DRILLING AND COMPLETION PRACTICES IN THE BOOCH SANDSTONE

OR

HOW TO MAKE MONEY DRILLING THE BOOCH

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OBJECTIVES

1. Characterize the Booch sandstone from the Operator's perspective
2. Drilling options: oil or gas target, air or mud drilling
3. Completion variables, especially fracture stimulation, and effects on production
4. Individual case studies of Booch oil and gas wells showing variability in reservoir and completion methods, and
5. Production optimization for the Booch sandstone.

Booch sandstone may be characterized as:

1. Poor quality reservoir:

- Low porosity: effective porosity = 10% density
- Poor permeability
- Laminated or thin, interbedded sandstone and shale beds
- Fine grained, poorly sorted, dirty, quartz arenite reservoir rock

Booch sandstone may be characterized as:

2. Low pressure:

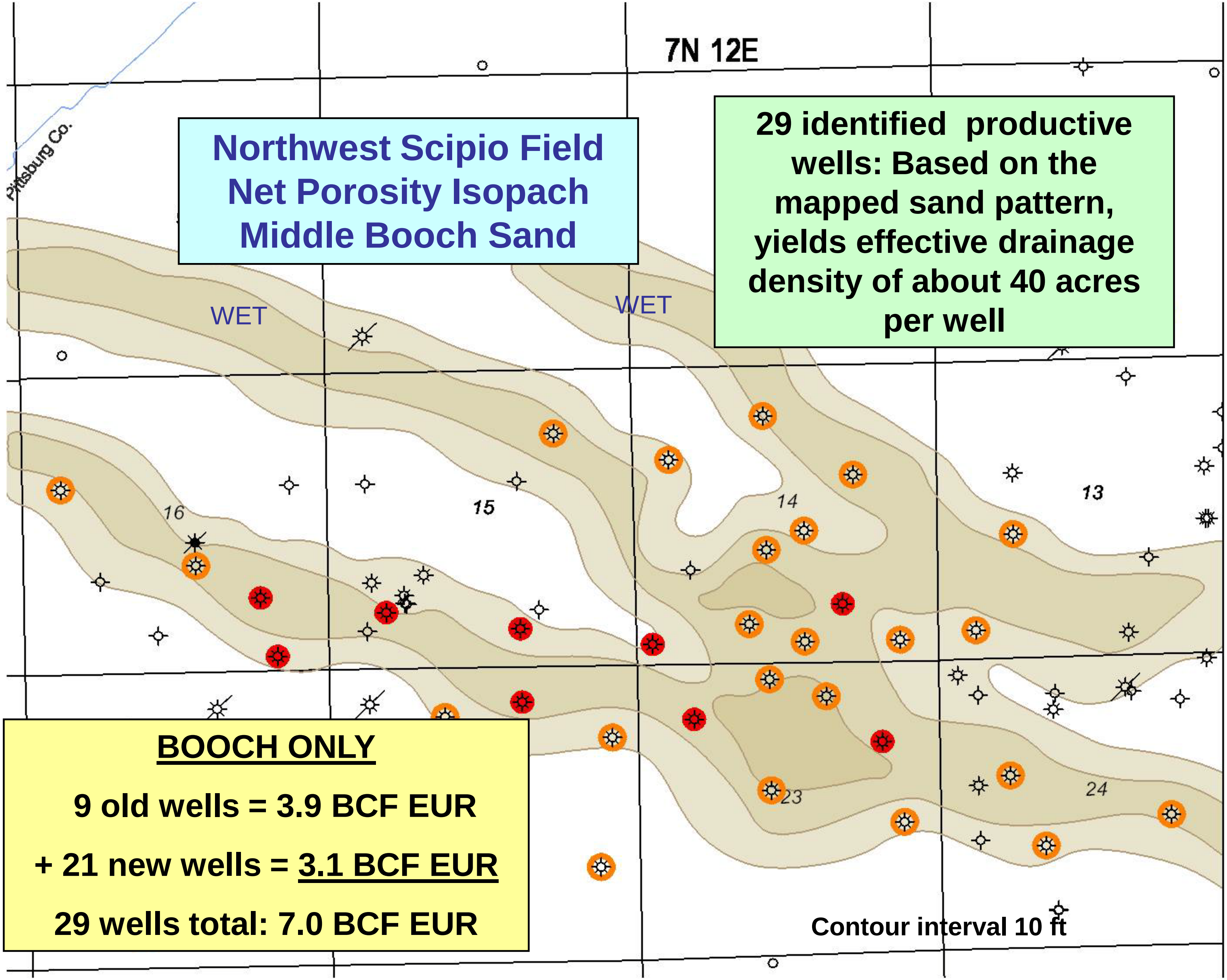
- Much of the gas-bearing portion of the Arkoma Basin is sub-normally pressured
- Observed surface pressure 600 psig max, usually 450-500 psig
- Oil-prone areas seem to have higher pressure gradients observed at the surface
- Observed surface pressure 900+ psig max
- Calculated hydrostatic pressure at 3,000 ft should equal approximately 1,370 psig

Booch sandstone may be characterized as:

3. Reservoir areal extent is usually limited:

- Mapped net sand patterns often 10 ft thick or less, with channel/ bar width only one-quarter to one-half mile wide

- Many areas on Arkoma shelf and basin are heavily drilled, resulting in large areas of very limited opportunity for additional development



Northwest Scipio Field
Net Porosity Isopach
Middle Booch Sand
29 identified productive wells: Based on the mapped sand pattern, yields effective drainage density of about 40 acres per well
7N 12E
Pittsburg Co.
WET
WET
16
15
14
13
23
24
BOOCH ONLY
9 old wells = 3.9 BCF EUR
+ 21 new wells = 3.1 BCF EUR
29 wells total: 7.0 BCF EUR
Contour interval 10 ft

Booch sandstone may be characterized as:

4. Sometimes difficult log analysis:

- Clay or shale content adversely affects water saturation equations
- Many Booch reservoirs produce oil with anomalously low Rt values
- Microlog is ineffective in many mud-drilled areas due to low permeability and probable skin damage while drilling
- Microlog does not work in air-drilled holes.

Booch sandstone may be characterized as:

5. Variable reservoir drive mechanisms:

- Both gas and oil traps exhibit a full range of reservoir drive mechanisms, from depletion drive to strong water drive.
- True water drive reservoirs probably are the least common.

6. Trapping mechanisms variable:

- Pure stratigraphic
- Pure structural
- Combination traps most prevalent.

BOOCH DRILLING AND COMPLETION PRACTICES

DRILLING OPTIONS

VERTICAL WELL

Mud Drilling

(Oil Objective)

Air Drilling

(Gas Objective)

HORIZONTAL WELL

Not discussed here

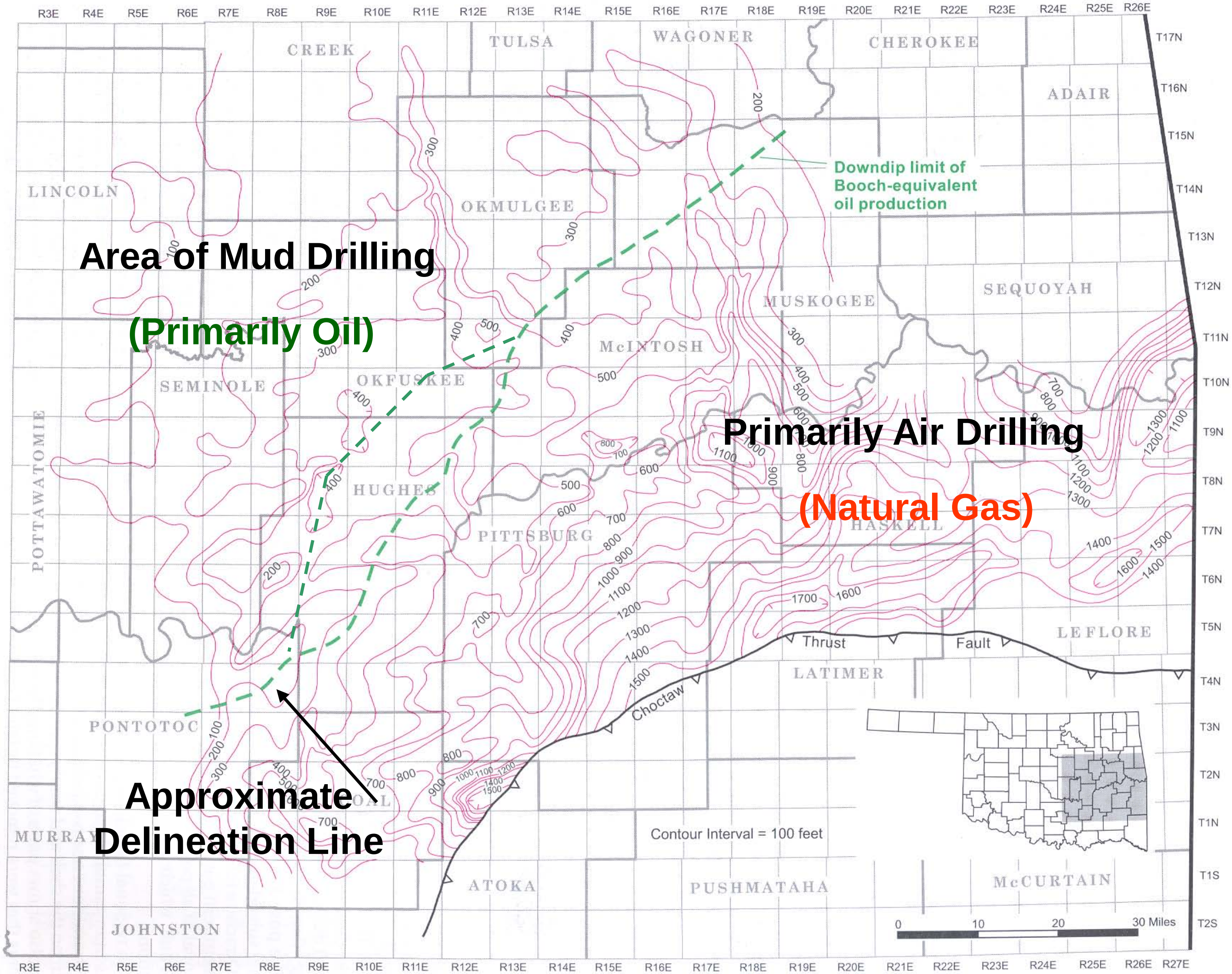


Figure 6. Regional isopach map of the Booch interval. This gross interval corresponds to the stratigraphic section from the top of PS-0 (McAlester coal marker) to the base of PS-6 (top of Hartshorne Formation). Hachures indicate isopach "thicks."


Conventional Mud
Drilling

ADVANTAGES OF MUD DRILLING

1. Provides total control in difficult drilling environments:
   - Hole stability
   - Deviation
   - Well control problems
   - Lost circulation control
2. Depth or borehole angle not a limiting factor
3. Full range of logging tools available for formation analysis
4. “Status quo”

DISADVANTAGES OF MUD DRILLING

1. Cost: Current rig contracts are on day rates, not footage, and range from about $10,000 per day up.
2. Slow compared to air drilling: Comparable 3,000 ft hole will take 3+ days with 24 hour, 4 man crew.
3. Larger location needed: 1.25+ acres or more.
4. Cost of mud program, drill bits, haul off fluids, etc.
5. Environmental impact of mud system: potential spills, pit liners, closed systems required in some areas; haul off and disposal of drilling fluids.
6. Slow rig up and rig down time: 12 hours minimum, usually have 15 loads or more.

Air Drilling: “Dusting” or “Misting”

ADVANTAGES OF AIR DRILLING

1. **Very Fast: Can drill wells up to about 2,600 ft in 2 days, or 3,200+ ft in 3 days, daylight only, including surface pipe. Newer style rigs use 24 hour crews, can drill typical well in 24 to 36 hours.**
2. **Rig up and rig down time is 3 to 4 hours maximum.**
3. **Economical: Current rate for shallow wells is about $12.00 per foot. Rates include hammers, bits, drilling materials.**
4. **Small rig uses one 2 or 3 man crew; larger rig 4 man crew in shifts.**
5. **Can drill large numbers of wells in a relatively short time.**
6. **Provides constant real-time formation analysis with sample cuttings instantaneously to surface; gas flows are easily detected.**
7. **Small location area (100 ft x 150 ft), able to drill in tight locales.**
8. **Blow pits not regulated by OCC (no pit liners required).**

DISADVANTAGES OF AIR DRILLING

1. Small rigs limited to shallow depths (3,300+ ft or less).
2. Potential hole deviation problems (specifically excluded from measurement in drilling contracts).
3. Hole stability questionable in problem shale areas: sloughing or heaving shales can collapse around drill string and cause drill pipe to get stuck.
4. Difficulty in dealing with shallow water flows: cannot keep hole unloaded, slows ROP significantly, must haul off saltwater.
5. Slow trip time: small rigs are truck mounted 25 ft or 30 ft derricks, only able to trip one joint of drill pipe at a time, and have no place to stand up pipe. Pipe must be laid down one joint at a time, which is labor intensive.
6. Small rigs unable to economically run production casing (R-1 only).

Air vs Mud Drilling: Which One?

