Overview of Shale Gas Stimulation Techniques*

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Abstract

While shale gas has been produced in the United States for well over 100 years beginning with the Devonian Shale in the Appalachian region, explosive growth in shale gas development has occurred over the last ten years. Shale gas reservoirs represent the nation's most significant natural gas resource which is currently economic, and they are expected to provide a substantial part of our natural gas supplies over the next 50 years. Major technological breakthroughs such as 3D seismic and horizontal drilling have played a part in the exploitation of shale resources. Stimulation techniques have also evolved over this period, demonstrating a significant impact on a well's ultimate performance and a resource play's economic viability.

Stimulation techniques developed in the Barnett Shale of North Texas have been very successful in expanding the play beyond its early area bounds. Keys to this success are based on an understanding of the geological setting, the mineralogical description of the shale, rock mechanical properties of the shale and its bounding layers both above and below, structural geology and offset activity around the well of interest. The specific conditions related to a tract of acreage are unique and adjustments to the well plan should be made accordingly. While success in stimulating the Barnett Shale of north Texas has become somewhat commonplace, other shale resource plays have demonstrated a variation of reservoir characteristics which have required alternative stimulation techniques. This presentation briefly reviews the evolution of stimulation practices in the Barnett Shale of North Texas and expands into the current efforts that are ongoing in the other major shale plays such as the Woodford in Oklahoma, the Woodford and Barnett in West Texas, the Fayetteville in Arkansas, the Devonian and New Albany in the Appalachian region, and the Floyd in Alabama.

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Common Questions

- “What is so complicated about pumping water and sand?”
- “How do you know what rate to pump at?”
- “How do you control the direction of the frac?”
- “Is simo-fracing really doing any good?
- “Why would anyone ever pump cross-linked gel again?”
- “Does it matter where the lateral is placed for fracing”

Geological Description

<u>Geology</u> - **Stratigraphic and Structural**

Impacts all phases of completion design

- Shale thickness, composition, depositional environment
- Bounding rock layers above and below for frac containment
- Natural fractures – density, orientation, mineralization
- Faulting, Karsts, formation dip and structural influences

  on frac gradients

Goals for Shale Gas Completions

- ***Contact*** the maximum amount of reservoir surface area for production performance.
- ***Contain*** the contact area to within the shale gas reservoir.
- ***Create*** geometrical pattern to develop the reservoir in a consistent and predictable manner.
- ***Optimize*** the completion design for economic results – cost controls.

Technological Milestones

- Early 1900's: Shale gas becomes productive. N_2 foam fracs
- 1983: Mitchell drills 1st Barnett Shale well: C.W. Slay No. 1
- 80-90s: Evolution of X-linked gel technology in vertical wells
- 1991: 1st Horizontal Barnett well MEC: T.P. Sims "B" 1H
  Identified fracture azimuth – Max Principal stress
- 1996: Intro of slick water fracs (SWF) & Microseismic
- 1998: SW refracs of original gel fracs
- 2002: Horizontal laterals with multi-stage SWFs
- 2004: 3D seismic tool to avoid karsts and faulting
- 2005: Shift focus to increasing recovery factor
- 2007: Multi-well pads and cluster drilling

Vertical vs. Horizontal ?

- ***Considerations :***
  - Total shale thickness
  - Number of segmented shale reservoirs
  - Frac barriers present and characterization
  - Depth of shale gas formation
  - Stability of the shale target and overlying beds
  - Lease configuration and spacing requirements

Horizontal Development Planning

- Surface use / pad sites
- Wellbore layout
- Lateral spacing
- Drilling order
- Completion order
- Timing between completions
- Load water recovery

