Concepts of Scale: Horizontal Development of Wolfcamp Shale Oil of the Southern Midland Basin*

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Abstract

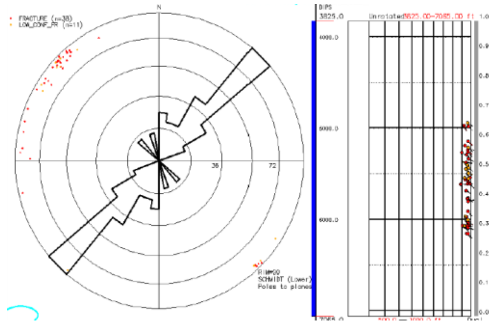
Successful development of Wolfcamp shale oil relies on complex inter-relationships within and between a wide variety of scientific disciplines, financial entities, and company partnerships. The issues and nuances within any sub-category alone could fill a book. But many broad considerations can be highlighted in the exploration and development of Wolfcamp shale oil by examining "Concepts of Scale". An English teacher might describe "Concepts of Scale" as a recurring thematic element. And if the view is sufficiently twisted with respect to all of the following observations, scale always has some role in the process.

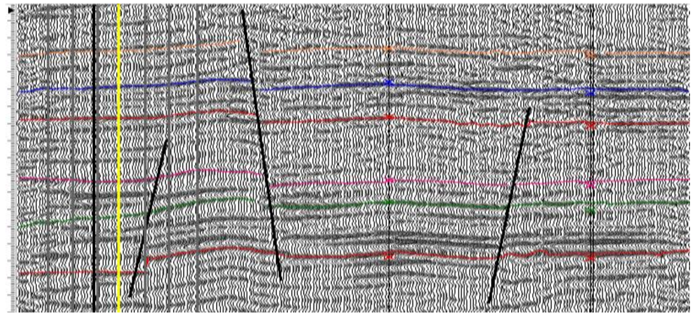
This presentation is split into two parts, but still has no chance to thoroughly explore any particular aspect. No matter. The following observations are an eclectic grouping - just a sampling of unrelated issues. Just look for those "Concepts of Scale" in very diverse ways and in very diverse corners of our industry.

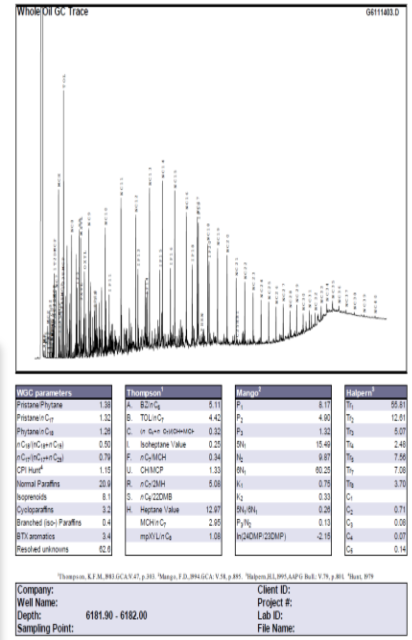
The first part of this presentation focuses on the scientific disciplines, grouped as geosciences and engineering. Geoscience observations include depositional fabrics, gas show variations, and comparative numbers of lateral landing zones ("benches"). Engineering observations include variations in hydraulic fracture stage designs (trends in numbers of stages, numbers of clusters, amounts of fluid and proppant), contrasting reservoir responses to hydraulic fracture stimulation from micro-seismic evaluation and counter-intuitive goals for stimulated reservoir volumes.

The second part of this presentation focuses on the business disciplines, grouped as land, development capital, and company partnerships. Land observations include the geographical and mineral ownership complexities of potential lease configurations. Development capital observations emphasize the rapidly changing aspects of quantity and timing. Company partnership observations encompass working interest sharing, data sharing, and the potential optimal strategies involved.

Hopefully this will encourage companies/asset teams to step back from their projects, evaluate strategy and available resources, and re-examine work flows and communication processes. Maybe even glimpse a forest not seen before.

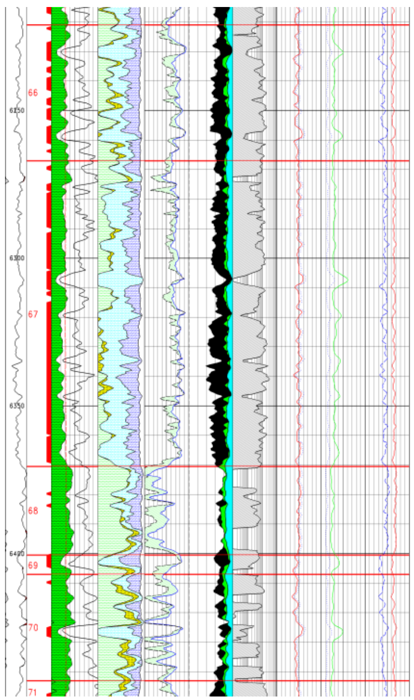


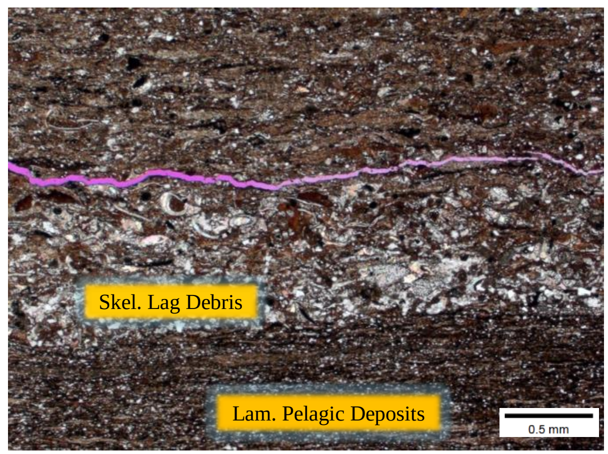


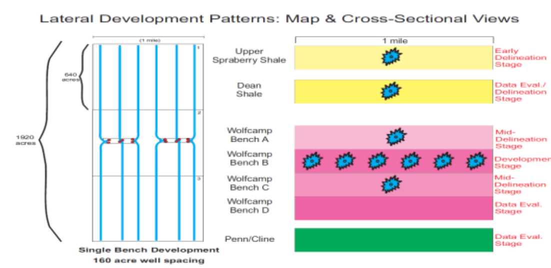


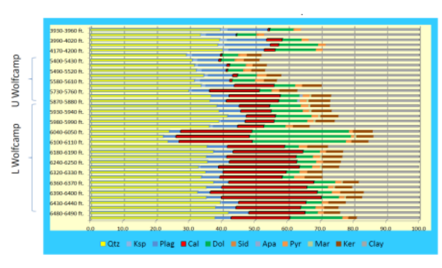
CONCEPTS OF SCALE

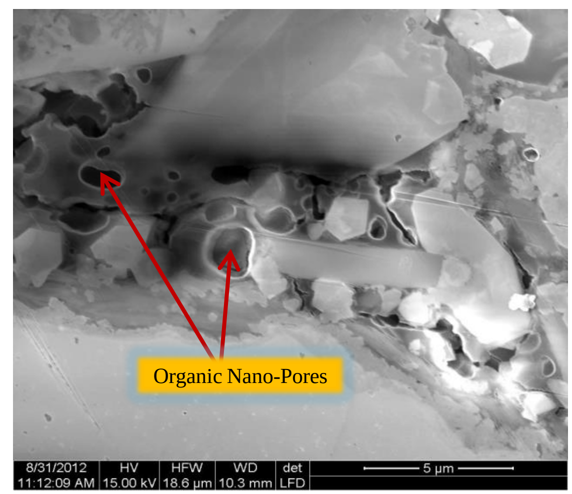
Horizontal Development of Wolfcamp Shale Oil
Southern Midland Basin











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David Dally, Geologist, Lone Star Production Company

Disclaimer

If I were you, I wouldn't rely on any word spoken, diagram displayed, or concept as related herein.

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Who is Lone Star Production Company?

- Prospect Generating Company
- Southern Midland Basin Focus:
  - ~2006 in Ellenburger & Wolfberry
  - Re-Focused on Wolfcamp Shales ~2009
- Partners with Medium - Large Operators
- Reserves Non-Op. WI in All Prospects
- Remains Deeply Involved in All Its Prospects
  - Land - Geoscience - Engineering - Research
  - Does Not Sell Any of Its Interests
- More Details: Exploring Partnership Strategies

"Concepts of Scale"

as a "*recurring thematic element*" in:

1st Discussion
- Geosciences
- Engineering

2nd Discussion
- Land
- Capital
- Partnerships

This is a random, eclectic group of topics. They are inspired by the question:

"What would you have liked to know about the Wolfcamp Shale Oil Play as you became involved with it?" - *David Entzminger, Sept. 2013*

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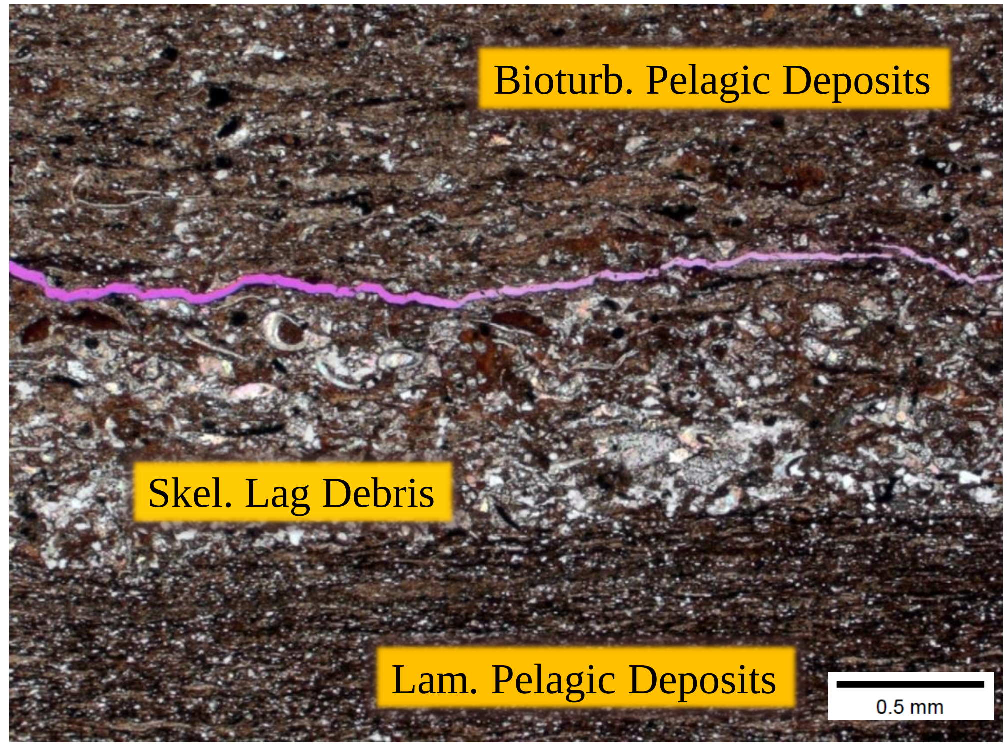
Geosciences: Facies, Laminations & Textures

Woodford Shale Outcrop (but identical to image log textures found in Wolfcamp Shales in subsurface – a few feet tall)

5-10” Thick; Abndt. Vert. Fracs.