Natural Gas Objective:

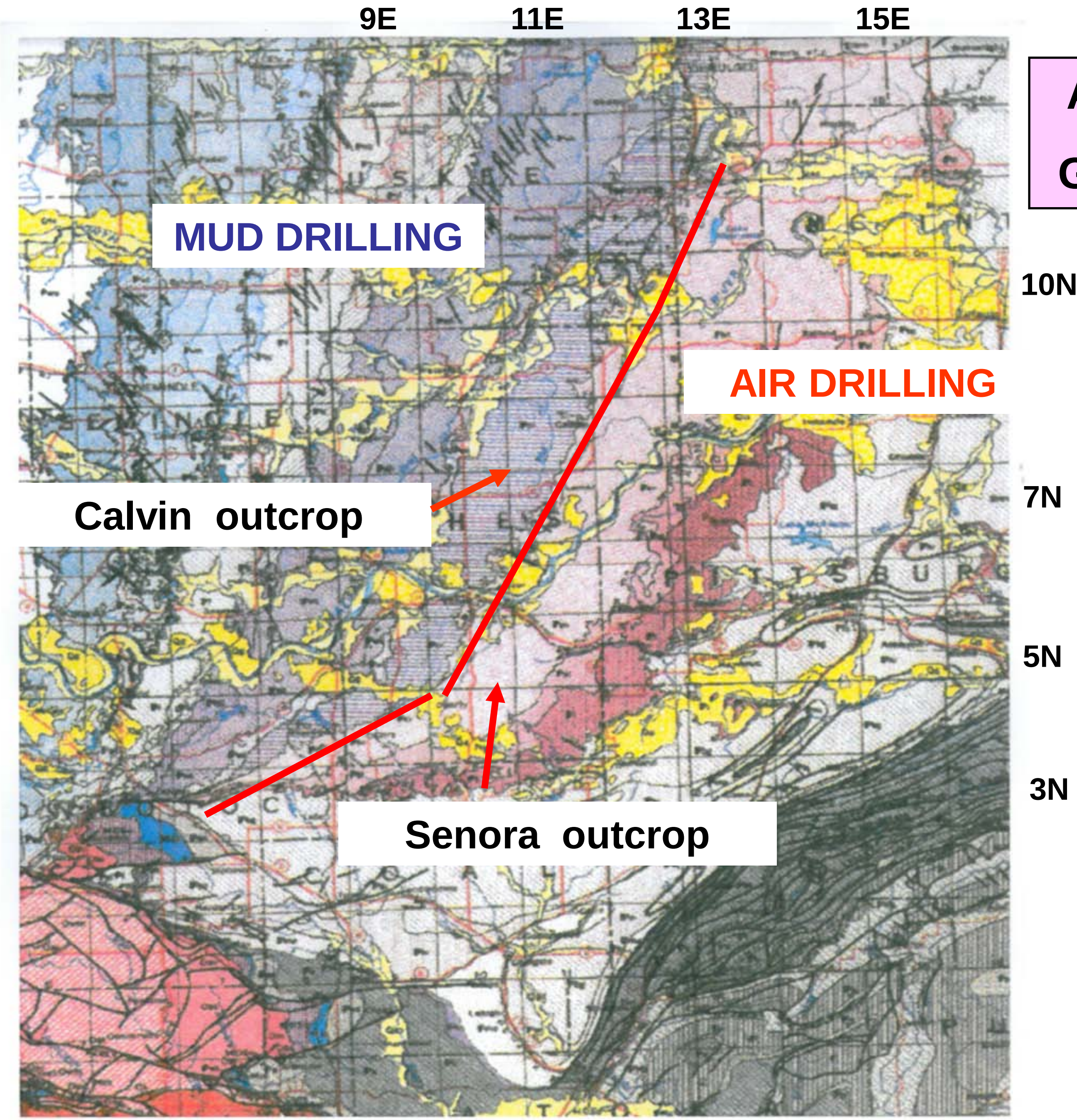
Generally choose air drilling due to low cost, shallow depth, small location, ease of move in and move out, and instant formation content analysis. Gas-prone areas coincidentally are located updip of the Calvin Formation outcrop.

Oil Objective:

Generally choose mud drilling since oil prone areas are generally located in areas west or downdip of the Calvin Formation outcrop at the surface.

The Calvin contains a higher percentage of thick shallow water sands that air drilling techniques are unable to economically handle.

Air vs Mud Drilling Geologic Boundary



Calvin Outcrop
Mud Drill

Senora Outcrop
Air Drill

Geologic Map of
Oklahoma, c. 1954

Booch Completion Practices:
Acidizing

<u>Objective</u>: Pump reactive fluid (acid) into perforations in order to dissolve cement and mud materials that may inhibit fluid or gas flow into the wellbore.

- **Drilling muds are designed to coat the borehole wall to prevent fluid loss while drilling through the formation.**
- **These coatings must later be removed or bypassed in order for fluids or gas to flow from formation to wellbore.**
- **Cement may invade the formation while cementing casing; need to ensure the pathway from perforations to wellbore is open and clear of debris.**

Acidizing removes these deposits and/or debris and may also induce flow channels from the formation to the wellbore.

Booch Completion Practices:
Acidizing

Booch sandstone generally does NOT contain calcareous cement, so pumping acid deep into the formation is unnecessary.

Common acid treatments for Booch sands varies from 250 to 750 gallons of 7½ % to 15% HCl, with additives designed to clean up or dissolve mud chemicals and to inhibit reaction with clay minerals in the formation.

Acidizing

Fluid flowback after an acid job: Normal procedure is to swab back the acid treatment.

Typically will recover 60% to 100% of fluid introduced into the formation by swabbing.

During the acid job, ISIP and pump rate vs breakdown pressure are indicative of permeability, and used to help design the follow-up fracture stimulation treatment.

Spearhead acid jobs not recommended due to need to determine permeability prior to designing frac job

FRACTURE STIMULATION

Goal: the goal of Fracture Stimulation in low permeability rocks is to induce an artificial fracture to serve as a flow channel from deep in the formation to the wellbore.

Most common Booch fracture stimulation treatments:

Natural gas wells: Nitrogen or CO_2 foam fracs

Oil wells: slick water or gelled water fracs

FRACTURE STIMULATION

- Induced fracture will follow path of least resistance (anisotropy)
- Induced fracture is held open with a propping agent, such as various sieve sizes of quartz sand or other materials
- Effective fracture stimulation results in increased flow of hydrocarbons to the wellbore, hence higher initial flow rates and better economics (quicker payout).
- Induced fractures range from long narrow cracks to (hopefully) shorter, wider fractures held open by proppants.
- Fractures propagate both vertically and horizontally away from wellbore, dependent on frac type and pump rate and pump pressure

FRACTURE STIMULATION TECHNIQUES

Water and Gelled Water Fracs: Generally used in oil productive reservoirs

Gelled water has higher viscosity than plain or ‘slick’ water, thus creating a greater fracture width and length than water alone

Gelled fracs (crosslinked gels) carry greater volumes of proppant, pumping in various stages, to hold induced fractures open during and after flowback

‘Crosslinked gel’ simply means chemically linking molecules together to create a more viscous fluid

FRACTURE STIMULATION TECHNIQUES

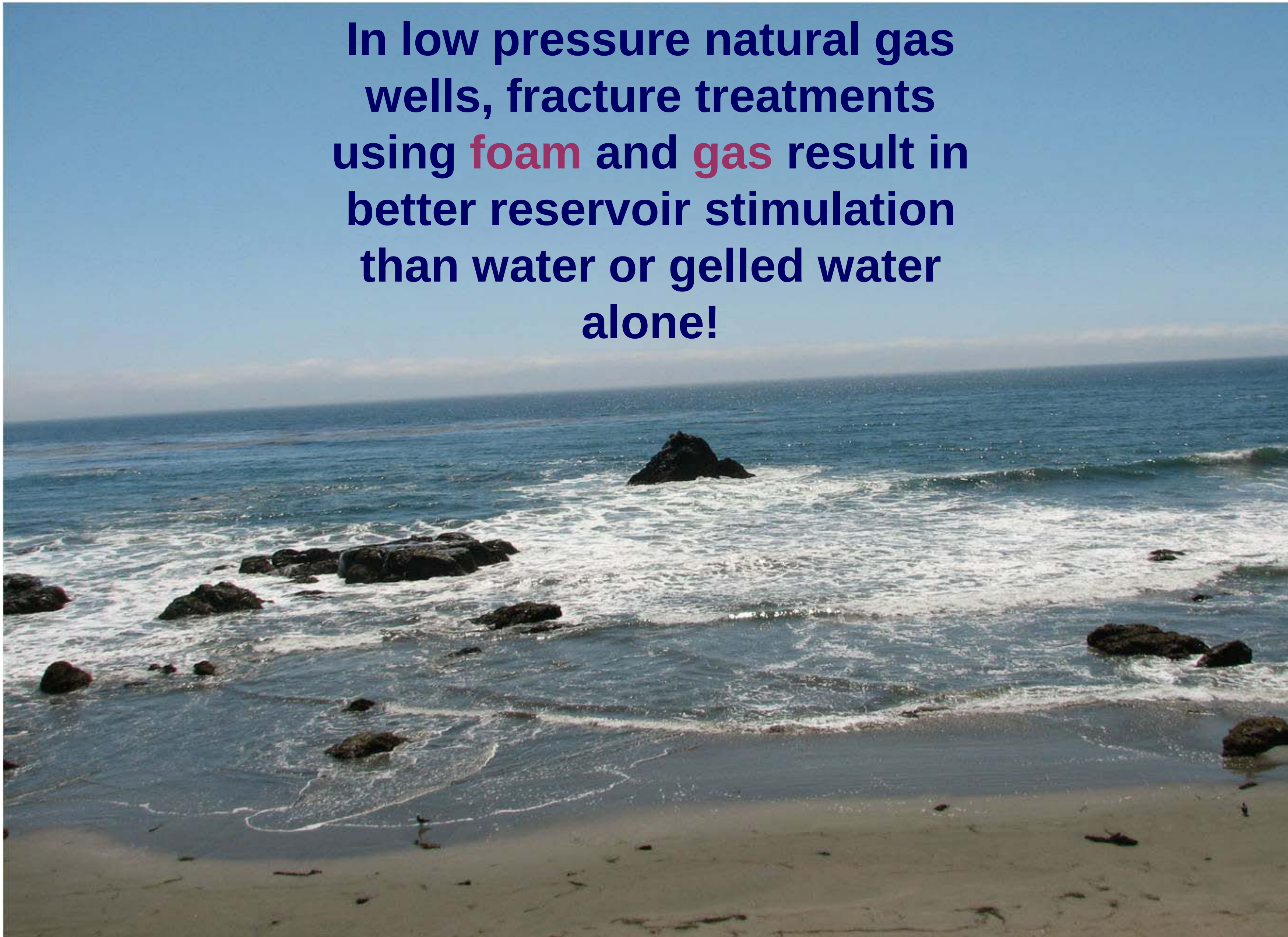
In the average Booch oil reservoir, experience has found that gelled water fracs, utilizing about 800 bbls of crosslinked gelled water with 30,000 to 40,000 lbs of 30/40 mesh sand is effective.

The well is generally placed on pump to aid flowback, starting with propane and converting to casinghead gas within a few days

Well typically produces all water for a few days, recovering 10 – 30% of load before showing oil at the bleeder valve

Pump rates and flowback governed by size of pumping unit

In low pressure natural gas wells, fracture treatments using foam and gas result in better reservoir stimulation than water or gelled water alone!



STIMULATION TECHNIQUES: FOAM FRACTURING

Primarily used for natural gas wells

Characteristics of foams and foam fracturing:

- Foams are gas-in-liquid dispersions similar to an emulsion
- Liquid used can be water, acid, alcohol, or oil
- Foaming agent usually Nitrogen or Carbon Dioxide

STIMULATION TECHNIQUES: FOAM FRACTURING

Quality: Volume percentage of gas in foam is termed "Quality" or "Q"

- **Most fracturing foams are in range of 65 to 85 Q**
- **Foam qualities less than 54Q do not enhance flowback of liquids**
- **Foam qualities greater than about 92Q become a mist, and are not viscous enough to fracture**
- **Experience dictates foam qualities between 65Q and 75Q are best for Booch and Hartshorne gas-bearing sandstones in the Arkoma region.**

STIMULATION TECHNIQUES: FOAM FRACTURING

Nitrogen versus Carbon Dioxide

- Both arrive at location as refrigerated liquids, then pumped downhole as gas through heat exchanger
- CO_2 much more expensive than N_2, much harder to locate and schedule for delivery to wellsite
- CO_2 is more volatile than N_2, requires greater care in handling while pumping than does N_2
- CO_2 is corrosive to equipment, N_2 is inert
- Pipelines will not accept volumes of CO_2 > 2% into system, whereas N_2 limits are higher (3% +/-)

Nitrogen is gas of choice for most producers

STIMULATION TECHNIQUES

Nitrogen Foam stimulation treatment advantages:

- Improved proppant placement in reservoir
- Rapid cleanup of treatment fluids, usually eliminating need for swabbing after treatment
- Less formation damage resulting from treatment fluid

Nitrogen Foam is the preferred fracturing fluid for shallow, low pressure reservoirs, such as the Booch and Hartshorne sandstones in the Mid-Continent and Arkoma Basin area.


CUDD
PRESSURE CONTROL
1977

STIMULATION TECHNIQUES: FOAM FRACTURING

Flowback and Fluid Loss Control

- Nitrogen gas entrained in foam is released as the bubbles in the foam degrade, and the gas flows to point of least resistance (wellbore) carrying liquid to the surface.
- Fluid loss of foam into formation (leak-off) increases rapidly where permeability is more than 5 md or natural fractures are present.
- Foam becomes ineffective at permeability more than 20+ md.
  - Nitrogen gas does not flow to wellbore but is lost in formation, therefore becomes ineffective.
- In spite of leak-off prevention, experience shows only 50 – 60+% of treatment fluid is ever recovered from the Booch formation after N2 foam fracture stimulation treatments.