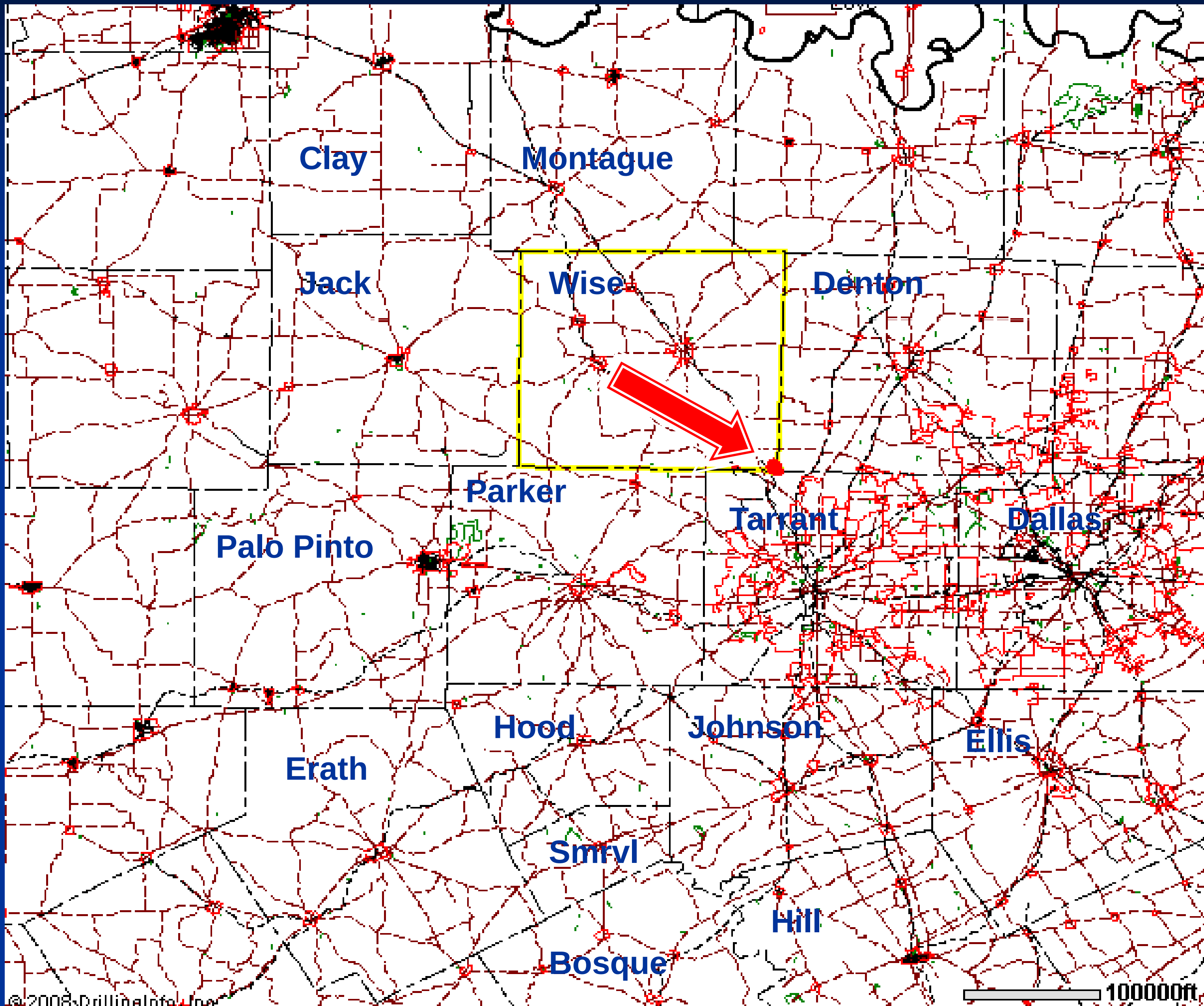
Horizontal Completion Design

- Hole and casing size
- Lateral length
- Stratigraphic position (target interval)
- Azimuth orientation
- Cemented, Uncemented or open-hole
- Number of stages
- Perforation design
- Pump rate
- Fluid volume
- Sand volume, sieve size, density and pump schedule
- Water resources and availability
- Diversion type (frac plugs, sleeves, etc)
- Lateral spacing issues and timing