0.25-0.1” Thick; Less Vert. Fracs.

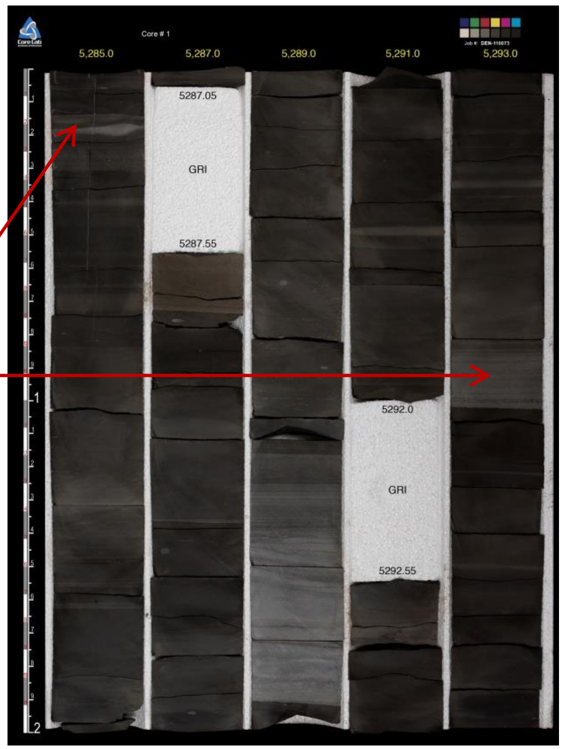


~3 mm

Wolfcamp Shale Thin Section

Very Fine Laminae: ~1mm Thick

Wolfcamp Shale Core: A Bench (box 2’ tall)

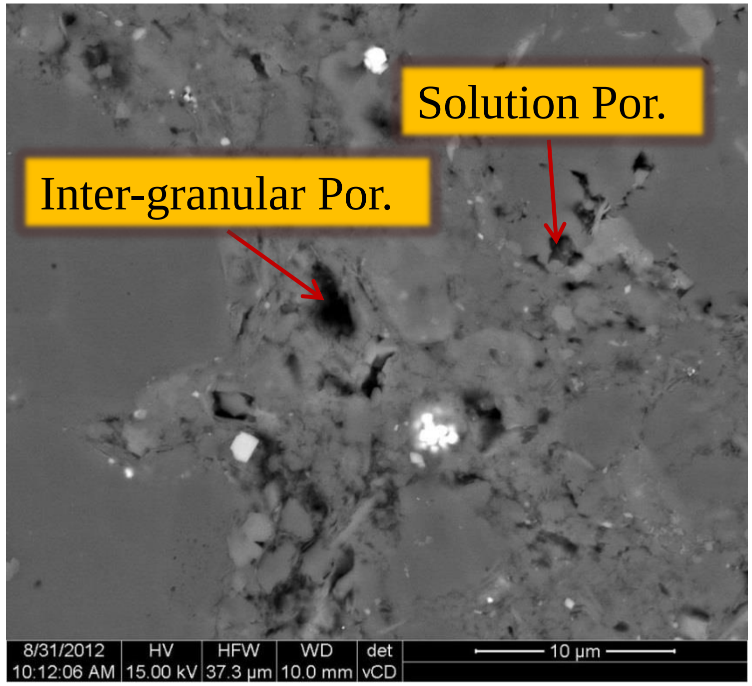


Detailed Laminae: 0.1-0.01” Thick

SEM Micrographs

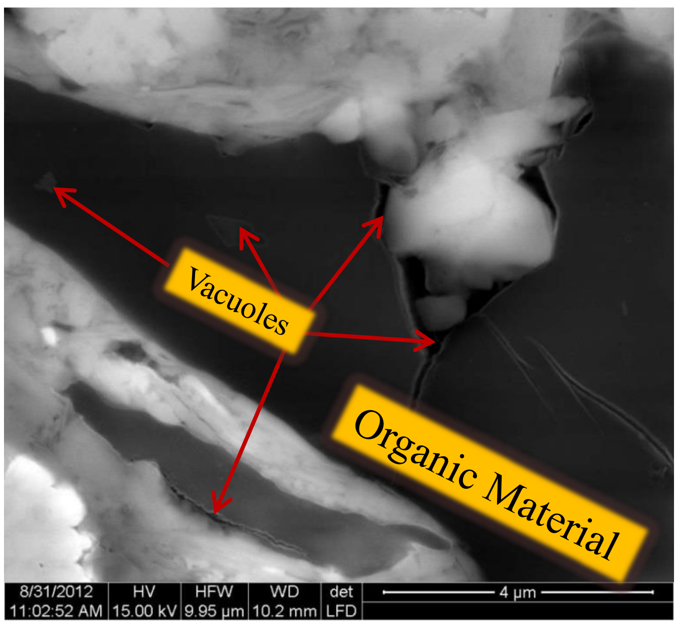
Dual Porosity-Permeability Systems

~35 microns



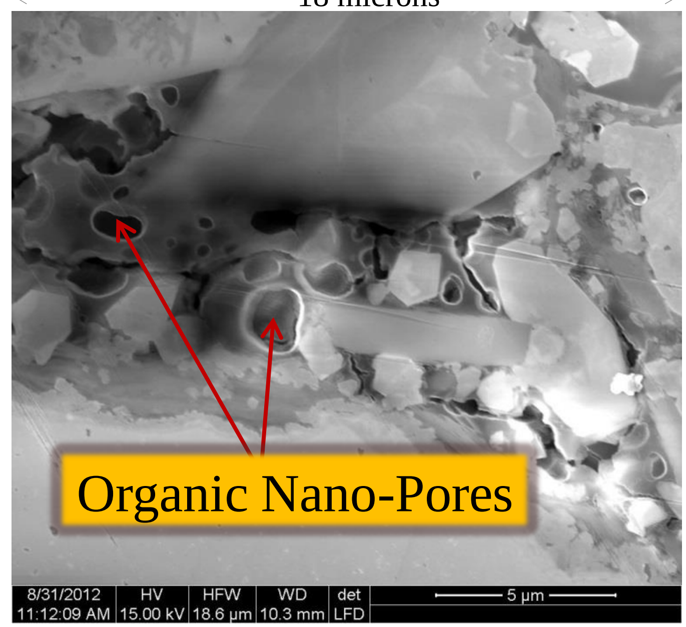
Various Intergranular Networks-Found in Both Pelagic and Debris Flow Matrix Textures

~12 microns



Vacuole & Nano-Pore Based Networks-Created in Organic Matter During Hydrocarbon Generation

~18 microns



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Geosciences: Mud Log Shows

Gas and Sample Shows are Critical Evidence of Hydrocarbons

- Historical Mud Logs are a Primary Regional Reconnaissance Tool, but…
  - Historical Mud Logging De-Emphasized Shale Analysis
  - Results are EXTREMELY Variable
  - Accuracy Too Poor for Quantitative Analysis
  - Inherent Wolfcamp Shale Show Behavior Varies Widely
  - Comparative "Scale" Issues Practically Unresolvable

- How to Use the Old Data?
  - Wolfcamp Shale Shows Thoroughly Mixed Across Any Map
  - No Shows-Moderate Shows-Great Shows: with/without Sample Shows
  - Look for a Partial Presence of Shows; Do Not Expect Consistency
  - Major Trouble Flag: Little or No Sign of Shows Anywhere

- Modern Mudlog Data is Much Better... Right?? Sort of, but…..
- Shale Facies Change Rapidly, both Vertically and Laterally, and SO DO SHOWS

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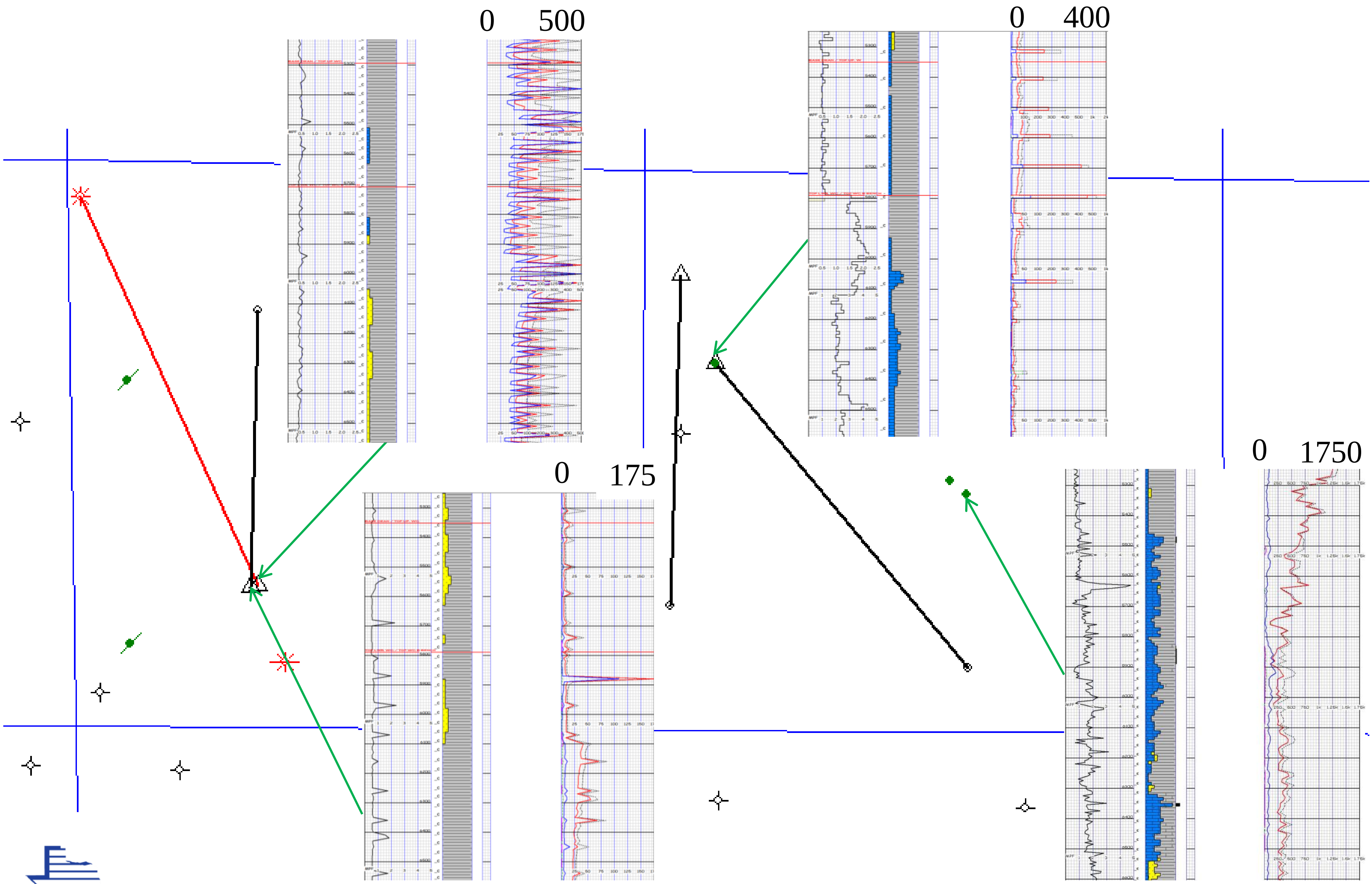
Mud Log Show Variance between Wells



