

Experiences in the Salt Creek Field CO₂ Flood

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5th Annual Wellbore Integrity Network

May 13-14, 2009

Calgary, Alberta



Thank you

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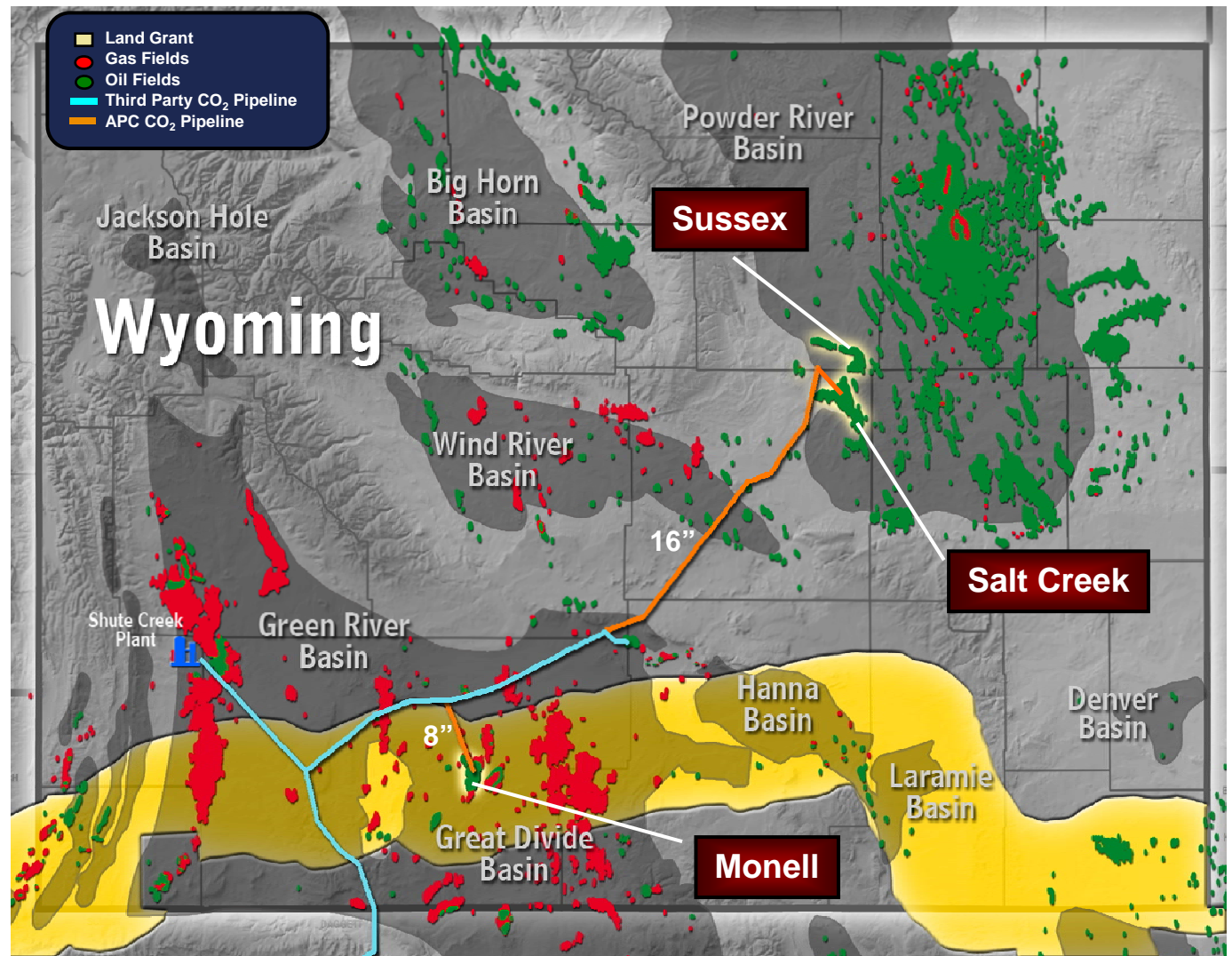
Outline

- Field/System Overview
- Challenges
 - Wells
 - Others
- Lessons Learned
- Benefits
- Questions



Anadarko's Wyoming EOR Assets

- Fields
 - Monell
 - Salt Creek
 - Sussex
- Pipelines
 - 33 mile, 8"
 - 125 mile, 16"
- CO₂ Supply
 - XOM Shute Creek



