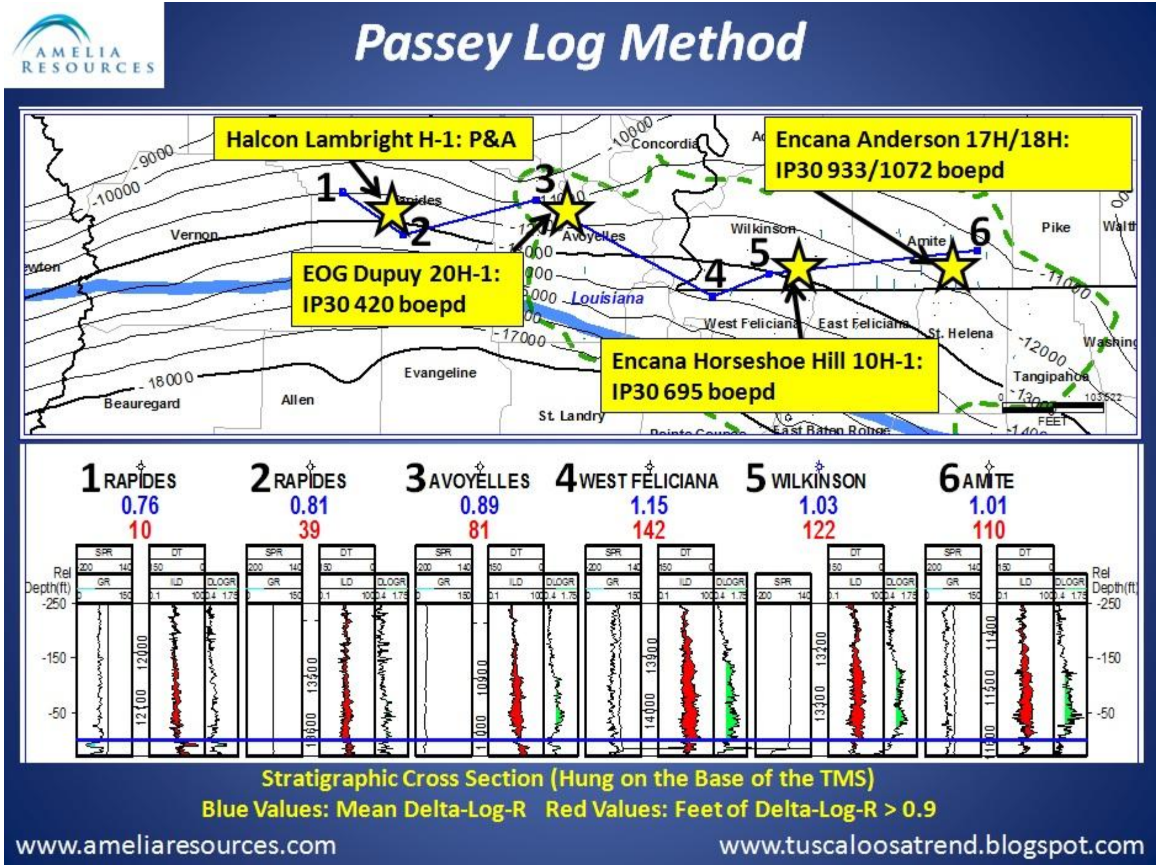
Calculated TOC & Sweet Spots



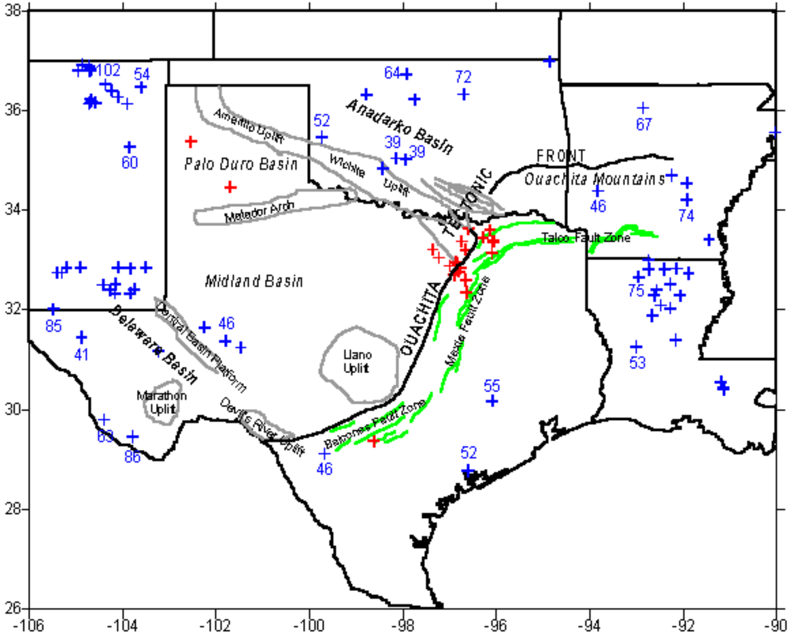
- Identify interval in the trend wells
- Digitized logs (Density-Neutron / Photoelectric index (Pe)
- Review TOC available sample data
- Develop a calibrated TOC model
- Passey Method
- Calculate TOC and porosity for the interval
- Correlate and map the geological and petrophysical results
- Connect the production data to the TOC and petrophysical maps