All Wells Used Same Mud Logging Co.; Very Similar Time Period

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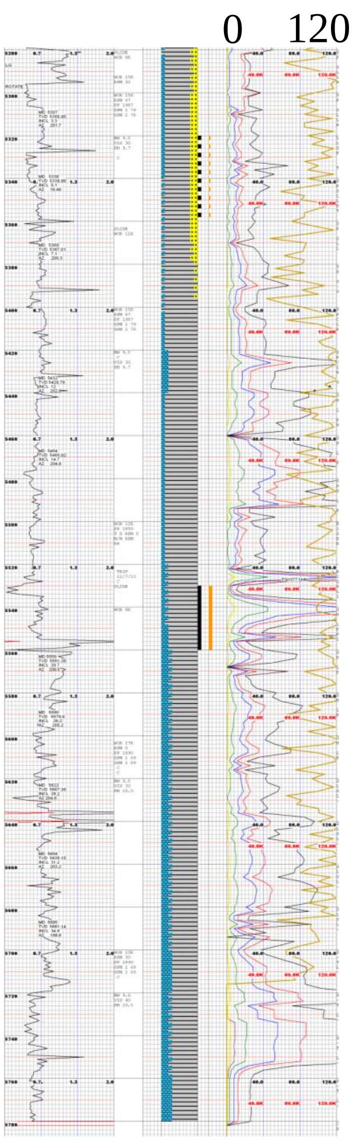
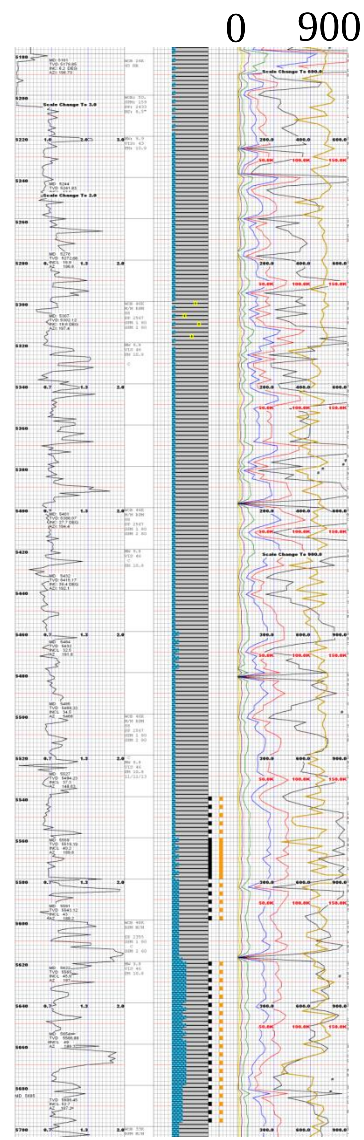
Mud Log Show Variance between Sidetracts of Same Well



Original Curve

Sidetract Curve



Situation: Original curve was not building angle quickly enough to land in our target. We plugged back and built curve slightly more aggressively to land in proper lateral position.

Potential Variables Held Constant:

Mudlogging: company, personnel, equipment; all the same
Mud System: constant
Drlg. Process: constant, but used a down hole mud motor with a more aggressive angle
Delay: ~2 days to set plug and return to drlg.

Mudlogging Results:

Almost an Order Of Magnitude Incr. in Gas Shows

*Small changes in rock facies can result in big changes in shows!

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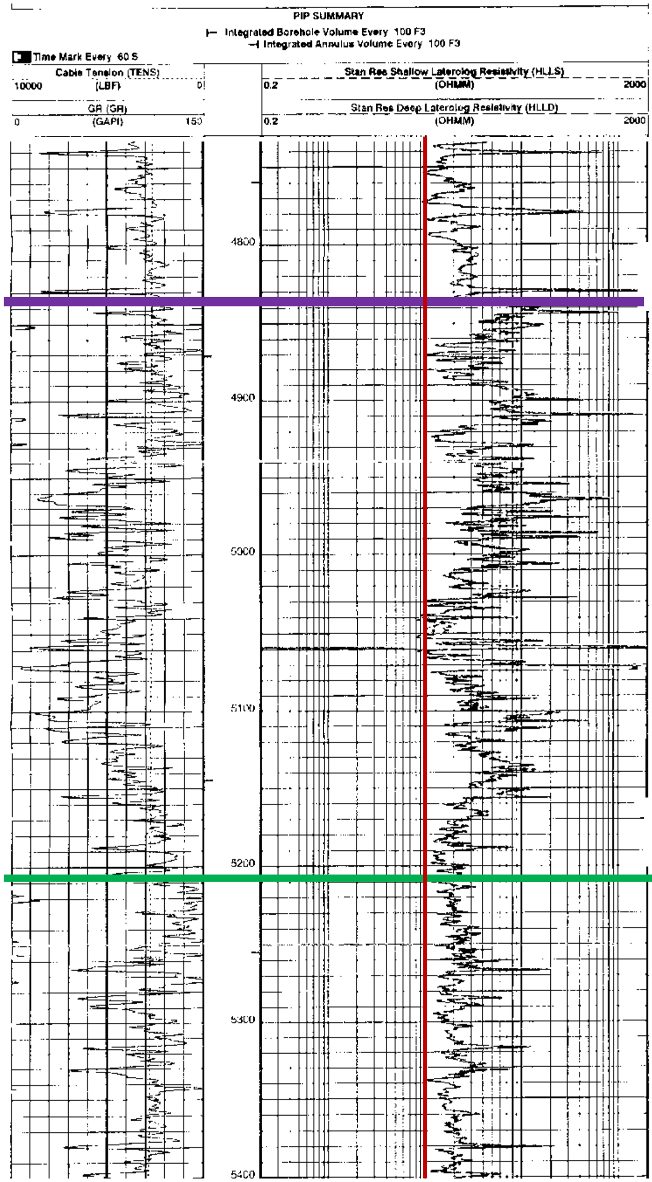
Geosciences: Resistivity Logs - Brines

Low Conc. Brine: RM= 1.128 @79F



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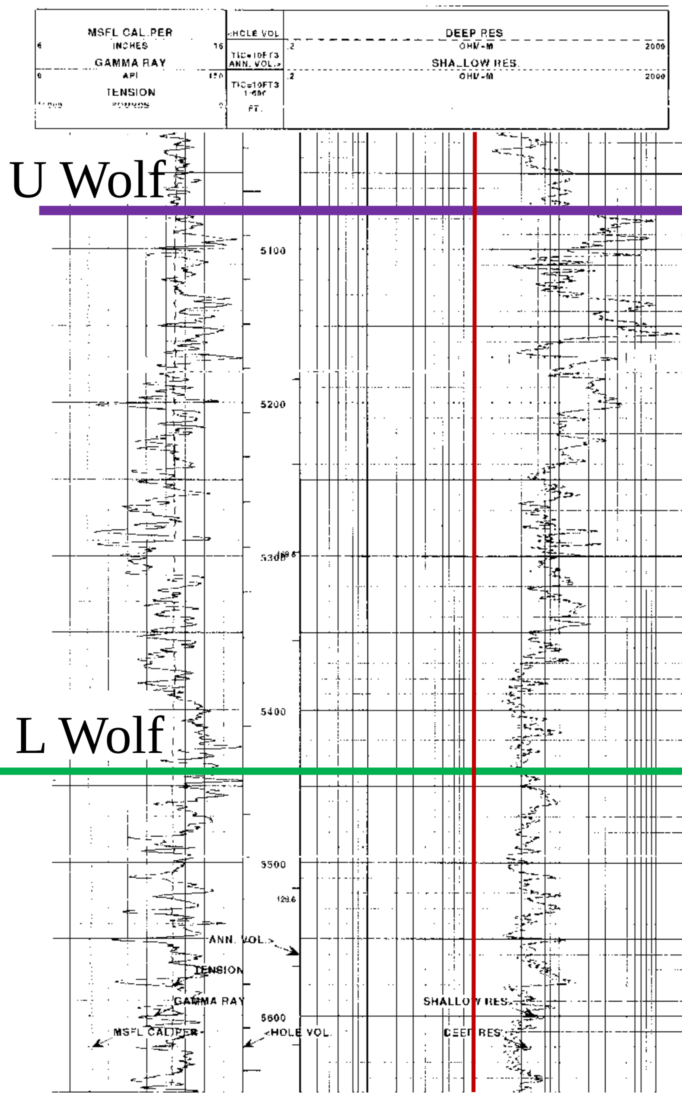
Med. Conc. Brine: RM= .172 @72F



