Horizontal Well Technology Applications for Improved Reservoir Depletion, Kern River Oil Field*

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Abstract

Estimated to have over 3.5 billion barrels of original oil in place, the 114 year old Kern River Oil Field was a sleeping giant until the late 1960's when steam flooding began and oil production ramped up from 19,000 to over 142,000 BOPD by the mid 1980's. In 2007 the cumulative production reached two billion barrels of heavy oil. With the introduction of horizontal wells in 2007 the production decline curve that had been at approximately 6% began to flatten and today the decline rate is at 1 to 2%. Current production from the field is about 70,000 BOPD. Since the discovery of the field, over 20,000 wells have been drilled with the largest producers, horizontal wells, drilled in the last 6 years.

The reservoir consists of amalgamated braided stream channels with the top of the reservoir encountered 50 to 1000 feet below the surface. Porosities range between 29-33% and permeability is 1-8 Darcies. Nine producing zones are recognized in the stratigraphic column with additional stratigraphic complexity introduced by the braided stream depositional setting. Average oil gravity is 13 degree API and average viscosity is 4,000 centipoise at initial reservoir temperature.

The primary tool utilized for development of the field is 3-D earth modeling to integrate the large volume of well data with reservoir temperature and saturation over time. The full field 3-D reservoir model (FFM) was built using over 12,000 open hole logs for lithologic data and incorporating the most recent saturation information from C/O logs, resulting in a 155 million cell model resolved into 50 ft x 50 ft x 2 ft cells.

An example of recent application of the surveillance data and FFM to improve oil recovery is demonstrated in the drilling of horizontal wells into heated areas of the reservoir. Wells are targeted where the oil recovery predicted by decline curve analysis is substantially less than the volumetrically calculated recovery using the FFM. Since 2007, over 400 horizontal wells have been drilled to improve recovery of remaining oil, adding over 17,000 BOPD of new production. The wells target zones below 400 feet TVD and typically have laterals of approximately 1600 feet. Initial production rates from the horizontal producers are several times greater than offset vertical producers. Substantial additional

development opportunities also exist for application of shallow horizontal drilling, which is an area of current technology focus for the development team.

Horizontal Well Technology Application for Improved Reservoir Depletion, Kern River Field

Chevron

Human Energy®

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AAPG Annual Convention & Exhibition
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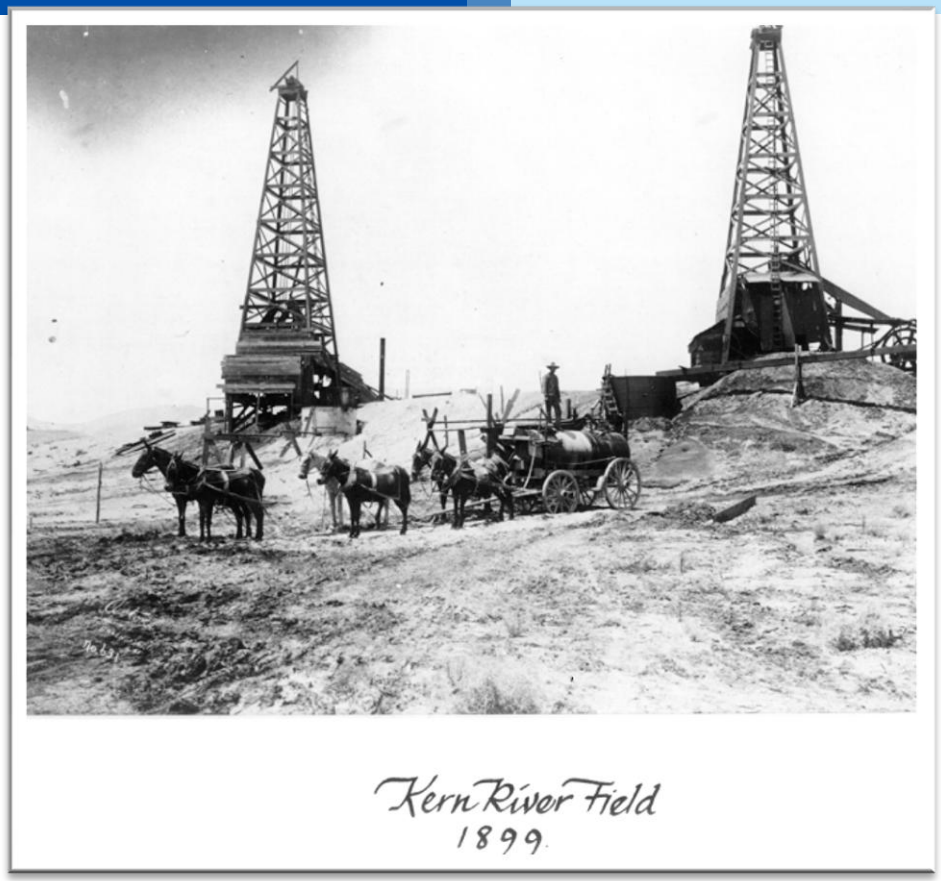
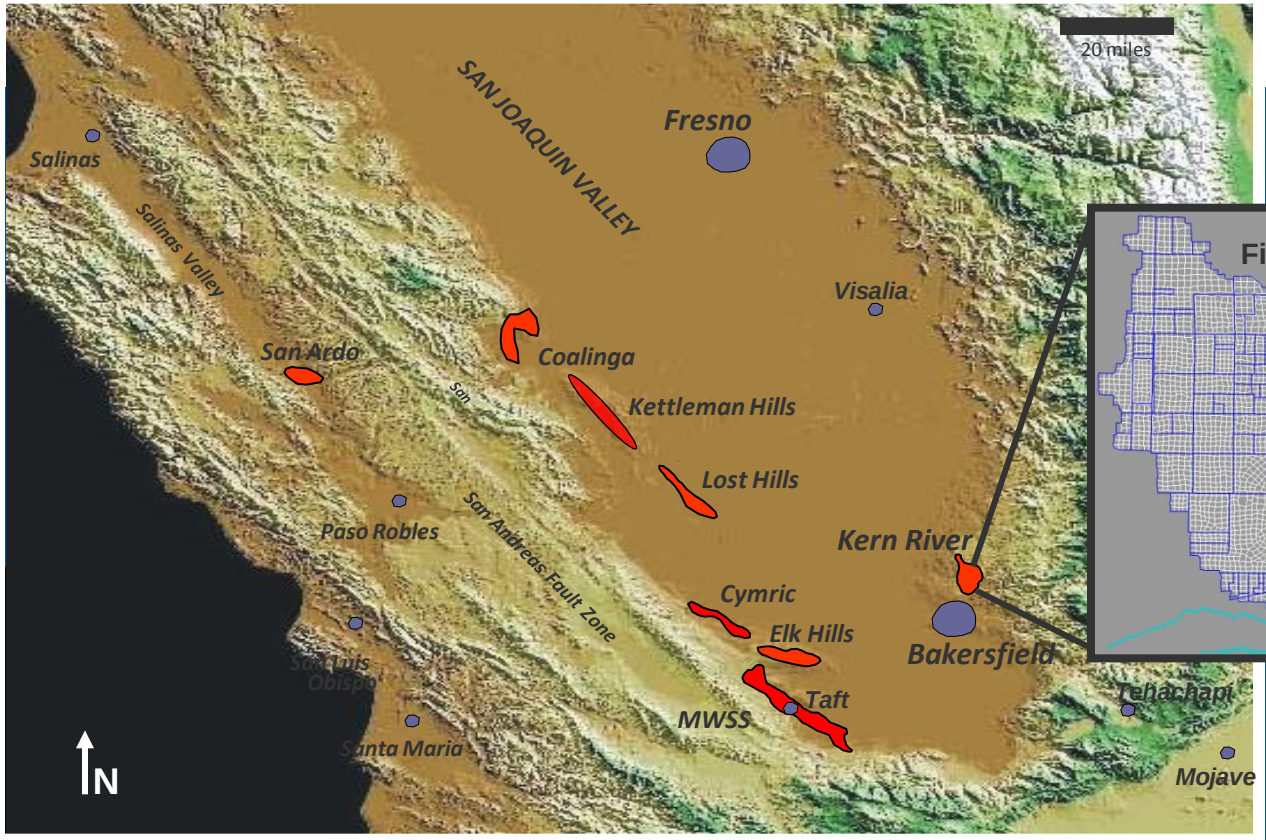


Presentation Outline

- Overview of Kern River Field
  - Kern River horizontal well project summary
  - Depositional Facies & Stratigraphic Architectures
- Horizontal target selection process
- The future of horizontal wells
  - Shallow horizontal wells
  - Cold horizontal expansion projects