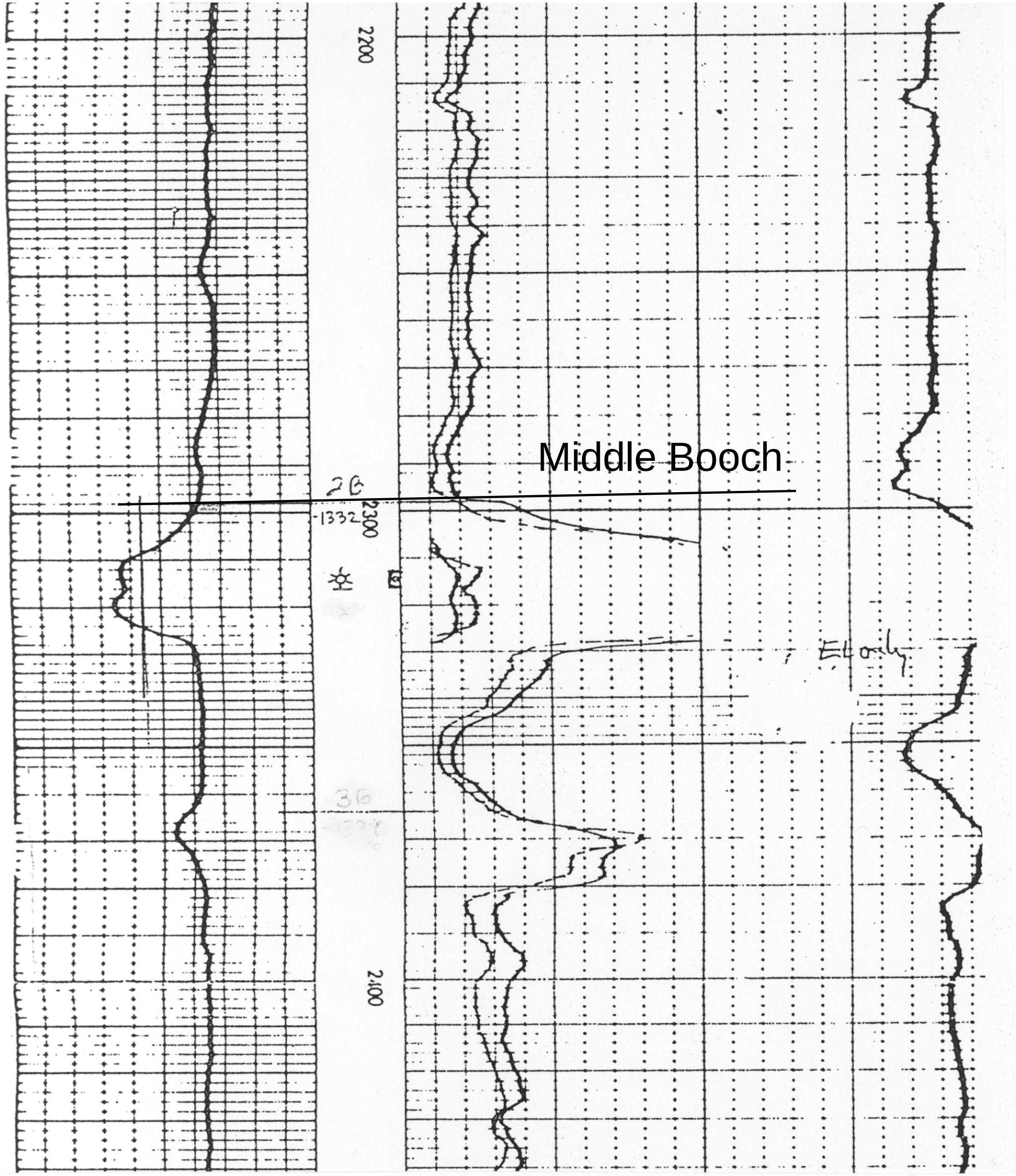
STIMULATION TECHNIQUES: FOAM FRACTURING

Poor flowback procedures can ruin a nitrogen foam frac job!

- Because foams can support proppant, poor flowback procedures can cause a foam to pull proppant out of the induced fracture and create flowback to surface, if flowback initiated before foam breaks.
- Fracture must be allowed to close around proppant before flowback starts.
- Too short of shut-in time allows proppant to flow back to surface.
- Too long a shut-in time allows flowback energy created by dispersed gas (N2 or CO2) to dissipate into the formation instead of flowing back to the surface.
- Experience indicates a shut-in time of 2 to 3 hours is optimal.

BOOCH CASE HISTORIES

1.	Theel	14-7N-12E	Mud	Gas	Natural (?)
2.	Stipe	28-7N-12E	Air	Gas	CO_2 foam frac
3.	Falcon Club	21-7N-12E	Mud	Gas	N_2 foam frac
4.	Lakeside	36-8N-8E	Mud	Oil	Gelled Water
5.	Merriman	4-5N-9E	Mud	Oil	Gelled Water



Otha Grimes 1-14 Theel

C SE 14-7N-12E

Pittsburg County

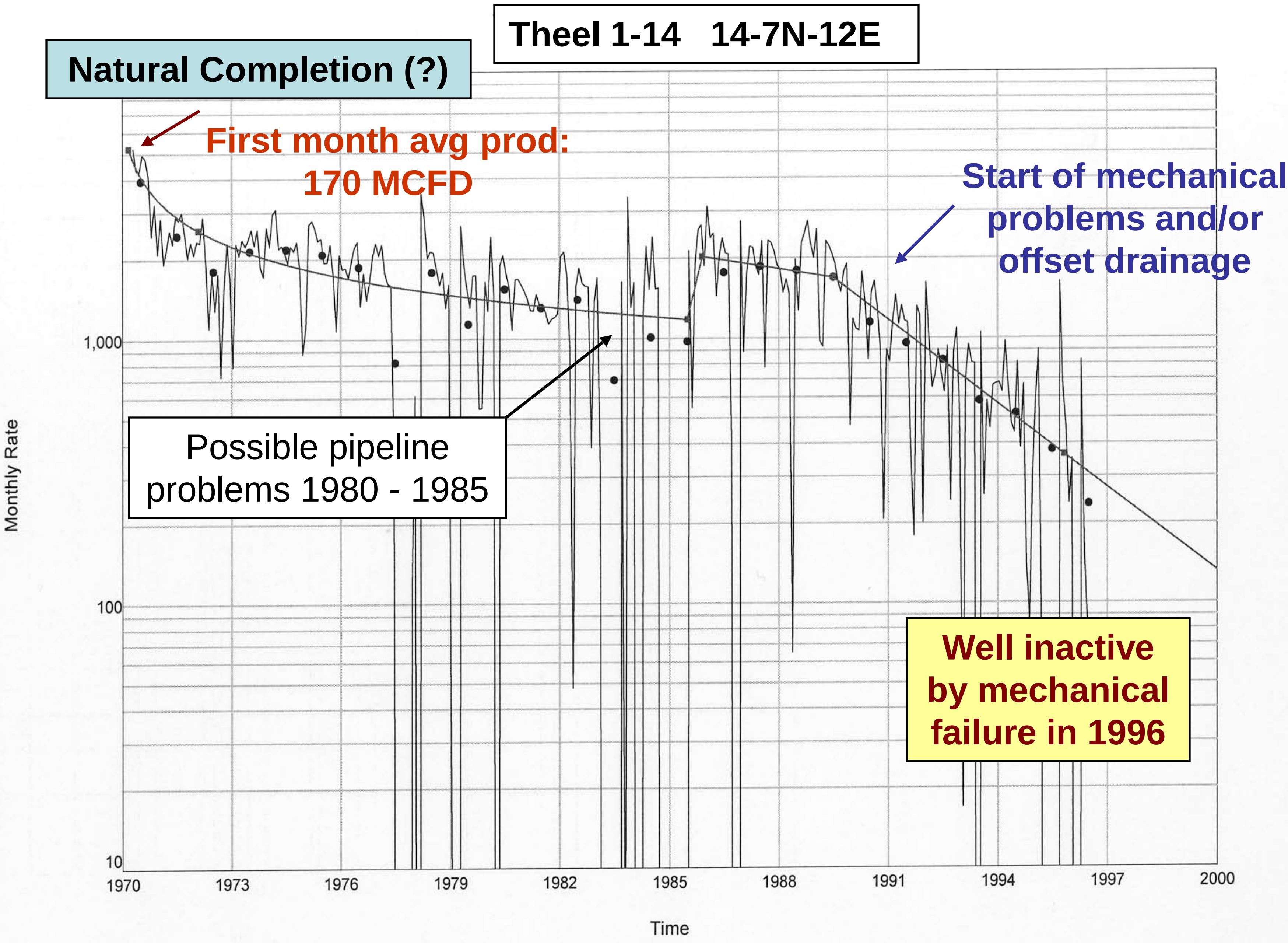
Spud 12/21/67, no info released

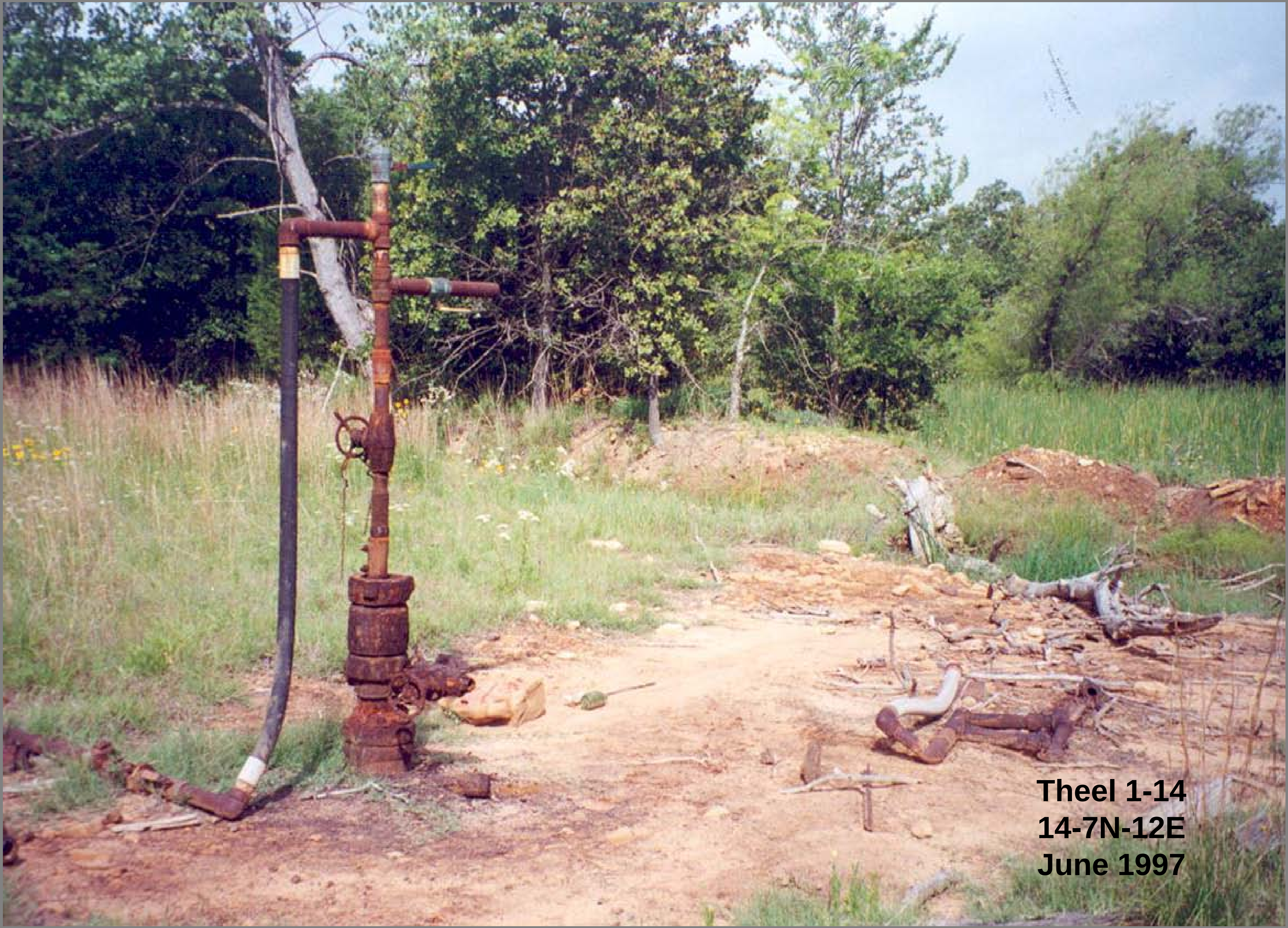
Produced 453 MMCF prior to abandonment in 1996

Natural Completion (?)