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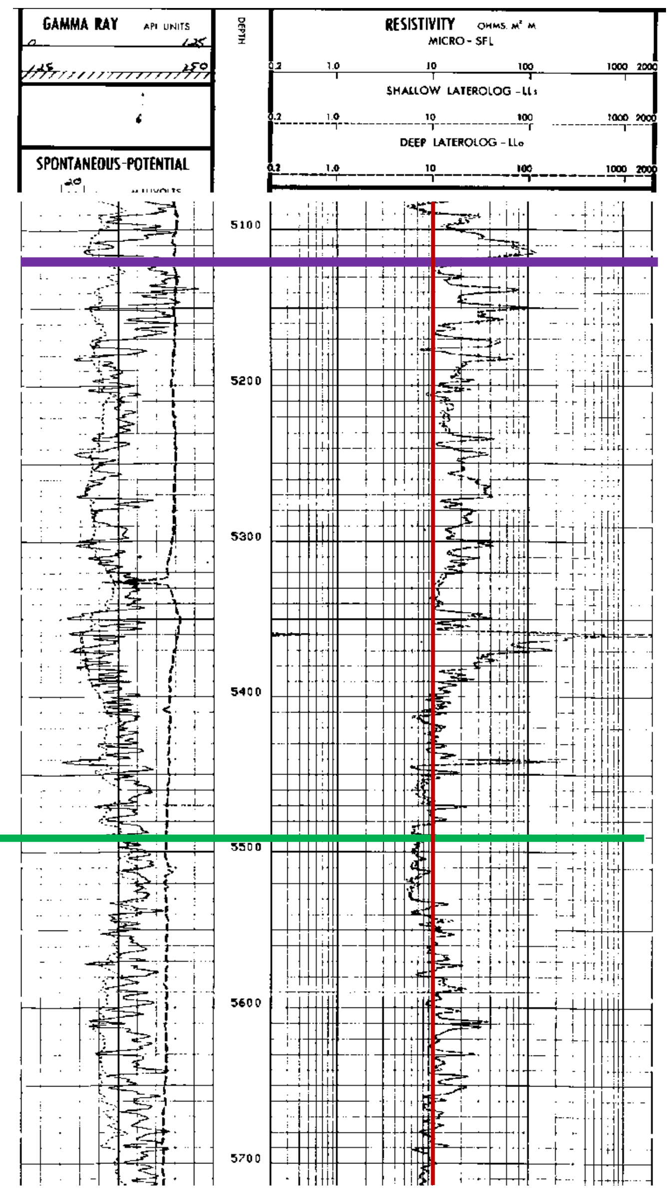
High Conc. Brine Gel: RM= .044 @82F



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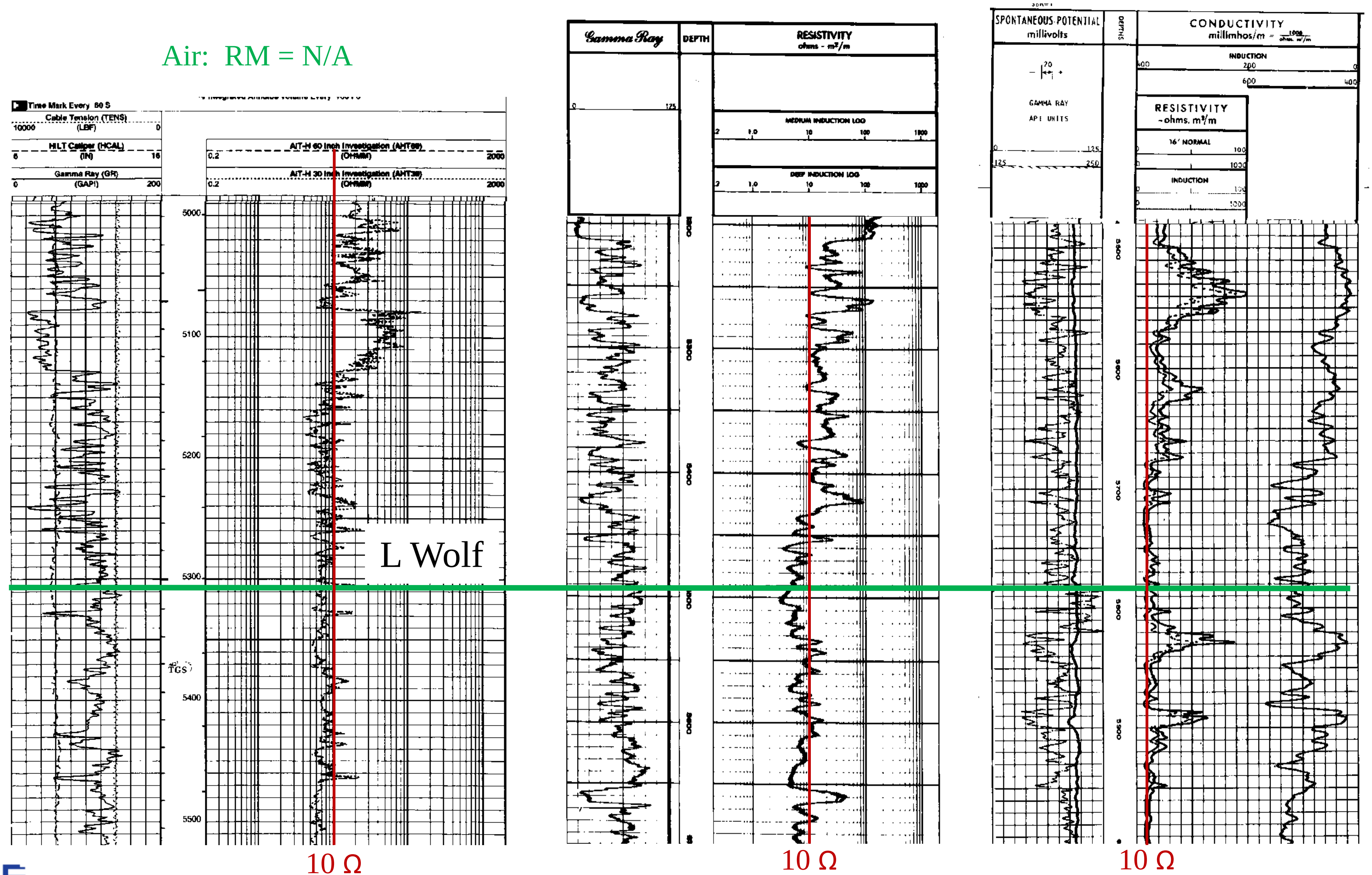
Resistivity Logs - Others

Air: RM = N/A

Oil Base: RM ~ ∞

Fresh Water Mud: RM= 3.28 @78F



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General Logging Issues

- Resistivity "Scales" are Hard to Use
  - Fluid Chemistries, Tool Vintages, Environmental Conditions HIGHLY Variable
  - Quantitative Analysis: Difficult Even in Small, Local Log Groups
  - Qualitative Analysis Can be Very Helpful (much faster-*with caveats*)
  - Resistivity Mapping Useful; but *Requires* Interpretive Care

- What about "Scaling" Issues with Other Logs?
  - Resistivity Logs – Easy to Handle Compared to Other Logs
  - Scale Normalization for Neutron Logs? Scary! (*to me, at least*)
  - Other Logs? All Long, Arduous Roads

- Petrophysics: A Major Issue to be Managed *Effectively*!
  - Vast Array Of Priceless Log/Core Data
  - Needed: Army of Petrophysicists
  - Accurate, Quantitative Results Require Incredible Time and Resources
  - Business/Economic Practical Limits on these Efforts

Geosciences: Targets-Thicknesses-Benches

Other Major Shale Oil Plays

Eagle Ford Shale Oil
Eaglebine??
Other 1-2??

1 Obviously Excl. Bench
1 2nd Bench-Delineating
2 Pot. Additional Plays?

Bakken Shale Oil
Three Forks 1
Three Forks 2, 3 & 4??

1 Obviously Excl. Bench
1 2nd. Bench-Delin., Prob. Excl.
3 Pot./Prob. Limited Benches

What I Didn't Know 5 Years Ago: How Lucky We Are In The Permian Basin!

Wolfcamp Shale Oil Play: *Southern* Midland Basin

2-3 Clearfork Shale Benches

Extensive Cuttings Analysis: Excl. ϕ-k-TOC-Tmax
Data Eval. Stage; No Lateral Tests; Reservoir Press?

4 Spraberry Shale Benches

Up. & Lwr. Spra, Jo Mill and Dean *Shales*
Ext. Cut. & Core Analysis: Excl. ϕ-k-TOC-Tmax
Early Dev. Stage; Several Vert. Tests in All 4
Lateral Tests in Lwr. Spa. & Dean *Shales*

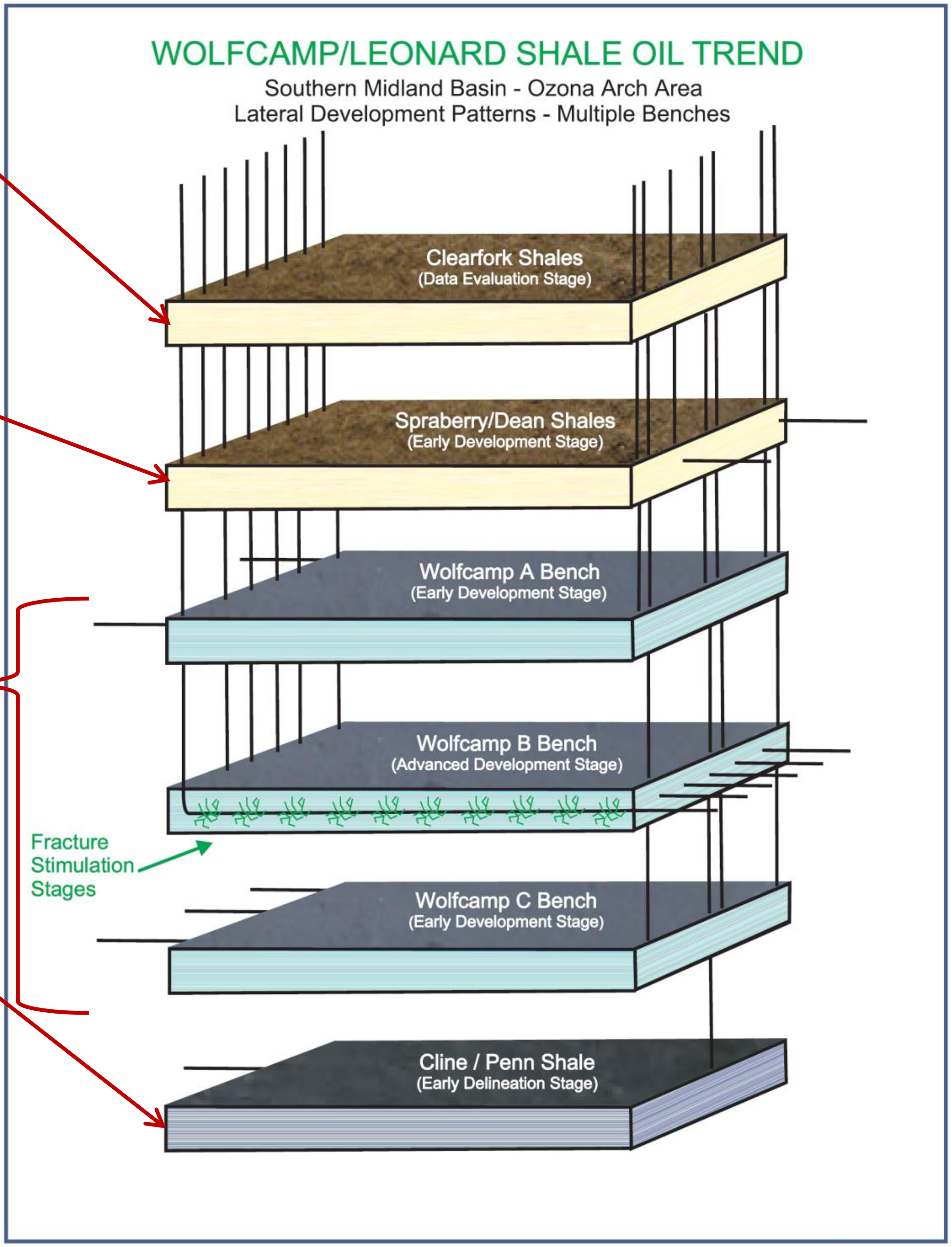
4 Wolfcamp Shale Benches

Benches A, B & C: Extensive Dev. Area Wide
Bench D: Cutting Analysis: Excl. ϕ-k-TOC-Tmax
Data Eval. Stage; No Lateral Tests