Location of Kern River Field



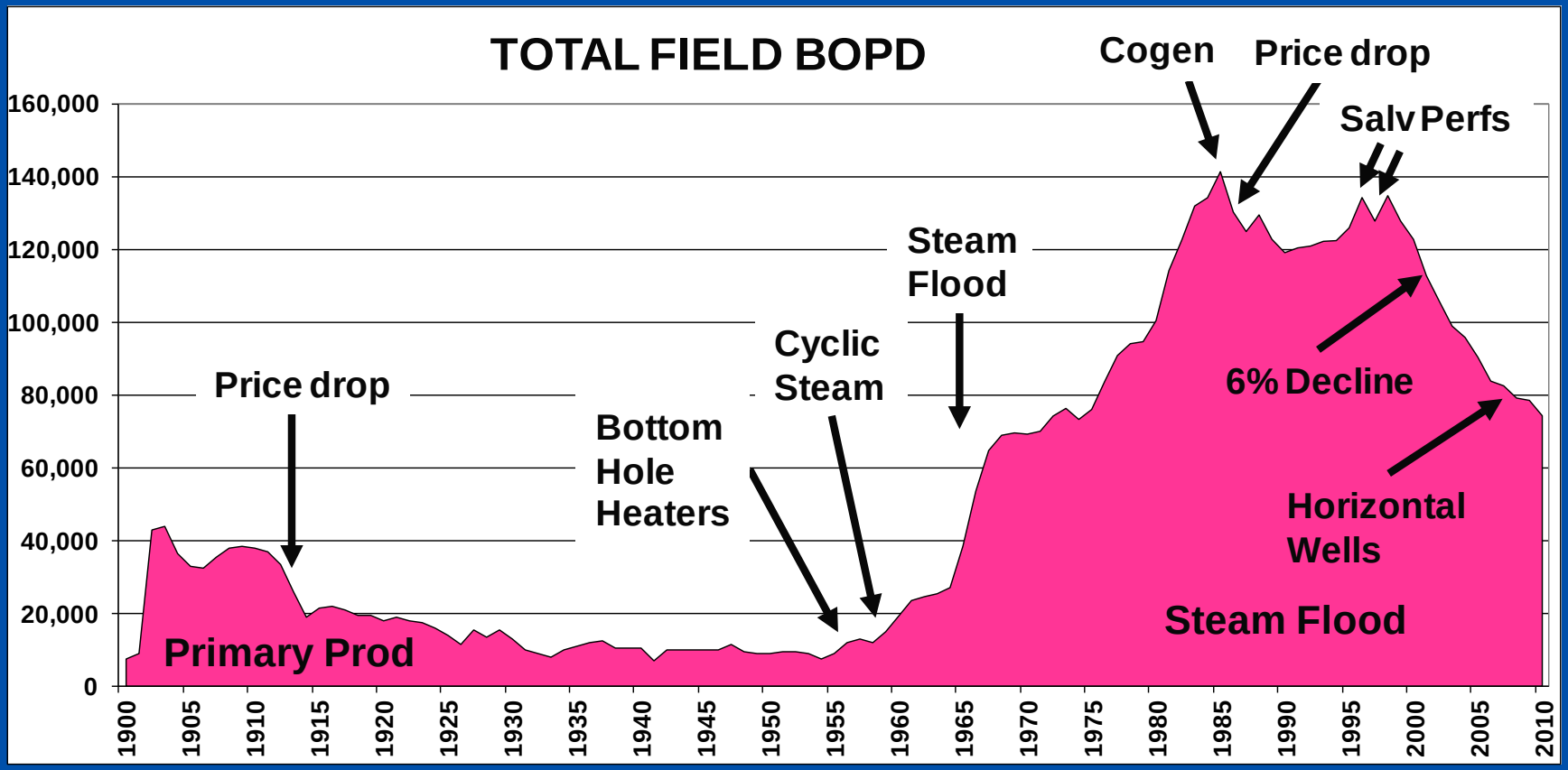
Chevron-interest Fields

Located in the San Joaquin Valley near Bakersfield, California

Kern River Reservoir Properties

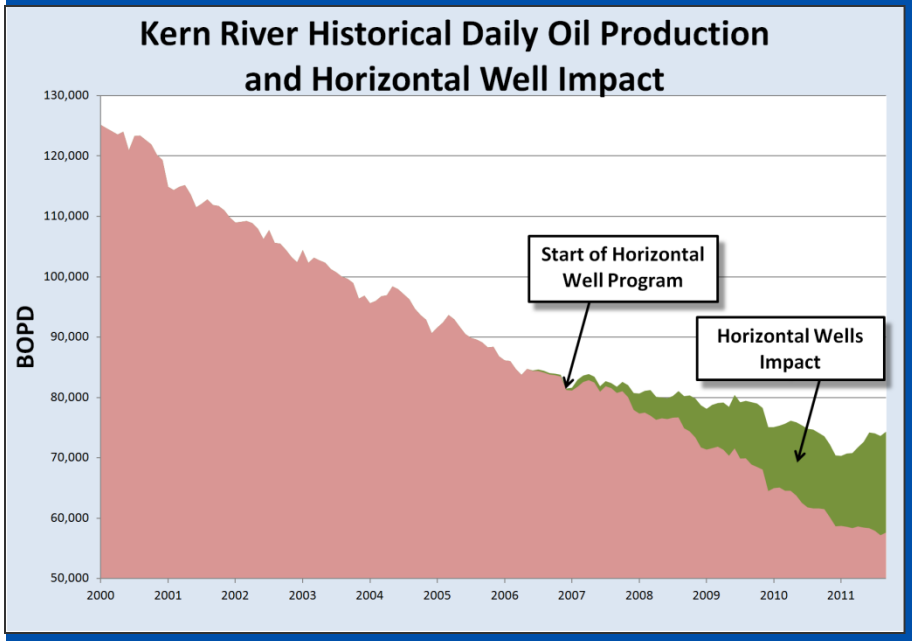
- **Formation:** Kern River Formation – Upper Miocene
- **Lithology:** Sandstone/Braided Stream
- **Recovery Method:** Steam Assisted Gravity Drainage
- **Avg Net to Gross:** 76%
- **Avg Porosity:** 31%
- **Avg Permeability:** 2,000 mD
- **OOIP:** > 3.5 Billion BO
- **Cum production:** > 2.2 Billion BO
- **Current production rate:** ~70,000 BOPD
- **Well count**: > 18,000 drilled (~9,200 currently on production)

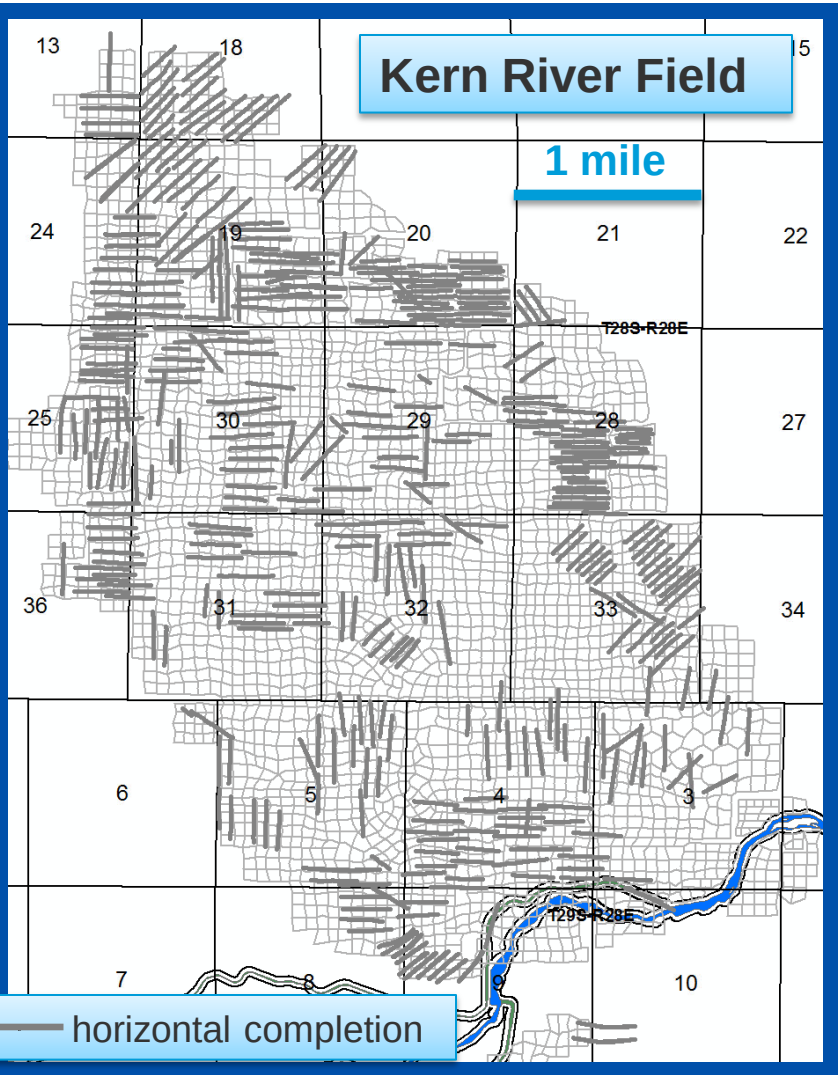
Production History, 1899 to Present



Impact of Horizontal Wells in Kern River Field

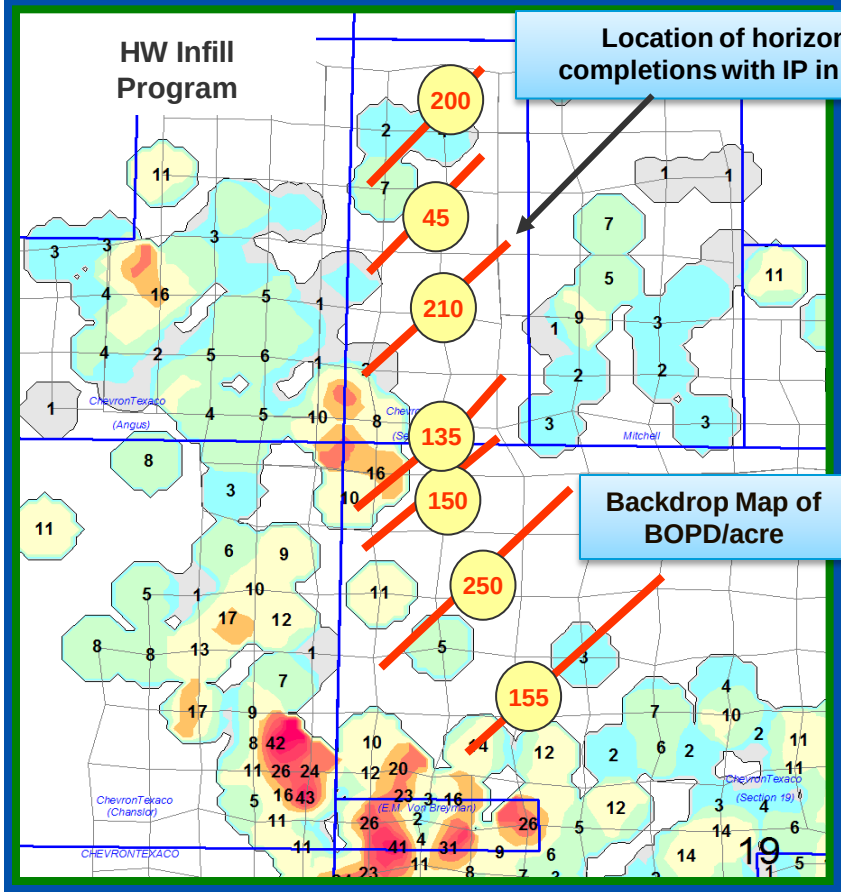
4% of the producing wells are horizontal but they account for 24% of the production.