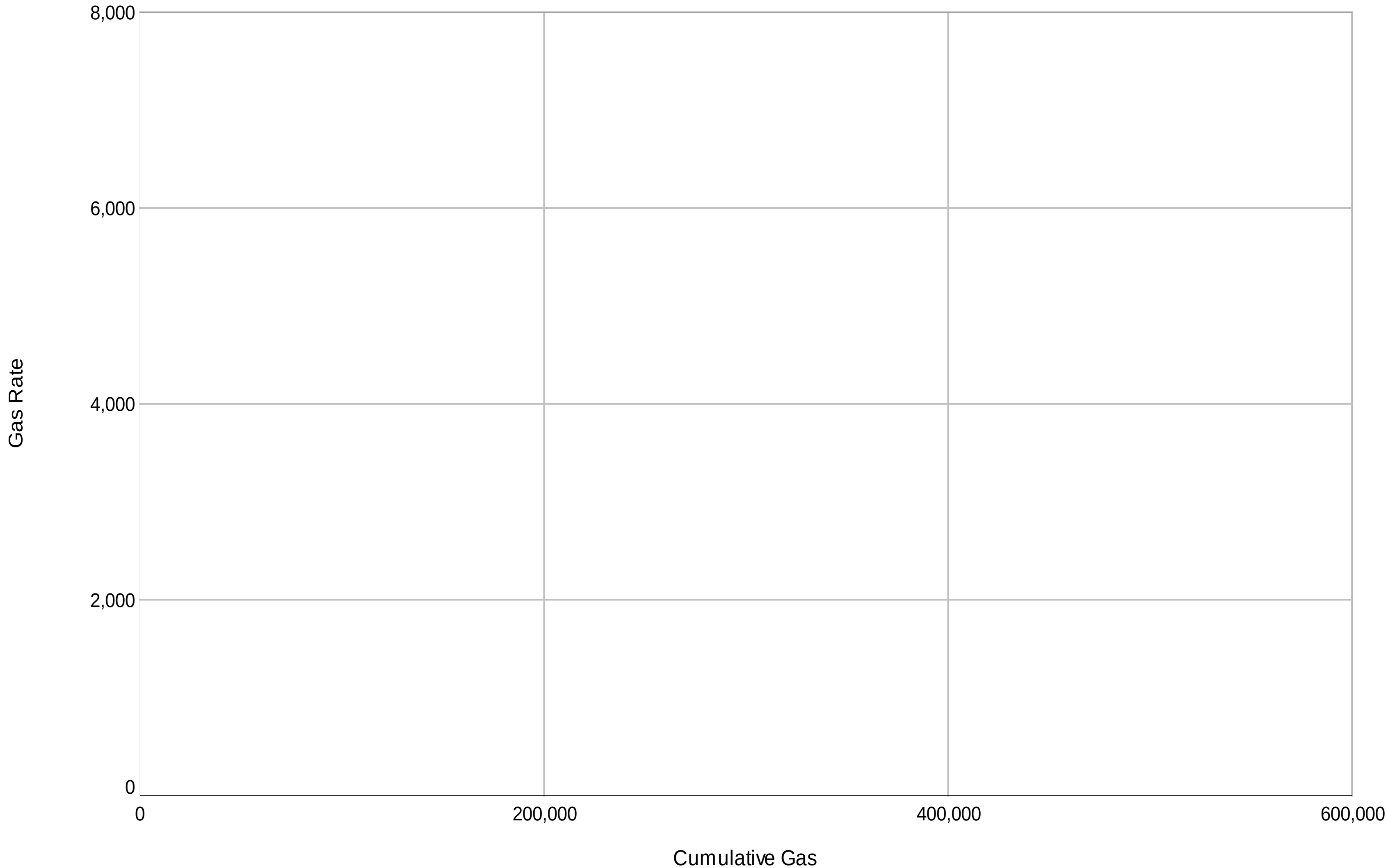
Mud Drilled Hole

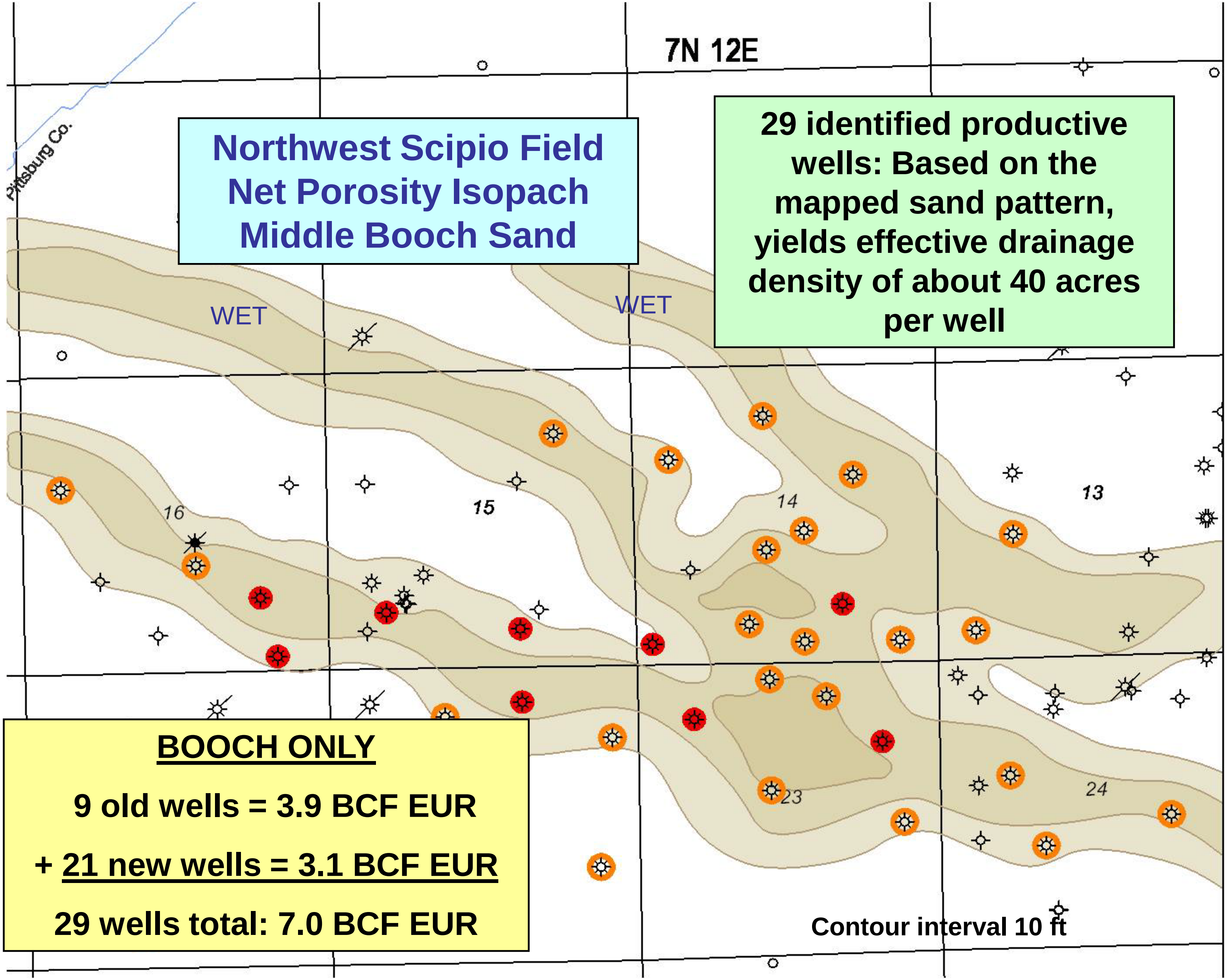
No other logs available


Theel 1-14 14-7N-12E
Natural Completion (?)
First month avg prod:
170 MCFD
Start of mechanical
problems and/or
offset drainage
Possible pipeline
problems 1980 - 1985
Well inactive
by mechanical
failure in 1996
Monthly Rate
1,000
100
10
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Time


Theel 1-14
14-7N-12E
June 1997

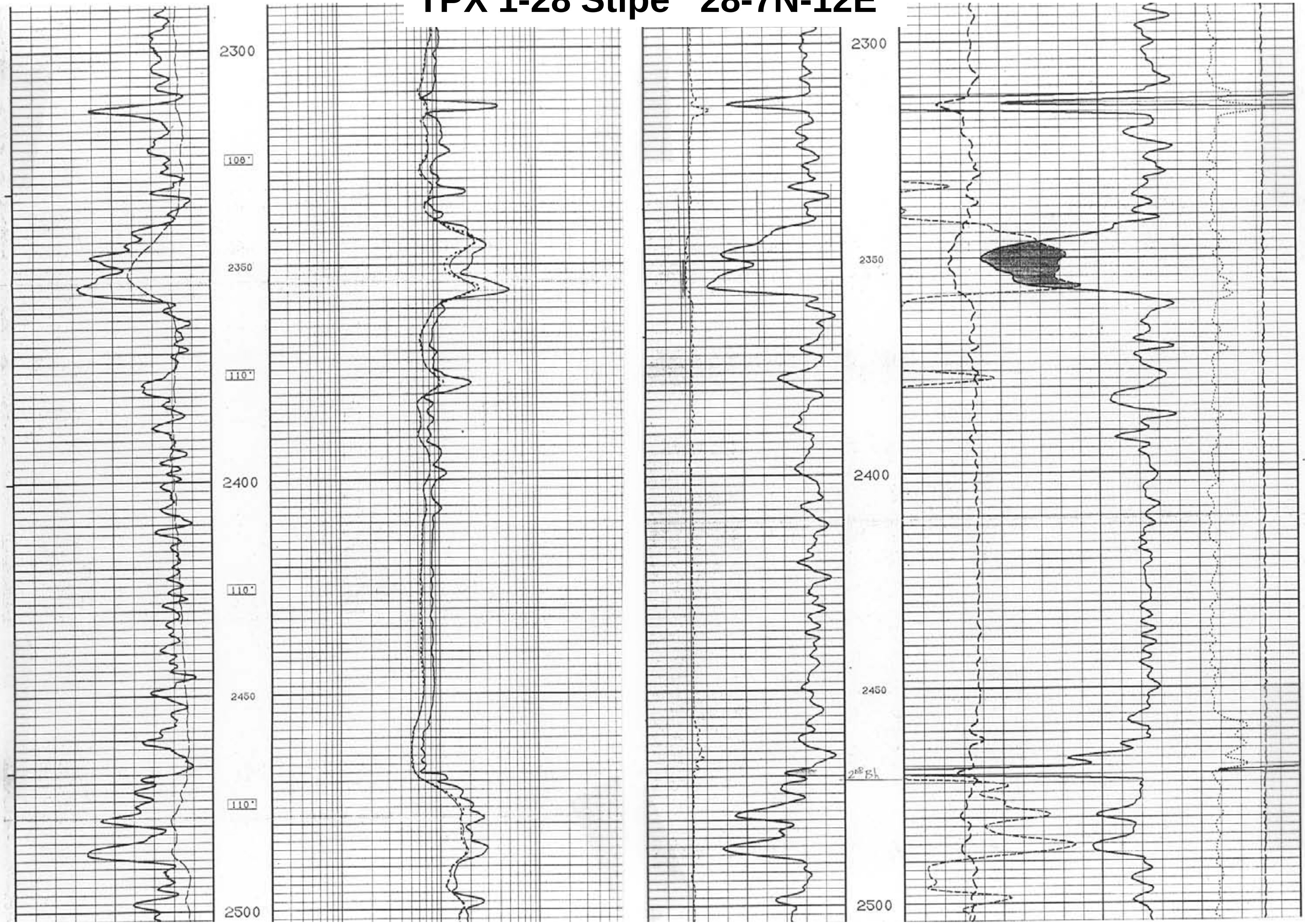

June 1997


Gas Rate
8,000
6,000
4,000
2,000
0
0
200,000
400,000
600,000
Cumulative Gas

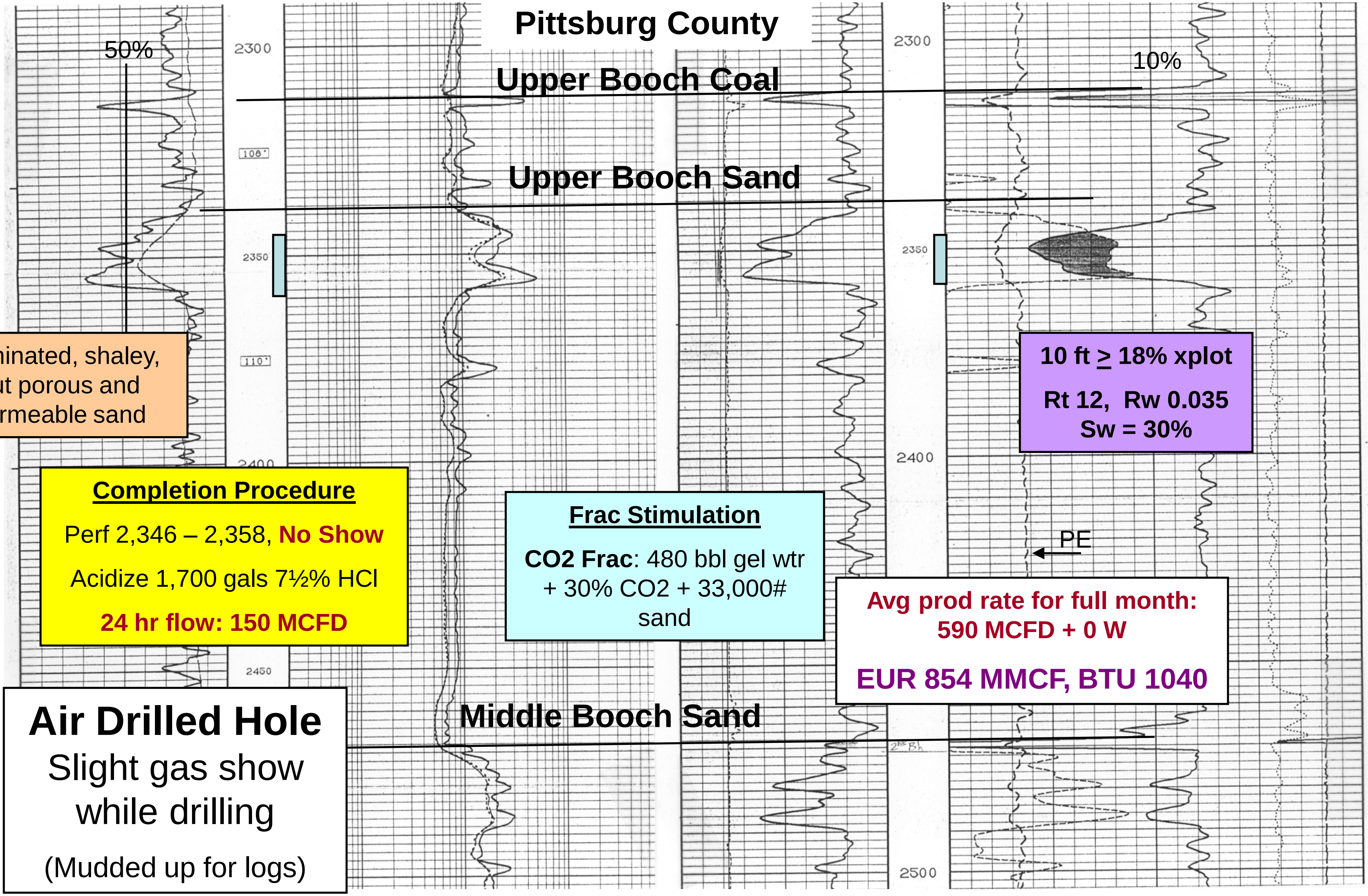


Northwest Scipio Field
Net Porosity Isopach
Middle Booch Sand
29 identified productive wells: Based on the mapped sand pattern, yields effective drainage density of about 40 acres per well
7N 12E
Pittsburg Co.
WET
WET
16
15
14
13
23
24
BOOCH ONLY
9 old wells = 3.9 BCF EUR
+ 21 new wells = 3.1 BCF EUR
29 wells total: 7.0 BCF EUR
Contour interval 10 ft