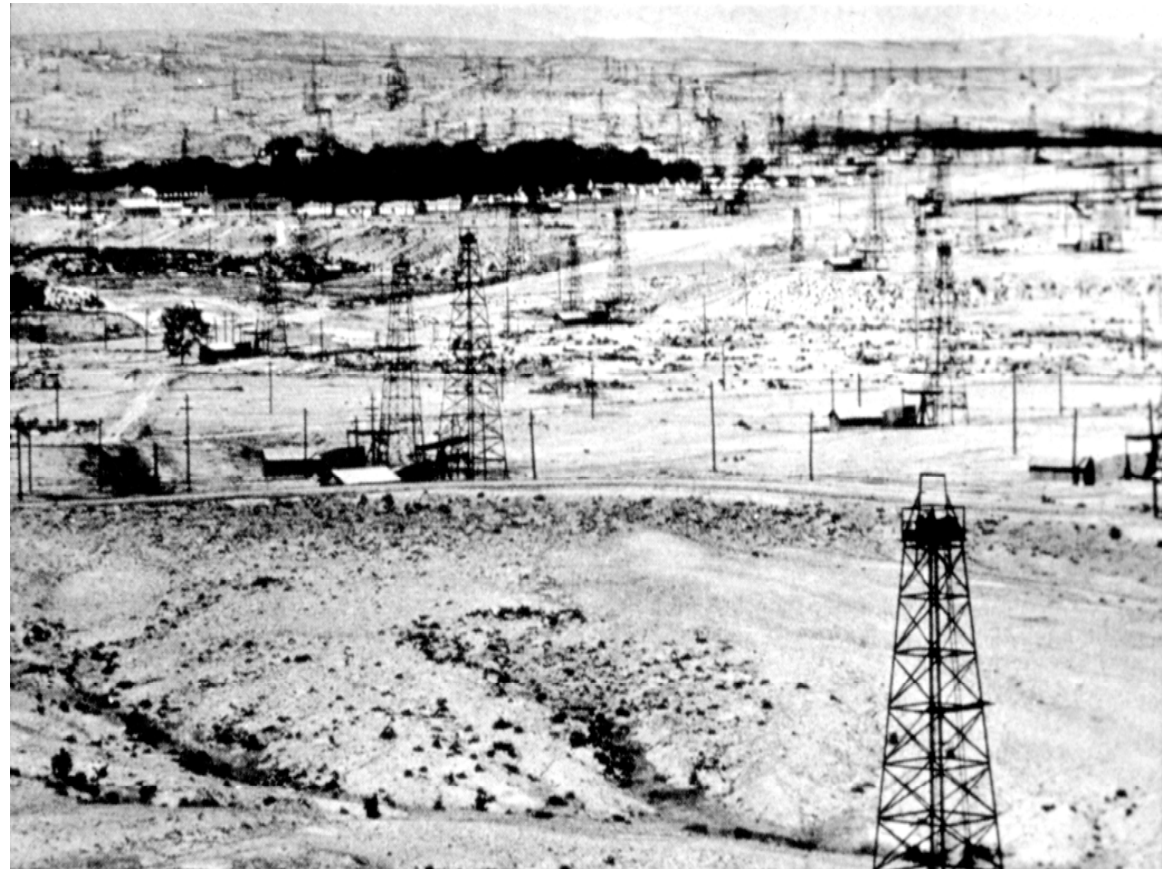
Salt Creek – Overview

History

- Discovered in 1908
- >4,000 wells drilled
- 1.7 Bbbl of OOIP
- 0.7 Bbbl cum. production
- 10 producing horizons
- Depths range from 22' to 4,500'
 - Second Wall Creek ~ 1,800'
- Waterflooding began mid-1960s
- CO₂ injection began Jan 2004
 - CO₂ production began May 2004
- >90% located on BLM acreage
- Planned Sequestration of ~40 million tons (700 BCF) of CO₂

Current Rates

- 8,000 b/d from CO₂, (9,500 b/d total)
- 350 MMcf/d CO₂ injection
 - ~125 MMcf/d new CO₂
 - ~225 MMcf/d recycled CO₂
- CO₂-EOR Cumulative > 8 MMBO



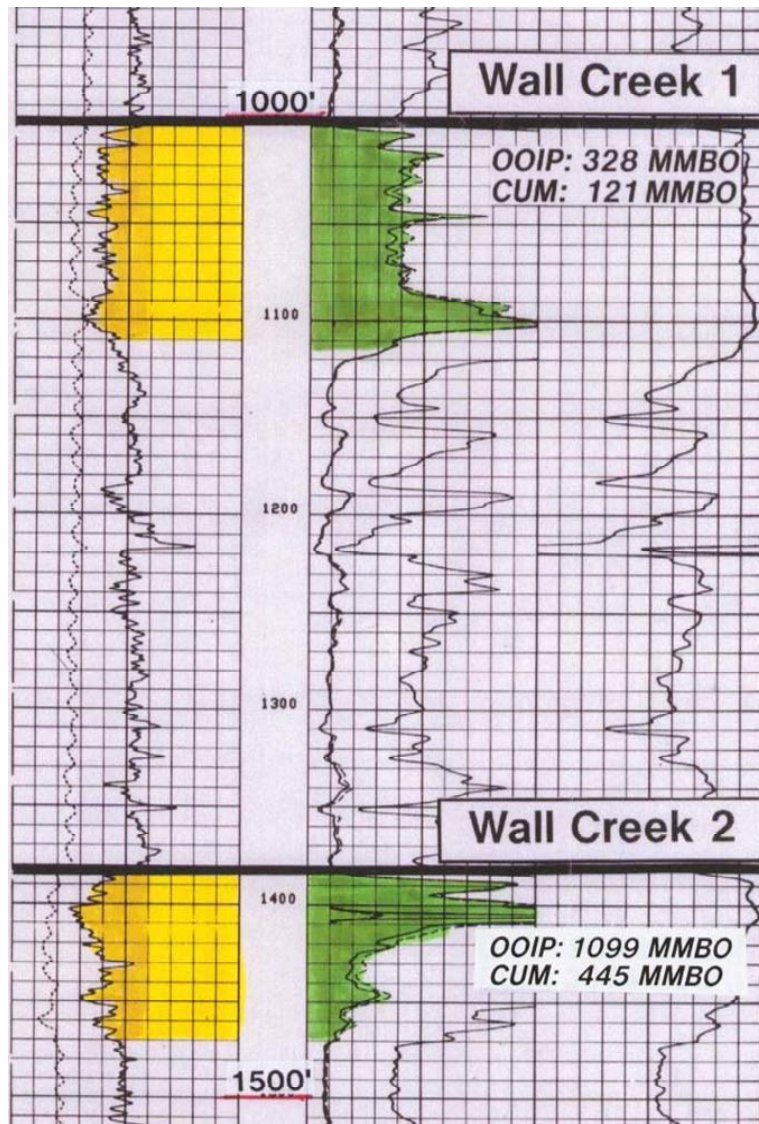
Salt Creek Oil Field, early 1920s.