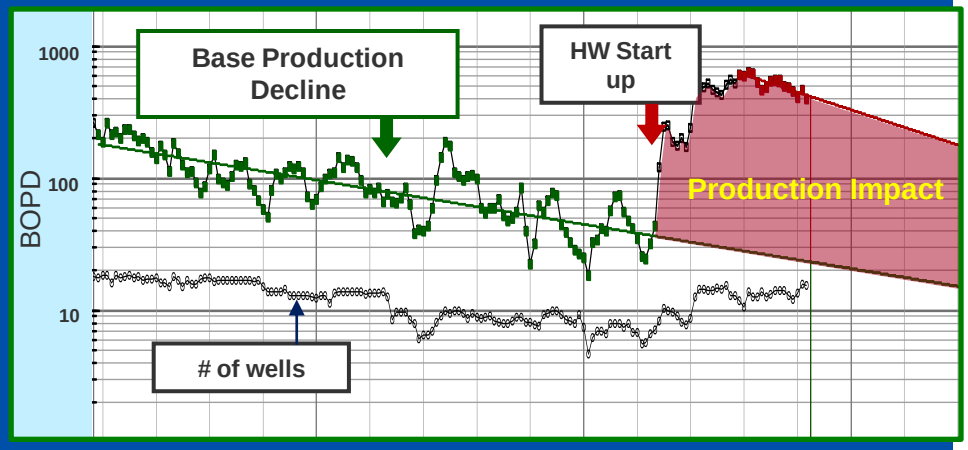




Impact of Horizontal Wells

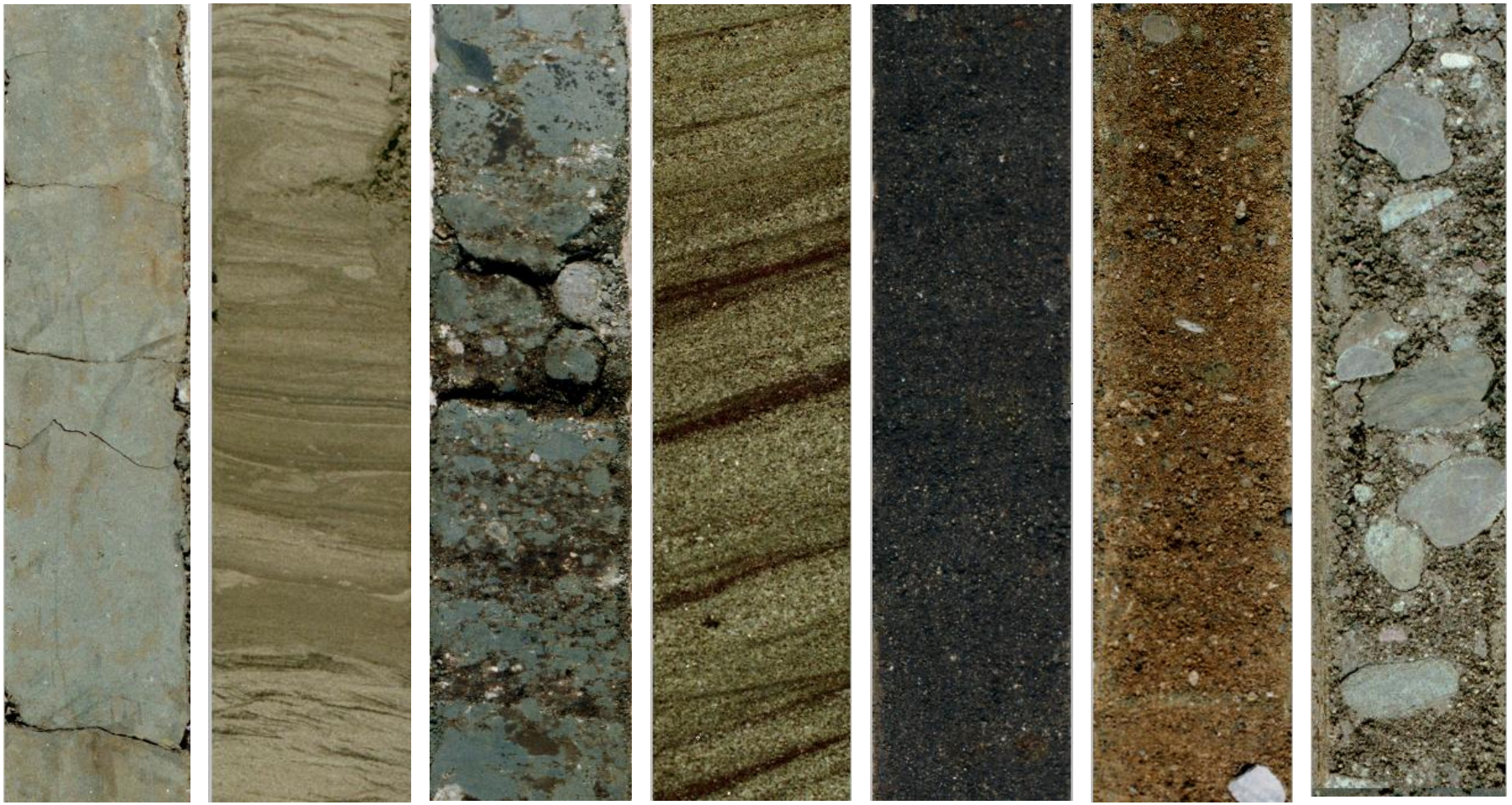
In areas where vertical wells typically produce less than 10 BOPD, a horizontal well can produce over 100 BOPD



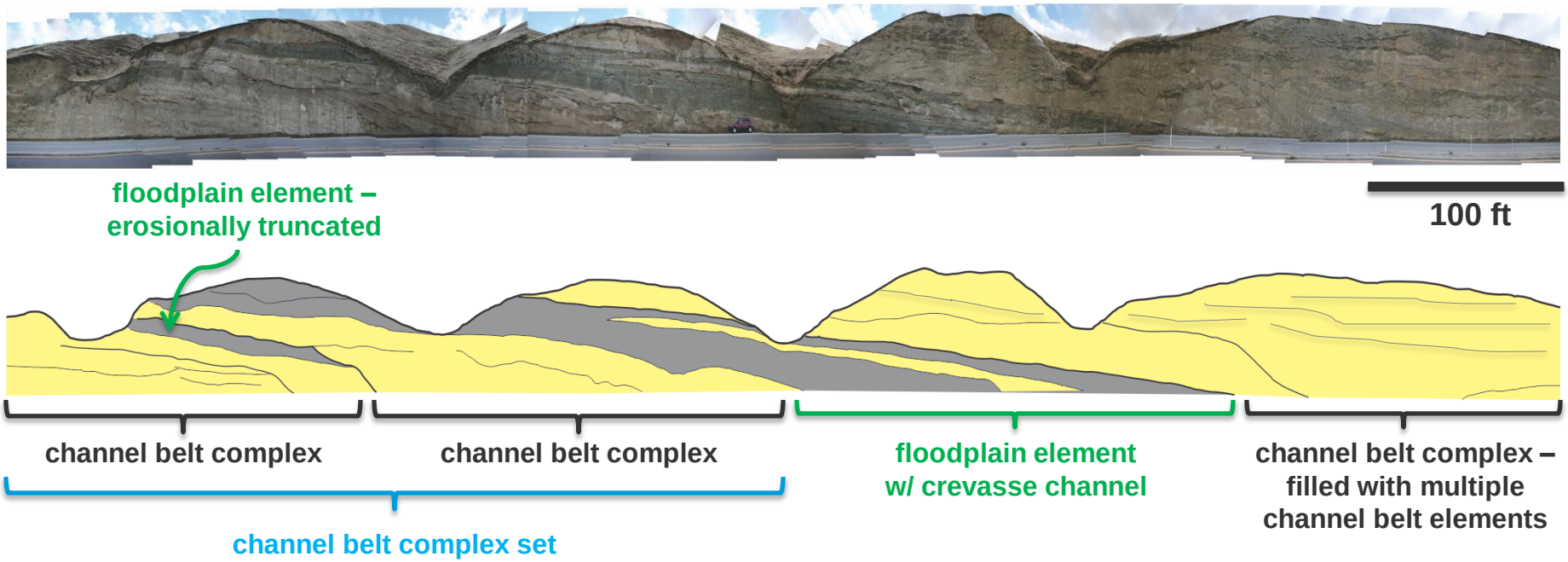


Since 2007 Chevron has drilled over 439 horizontal wells that currently add over 16,000 BOPD, improve recovery, and flatten the decline rate.

Depositional Facies – Fluvial Sediments

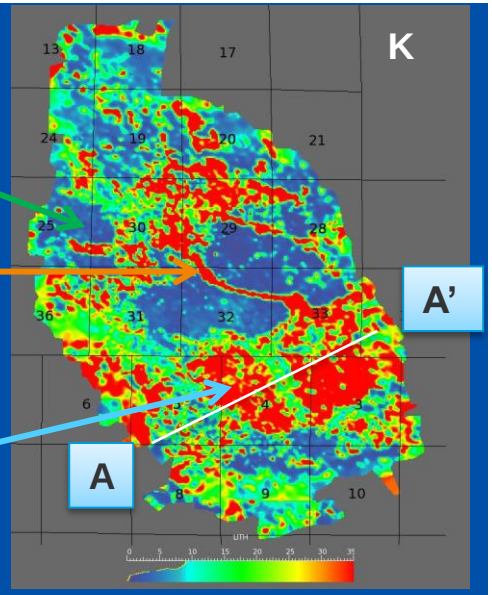


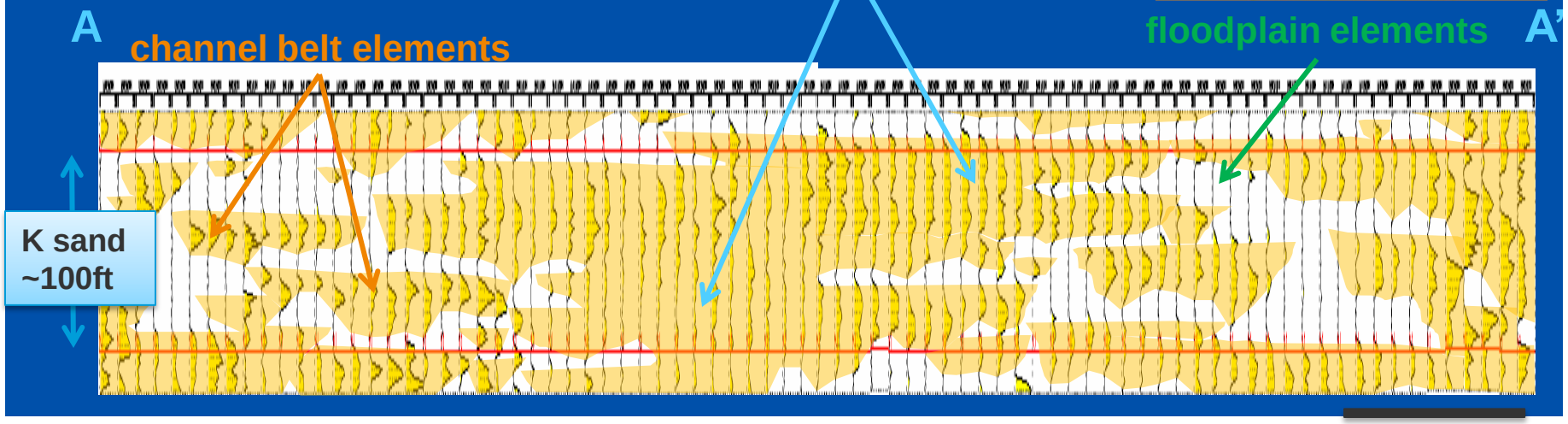
Kern River Outcrop – Aiding in Stratigraphic Interpretation (no analogue necessary!)