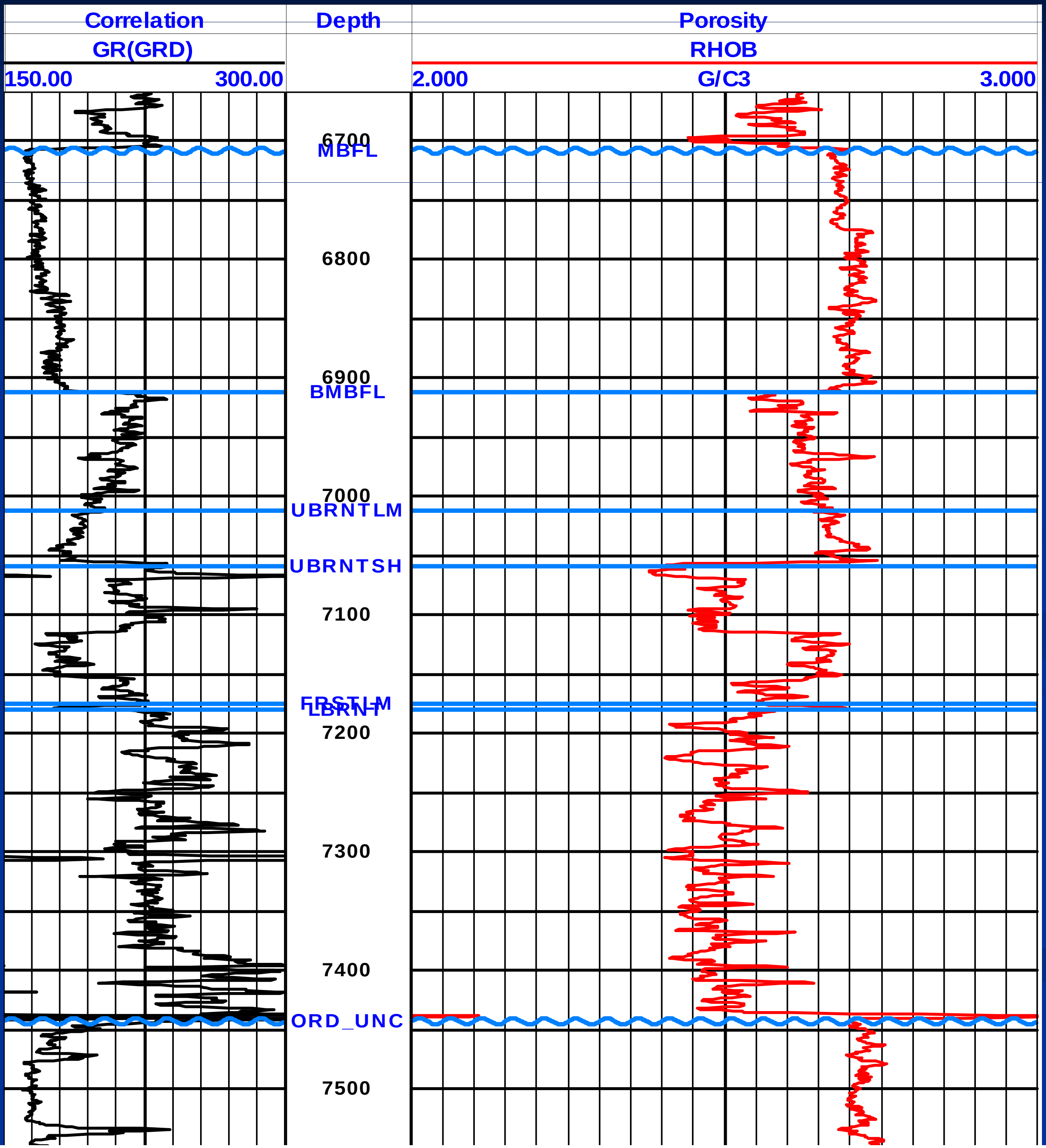
Annual Top Gun Barnett Designs

- 2001: 3.5 Bcf Vert 1.3 MMgals & 170K 20/40 Tarrant Co.
- 2002: 5.1 Bcf 2004' Horiz 1 Stg Uncmtd 2.6 MMgals & 573k 40/70, Wise 200k 20/40
- 2003: 6.6 Bcf 2062' Horiz 1 Stg Uncmtd 2.86 MMgals & 22k 100M, Tarrant 270k 40/70 and 150k 20/40
- 2004: 7.8 Bcf 2817' Horiz 2 Stg Cmtd 4.28 MMgals & 991k 40/70 Tarrant
- 2005: 9.1 Bcf 3224' Horiz 3 Stg Cmtd 5.25 MMgals & 2311k 30/70, Tarrant 593k 20/40
- 2006: 7.1 Bcf 4063' Horiz 8 Stg Cmtd 5.10 MMgals & 3677k 100M, Johnson 1194k 30/70
- 2007: 7.2 Bcf 4472' Horiz 10 Stg Cmtd 6.70 MMgals & 6820k 100M Johnson