Required Credit: AMOCO Refining Co. Collection, Casper College Library.

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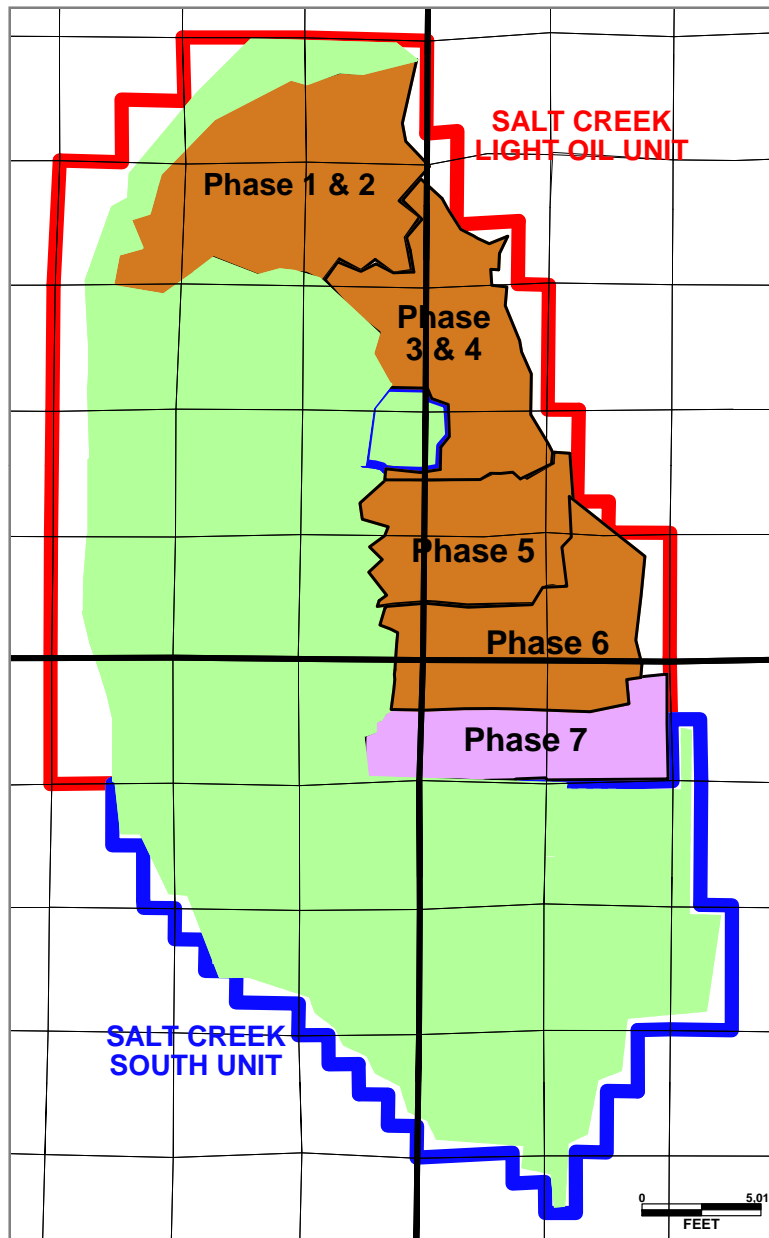
Salt Creek Type Log – Wall Creek 1 & 2



Wall Creek 2 (Primary Horizon)