TPX 1-28 Stipe 28-7N-12E



TPX 1-28 Stipe
SW/4 28-7N-12E
Pittsburg County



Laminated, shaley, but porous and permeable sand

Completion Procedure

Perf 2,346 – 2,358, **No Show**

Acidize 1,700 gals 7½% HCl

24 hr flow: 150 MCFD

Frac Stimulation

CO2 Frac: 480 bbl gel wtr + 30% CO2 + 33,000# sand

10 ft ≥ 18% xplot

Rt 12, Rw 0.035
Sw = 30%

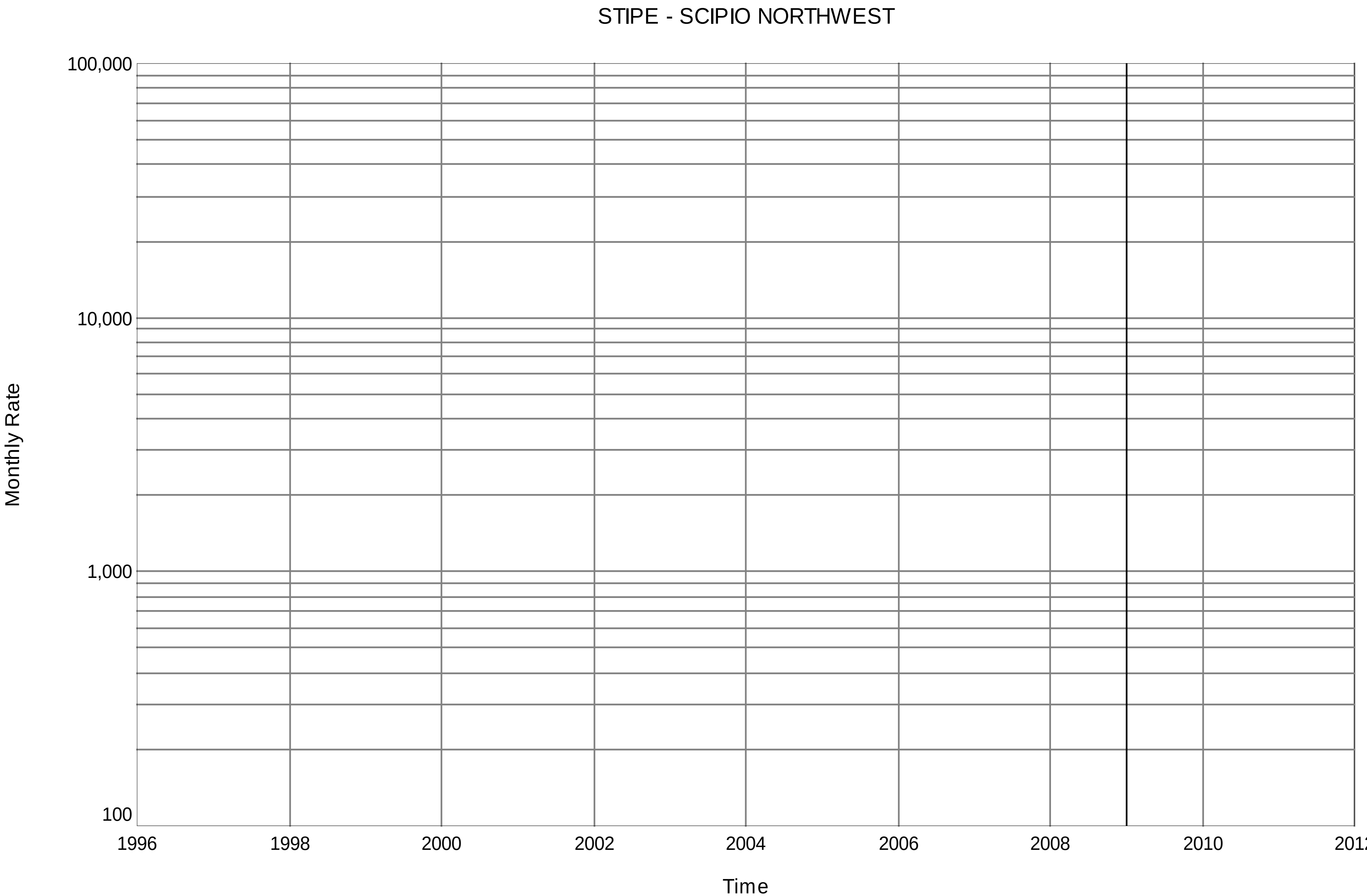
Avg prod rate for full month:
590 MCFD + 0 W

EUR 854 MMCF, BTU 1040

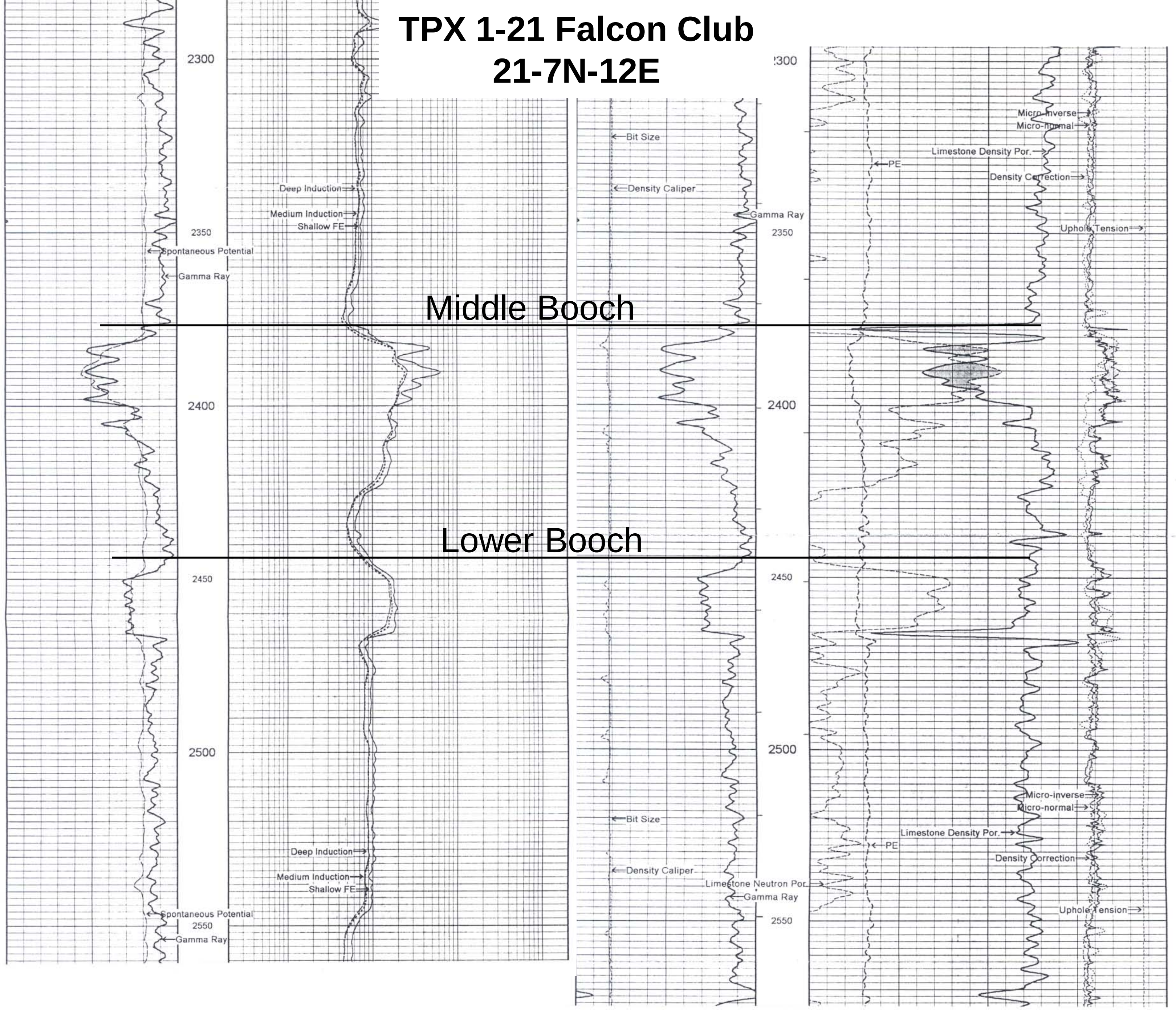
Air Drilled Hole

Slight gas show while drilling

(Mudded up for logs)

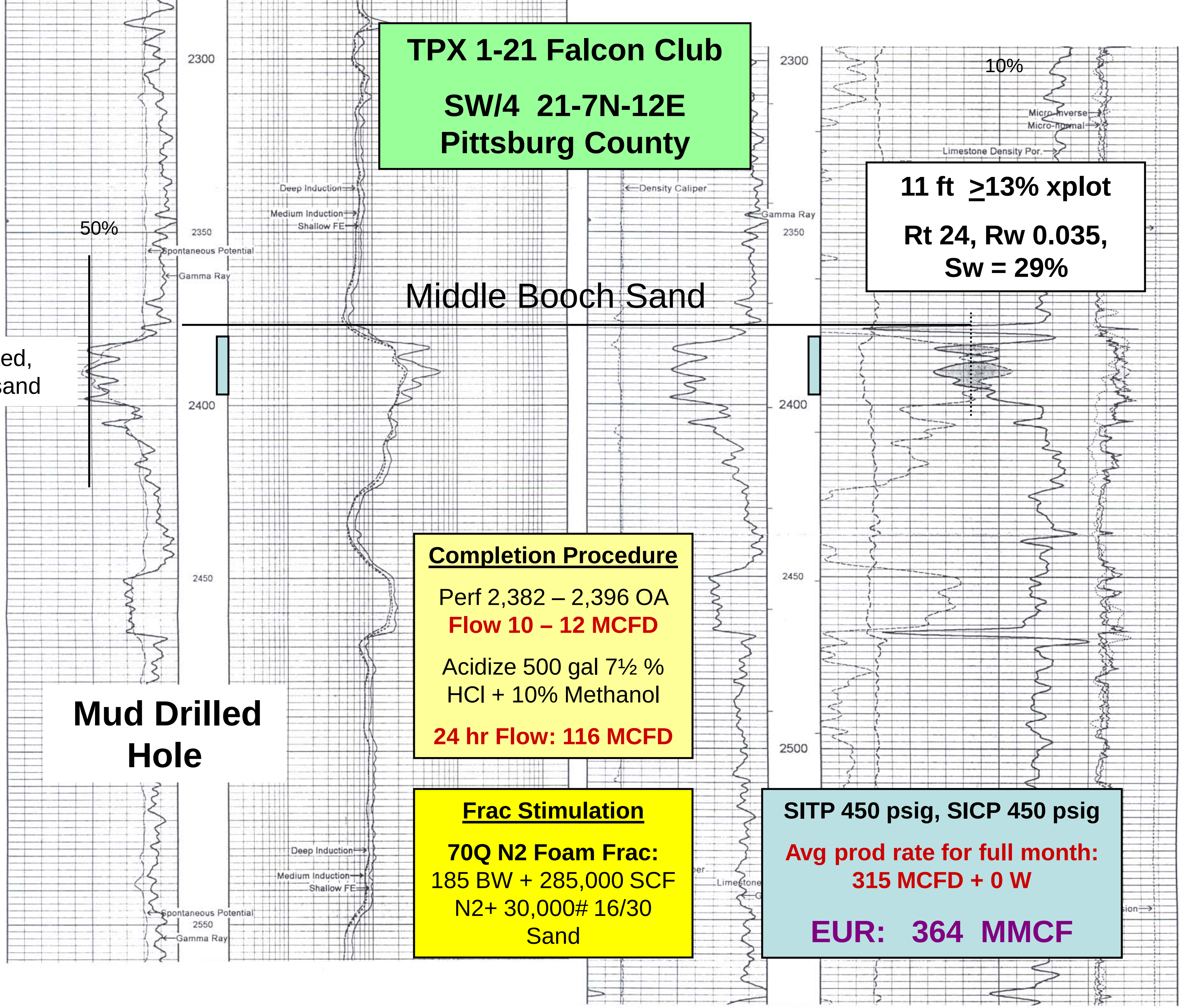

STIPE - SCIPIO NORTHWEST
100,000
10,000
1,000
100
Monthly Rate
1996
1998
2000
2002
2004
2006
2008
2010
2012
Time