Birthplace of the Barnett – CW Slay

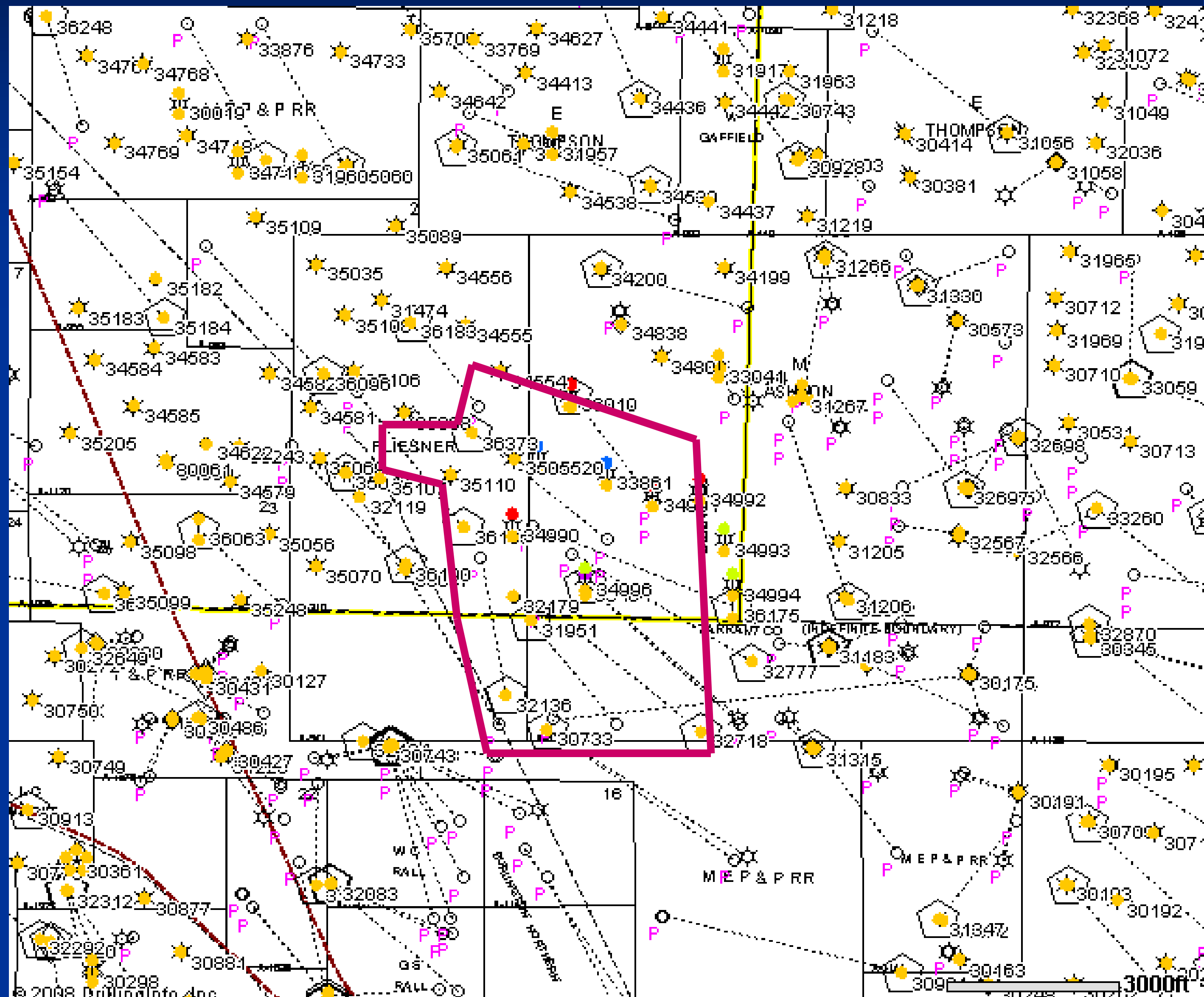


Devon: C.W. Slay No. 1



Devon: C.W. Slay Unit

- 12 wells on 704 ac
- 9 vert, 3 Hrz + 4 Drlg
- Cum Prod = 11.5 Bcf
- Feb 08 = 7.2 MMcfd
- EUR_V = 1.9 Bcf/well
- EUR_H = 4.0 Bcf/well
- PDPs = 30 Bcf