Dotsey, Pete. Logs Reveal Marcellus Sweet Spots.
http://www.tgs.com/uploadedFiles/CorporateWebsite/Modules/Articles_and_Papers/Articles/0311-tgs-marcellus-petrophysical-analysis.pdf

Calculated TOC & Sweet Spots



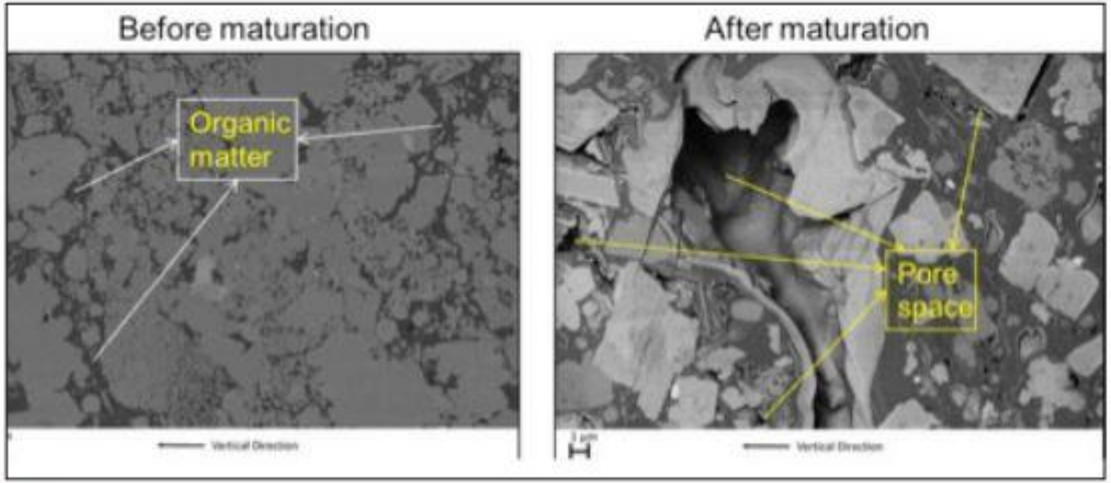
Thermal Heat Flows & Maturation / Porosity



- Basin-level heat flow / thermal patterns will help develop ideas of trends in preferential maturation
- Thermal maturation of kerogen / high TOC areas may lead to the enhancement of porosity (organic nano- and micro-porosity)
- Find heat-flow maps, along with the position of basement uplifts and tectonic activity

Negraru, P. and David Blackwell. (2003) Heat Flow in Texas. http://geology.heroy.smu.edu/~negraru/Heat_texas/