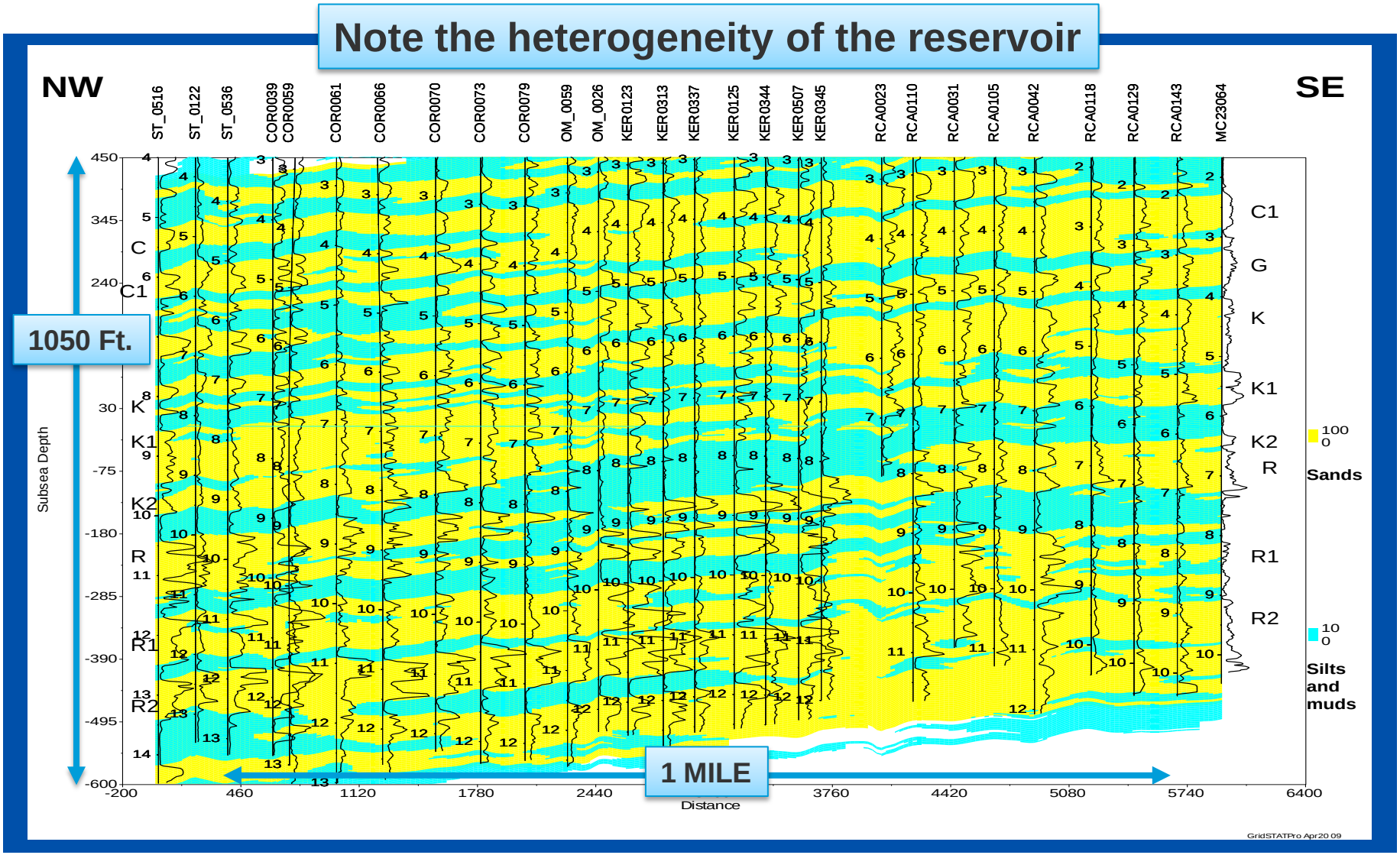
Large Scale Stratigraphic Architecture

- Large scale architectures observed at outcrop are observed in well logs.
  - Magnitudes of erosional relief observed at outcrop can be used as a guide in correlation of units.





Kern River Reservoir Architecture



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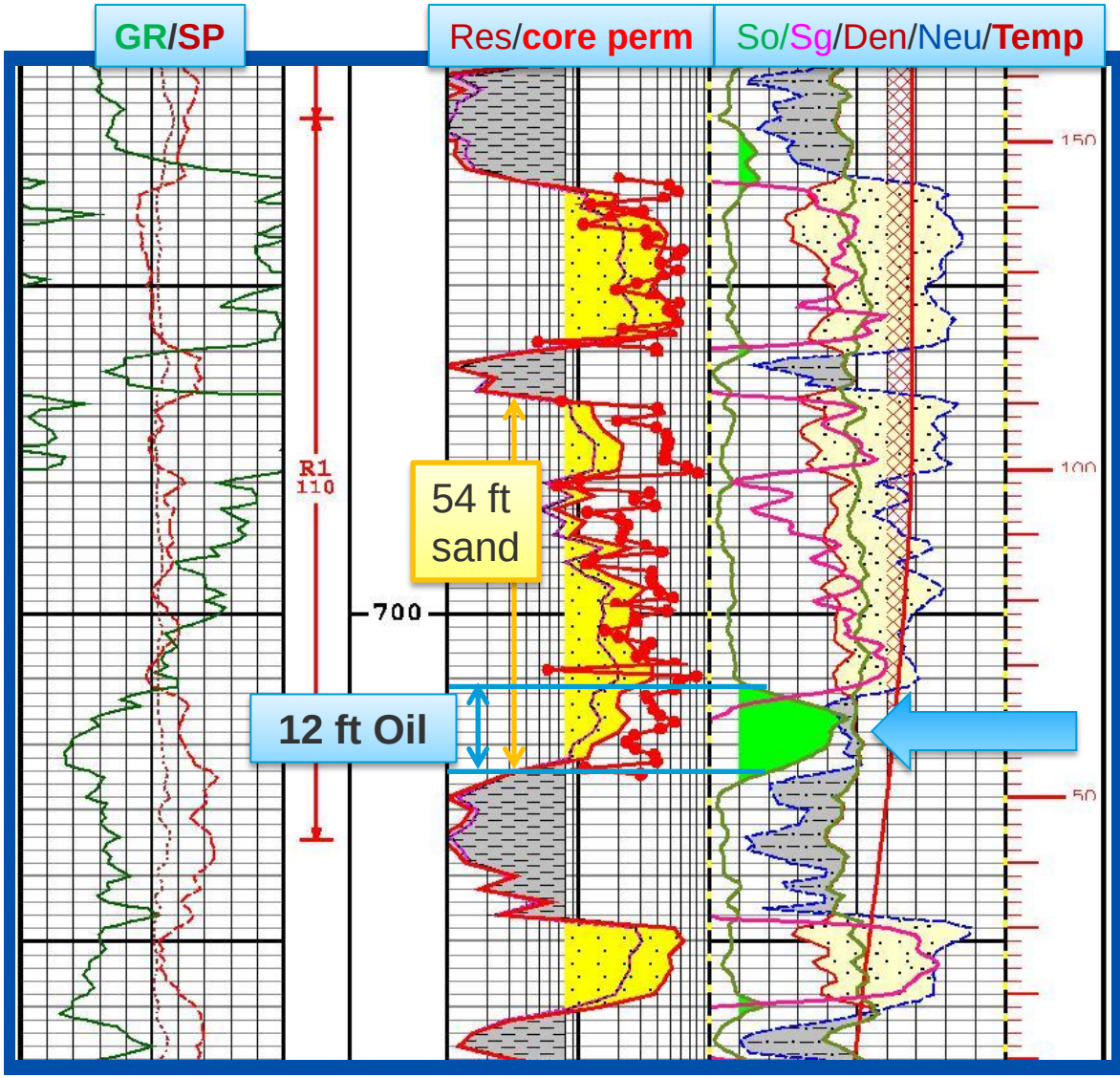
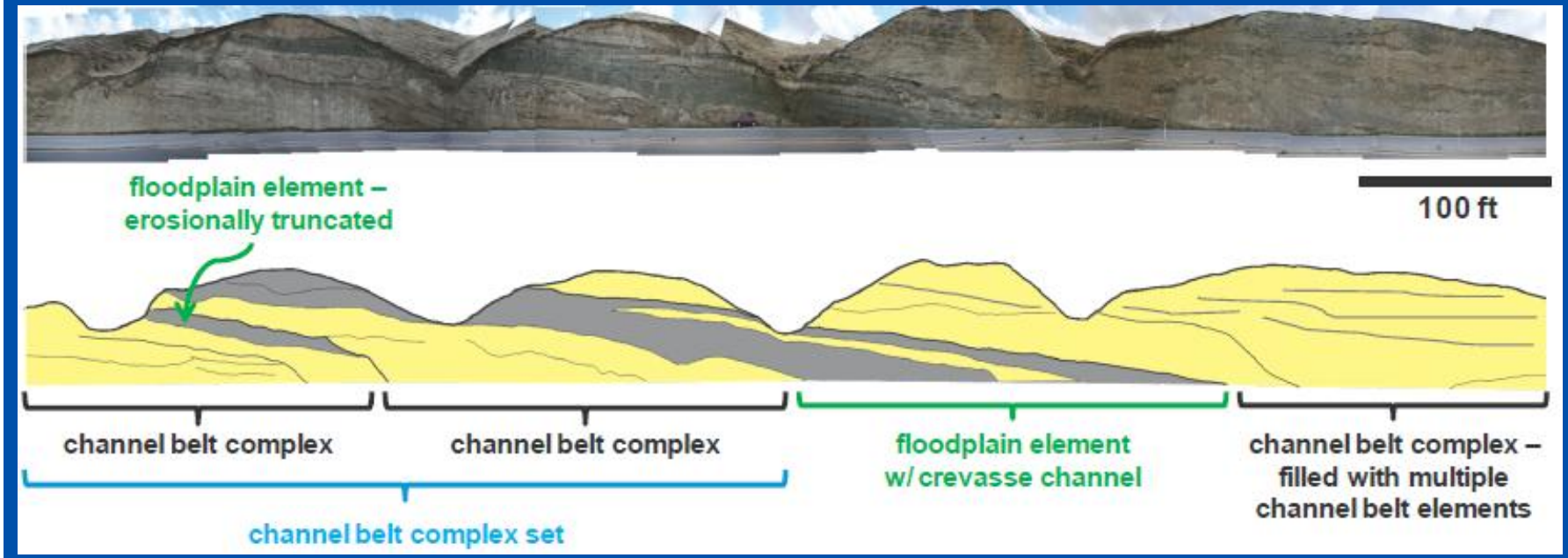
Horizontal Candidate Development



