New Horizontal Play Targeting Fluvial Sandstones in a Basin-Centered Gas System around Jonah Field, WY

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Abstract

New horizontal wells around Jonah Field of the northern Greater Green River Basin support the presence of a prolific basin-centered gas system outside of the historical field extents. Jonah Field is located along the basin axis between the Pinedale Anticline and the LaBarge Platform and produces primarily from vertical wells in Upper Cretaceous Lance Formation sandstones. Braided and stacked fluvial sandstone channels generally range in thicknesses from 10 to 150 ft and in width from 100 to 1500 ft. Silt, mudstone, shale, overbank, floodplain, and lacustrine facies, however, interweave throughout the sandstone intervals and are considered unproductive and potential stratigraphic hazards. Development of the Jonah Field has typically been most successful in structural highs of fault blocks. These structural features further act as discontinuities that truncate the already complex geometry of the sandstone reservoirs. Development has generally avoided down-dip and east of these faults, due to several factors: 1) diminished production to the east, 2) lower net to gross reservoirs and thicker shales, 3) higher risk of structural hazards, and 4) increased drilling depths in the syncline between Jonah Field and the Pinedale Anticline. Importantly, lower EURs of vertical wells drilled in this down-dip portion of the field are mainly due to lesser net sand footages rather than unfavorable gas saturations. Today, a new horizontal drilling program tests the viability of the synclinal margin of Jonah Field as well areas outside the classic field-defining faults. Despite challenging stratigraphic and structural complexities in these areas, long-reach horizontal wells have yielded excellent results. We attribute the early success of this new Rockies horizontal play to careful well-planning and targeting, stratigraphic traps, and widespread basin-centered gas saturation.

Conclusions

- New horizontal wells around Jonah Field of the northern Greater Green River Basin **support the presence of a prolific basin-centered gas system** outside of the historical field extents
- Today, a new horizontal drilling program tests the viability of the synclinal margin of Jonah Field as well **areas outside the classic field-defining faults**

- Despite challenging stratigraphic and structural complexities in these areas, **long-reach horizontal wells have yielded excellent results**

- **We attribute the early success of this new Rockies horizontal play to careful well-planning and targeting, stratigraphic traps, and widespread basin-centered gas saturation**

Acknowledgments

Thank you to the Jonah G&G, Production, Reservoir and Drilling teams for comments, figures and other contributions to this presentation.

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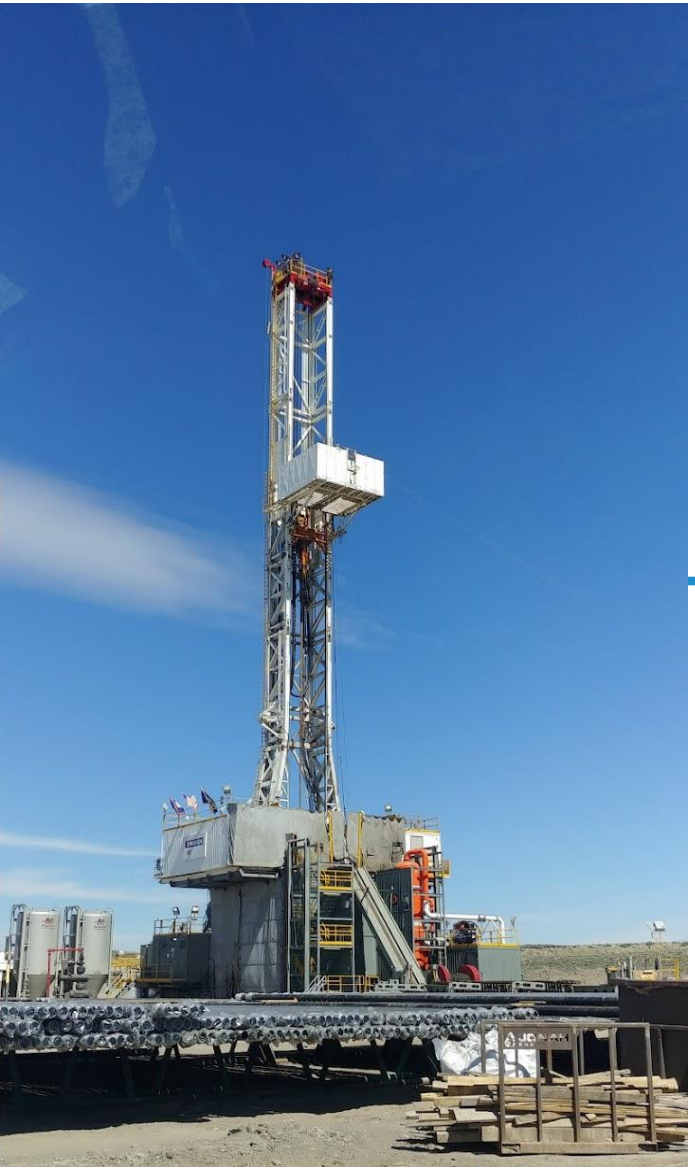