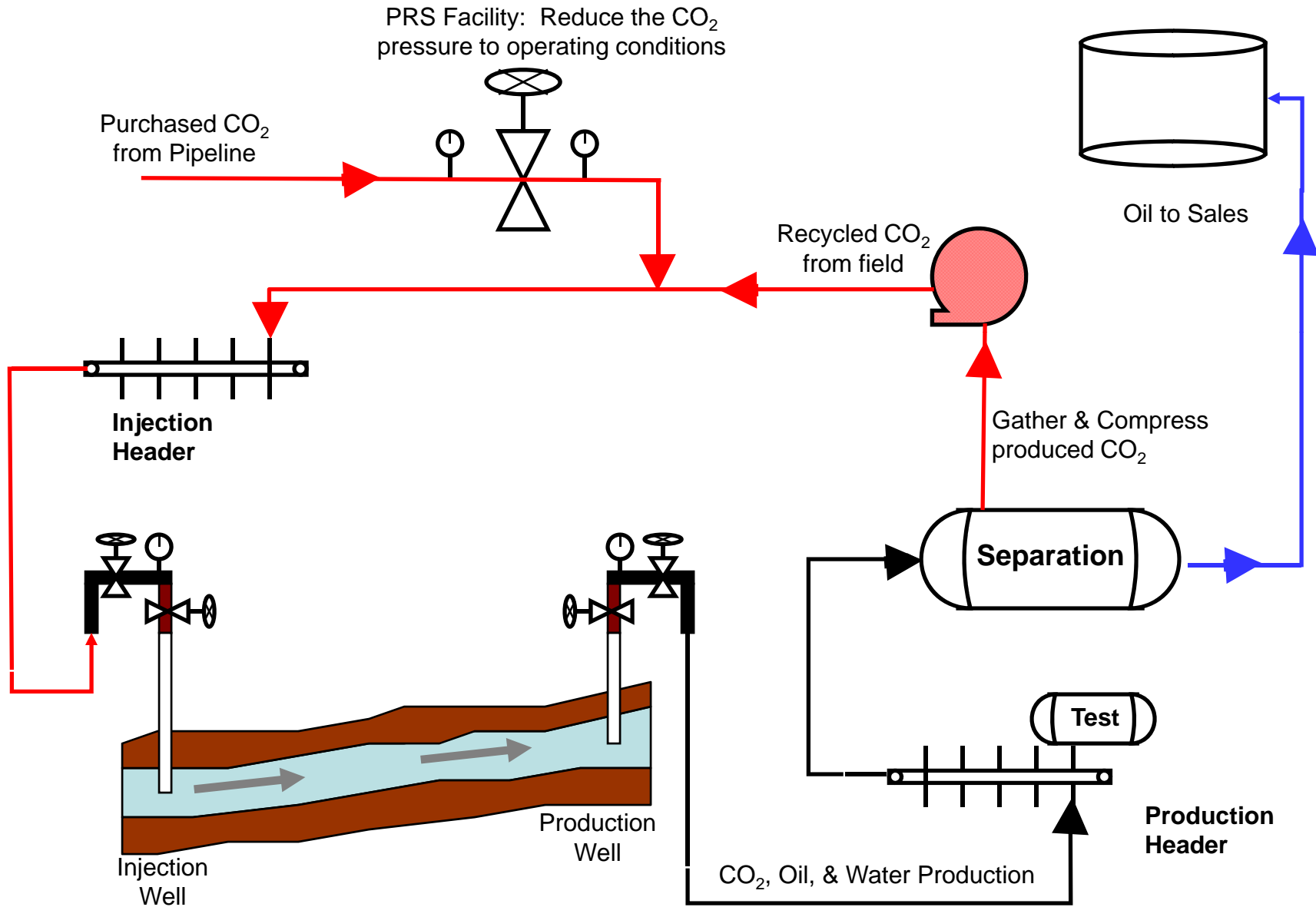
- Salt Creek structure is a large asymmetrical anticline
- Area: 40 sq. miles
- Depth: 1,500 - 2,500'
- Thickness: 130' grs / 70' net
- Por / Perm: 19% por / 52 mD
- 39 API; MMP 1,250 psi
- Primary: 1917 – 67
- Waterflood: 1967 – present
- CO₂: 2004 – present