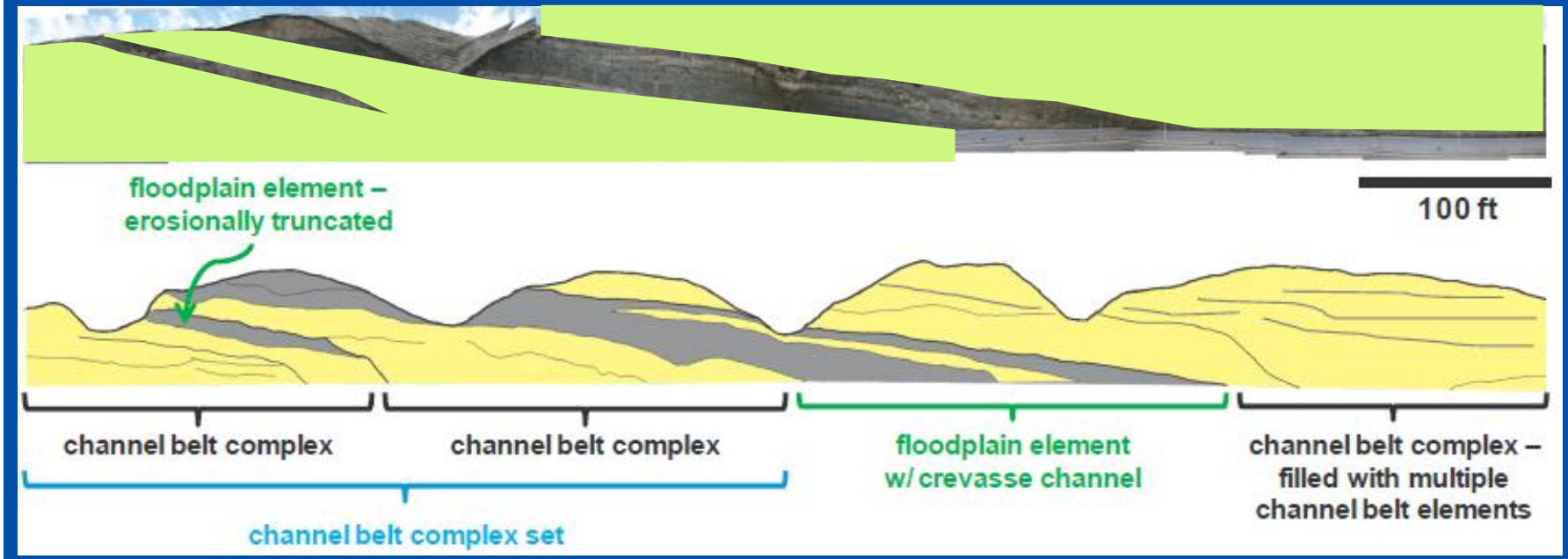
We target the thin layer of oil remaining at the base of a good quality hot sand

- Very Mature Steamflood
- Historically good drainage
- High resistivity
- High temperature
- Minimum oil saturation
- Targetable thickness of fluid filled sand