TPX 1-21 Falcon Club
21-7N-12E



TPX 1-21 Falcon Club

SW/4 21-7N-12E
Pittsburg County



11 ft ≥13% xplot

Rt 24, Rw 0.035, Sw = 29%

Mud Drilled Hole

Completion Procedure

Perf 2,382 – 2,396 OA
Flow 10 – 12 MCFD

Acidize 500 gal 7½ % HCl + 10% Methanol

24 hr Flow: 116 MCFD

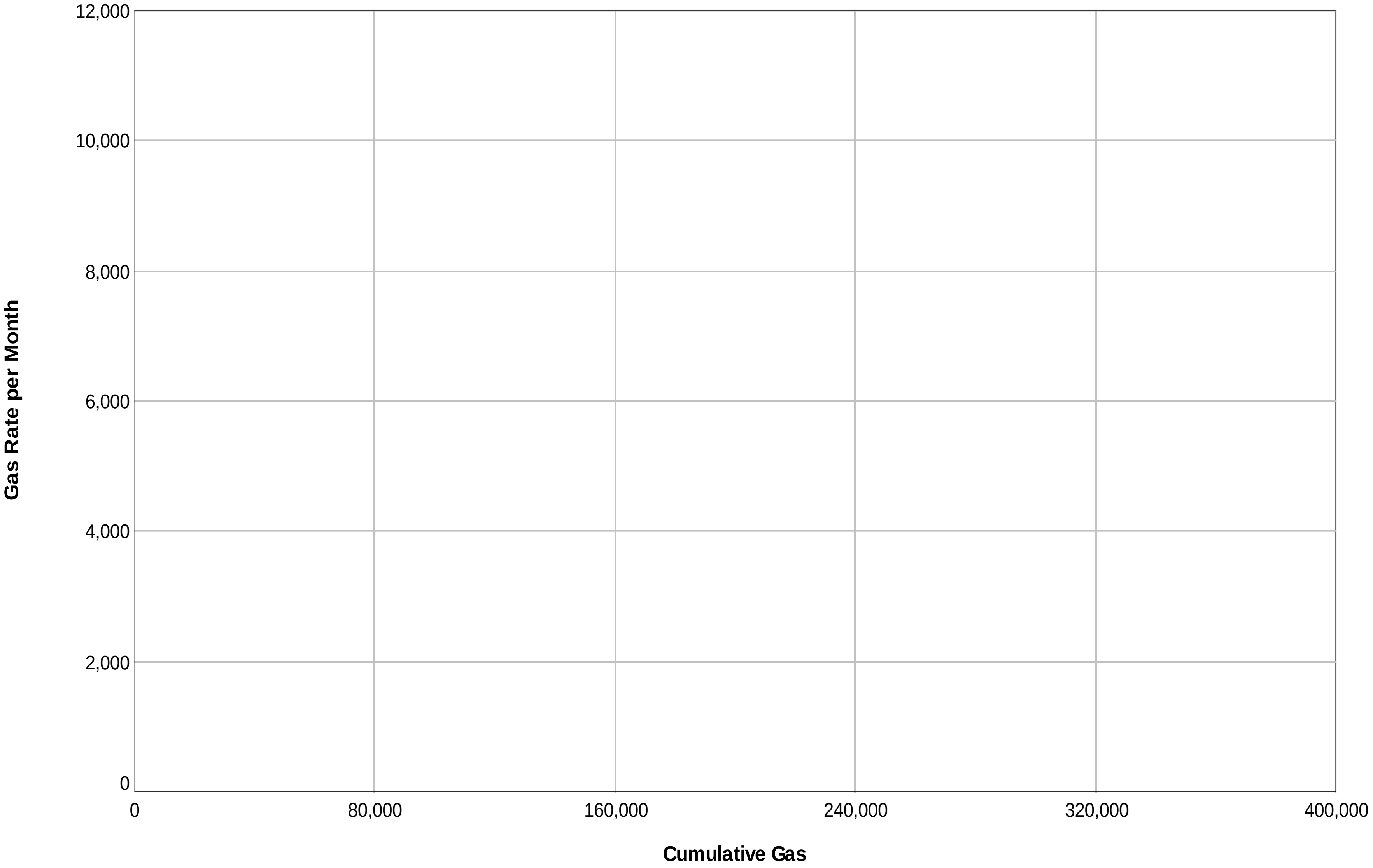
Frac Stimulation

70Q N2 Foam Frac:
185 BW + 285,000 SCF N2+ 30,000# 16/30 Sand

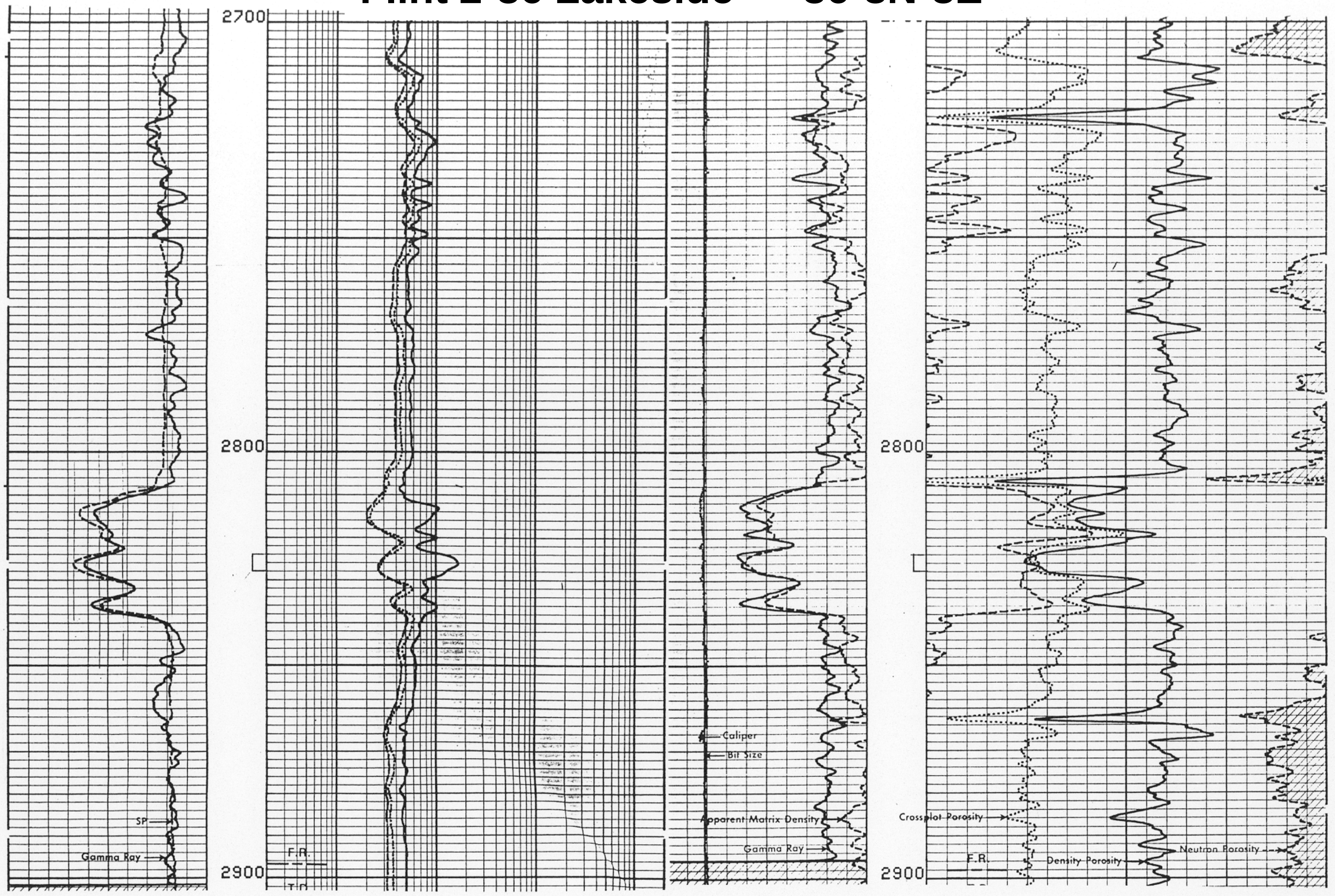
SITP 450 psig, SICP 450 psig

Avg prod rate for full month: 315 MCFD + 0 W

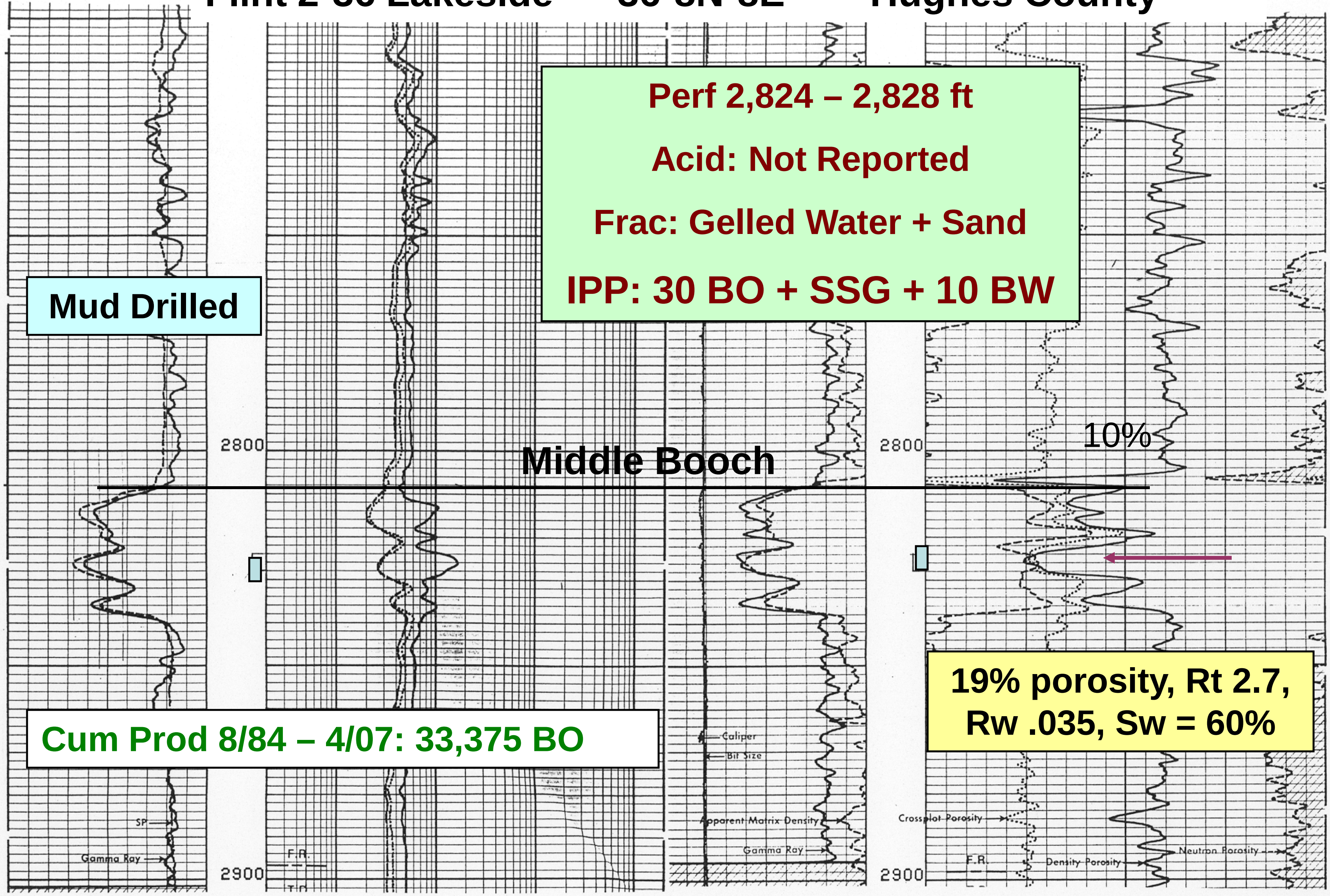
EUR: 364 MMCF

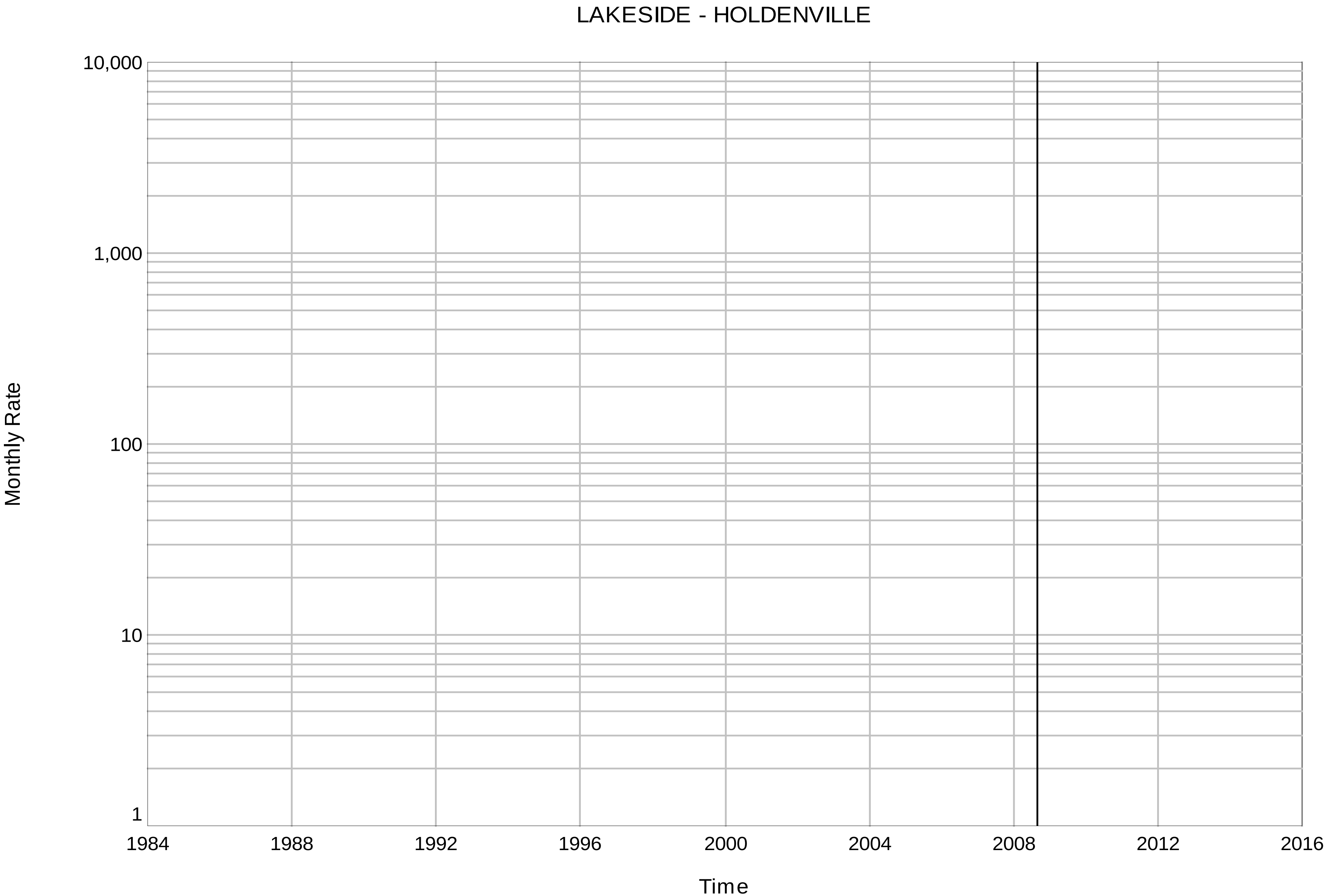

Gas Rate per Month
12,000
10,000
8,000
6,000
4,000
2,000
0
0
80,000
160,000
240,000
320,000
400,000
Cumulative Gas