WC2 CO₂ Flood

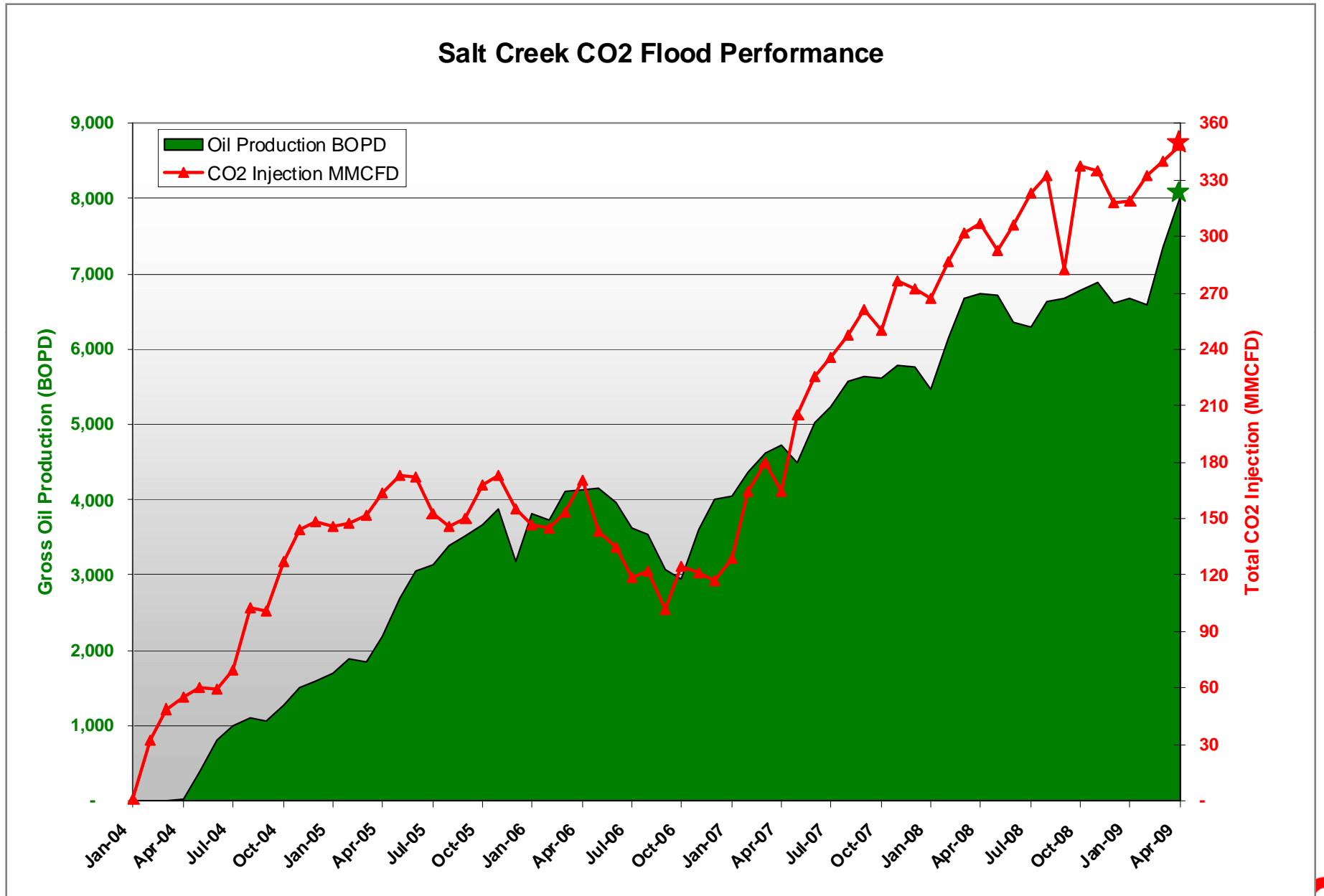


- Oil: 39° API
- MMP: 1,275 psi @ 105°
- Miscible areas on flanks
- Flood Type: (WAG)
Water Alternating Gas
- Producers: Flowing wells (against surface backpressure of 200 – 400 psi)

CO₂ Flow Process at Salt Creek



~8 MMBOE from Salt Creek CO2 flood



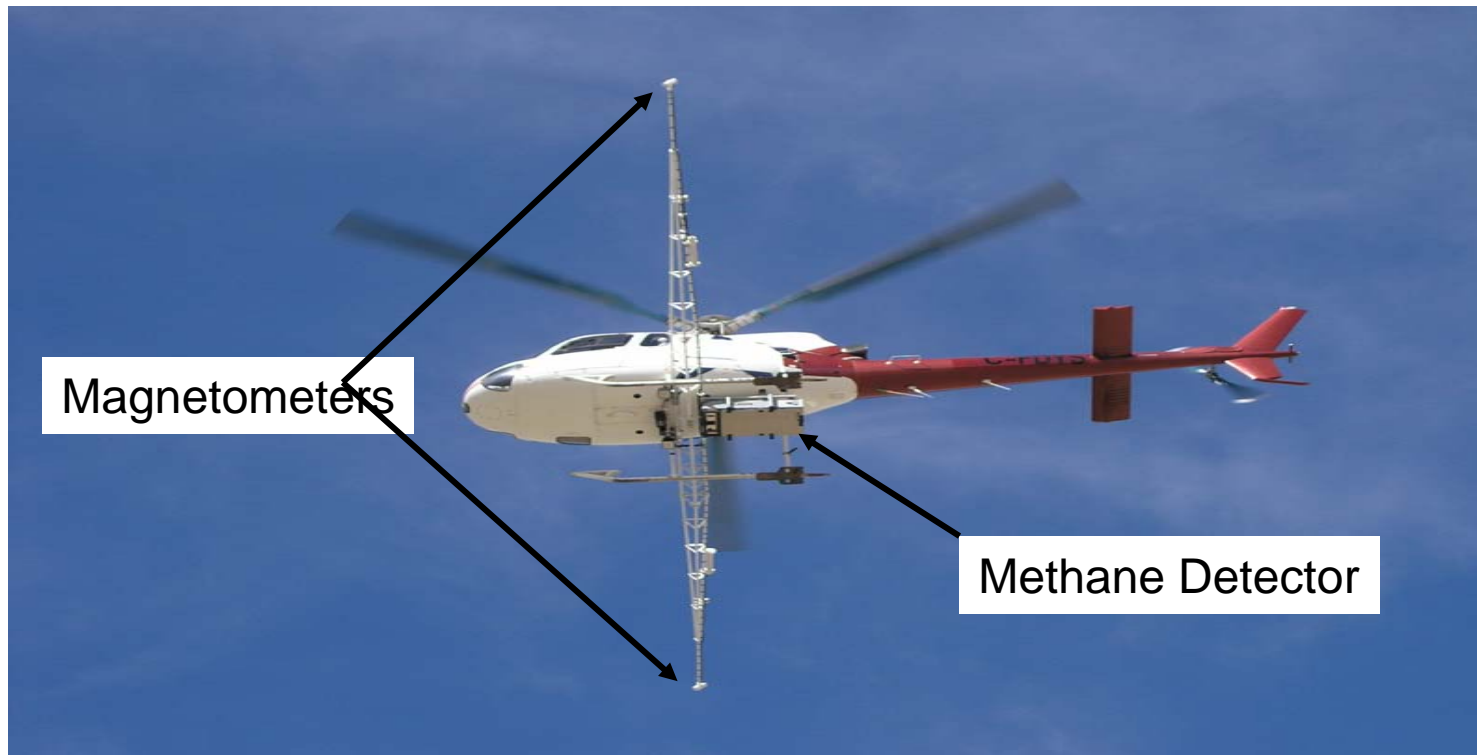
Pre-CO₂ Development – What did we have?