- 4 add'l horiz wells
  Est'd Rsvs = 16 Bcf
- Total EUR = 46 Bcf
- Avg Spacing = 44 ac
- 41.8 Bcf per SqMi
- ~ 28% R_f 150 B/SqMi



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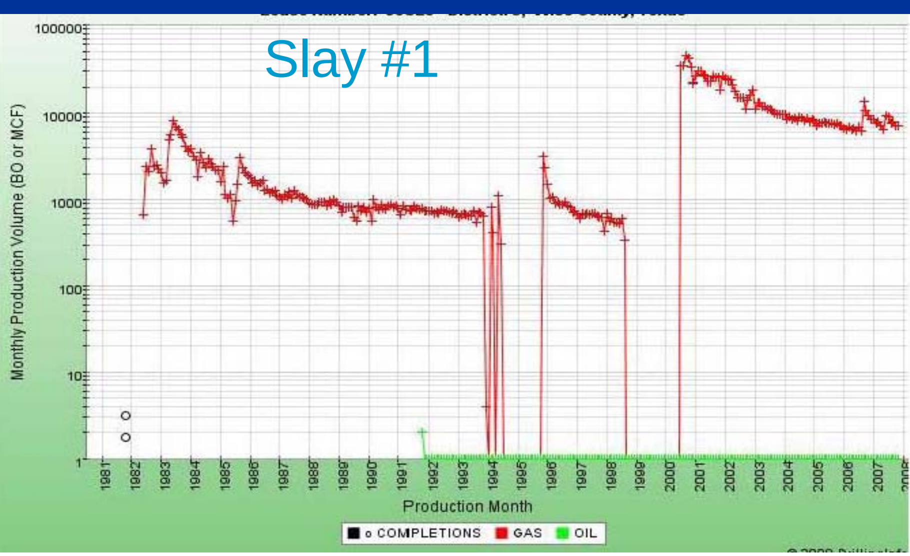
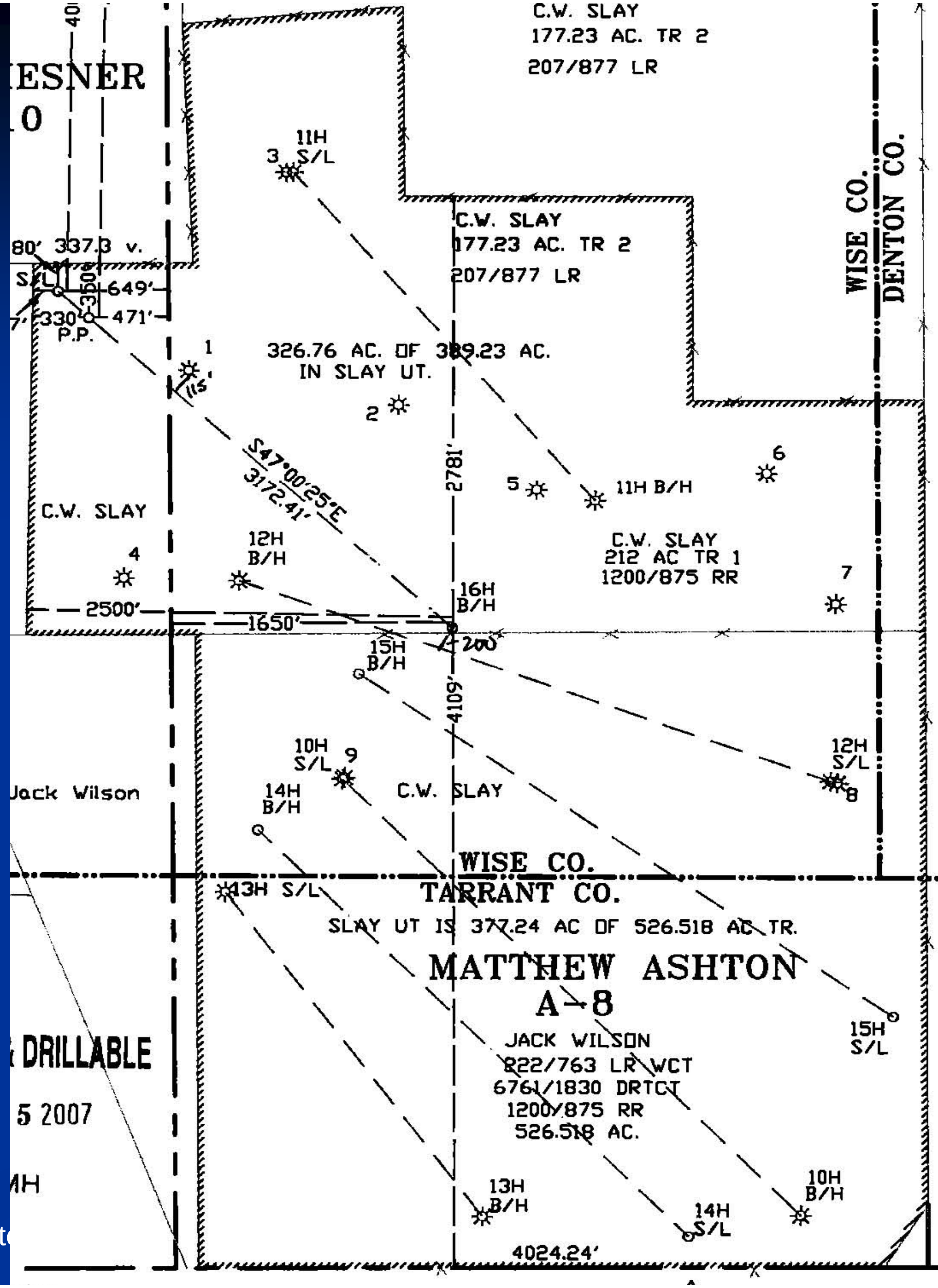
C.W. Slay Unit