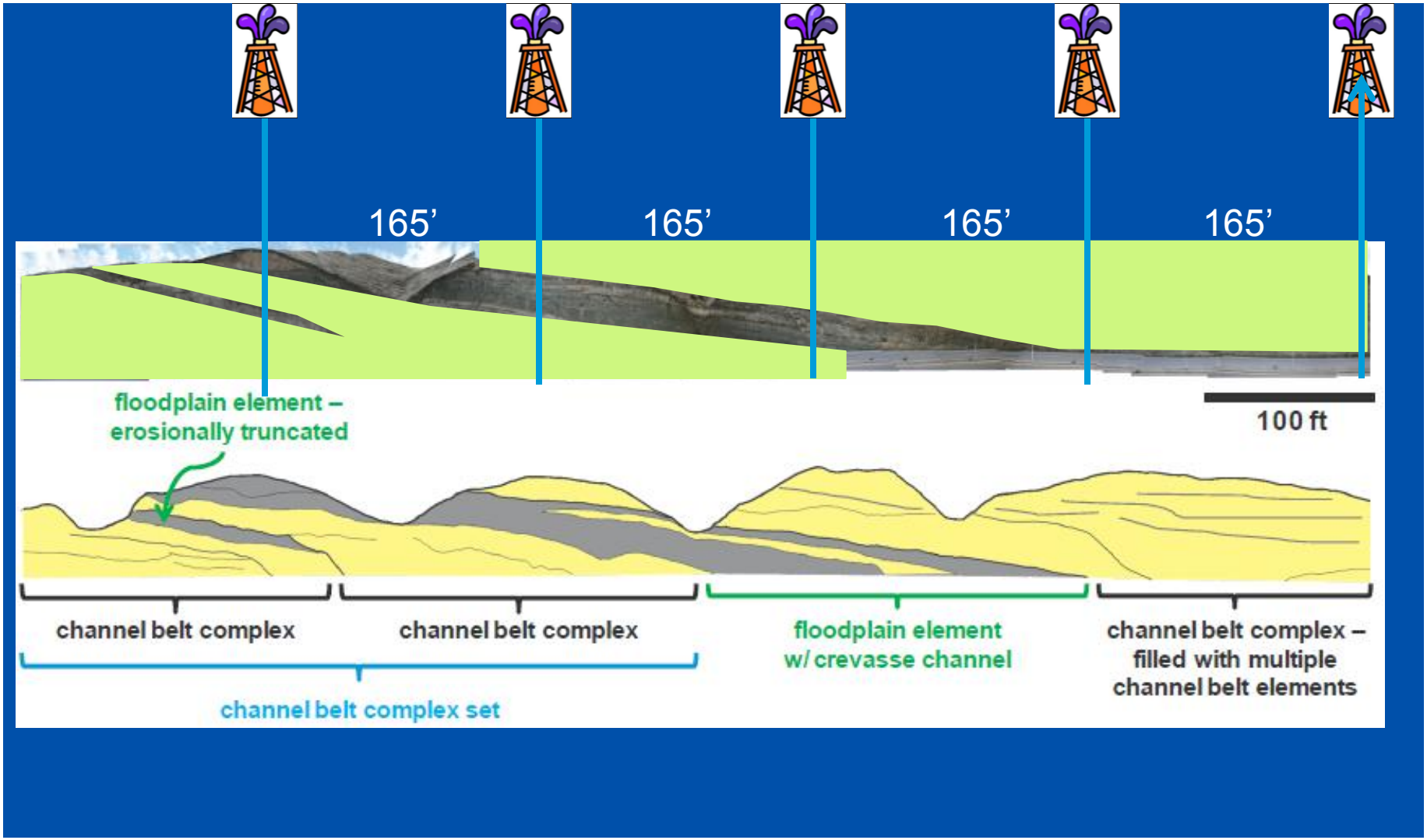
Kern River Outcrop



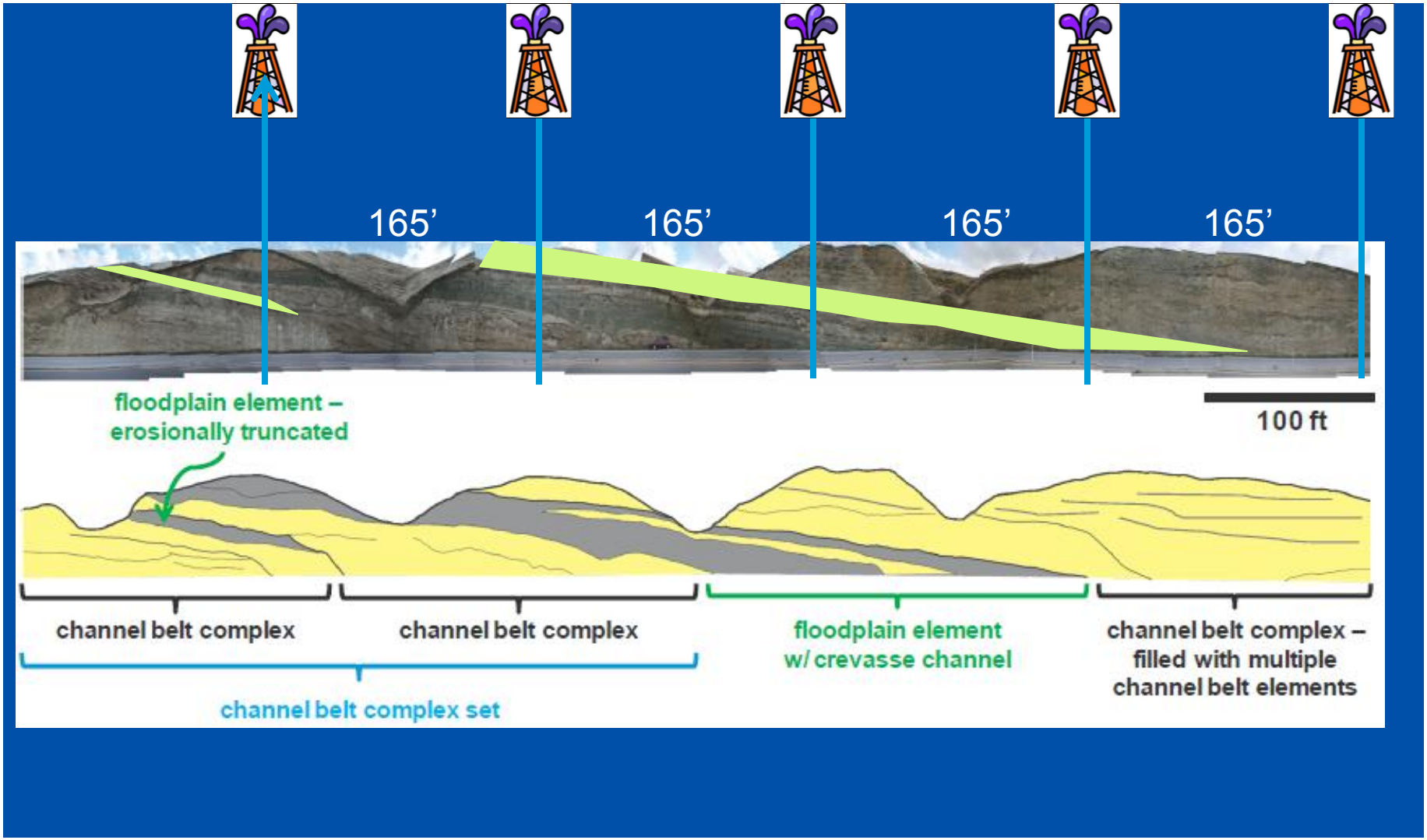
Original Oil in Place



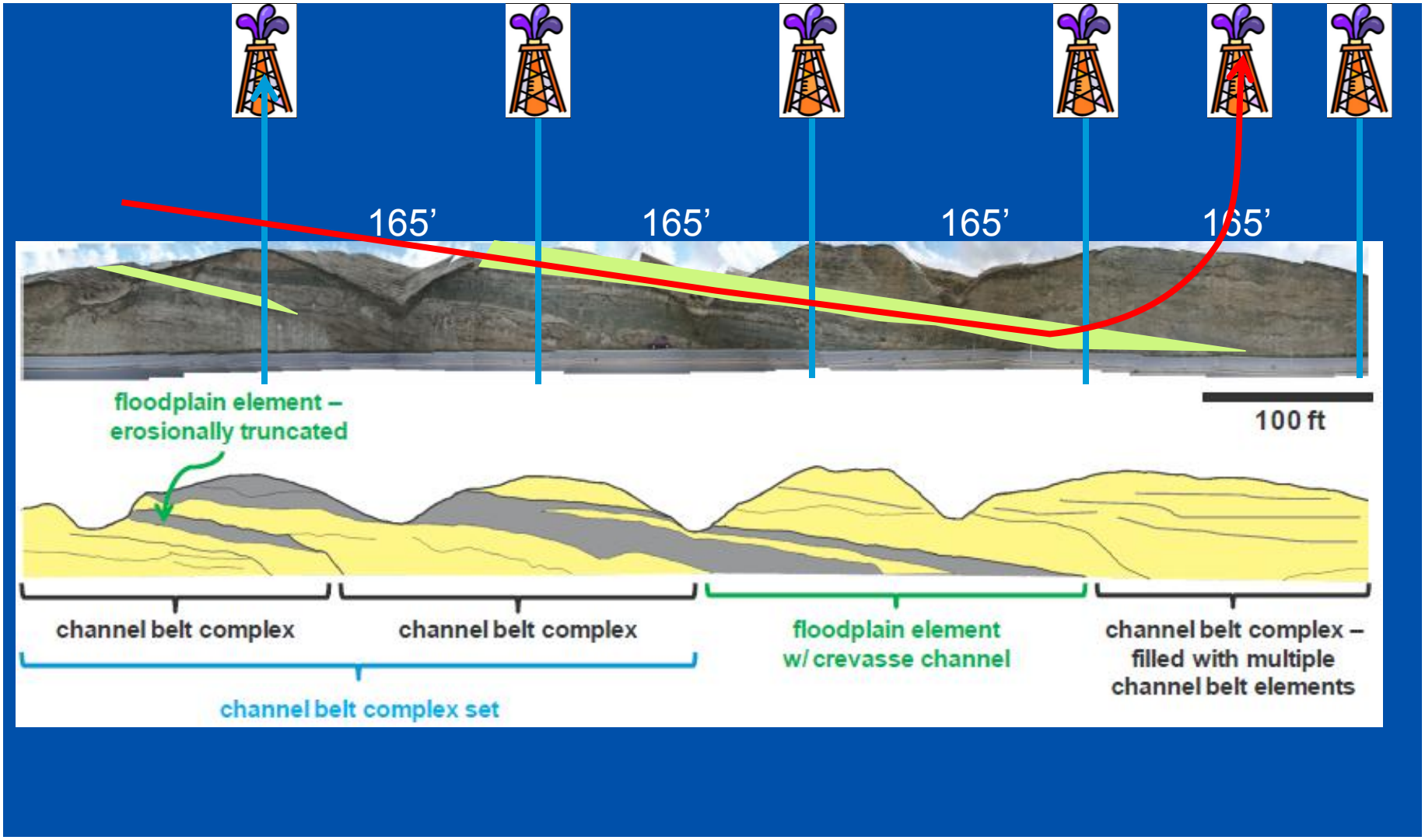
Original Oil in Place – Vertical Well Development



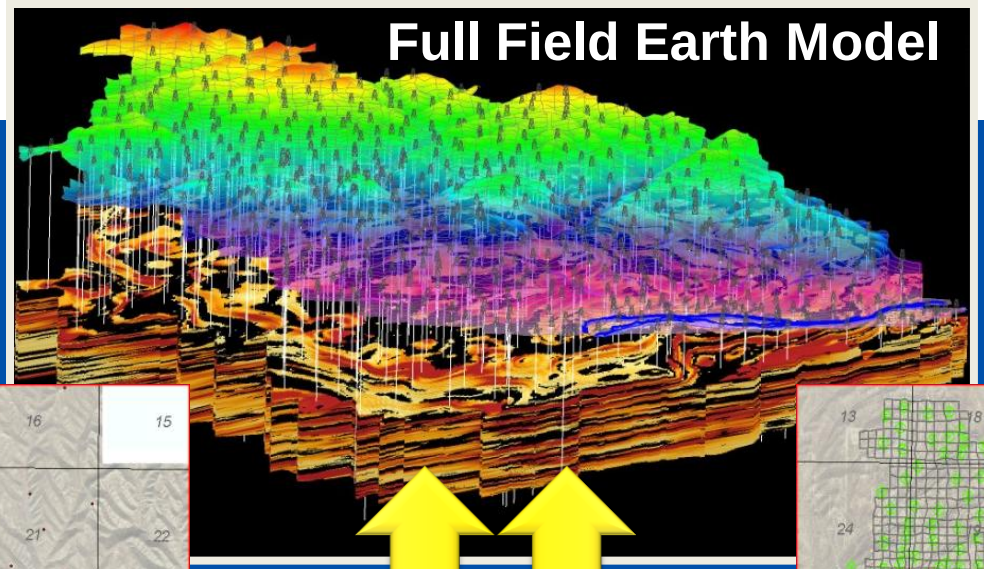
Only a thin layer of oil remains after decades of production – vertical wells produce 0 to 10 BOPD



A well placed horizontal well can produce > 100 BOPD

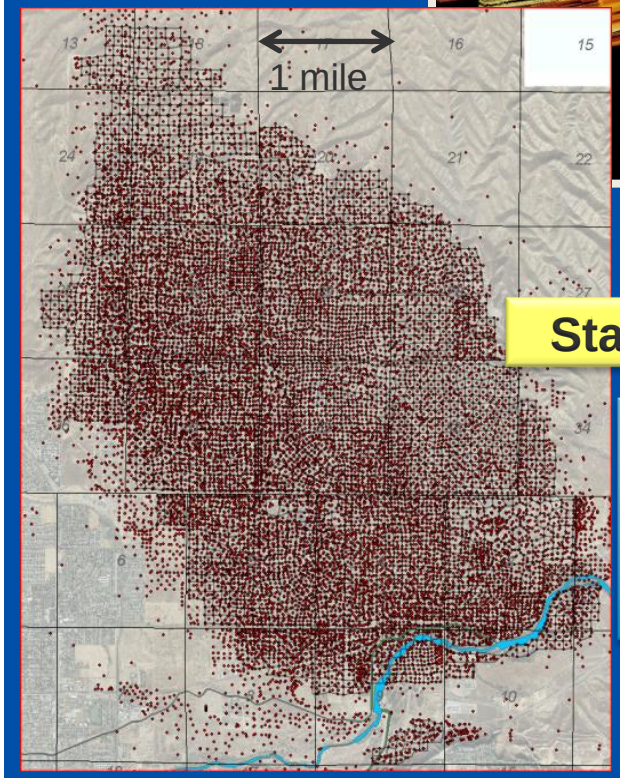


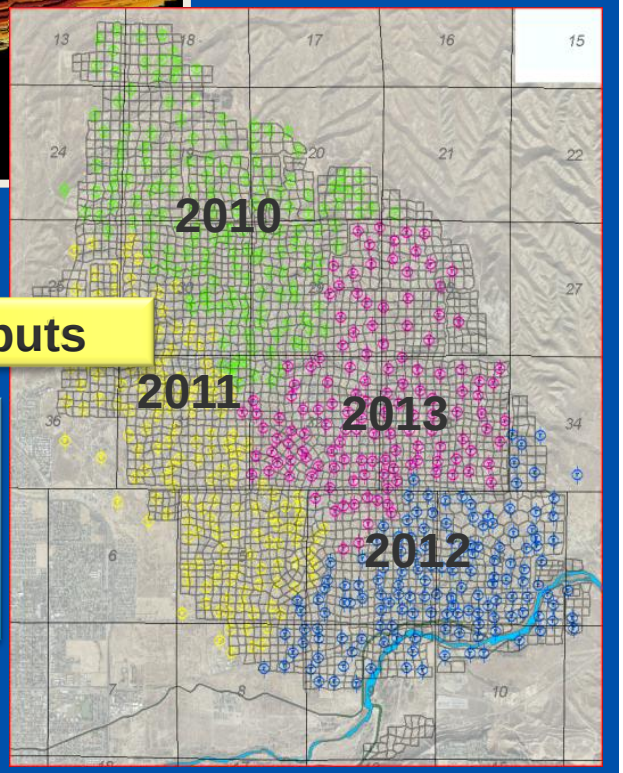
Static and Temporal Data Distribution – 4D Modeling