- More than 4,000 wells drilled; ~70% prior to 1930
 - ~1,000 well waterflood producing +/- 5,000 b/d; 99.4% water cut
 - High well density with the Second Wall Creek formation developed on ~ 4-acre spacing
 - Limited open-hole log data – Most wells drilled prior to this technology existing
 - Existing production/injection casing not designed for corrosive CO₂ service & of questionable integrity
 - Over 3,000 plugged and inactive wells with questionable cement isolation & questionable plugging quality
 - Incomplete well data & numerous unknown wellbores

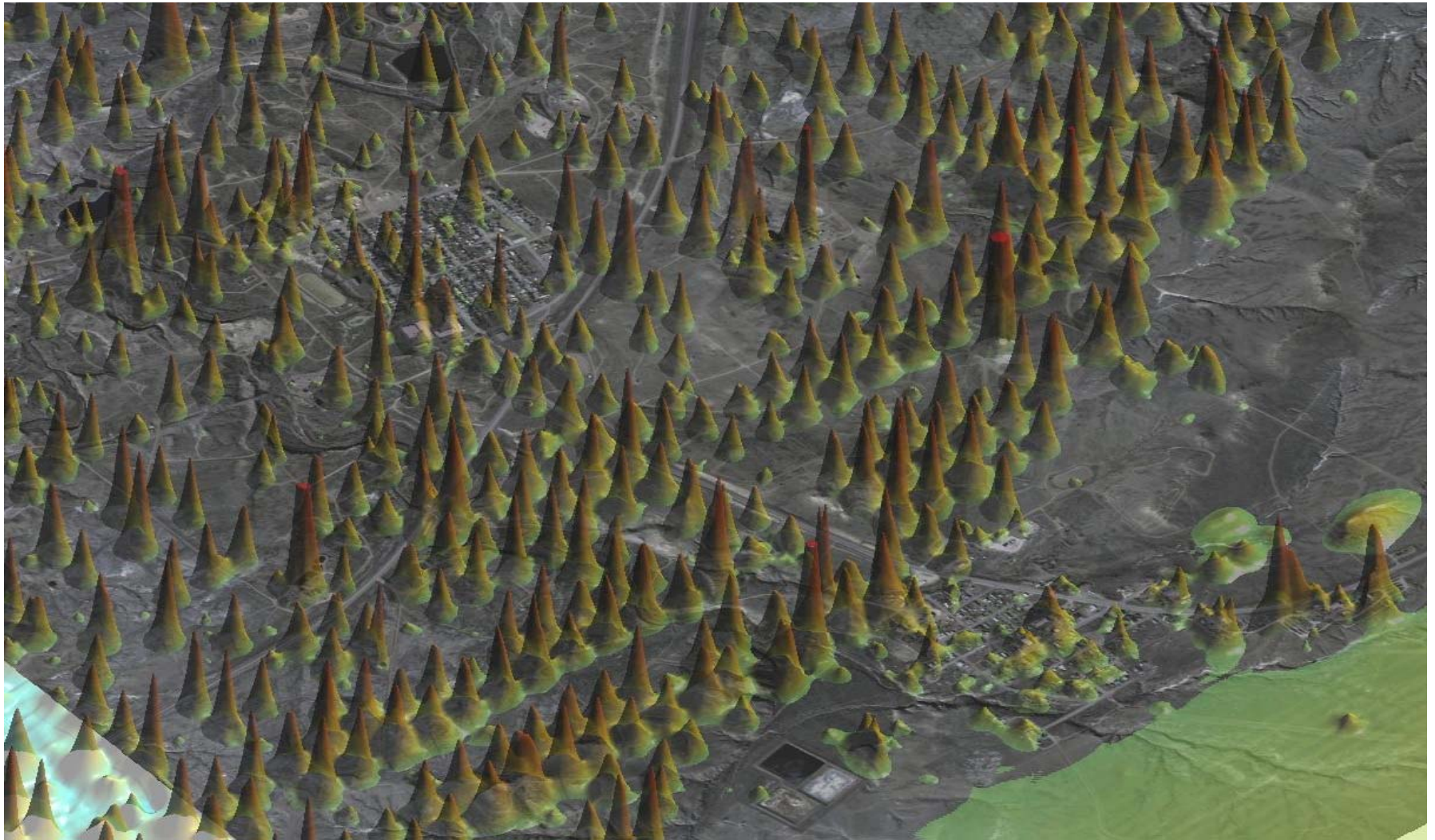


Well Challenges

- Identification of all existing wellbores
 - Extensive record searches, conventional & unconventional. Difficult because of limited or nonexistent records for numerous wells
 - Magnetic surveys, both aerial and ground