1 (2?) Cline (Penn) Shale Benches

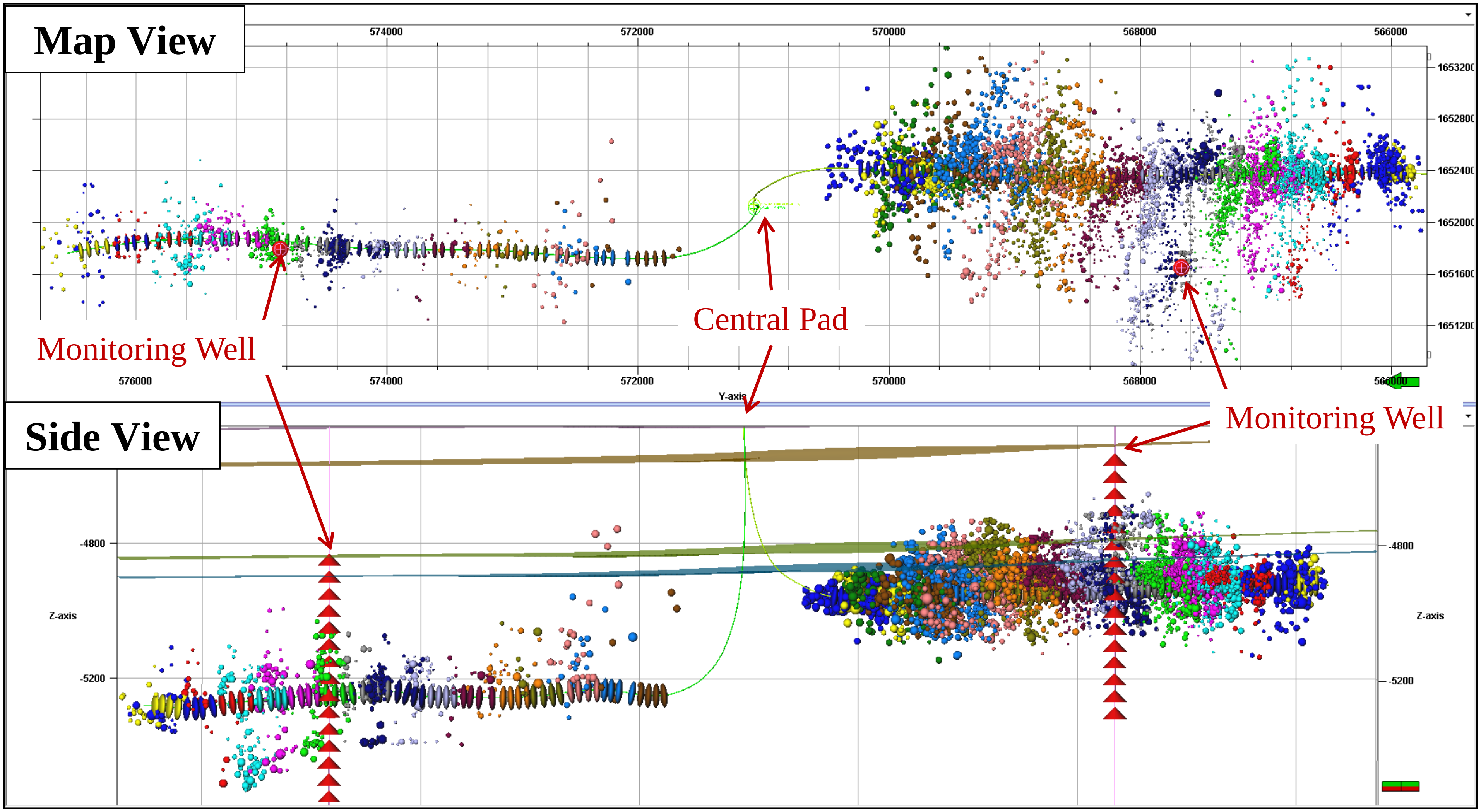
Best Deep Basin-N Flk Ozona Arch & Northward
Early Lateral Dev. Stage in Primary Bench

3 Benches in Ext. Development
3 Benches in Early Delineation
11-13 Ult. Bench Development



Engineering: Stimulation Variability Imaged by Micro-Seismic

Simultaneously Frac'd and Microseismically Monitored Wells - Same Pad



Well #1: WC Bench C

Well #2: WC Bench B

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Example Stage 8: Well #1; WC Bench C

Map View

Side View

Events cluster during end of job when 40-70 sand hits formation

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Example Stage 9: Well #2; WC Bench B

Events mostly cluster during initial pad; minor when 100 mesh sand hits formation

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Engineering: Empirical Fracture Gradients

Numerous Vert. Wolfberry Wells Examined; Published Data

Dean
Frac. Grad: ~0.60-0.70

"Mylar Chip Bag Syndrome"

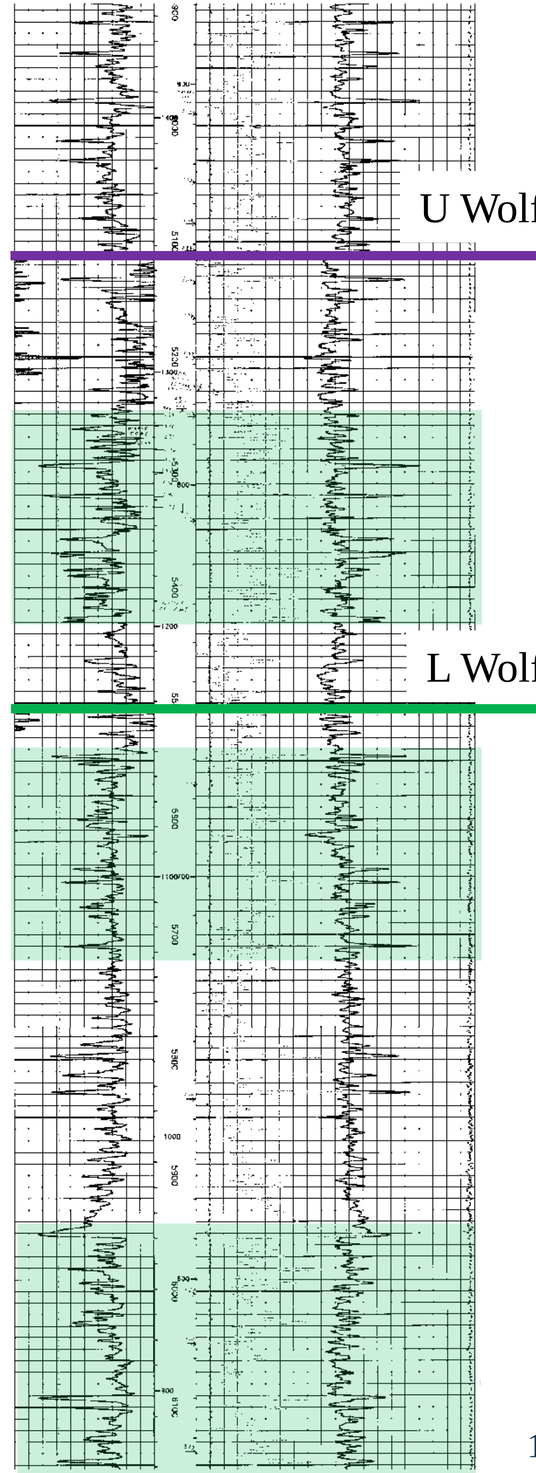
A Bench = Usually Highest OOIP
Dean = Lowest Frac. Grad.
Bench A = Highest Frac. Grad.
Early A Bench Laterals Suffered