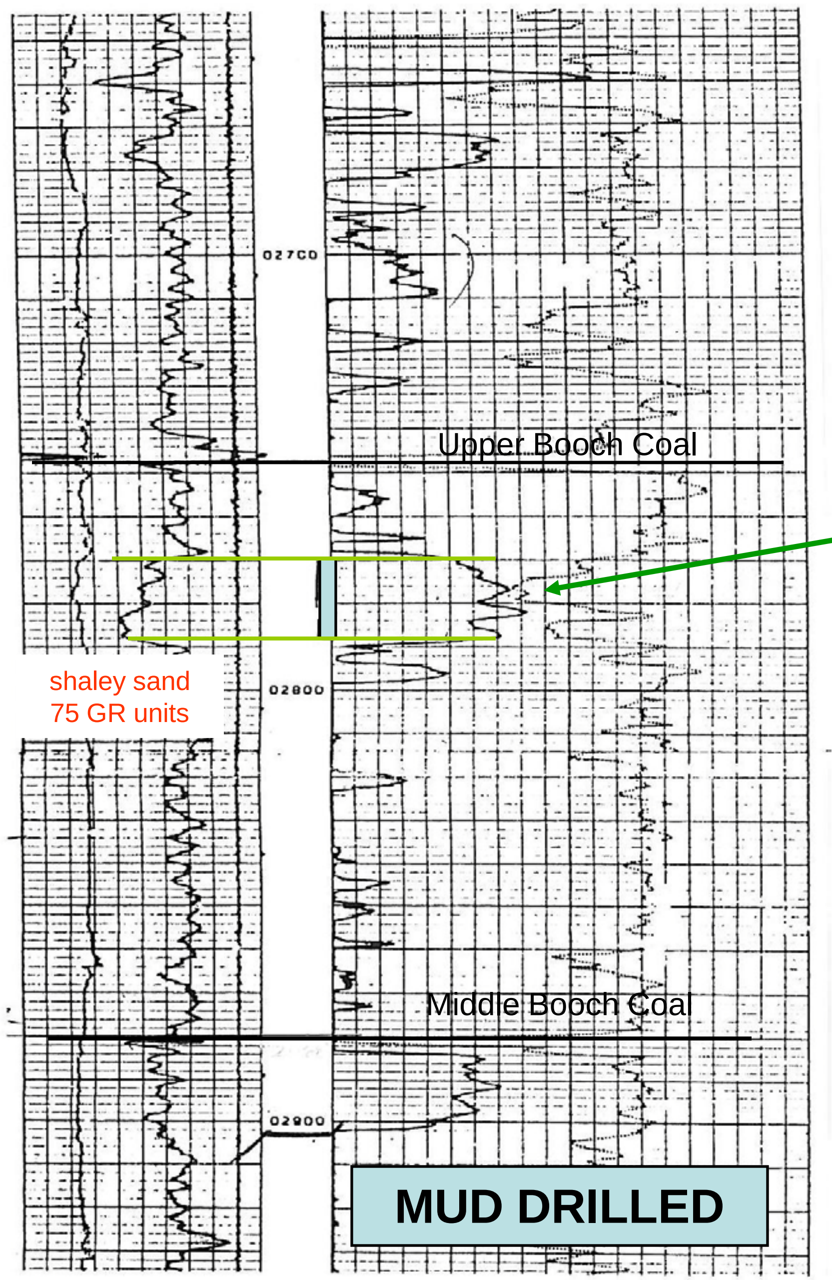
Flint 2-36 Lakeside 36-8N-8E



Flint 2-36 Lakeside 36-8N-8E Hughes County




LAKESIDE - HOLDENVILLE
10,000
1,000
100
10
1
Monthly Rate
1984
1988
1992
1996
2000
2004
2008
2012
2016
Time



Prime 1-4 Merriman
Section 4-5N-9E
Hughes County

(DIL not available)

Perf Upper Booch 2770 – 2788 OA

10' net density porosity ≥10%
No crossplot porosity

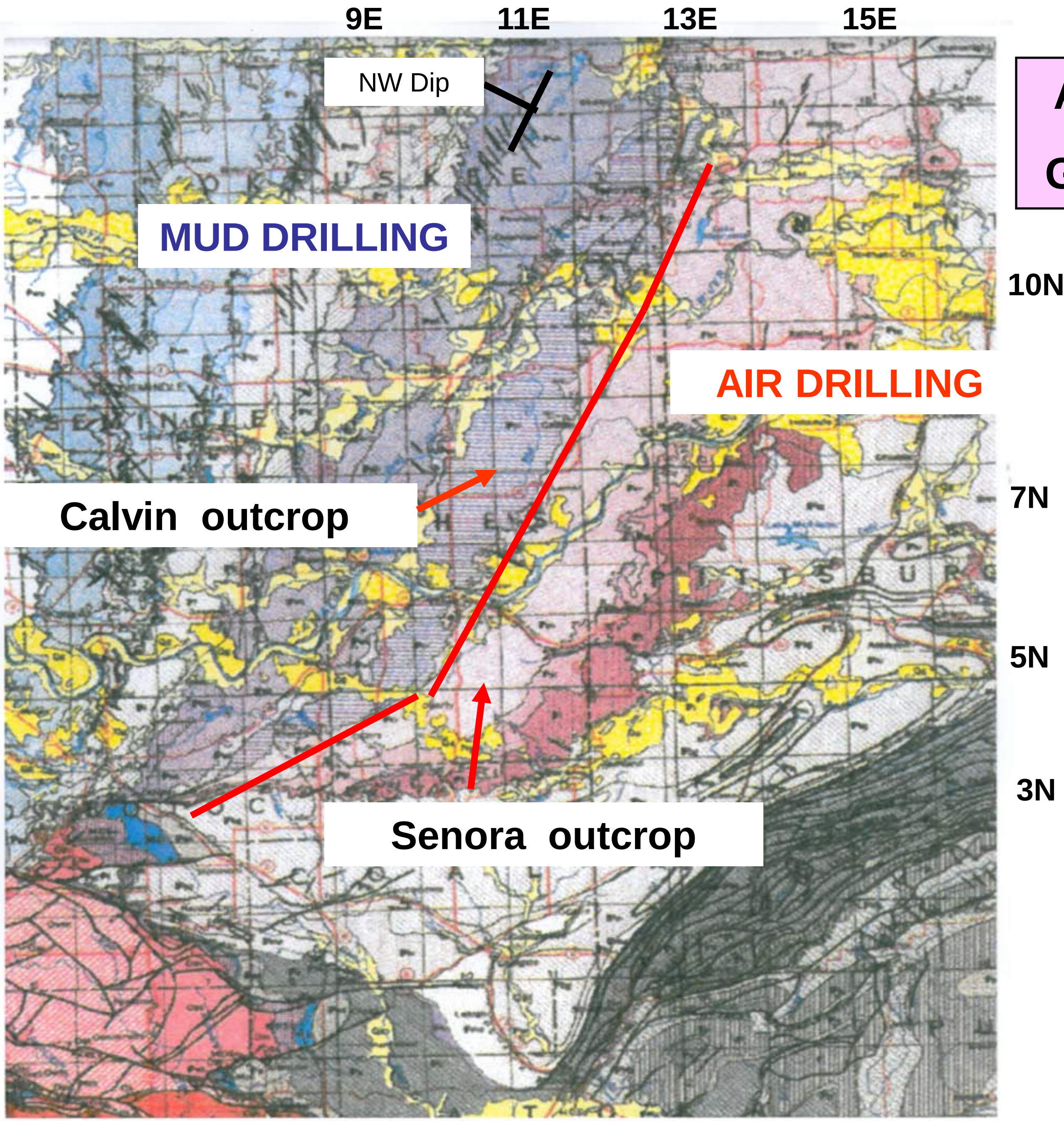
Acidize 1000 gals 7½ % HCL

Frac 33,600 gals water + 38,600 lbs sand

IPF 65 BOPD, ¾" ck, FTP 50 psig, gravity 34 deg

DOFS: August 1981

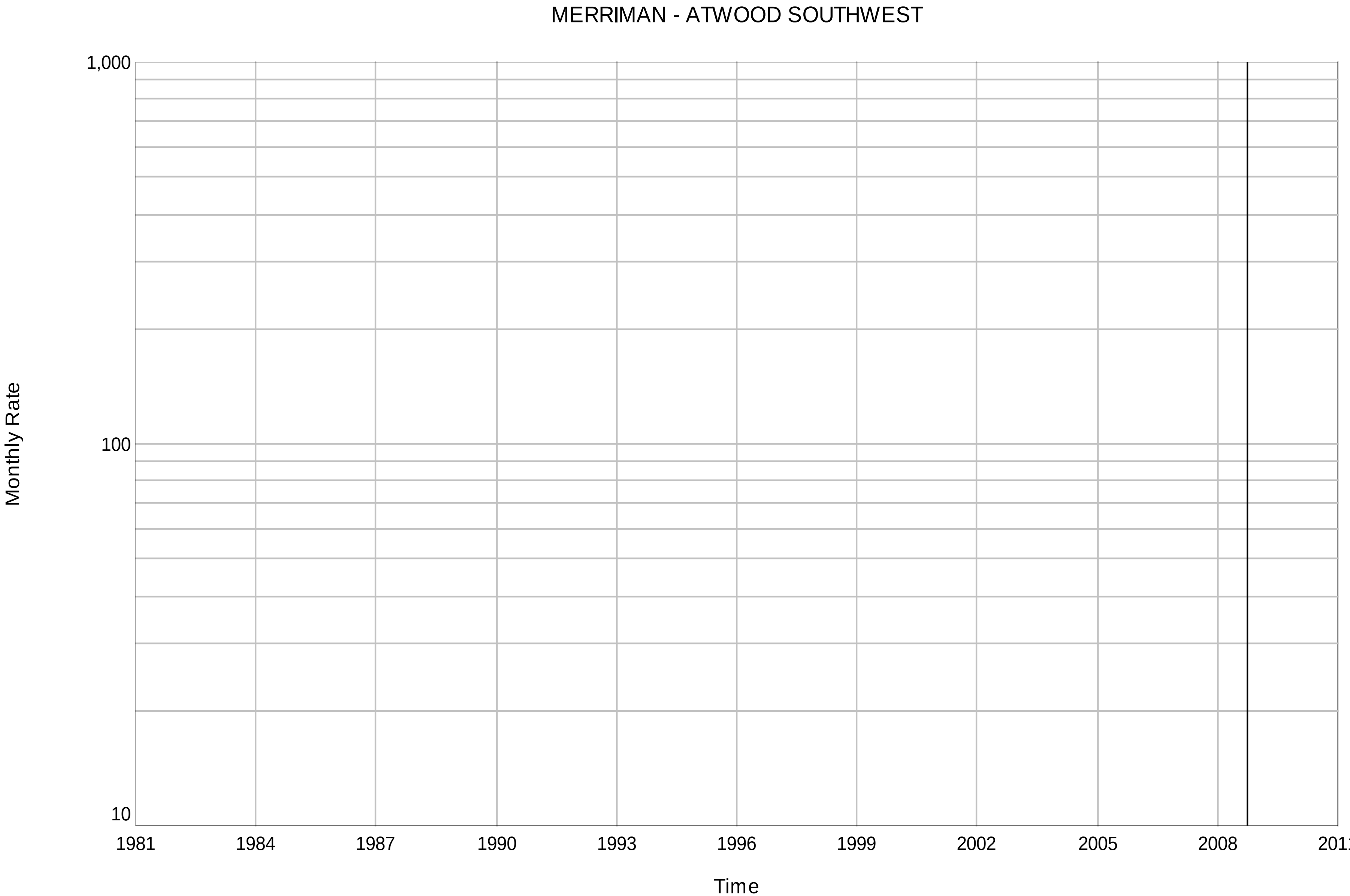
Air vs Mud Drilling
Geologic Boundary



Calvin Outcrop
Mud Drill

Senora Outcrop
Air Drill

Geologic Map of Oklahoma, c. 1954


MERRIMAN - ATWOOD SOUTHWEST
1,000
100
10
Monthly Rate
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
Time

PRODUCTION OPTIMIZATION FOR THE BOOCH SANDSTONE

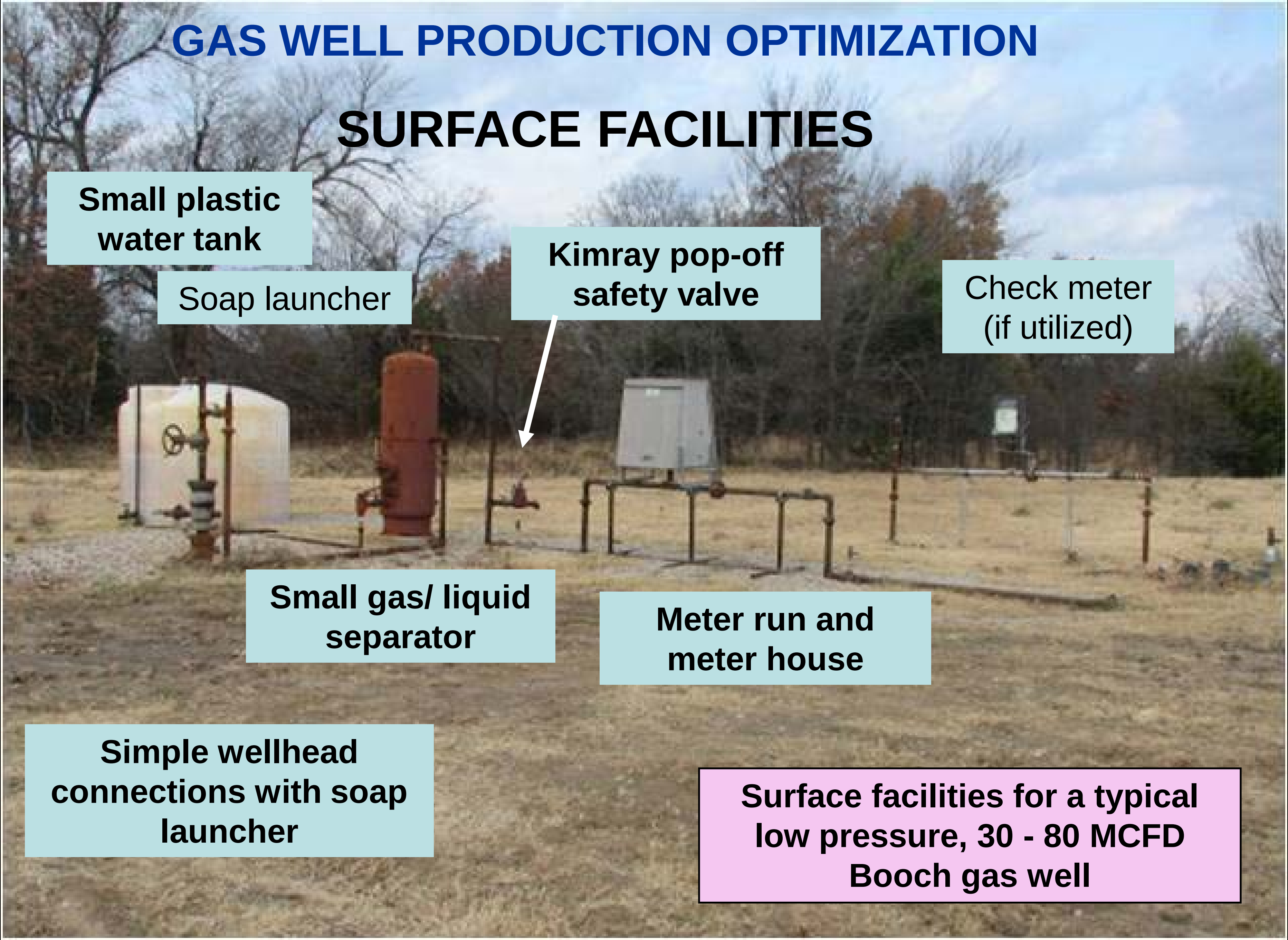
Production Optimization for the Booch Sandstone: Gas Wells

Ensure well is as near water-free at time of initial gas sales as possible:

- Swab back acid until dry (no water).
- Flowback frac job to atmosphere (no back pressure) until well is dry after a foam-assisted fracture stimulation treatment.
- Keep spacing between wells reasonable: gas wells drain 120 to 160 acres!