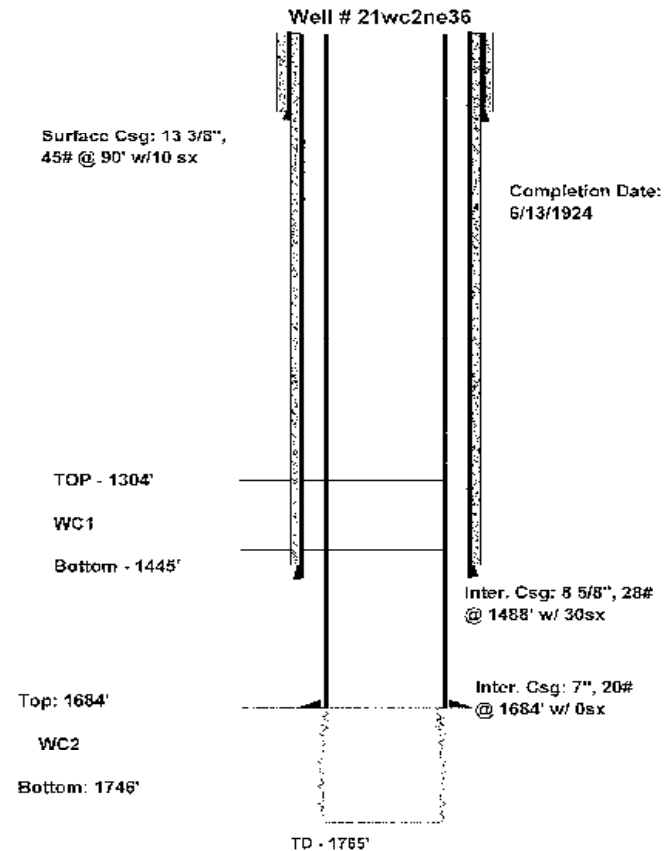


3D Perspective of Magnetic Survey



Well Challenges (cont.)

- Hyper-mature wellbores with minimal to no original cement and questionable wellbore integrity
 - Cement is critical to keep CO₂ contained in target reservoir
 - Significant efforts to quantify cement quality, CBLs, temp logs, tracers, etc.
 - Squeeze cementing is very common
- Effective cement blends
 - Presently Type I/II cement is used.
 - Work in low temps < 105 F
 - Available & economic
 - Low permeability (finer grind)
 - Performs well in acid resistance testing and is rated as sulfate resistant



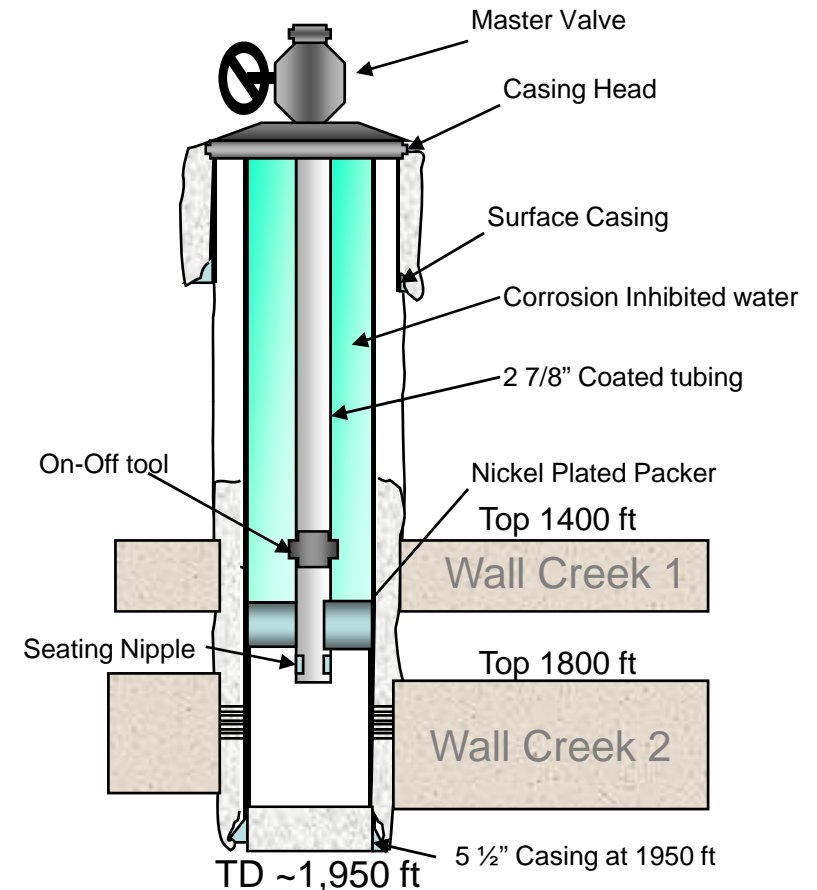
Well Challenges (cont.)