Examined: 21 Wells; ~480 stages
A, B, & C Bench horz. wells

"A" Bench
Frac. Grad: ~0.85-1.05

"B" Bench
Frac. Grad: ~0.65-0.80

"C" Bench
Frac. Grad: ~0.75-0.90



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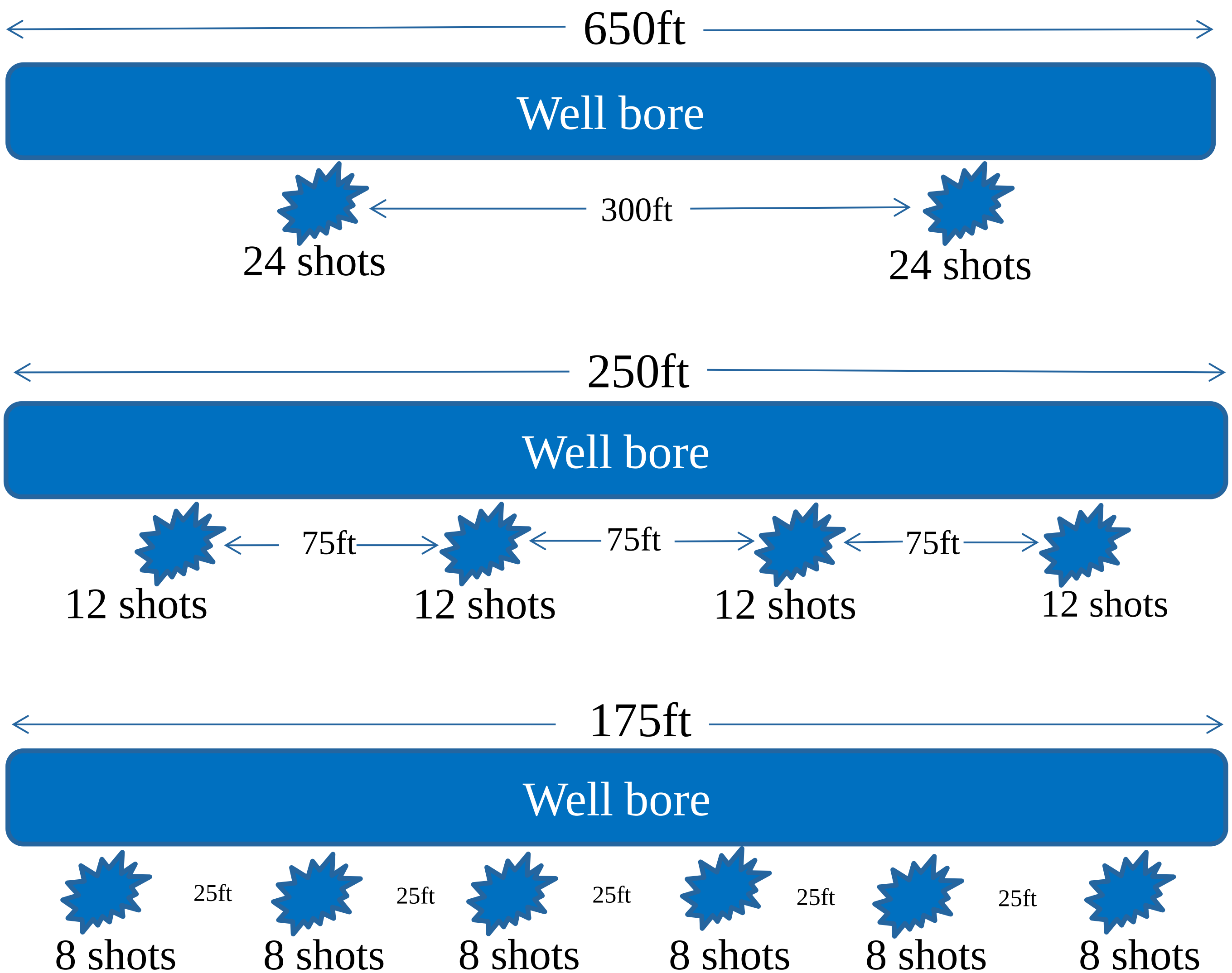
Engineering: Evolution of Fracture Stimulation Techniques



General Stage Designs

X-Link Gel
Fresh Water
Frac Wings
Mod. Amt. Crs. Sd

Slick Water
Fresh & Saline Water
Complex Frac. Pattern
Med-Lrg. Amt. Fine Sd

↑Slick Wtr. (↓Lin Gel)
Saline Prod. Water
Complex Frac. Pattern
Lrg. Amt. Fine+Crs. Sd

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Shortened Stage Length or "SSL" Techniques – Increasingly Used

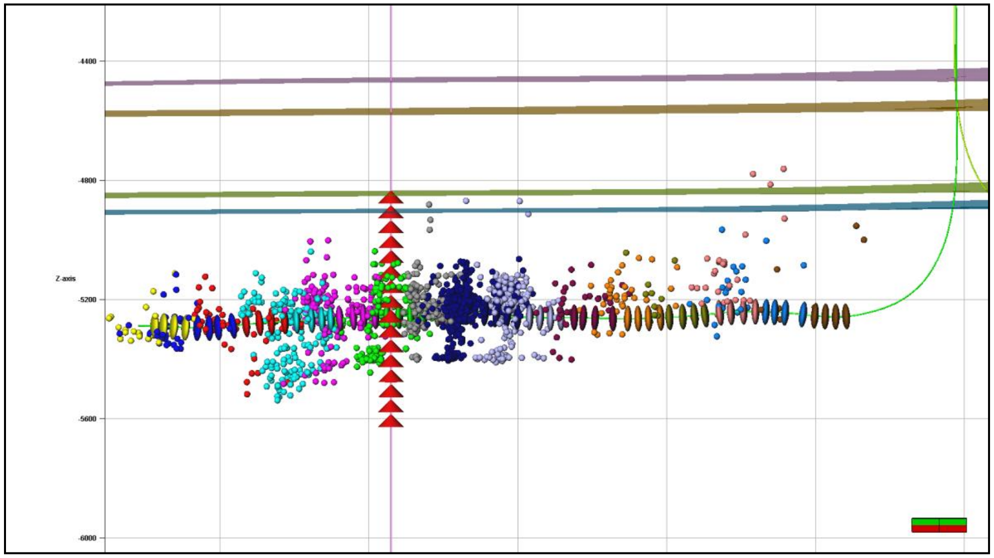
Fracture Stimulation Trends

	2010-2011	Last 6 Mos.
Lateral Lengths	3000' – 4000'	5000' – 10,000'+
No. of Stages	6 – 15	20 – 40+
No. of Clusters	2 – 3	4 – 6+
Fluid Type	Fresh X-Link Gels (early slick water)	Saline/Prod. Wtr.-Slick (ltd. hybrid gels)
Fluid Vol. bbls./stage	3,000 – 5,000	5,000 – 8,000+
Sand Type	20-40, 30-50, 40-70 (some 100)	100, 40-70, coarse tail in (ltd. resin coated)
Sand lbs./stage	150,000 – 300,000	250,000 – 450,000++
Rates BPM	50 – 70	80 – 100
Objective Frac Style	Wing	Complex – incl. Nat. Frac.
Frac Containment	Fair - Poor	Height-Good; Length-Fair

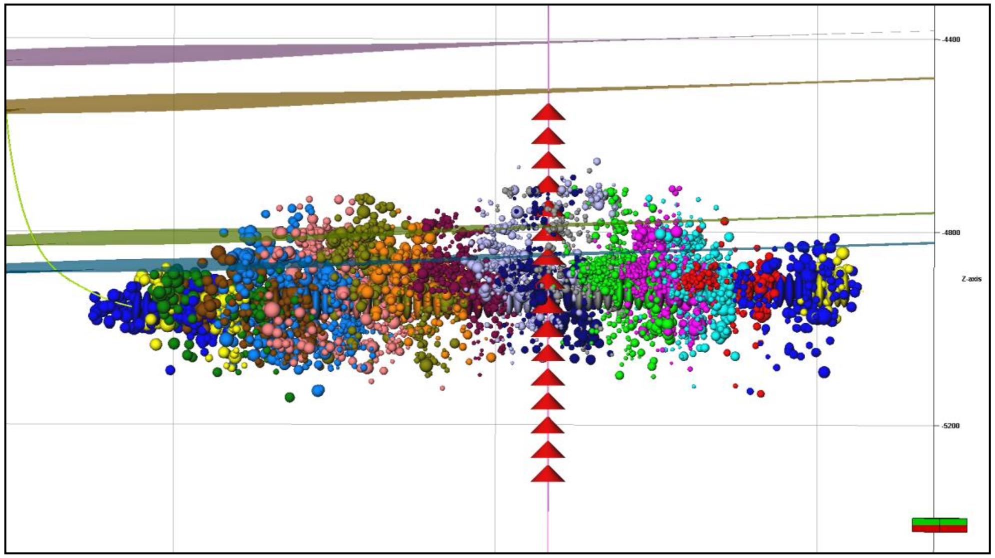
Dramatic Increase in Scale of Materials

Engineering: Stimulated Rock Volumes (SRVs)

Side Views



Well #1: Smaller SRVs
Better IP, IP 30, (EUR? maybe)



Well #2: Larger SRVs
Lesser IP, IP 30, (EUR? maybe)

Potential Re-Think on SRVs:

SRV ↓ (Scale Down)
Frac Height & Length ↓(Scale Down)
Near Well Bore Frac Complexity ↑ (Scale Up)
Recovery Factor Must ↑ (Scale Up)

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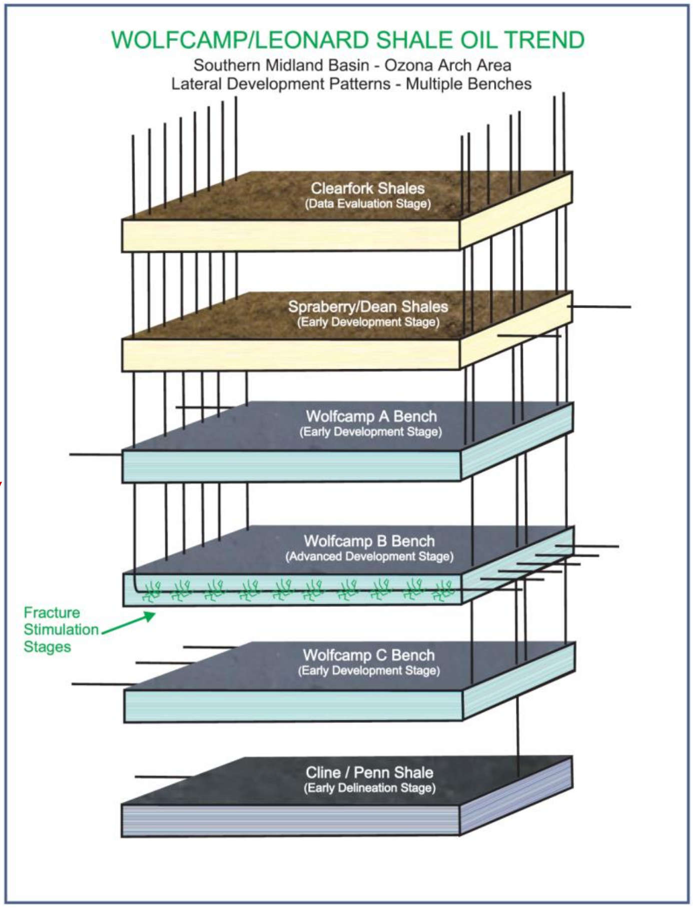
Engineering: Lateral Landing Zones and Densities

- SRV ↓ (Scale Down) <u>IMPLICATIONS</u>
  - Lateral Drainage Radii ↓
  - Laterals Spaced Across a Section ↑
  - New Benches May be Established Between Existing Benches

- Operators Currently "Test Spacing" Laterals
  - Vertical Separations: ~120' ranging to ~400'
  - Laterals Across a Section: 4–6–7–8–12–16
  - Variety of Unique Geometries and Frac Techniques
  - Similar to Test Trends in Bakken and Eagle Ford

- <u>SCALE</u> Impact on Stratigraphic Column
  - Originally Projected 11-13 Ult. Benches
  - Might be Seriously Underestimated