TOC and Organic Porosity

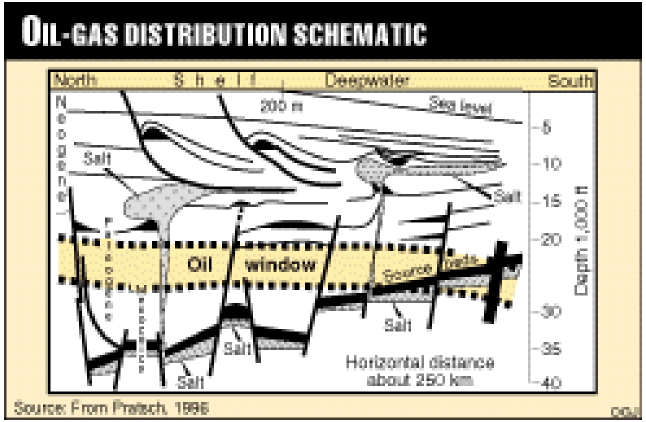


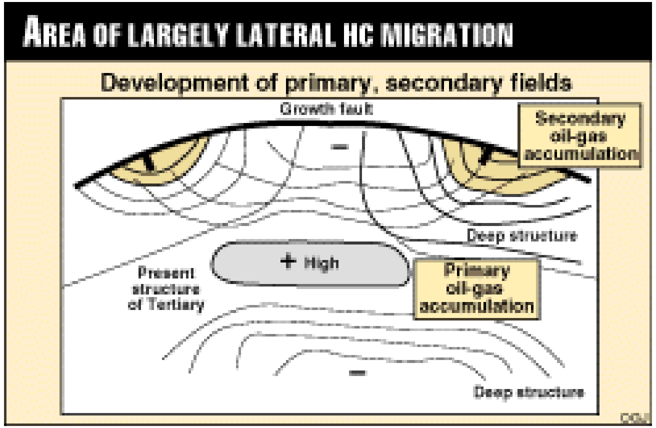
SEM images

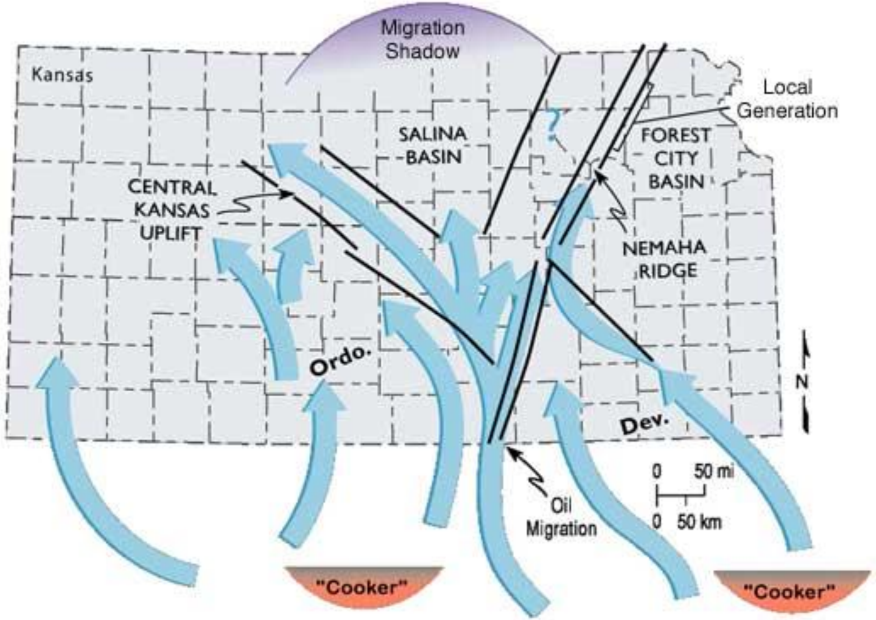
- Kerogen micro-porosity and nano-porosity
- Occur as a result of expulsion / adsorption in the thermal maturation process
- "Loucks' porosity"
- Intraparticle pores
- Look at basin modeling

Loucks, R.G., etal. (2011) Origin and classification of pores in mudstones from shale-gas systems.
http://www.searchanddiscovery.com/documents/2011/40855loucks/ndx_loucks.pdf