- Effective sealing with high durometer packing/sealing elements
 - High durometer elements unsuitable at Salt Creek, presently 60 - 80 durometer elements are used
- High volume of well work
 - >1200 wells worked over in Phases 1-6
 - 95+% success rate in reactivating plugged wells
- High pore pressure gradients
 - 14 to 18 ppg equivalent



Salt Creek Well Design / Requirements

- Every well is evaluated, make no assumptions of adequacy
- Existing wellbores used when possible – typically extensive work is required
- Zonal isolation required in all wells, including P&A wells
- Basic Well Requirements
 - Pressure integrity within the casing above perforated interval
 - 100' of behind-pipe cement above the WC2 & WC1
- All CO₂/Water injected down tubing - internally lined, coated, or fiberglass
- Nickel plated packers used to mitigate potential corrosive effects, and to aid in isolation
- Injectors and producers are equipped identically



Lessons Learned

- Cement isolation above both the WC1 and WC2 is required to prevent behind pipe fluid movement
 - Properly designed common oilfield cements are effective in carbonic acid solutions
 - CBLs have proven to be effective for evaluation
- Perform well work in advance of CO2 development, all objectives are more attainable in a lower pressure environment
- All wells drill to the WC1 or deeper will be evaluated and worked on as necessary, this includes making sure that all inactive wells are plugged properly. If records are uncertain, rig up and confirm the status of the wellbore. This will mitigate potential wellbore integrity issues
- Casing will be pressure tested. Pressure requirements will vary as individual well reliability requirements increase. This will mitigate potential wellbore integrity issues
- All packers will utilize sealing elements rated no higher than 80 durometer to allow for a better packer seal within the wellbore
- Wellheads will utilize a tubing hanger equipped to handle a back pressure valve, and will be flange connected to the master valve. This expedites well control and improves safety
- Step-rate tests will be performed and are critical for optimizing injection rates and pressures
- Remedial cement work is the most effective way to correct most wellbore integrity problems
- Slimhole completions using fiberglass tubing/casing is a viable option on both existing older wells and newly drilled wells. Fiberglass pipe will be cemented to surface.

Lessons Learned (cont.)

- Well problems can occur. At the first indication of a problem be prepared to utilize one, or more, of the following diagnostic tools:
 - Injector / producer pattern reviews (High level check)
 - Reservoir pressure evaluation
 - Injection-Withdrawal ratios/Pattern balancing
 - Temperature logging (Joule-Thompson effect)
 - Common and useful in identifying both internal and external wellbore problems
 - Fiber Optic Cable can be run in some cases, allowing for fully distributed temperature logs
 - Radioactive tracer logging. Can be performed with both gas and liquid transported tracer material
 - Can also identify internal and external wellbore problems
 - Gas tracer material can be run with CO₂
 - Other technologies
 - Noise logs
 - Seismic
 - Interwell Tracers

Other Challenges

- Continued Waterflood Operations concurrent with CO₂ Development & Ops
- Significant project activity beyond Second Wall Creek Development
- Challenging Regulatory Environment
 - Environment Assessments
 - Wildlife Stipulations
 - Oversight by both State & Federal Agencies
 - Long permit lead times
 - Changing regulatory requirements



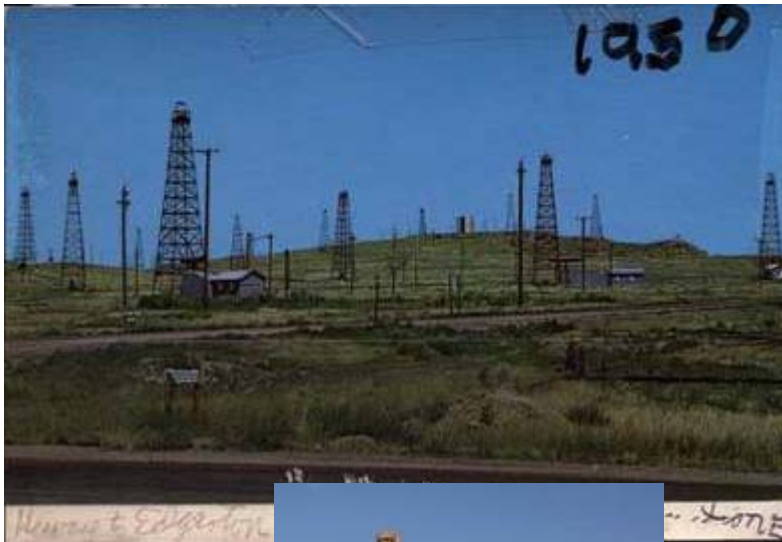
Non-Typical Benefits

- Salt Creek development viewed positively by State and Federal Agencies
 - Vintage plugged and abandoned wells are re-plugged to modern standards, reducing liability
 - Improving viewshed & more aggressive field reclamation
 - New flowlines reduce leak frequency, minimizing spills
 - CO₂ sequestration
- Salt Creek's brownfield development assists the regulatory agencies in meeting their stated multiple use objective, while minimizing new disturbance



Questions ??

The past ...



Today and beyond ...