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CONCEPTS OF SCALE

Horizontal Development of Wolfcamp Shale Oil
Southern Midland Basin

PART II

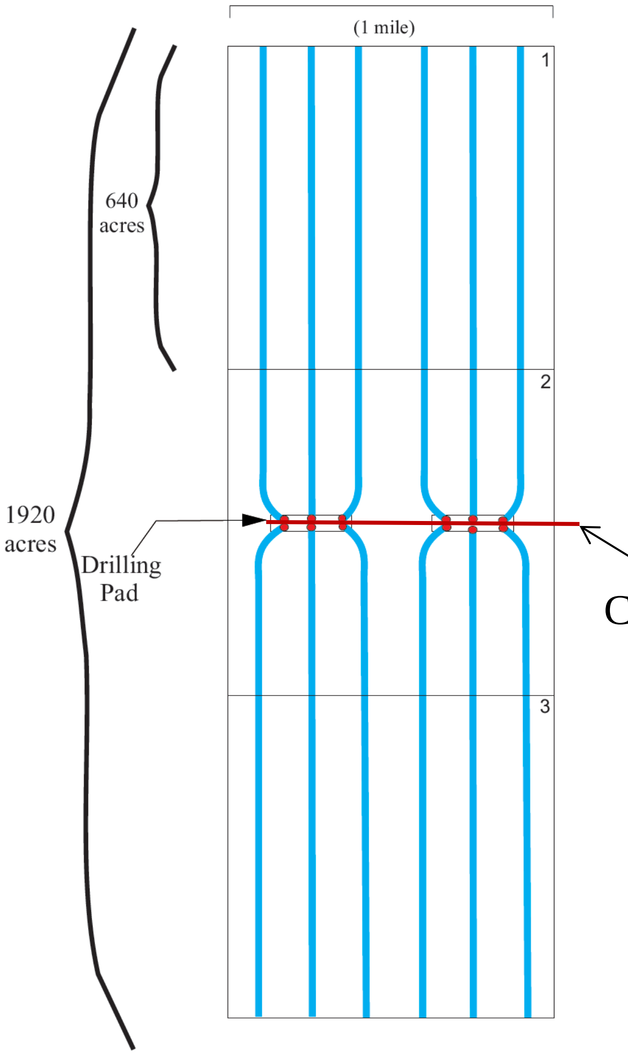
Land Capital Partnerships

These factors can contribute *as much or more* than the technical aspects to the success or failure of an operator's Wolfcamp Shale Oil project.

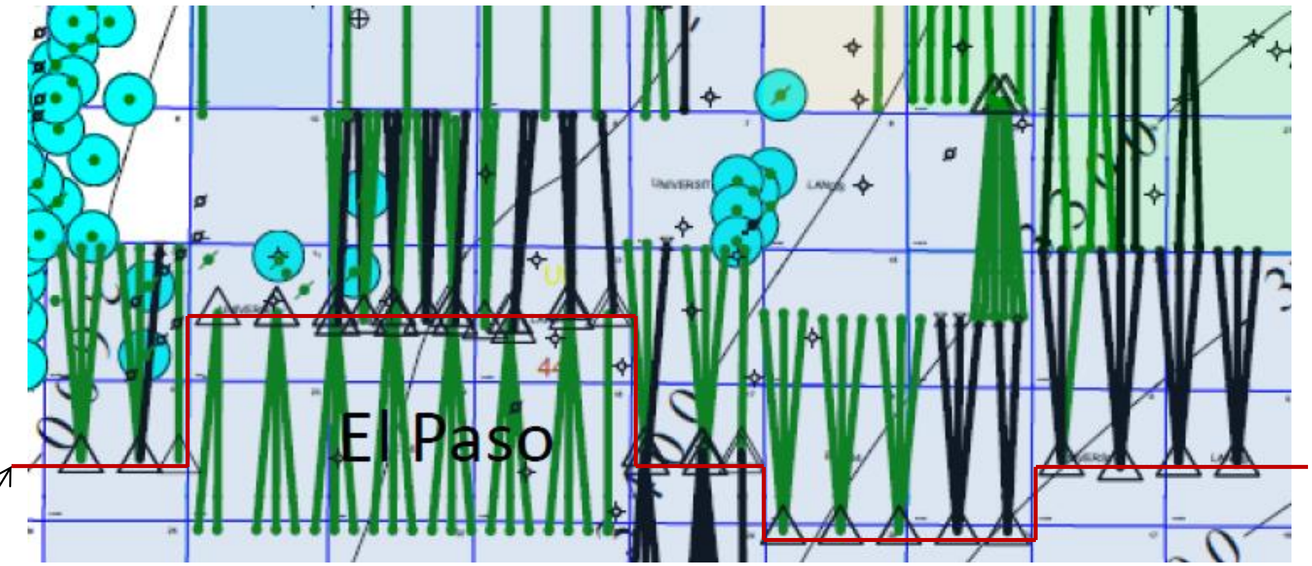
Land: Accommodating Lateral Drilling

Ideal: 1 Surf./Min.Own.
All Rights-All Depths

Real World *Near* Ideal: Univ. Lands (1 Surf./Min.Own.)
Almost Always All Rights-All Depths (some HBP issues)



Single B Bench Development
160 acre well spacing



Central Services Road

Centralized Facility Economies of **Scale**

$1MM+/well Cost Diff.

- Drilling Pads
- Frac Ponds
- Prod. Water Treat.-Stor.-Distrib.
- Gas, Electric & Water Supply/Sales
- Production Facilities
- Equipment Access and Security
- Bulk Materials Stor./Distrib./Security

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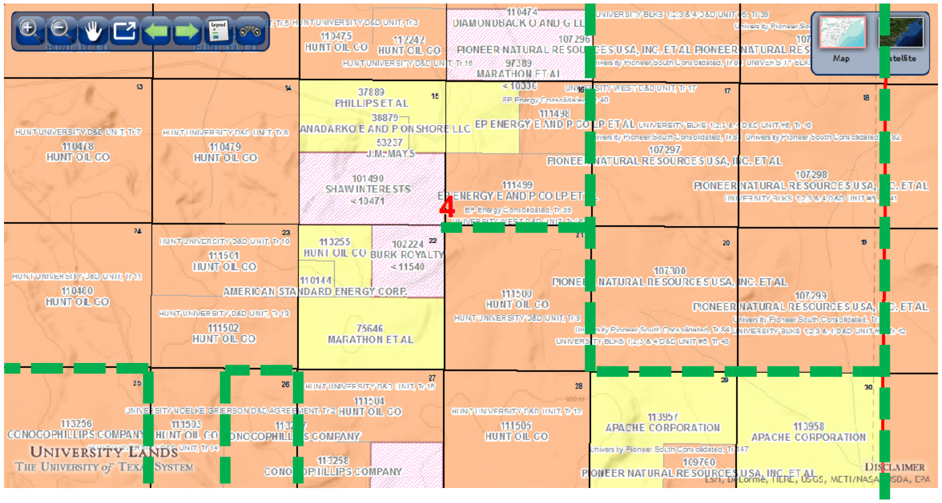
Moderately Fragmented Lease Configurations



University Lands

Many Good Lat. Drlg. Blocks Left
Pooled Interest Deals Likely
Land Complexity Moderate
(map view complexity only – no vert. frag. in model)

Fee Lands

Few Good Lat. Drlg. Blocks Left
Pooled Interest Deals Difficult
Large # Oper. & Fee Int. Owners
Land Complexity Mod.-High
(map view complexity only – no vert. frag. in model)

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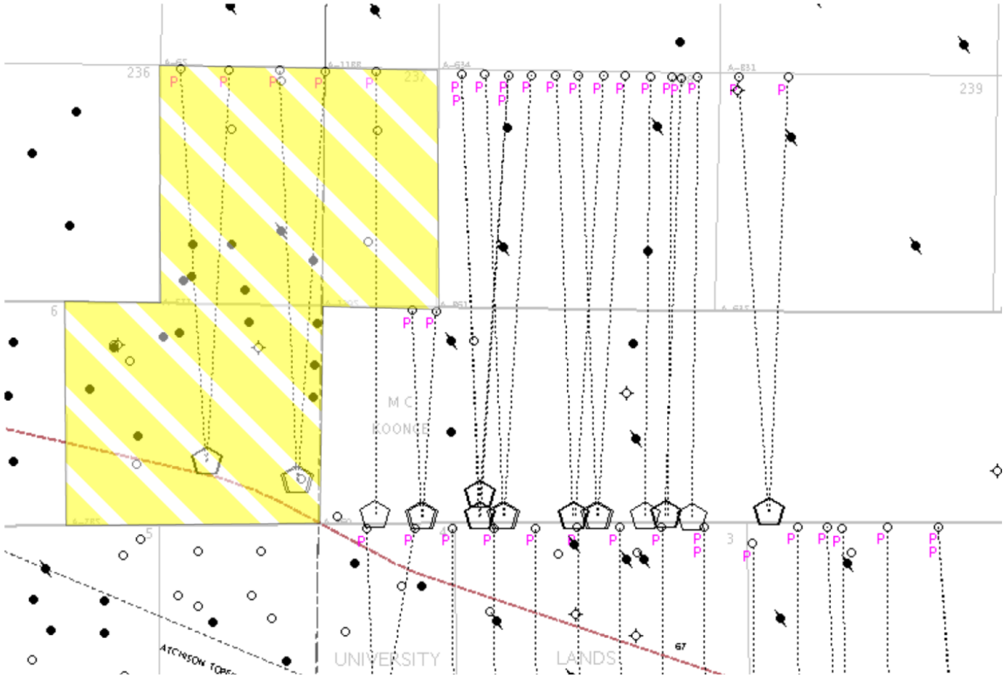
Include Vert. Frag. = “Rubics Cube” Leasing Puzzle

Highly Fragmented Lease Configurations

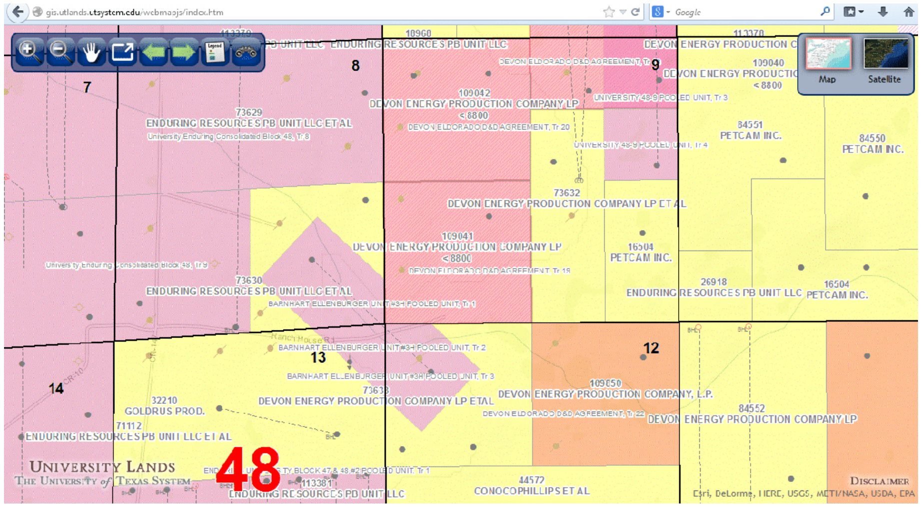


Fee Lands

~250 Undivided Royalty Interests
Not All Interests Leased-Never Will Be
Coordination of Lease Terms Challenging
Land Complexity High
(some complex vert. & horz. HBP ac. integration issues)

University Lands

Numerous Operators: Shale & Non-Shale
Lease Vintages: Recent-Decades Old
Very Complex Vert. & Horz. Severances
Land Complexity Extremely High
Still Just One Min./Surf. Owner!
(what if this was fee acreage?)



