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

Skel. Lag Debris
Lam. Pelagic Deposits
Organic Nano-Pores

David Dally, Geologist, Lone Star Production Company
If I were you, I wouldn’t rely on any word spoken, diagram displayed, or concept as related herein.
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
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.

Wolfcamp Shale Core:
- A Bench (box 2’ tall)
- Detailed Laminae: 0.1-0.01” Thick

Wolfcamp Shale Thin Section
- Very Fine Laminae: ~1mm Thick

Bioturb. Pelagic Deposits
Skel. Lag Debris
Lam. Pelagic Deposits

~3 mm
0.5 mm
SEM Micrographs

Dual Porosity-Permeability Systems

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

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

Organic Nano-Pores

Organic Material

Vacuoles

~35 microns

~12 microns

~18 microns
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
Mud Log Show Variance between Wells

All Wells Used Same Mud Logging Co.; Very Similar Time Period
**Mud Log Show Variance between Sidetracts of Same Well**

**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 Incre. in Gas Shows
- *Small changes in rock facies can result in big changes in shows!
Geosciences: Resistivity Logs - Brines

Low Conc. Brine: RM = 1.128 @ 79°F

Med. Conc. Brine: RM = 0.172 @ 72°F

High Conc. Brine Gel: RM = 0.044 @ 82°F
Resistivity Logs - Others

Air: \( RM = N/A \)

Oil Base: \( RM \sim \infty \)

Fresh Water Mud: \( RM = 3.28 \text{ @78F} \)
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**

<table>
<thead>
<tr>
<th>Eagle Ford Shale Oil</th>
<th>Bakken Shale Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eaglebine??</td>
<td>Three Forks 1</td>
</tr>
<tr>
<td>Other 1-2??</td>
<td>Three Forks 2, 3 &amp; 4??</td>
</tr>
</tbody>
</table>

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

- 1 Obviously Excl. Bench
- 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

4 Wolfcamp Shale Benches
Bench 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

Map View

Central Pad
Monitoring Well

Side View

Monitoring Well

Well #1: WC Bench C
Well #2: WC Bench B
Example Stage 8: Well #1; WC Bench C

Events cluster during end of job when 40-70 sand hits formation
Example Stage 9: Well #2; WC Bench B

Events mostly cluster during initial pad; minor when 100 mesh sand hits formation
Engineering: Empirical Fracture Gradients

Numerous Vert. Wolfberry Wells Examined; Published Data

“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

“Dean” Bench
Frac. Grad: ~0.60-0.70

“U Wolf”

“A” Bench
Frac. Grad: ~0.85-1.05

“L Wolf”

“B” Bench
Frac. Grad: ~0.65-0.80

“C” Bench
Frac. Grad: ~0.75-0.90
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

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

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)
Engineering: Lateral Landing Zones and Densities

- SRV ↓ (Scale Down) **IMPLICATIONS**
  - 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

- **SCALE** Impact on Stratigraphic Column
  - Originally Projected 11-13 Ult. Benches
  - Might be Seriously Underestimated
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)

Centralized Facility Economies of Scale
- 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

Central Services Road

$1MM+/well Cost Diff.

Single B Bench Development 160 acre well spacing
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)

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

**Regional Land Trends - Southern to Northern Midland Basin:**
- ↑↑ No. Surf./Min. Owners
- ↑↑↑ Vert. & Horz. Severance
- ↑↑↑ No. Leases
- ↑↑↑↑ No. of Oper.; HBP ac.

“Battlefield selection can lose the battle before it starts.” (variously paraphrased)
Capital: Potential Lateral Development Patterns

1 Bench: Wide Space Development

- Up. Clk. Shale
- Lwr. Clk. Shale
- Up. Spra. Shale
- Lwr. Spra. Shale
- Jo Mill Shale
- Dean Shale
- WC Bench A
- WC Bench B
- WC Bench C
- WC Bench D
- Penn/Cline

1 mile

Data Eval. / (Resv. Press?)

1 mile

Data Eval. / Early Delin.

Earliest Dev. Cntrl. & N. Mid. Basin

Early Dev. / Early Delin.

Early Dev.

Mature Dev.

Early Dev.

Data Eval.

Early Delin.

3 Benches Already Widely Developing:

- B Bench – Mature
- A Bench – Early…maturing
- C Bench – Early…maturing

1 Bench: Narrow Spaced Development

Data Eval. / Early Delin.

Early Dev.

Data Eval.

Early Delin.

If SRVs ↓ and Oil Recoveries ↑:

Frac Heights and Lengths ↓

Laterals Across Section ↑

Pot. Lateral Benches ↑
**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.

<table>
<thead>
<tr>
<th>Established Benches</th>
<th>WC B Bench</th>
<th>$ 76 - $152 MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Development</td>
<td>WC A Bench</td>
<td>$152 - $304 MM</td>
</tr>
<tr>
<td></td>
<td>WC C Bench</td>
<td>$228 - $456 MM</td>
</tr>
</tbody>
</table>

| 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 |               |

**Cum. Costs as Benches are Added**

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!
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

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

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

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

Many 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 \(^{\uparrow} \text{Knowledge}\)

**Working Interest Owners:**

- 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)*

**Lone Star Model:**

- 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 **Wide** 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
Many Thanks to: My Lone Star Partners:
T. Grant Johnson
Blake Patterson
Eli Huffman
Michael Wendt

Lone Star Prod./Ring Exploration Staff:
Laurence Gavard
Jamie Henry

Working Interest Partners (you know who you are!)

For all of their help finding/creating/permitting/critiquing some of the examples used in this presentation.

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