GAS WELL PRODUCTION OPTIMIZATION

SURFACE FACILITIES



GAS WELL PRODUCTION OPTIMIZATION

Low Pressure Wells Love Low Pressure Gathering Systems!

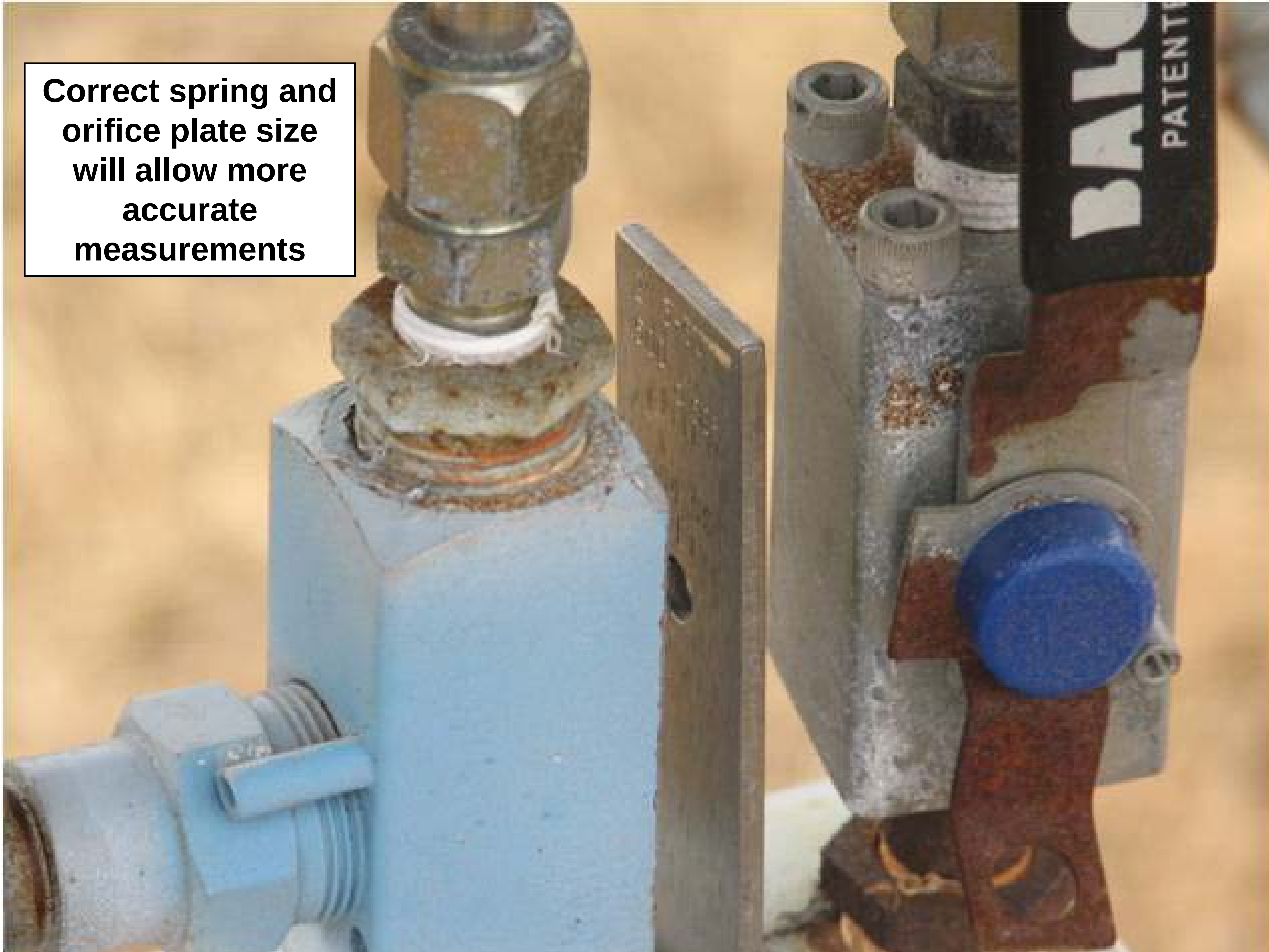
Low Pressure Wells Love Low Pressure Gathering Systems!

Gathering system suction should be as low as possible, with line pressure at the wellhead ideally less than 25 psig. Flow Tubing Pressure often 25 psig or less.

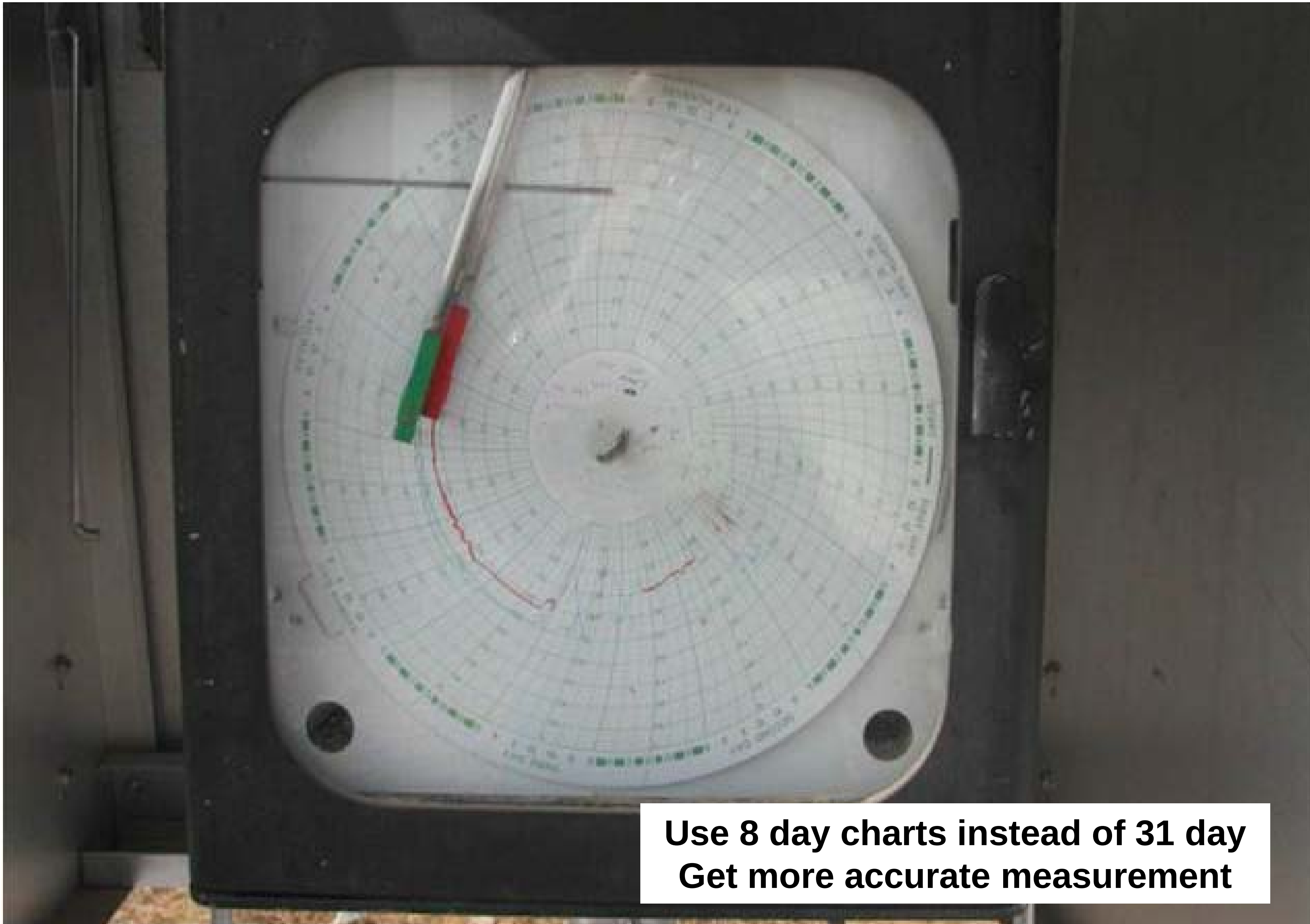
Very low line pressure at the wellhead generally means suction pressure on vacuum or near zero at the inlet valve to the compressor

Pittsburg Gathering, LLC compression station in 12-7N-12E for the NW Scipio gas field. Sold to Chesapeake in 2004.

Screw compressor in 34-7N-12E connecting the Wild Turkey low-pressure gas gathering system to Markwest pipeline (32 Booch, Hartshorne sand, and CBM wells)


Correct spring and orifice plate size will allow more accurate measurements

PRODUCTION OPTIMIZATION FOR BOOCH GAS WELLS



Use 8 day charts instead of 31 day
Get more accurate measurement

Production Optimization for the Booch Sandstone: Oil Wells

Reservoir: Evaluation parameters can be tricky

Acid: Swab back acid until well dries up

- Spearhead acid not recommended

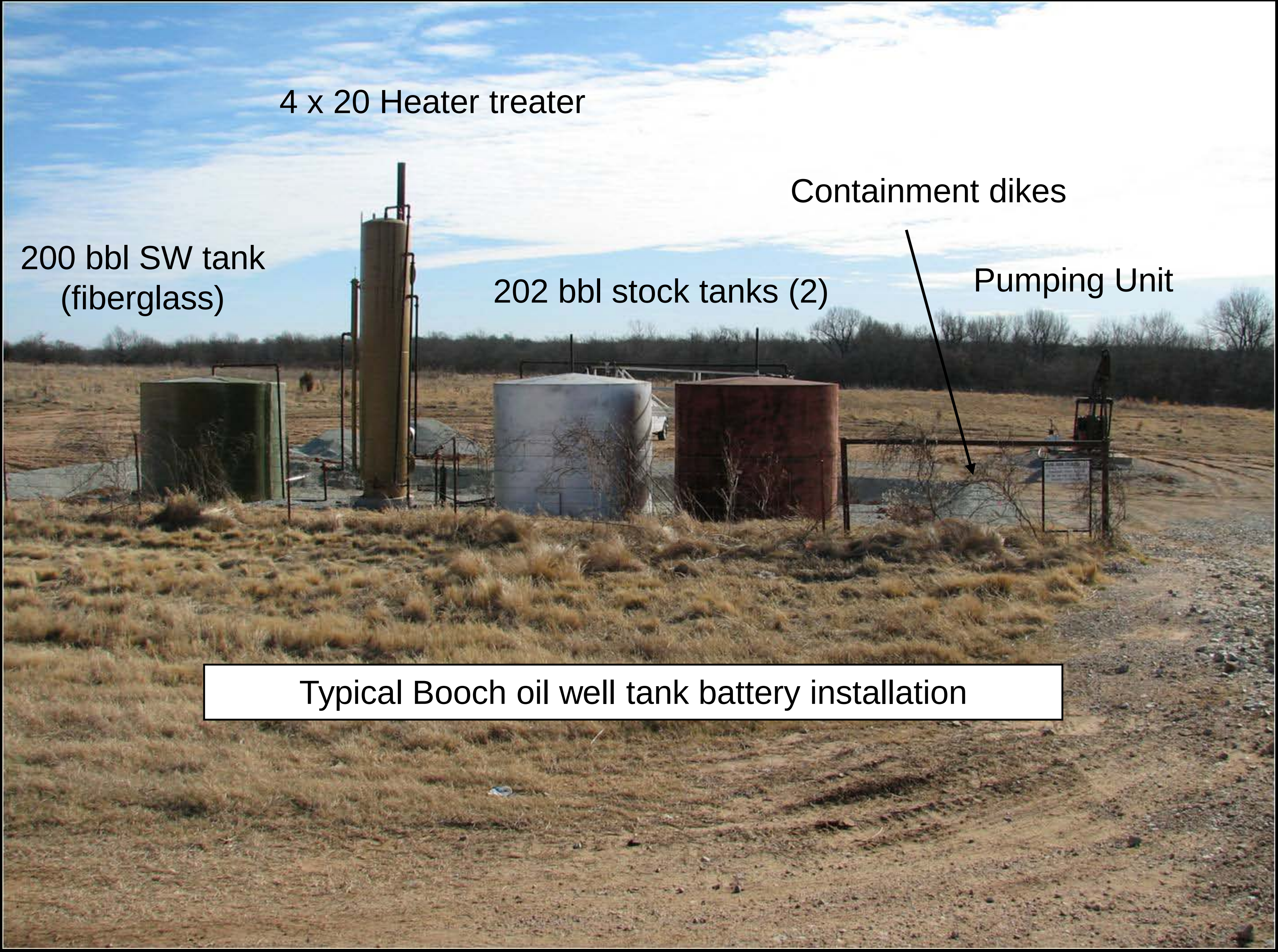
Gelled Water Frac: Do not begin flowback until after gel breaks down

Since there is little or no leakoff into formation, can wait days or weeks before flowback begins with no ill effects

PRODUCTION OPTIMIZATION FOR OIL WELLS IN THE BOOCH SANDSTONE

Drainage: Typical Booch oil well will drain between 20 and 40 acres in most areas.

Secondary Recovery in Booch Sand: Analyzed waterfloods show approx 60% additional production after primary recovery.



Typical Booch oil well tank battery installation


SUMMARY AND
CONCLUSIONS

Summary and Conclusions

1. The Booch is not a user-friendly sand. Low permeability, clay/ shale content, limited areal extent and low pressure are limiting factors.

2. Due to near-surface geology, air drilling is often used when targeting gas in the Booch, and mud is used when targeting oil.

3. Formation evaluation requires a knowledge of local trapping conditions, including variable production parameters and reservoir drive mechanisms.

4. Nitrogen foam fracture stimulation is the most widely accepted method of reservoir enhancement in gas wells.

Summary and Conclusions

5. Gelled water fracs are most common for Booch oil wells.

6. High initial decline rates are common, tapering off to very low decline, long-lived reserves.

7. Low cost surface facilities are adequate; measuring and collection equipment must be tailored to low pressure, low volume wells.

8. Low pressure wells love low pressure gathering systems.

When prospected, drilled and completed properly, the Booch can be a substantial asset for the producer and is a valuable part of an eastern Oklahoma oil and gas portfolio.