Land: General Strategies

Lease Characteristics Seriously Impact Projects:

Minimize Gross No. of Leases:
- ↑ Ease Ops. Compliance with Lease Terms
- ↓ Inter-Lease Conflicts
- ↓ Commitments/Expiration Drilling

Minimize No. Surf./Min. Owners

Minimize Vert. & Horz. Severances

Optimize Field Rules/Designations
- ↑ Acreage HBP
- ↑ Development Efficiency

<u>Regional Land *Trends* - Southern to Northern Midland Basin:</u>

↑↑ No. Surf./Min. Owners	↑↑ No. Leases
↑↑↑ Vert. & Horz. Severance	↑↑↑ No. of Oper.; HBP ac.

"Battlefield selection can lose the battle before it starts." (variously paraphrased)

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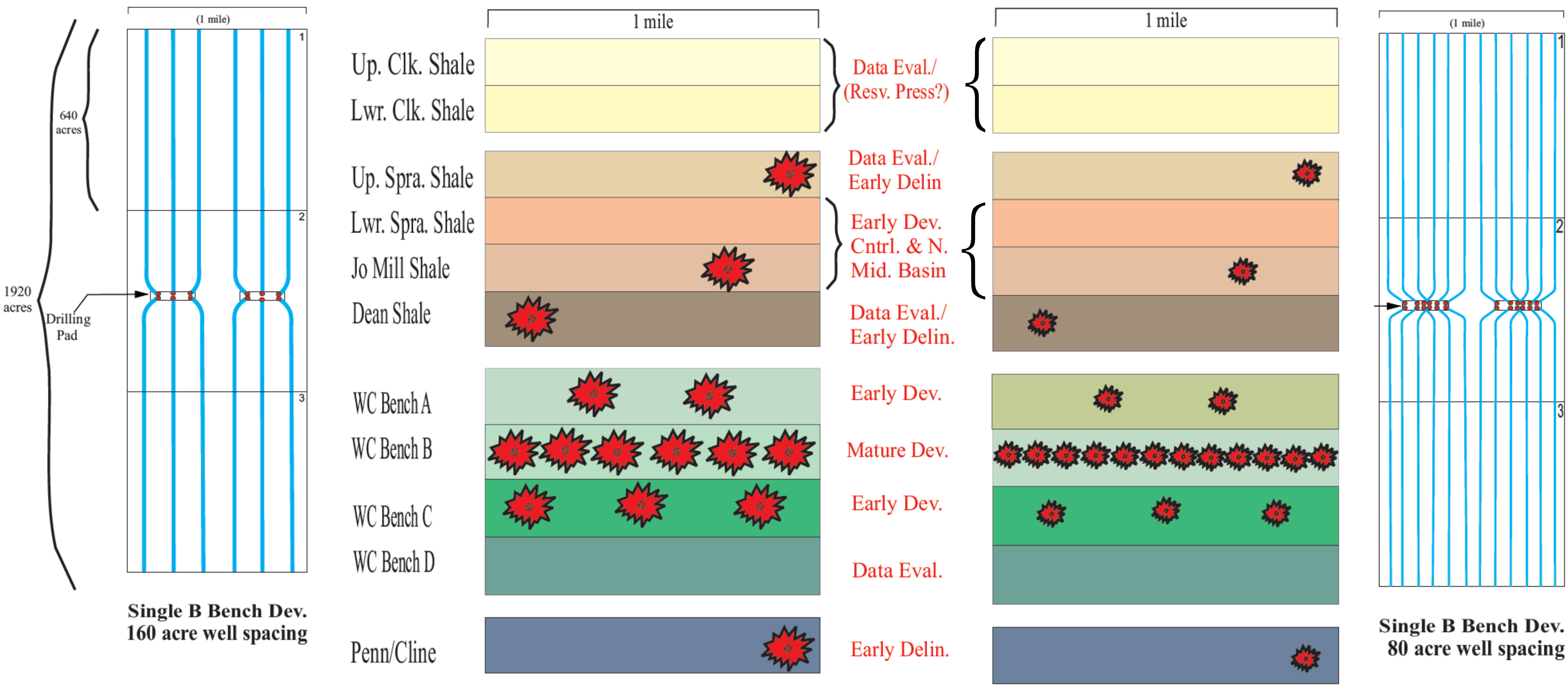
Capital: Potential Lateral Development Patterns

1 Bench: Wide Space Development

1 Bench: Narrow Spaced Development



<u>3 Benches Already Widely Developing:</u>

B Bench – Mature

A Bench – Early…maturing

C Bench – Early…maturing

<u>If SRVs ↓ and Oil Recoveries ↑:</u>

Frac Heights and Lengths ↓

Laterals Across Section ↑

Pot. Lateral Benches ↑

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Capital: Increased Volume Scale Change

6 Laterals/Bench-1920ac. Block

- 12 Development Wells
- 6 MMBOE Total Reserves
- ~Rev. $405MM gr.; $270 MM net
- ~Costs $72MM D&C; $4MM Facil.

12 Laterals/Bench-1920ac. Block

- 24 Development Wells
- 12 MMBOE Total Reserves
- ~Rev. $810MM gr.; $540 MM net
- ~Costs $144MM D&C; $8MM Facil.

		Cum. Costs as Benches are Added
Established Benches In Development	WC B Bench	$ 76 - $152 MM
	WC A Bench	$152 - $304 MM
	WC C Bench	$228 - $456 MM
Likely Benches to Develop	Cline/Penn Shale	$304 - $608 MM
	WC D Bench	$380 - $760 MM
Speculative Benches In Testing	4 Spraberry Benches	$$$$ - $$$$ MM
	Clear Fork Benches	

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Required Capital Outlays have Sky-rocketed!

Capital: Timing Scale Changes

Ideal Dev. Plan Across Section

- Drill All Laterals, All Benches
- Begin Fracs. Near Side Sec.
- Start Drill on Next Sec. over
- Finish Fracs. Far Side of Sec.
- Drill Plugs/Flow Back Near Side
- Begin Fracs. Next Sec. over
- Drill Plugs/Flow Back Far Side Sec.
- Capital Intensive-No Cash Flow

Practical Dev. Plan Across Section

- Drill 3-6 Laterals at One Time
- All Same Bench or Vert. Chevron Stack
- Frac. Laterals; Drill Plugs; Flow Back
- Watch Production Performance While Drill Next 3-6 Laterals
- Operations Interference Significant
- Reservoir Perform. Impact Significant
- Much Less Capital; Cash Flow

Capital Providers' Viewpoints: Lenders-Equity-Corp.Mgmt.-JV Partners

Prefer Drill Ready Projects
Apply Largest $ Amounts ASAP
Seek Cash Flow ASAP

Use Cash Flow/Bank Finan. to Fund Dev.
Some May De-Emphasize R&D
Some Tend to Favor Sell Out Early

Integrating Ideal / Practical Dev. Plans with Capital Expectations can be Challenging!

Lone Star Production Company

Partnerships: Why Have Any?

Situational Demands:

Competitive Leasing - Industry Pro Mineral Owner - HBP Acreage - Prospect Purchase

A Deal is Made in Order to Develop a Property

Technological Advancement:

A More Important Reason

<u>Recall Trends in Wolfberry?</u>

Low Cost/Lower Yield Ops.
High Cost/Higher Yield Ops.
Frac. Smaller/Fewer Stages
Frac. Virtually Every Foot
Fluids, Rates, Sands, Perfs, Amts.

Many Ideas & Years - No Consensus
Still Gen. Economic Production
Operator Culture Driven Solutions

<u>Horizontal Wolfcamp Shale Oil?</u>

Shale Issues & Complexities ↑↑↑
Think Wolfberry Issues on "Steroids"
Wrong Answers? – Been There, Done Lots
Single, Absolute Right Answers?-Prob. Not
(again, think Wolfberry)

<u>Many</u> Very Smart Shale Tech. Teams Exist
Very Different, Innovative Answers Exist
Interactions Spur ↑*Knowledge*

Scale of ↑*Knowledge* Critical to Pace of Optimization

Partnerships: Data Trading

Data Trading *Begins* the Process of ↑*Knowledge*

- Specified Data: One on One Between Operators
- Consortiums: Data Pools Among Participating Operators
- Group Acquired Data: i.e. Seismic Group Shoots

Limitations:

Data Can Lack Many Aspects of *Knowledge*:

- Context
- Acquisition Parameters
- Testing Conditions and Assumptions
- Sampling Methods
- Data Objectives
- Practical Experience

Data Require Ongoing Scientific Interaction to Develop into Knowledge

Data Trades Tend to be a Limited Transaction

Partnerships: WI Positions Spur Fastest ↑*Knowledge*

<u>Working Interest Owners:</u>

Generally Receive All Data
Interact with Operator's Technical Staff
Can Propose Operations
Conduct Independent Research
Leverage Data/Comparative Knowledge Among Diverse Projects

(Notable Foreign JV Partners "Buy" into These Concepts)

<u>Lone Star Model:</u>

Technically Driven Prospecting
Assemble/Analyze Geol./Geoph./Petrophy. Data/Land Position
★ Partner w/ Technically Skilled Operators (med.-lrg. cos.)
★ Retain WI on BIAPO (project basis)
★ Actively Pursue a <u>Wide</u> Range of Partners in a Play
Hold and Develop Successful Properties

Partnerships: Lone Star's Perspective

Lone Star Believes It Enjoys an Unprecedented Scale of Exposure to Knowledge

- 12 WI Partner's Geotechnical/Engineering Shale Teams
- Participation in >200,000 ac.; 14 Major Acreage Blocks
- Data: All Major Sectors S. Midland Basin
- Long History in Wolfcamp (Early Play Inception, 2009)
- Committed Abundant Major and Minor Mistakes
- WI Partners on 70+ wells; >50% Horizontals

(WI Partnerships Are Lone Star's Vehicle to Knowledge)

Knowledge→ Technical Advancements→ Optimizations→ ↑ROI

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I hope all of have enjoyed this chaotic journey through...”Concepts of Scale”

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