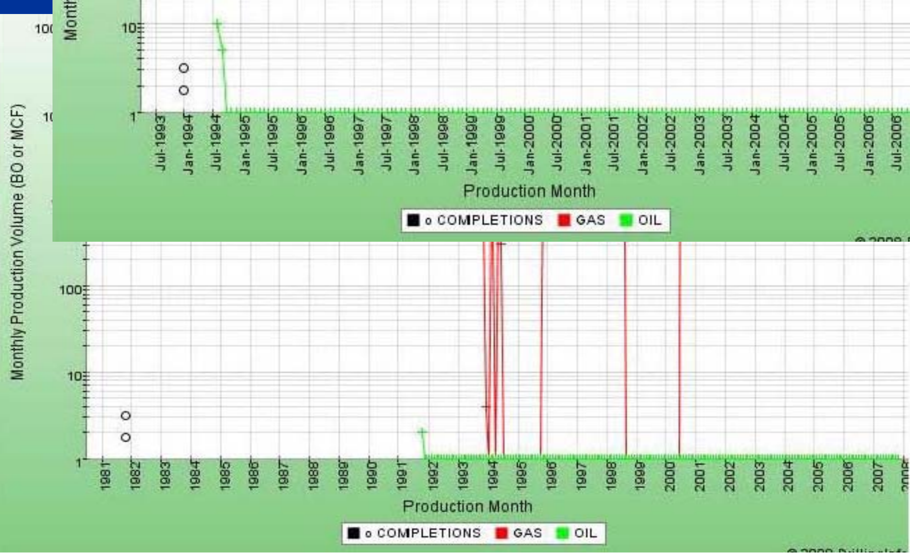
Frac Interference – 9/06

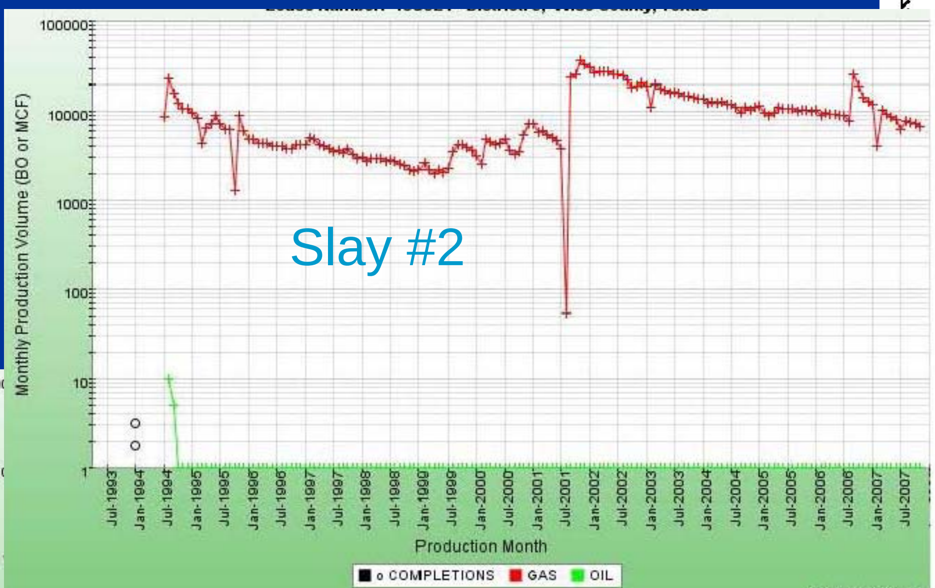


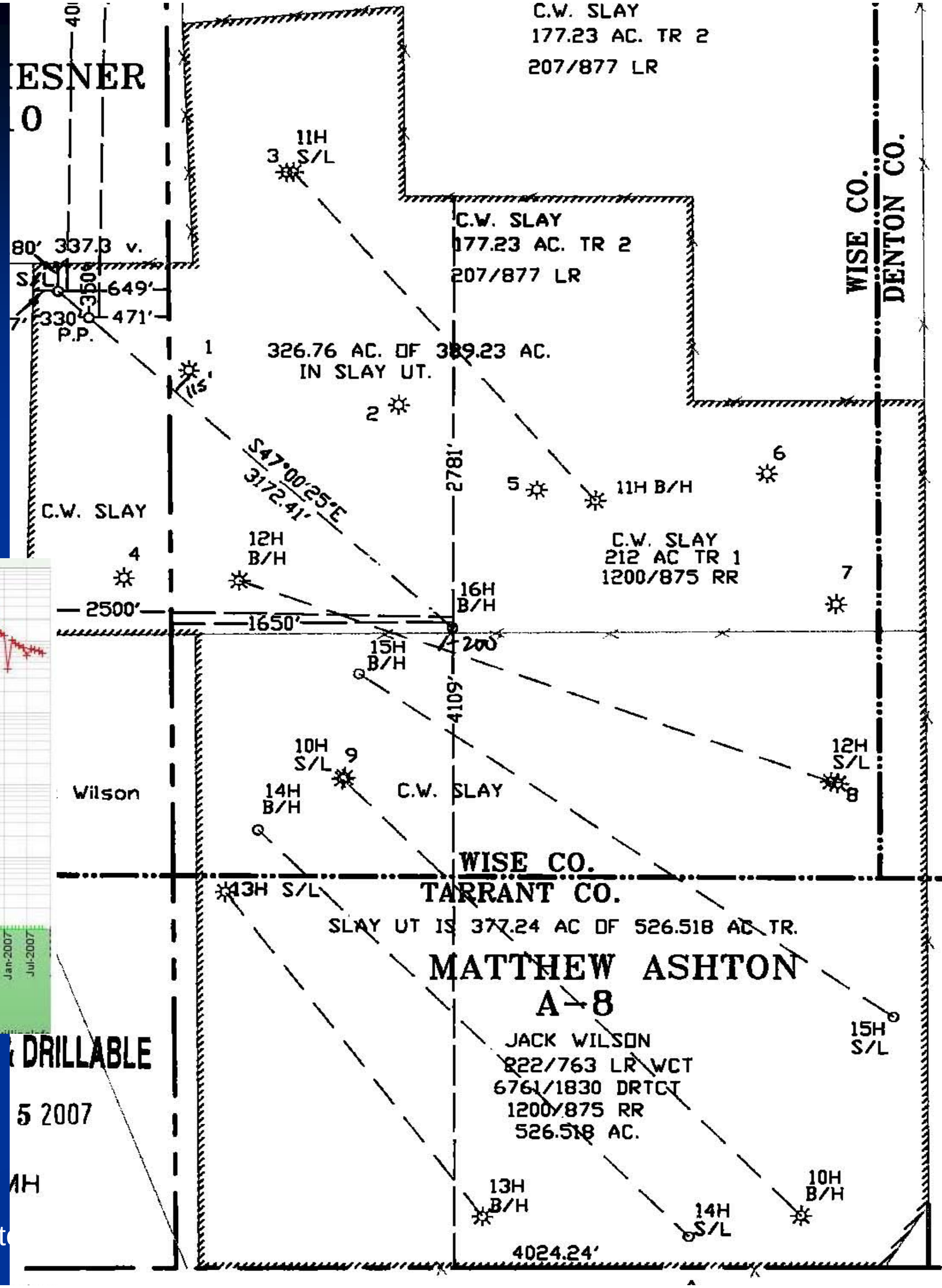


C.W. Slay Unit

Frac Interference – 9/06

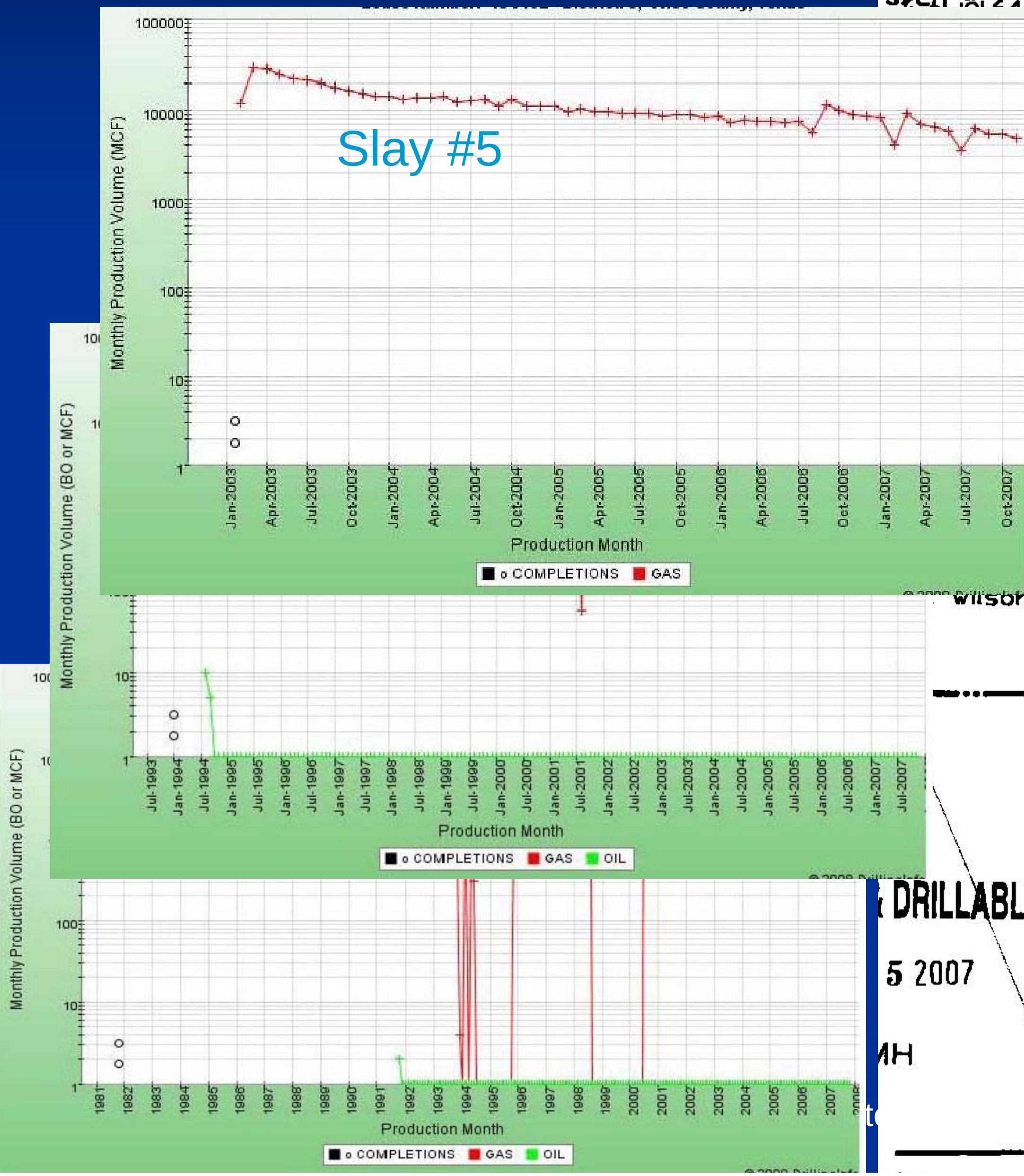


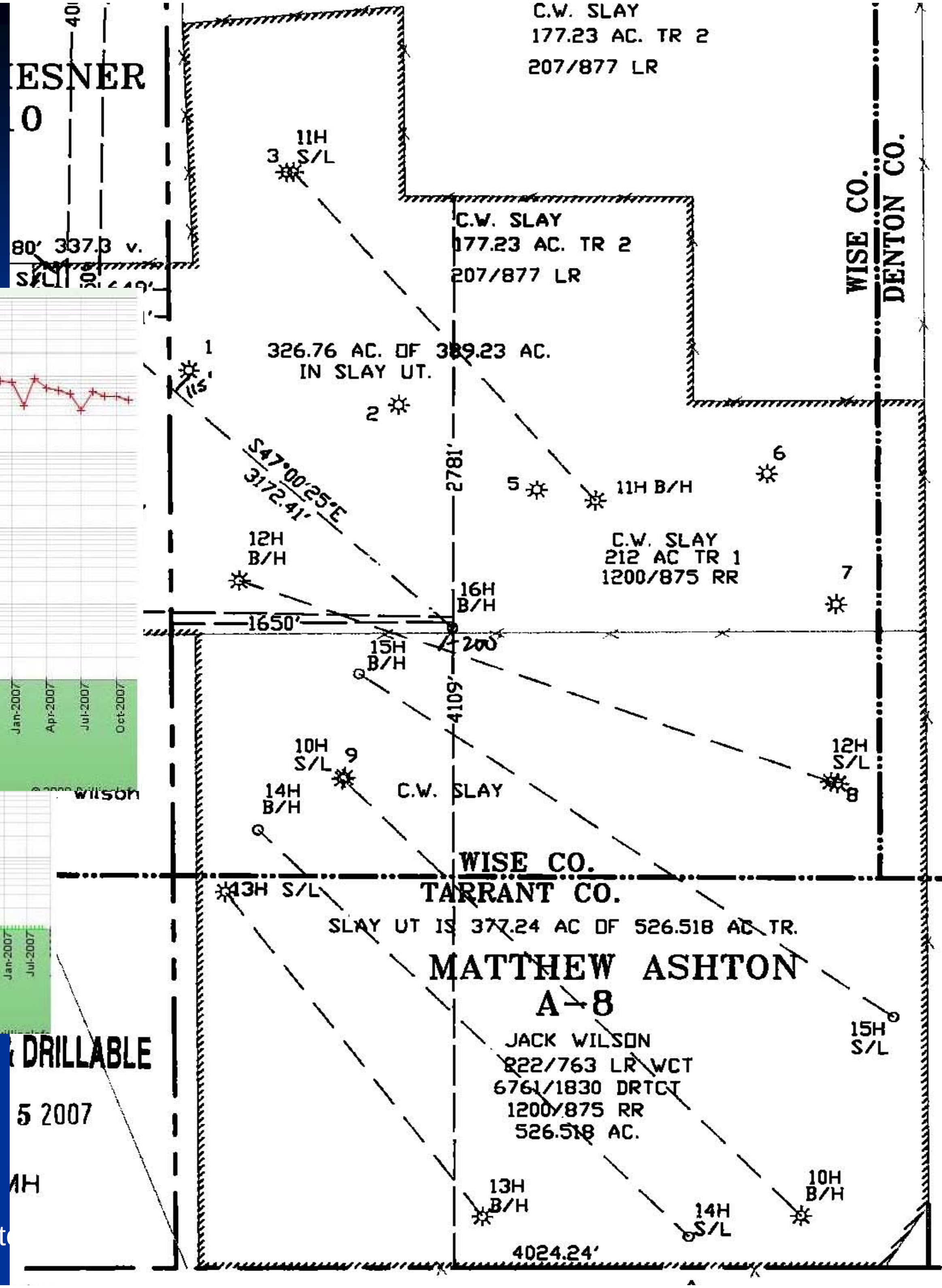




C.W. Slay Unit

Frac Interference – 9/06

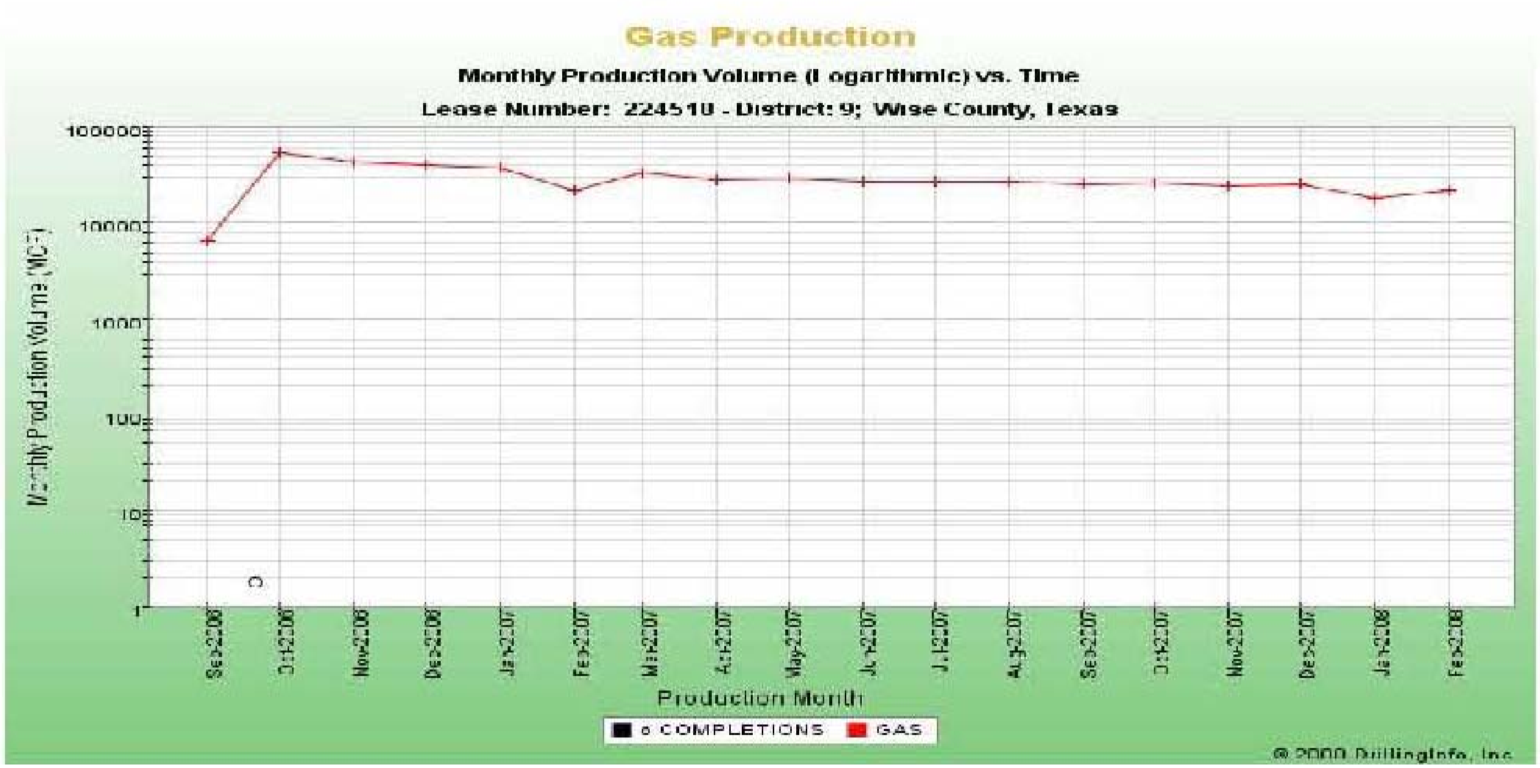




C.W. Slay No. 11H

- ~2000' Horizontal cemented completion with three stage frac
  - Stage #1: 0.80 MMgals SW; 20k# 100M & 264k# 40/70 Ottawa
  - Stage #2: 1.59 MMgals SW; 40k# 100M & 528k# 40/70 Ottawa
  - Stage #3 1.62 MMgals SW; 40k# 100M & 598k# 40/70 Ottawa

Field	Operator	Location