More than 12,000 wells are used to create the full field geologic model

About 700 observation wells provide current saturation and temperature data



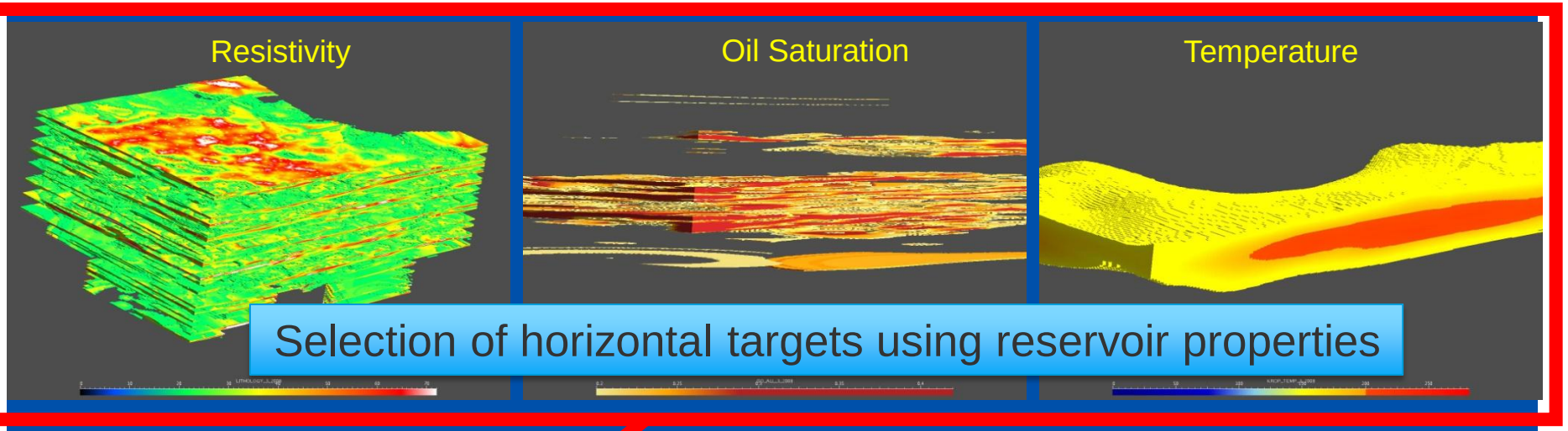


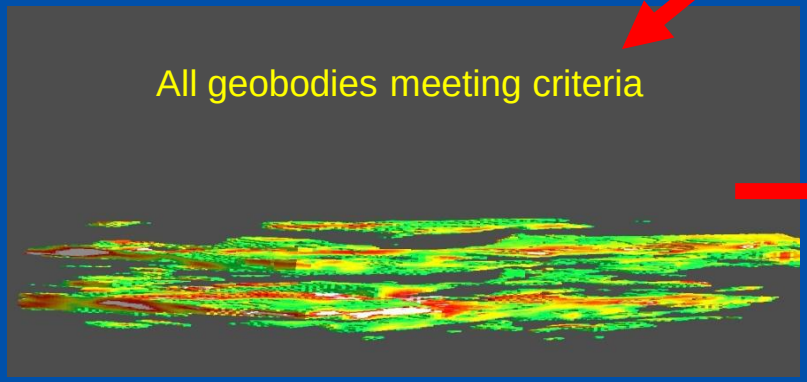
Static inputs

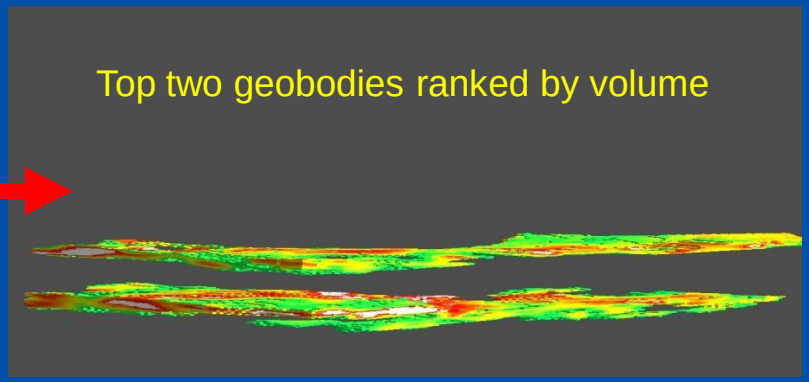
Fluid inputs

Full-field earth model with 155 million cells 50’x50’x2’

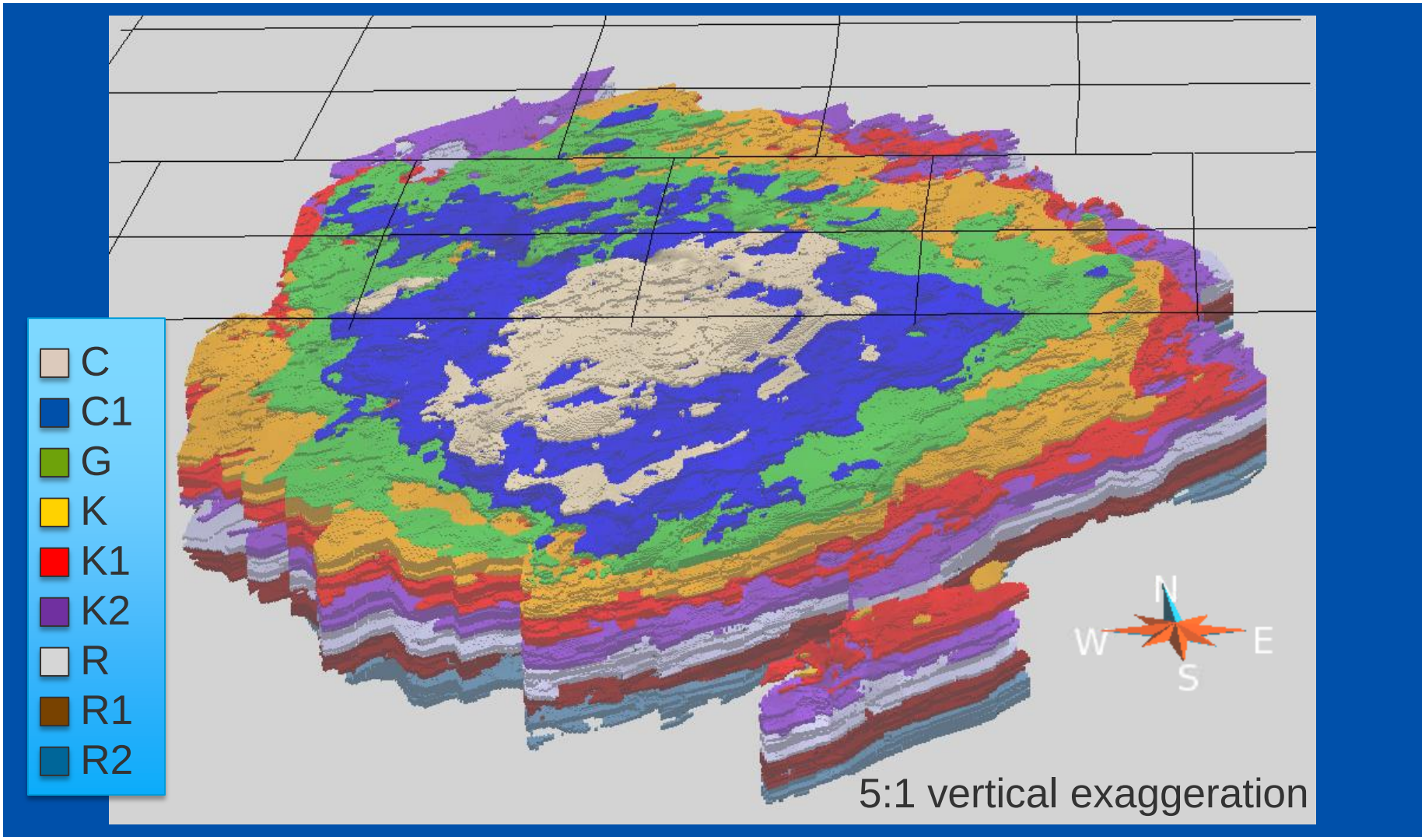
Horizontal Target Selection Process Using the Full Field Earth Model





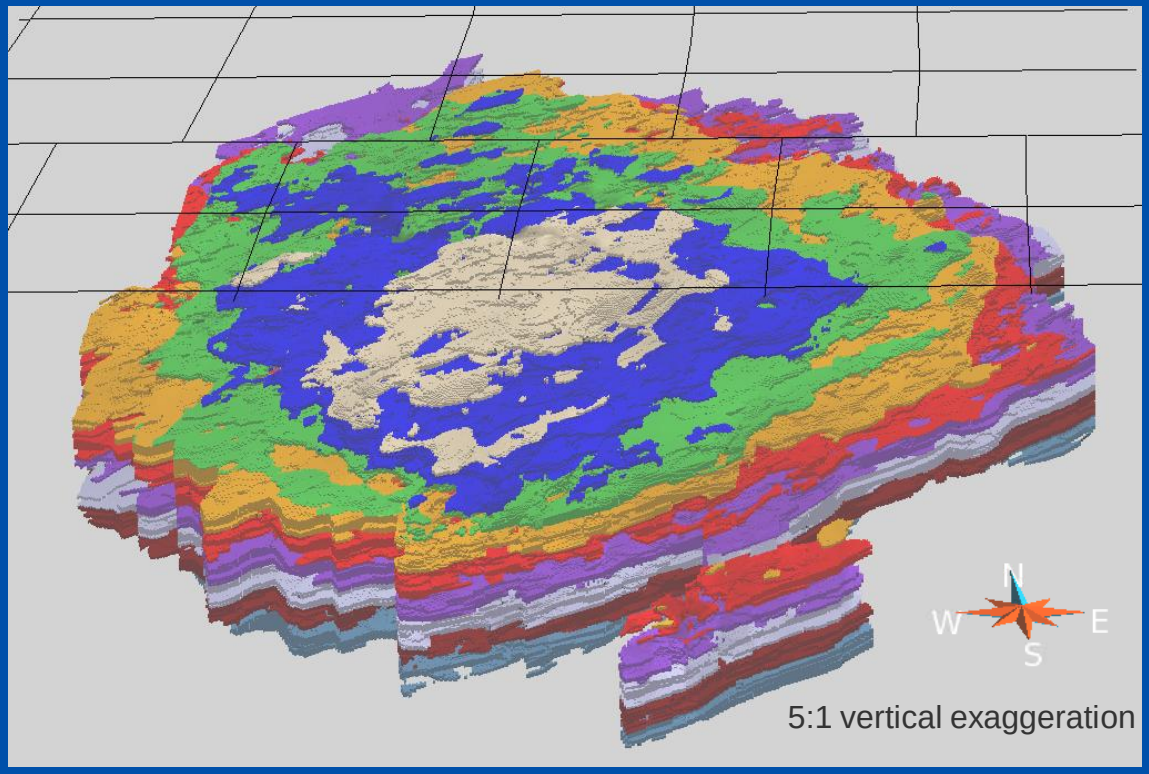


3D View of Remaining Oil in Kern River Field



Conventional Horizontal Well Opportunity

- 439 horizontal wells drilled
  - Currently drilling 120 horizontal wells per year
  - One new horizontal well every three days