Migration Pathways

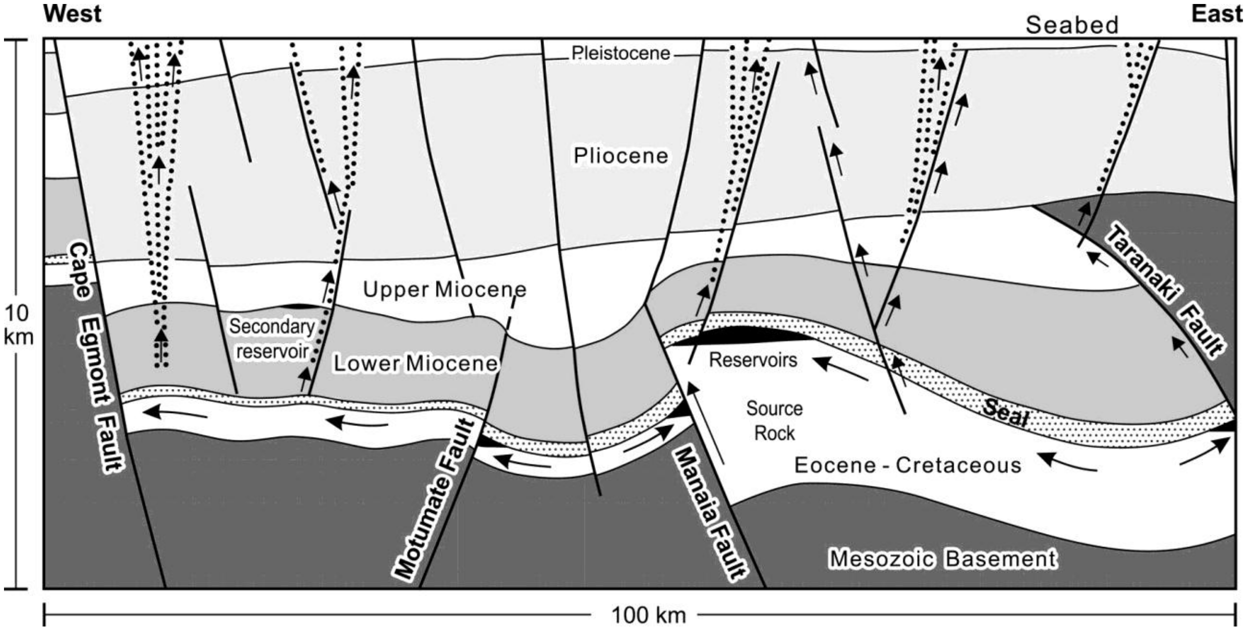






- Generation of oil
- Migration Pathways
- Can extend many miles

Faulting and Gas Migration Pathways



- Understand the major fault systems
- Normal faults and gas migration
- Active and ancient plate boundaries

Other factors --

- Understand the major fault systems
- Normal faults and gas migration
- Active and ancient plate boundaries
- Geomechanics: Young's modulus / Poisson's ratio
- Pore pressure

Concluding Considerations

Heterogeneity comes in many different forms.

- Know your reservoir and your lithologies.
- You may have fine-grained sand interbeds, or you may have more mudstone or marly facies.
- Understanding the nature of the heterogeneity (lithology, fracture density, pore architecture, diagenetic alteration / overgrowths really do matter).
- http://www.searchanddiscovery.com/pdfz/documents/2015/110214nash/ndx_nash.pdf.html

Fluid migration pathways matter more than you may think.

- While it’s easy to think of all shales as essentially self-sourcing (“my source rock is now my reservoir”), that’s not actually the case in all shales,

- and depending on the fracture networks and the pore architecture, you may have differentially enriched sediments which constitute excellent sweet spots.

- Understanding the **source, direction, and geochemistry of the reservoir fluids** (including gases) will help you pinpoint the sweet spots.

- http://www.searchanddiscovery.com/documents/2014/70173nash/ndx_nash.pdf

Connectivity, but for how long?

- Knowing how long your induced fractures will stay open,
- and which proppants seem to live up to their promise
- can make the difference between a well you'd like to purchase, or one you'd like to run from.
- (additional resource: http://www.searchanddiscovery.com/documents/2014/80352nash/nash-outline.pdf)

Frac Interference, Thief Zones, and other signs of over-muscling the frac design.

- The conventional wisdom suggests that the bigger the frac the better, and the more rock you “rubble-ize”, the better.

- But, some reservoirs exhibit behavior that deviates (dramatically) from conventional wisdom.

- Sometimes it is not easy to determine what exactly went on, but if there is frac interference or thief zones, it is an indication that there are ways to move the hydrocarbons, and that there is a certain level of responsiveness to stimulation.

- So, these areas bear reconsideration, particularly if there is high TOC. It’s important to keep in mind that recovery rates can hover around 10%, which means that there’s definitely oil in place.

Geochemistry can give you an edge.

- Whether you're looking at kerogen typing or isotopes which can help you with gas / oil fingerprinting,

- the more geochemical information you have,

- the better you can determine where to drill,

- and also the kinds of fluids to use in drilling and completion.

The stress regimes and pore pressure are potential solutions to “cliff-dive” decline curves.

- Understanding the stress regimes,
- pore pressure,
- and also the orientation of fractures,
- along with migration pathways,
- can help you fine-tune your completions in order to maintain flow and reduce the rapid declines.

Join the Dog Catchers Team!

Instead of euthanizing old dogs, catch them and revitalize them!

Revitalize me, don't euthanize me!!

- 1. Revitalize a well about to be plugged and abandoned for the price of plugging and abandoning.
- 2. Work on your well while prices are low. You're lucky that your well will be offline while the prices are low. Then your well will be back online and revitalized when the prices are higher.
- 3. Offer revitalization services for clusters of 5 - 10 wells in the same general area in the same field, which have had the same problem. This will allow you to achieve the best economies of scale. Further, the outcomes will provide better tests and better analyzable results.
- 4. You will be able to try more than one approach. And if you need equipment this is an excellent time to purchase.
- 5. Equipment. Compressors and heater treaters, for example, and different kinds of workover rigs . Use almost-new equipment purchased at auction prices.
- http://petrodogcatchers.blogspot.com/2015/12/dogcatchers-identify-catch-and.html

Meet the DogCatchers!

https://youtu.be/jn8xONtYwJw