NEWARK, EAST (BARNETT SHALE)	DEVON ENERGY PRODUCTION CO, L.P.	District: 9; Wise County, Texas
Lease Name	**Gas ID Number**	**Cumulative (since 1970)**
SLAY, C. W.	224518	517 MMCF
Wells		
42-497-36010(11)		



Evolution of industry practices

- Horizontal, cemented, multi-stage completions dominate.
- Multiple well pad sites becoming commonplace.
- Longer laterals ... ~3500'.   Some over 5000'.
- Refinements to increase recovery factor of gas resources:
  - More stages ... Control height growth and increase Rf.
  - Tighter perforation spacing... from ~200' to 50-75'.
  - Tighter lateral spacing... from 1500' to less than 200'.
  - Cluster wells (3-8 wells) with staggered target landing points.
  - Sequential and Simo fracs in well clusters.
  - Vertically stacked laterals in areas with good lower barriers.

Challenges Remain

- **Fracture initiation** in highly brittle shales.
  - Solution: Abrasive jet cutter, X-linked gel
- **Fracture extension** in low stress contrast areas.
  - Solution: Hybrid frac with X-linked gel stages
- **Borehole stability** in highly fractured and/or brittle shales.
  - Solution: OBM, extreme hole cleaning practices
- **Fracture containment** in weak and/or fractured barriers.
  - Solution: More Stages, less fluid, lower rate,
    bio-balls to lower frac initiation pressure

Thank you !