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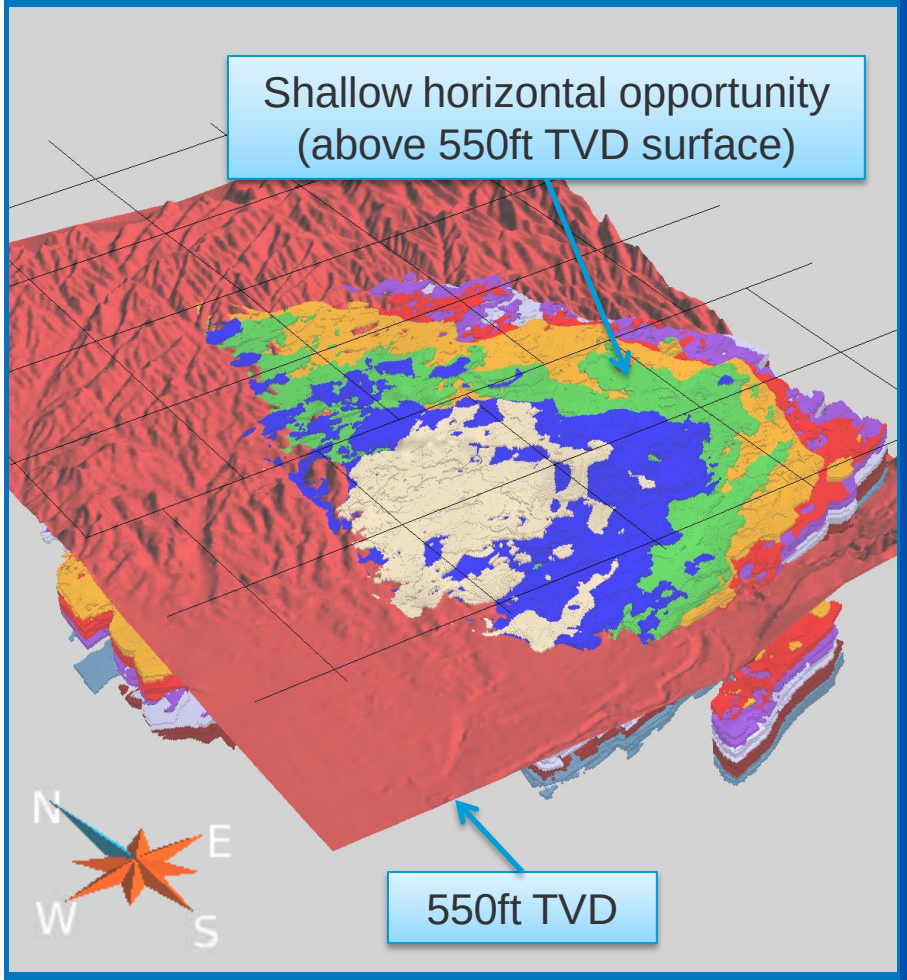
Kern River Future Horizontal well Plan

- Shallow horizontal wells targeting between 300 and 550 feet TVD
  - Two pilot projects demonstrated the ability to drill horizontal wells into targets as shallow as 350 feet TVD
- Thin and Cold Edge of Field Potential
  - Testing new development strategy for currently uneconomic cold oil along the fringe of the field
  - Oil sands are too thin for a normal vertical well thermal expansion project
  - Strategy:
    - Vertical injectors and horizontal producers
      - Two projects completed and under evaluation
    - Horizontal injectors and/or horizontal producers
      - Pilot project in planning stage

Shallow Horizontal Well Opportunity

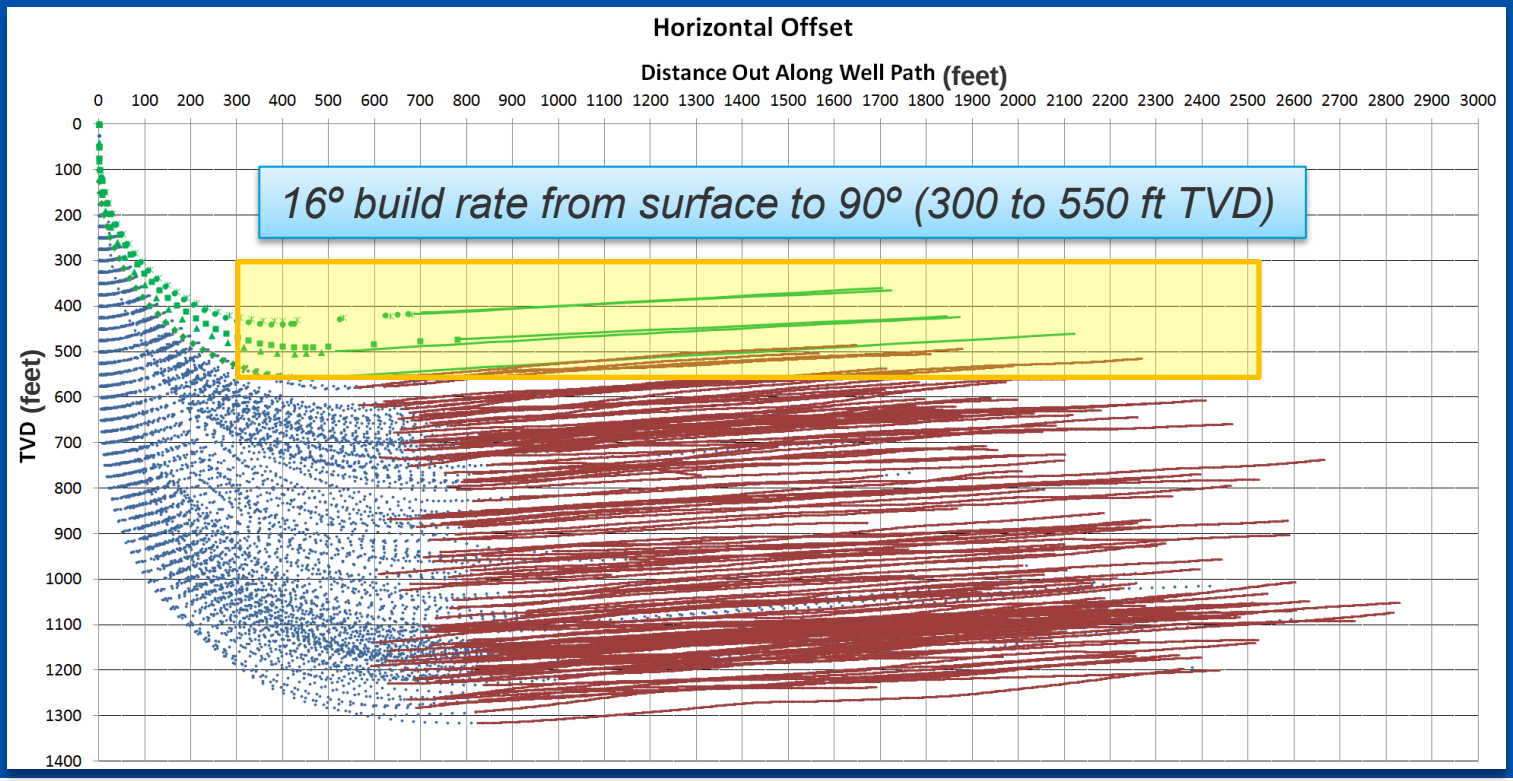


Shallow Horizontal Well Opportunity

- Thermally mature sands
- Eastern up-dip area
- Targeting same type of sands as conventional horizontals
  - 300 to 550 feet TVD

Shallow Horizontal Well Opportunity

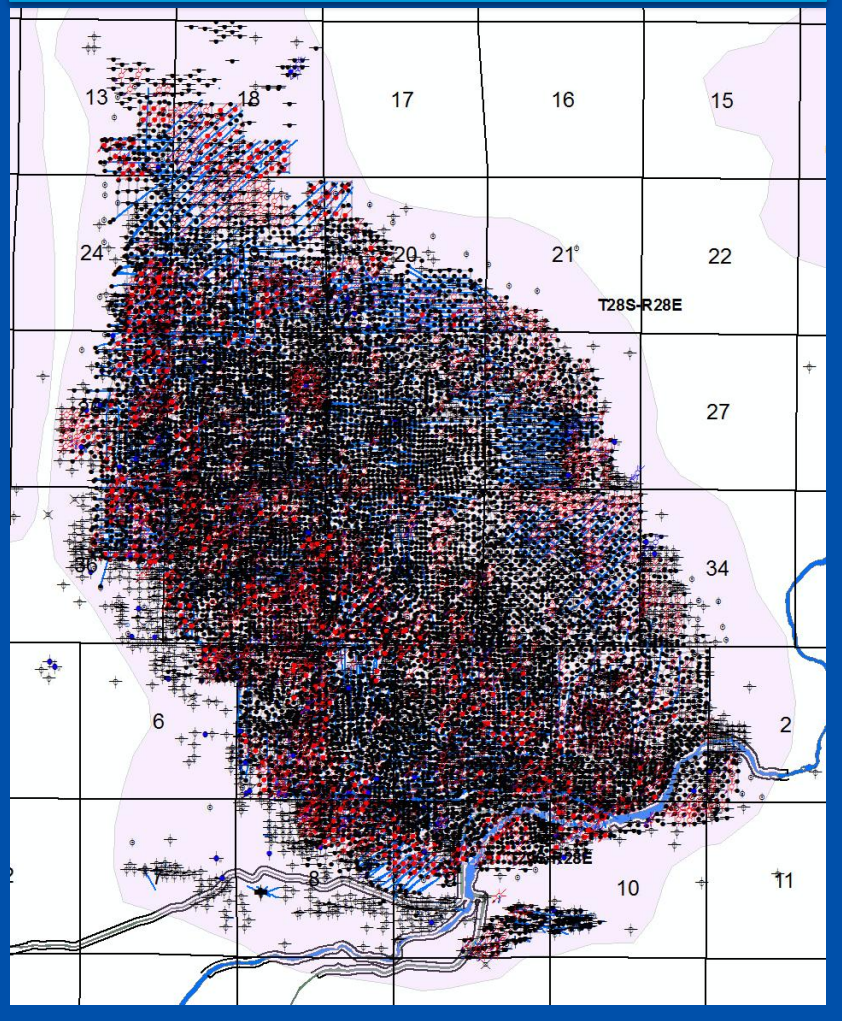
- 10 wells drilled to date with encouraging results
- Achieved record Extended Reach Drilling ratios for Chevron SJVBU
  - MD / TVD = 5.6 or Hz displacement / TVD = 4.9



Thin and Cold Edge of Field Potential

- Targeting thin and cold oil sands along edge of field
  - uneconomic with conventional thermal expansion strategies
- Requires new technology
  - Hybrid pattern configuration tested with encouraging results (horizontal producers and vertical injectors)
  - Pilot project with horizontal injectors in planning stage

Map of Kern River Field showing the locations of more than 18,000 wells



Summary

Lessons Learned:

- Horizontal wells can be an effective way to increase production and improve recovery in a very mature oil field

Best Practices:

- Drill an adequate number of observation wells to maintain a 4D reservoir model (accurately model current oil in place)
- Incorporate new technology into development plan

Challenges:

- Thin cold oil along edge of field
- Shallow horizontal wells