JONAH ENERGY LLC

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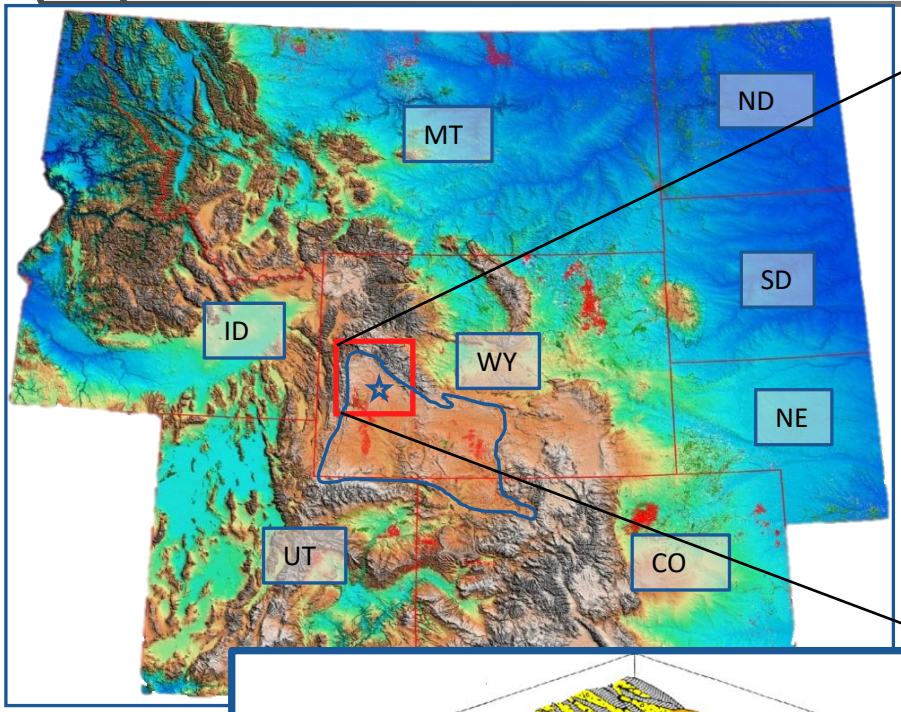
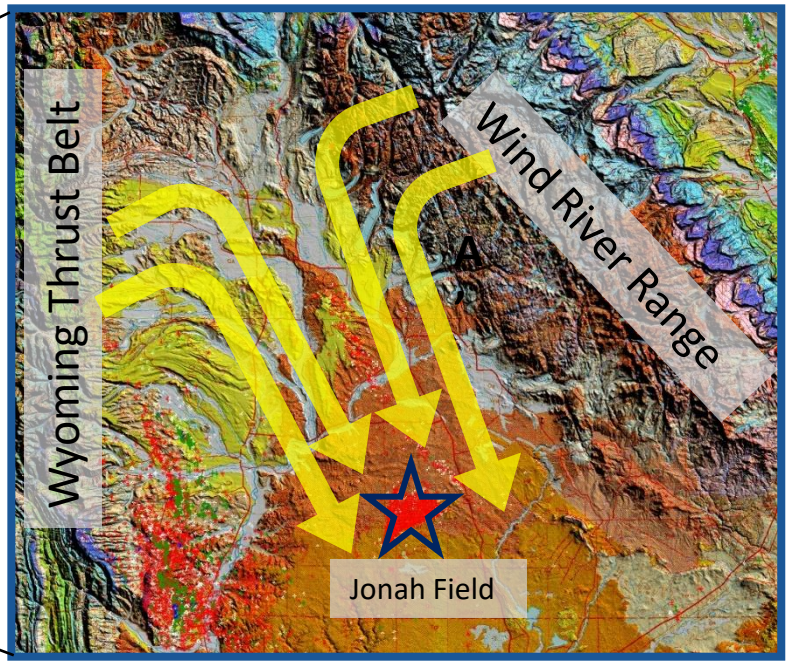
Overview

- Geologic background
  - Location and depositional style in the northern Green River Basin
  - Formation of Pinedale Anticline
  - Jonah Field stratigraphy
- Jonah Field development
  - Historical field development with vertical wells
    - › Structure controls and EURs
    - › Basin-centered gas concepts
    - › Methods to target down-dip acreage
- Horizontal development results
  - Horizontal well example: Curiosity 341-02-500H
  - Horizontal well example: Falcon 341-34-500H
  - Horizontal well example: Wildhorse 03-500H
  - Vertical development (2018-2019) vs horizontal development (2019-2022) summary
- Discussion and Conclusions

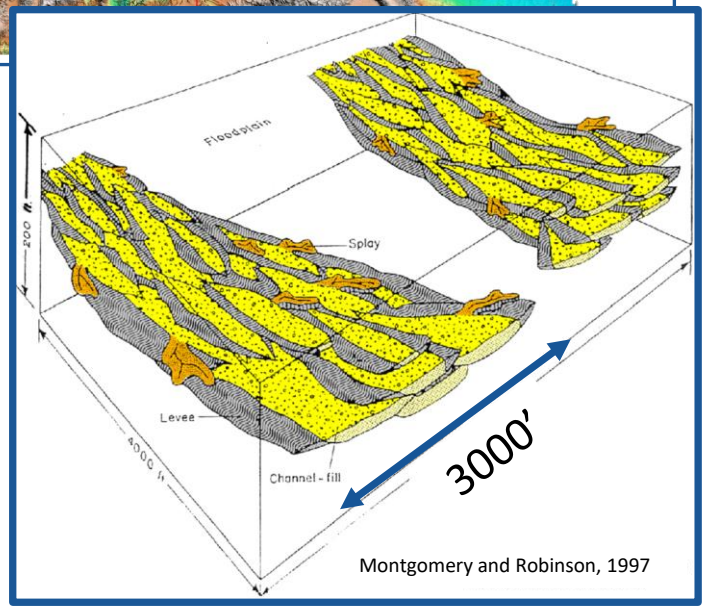
Greater Green River Fluvial System





~55 miles

USGS, 1985

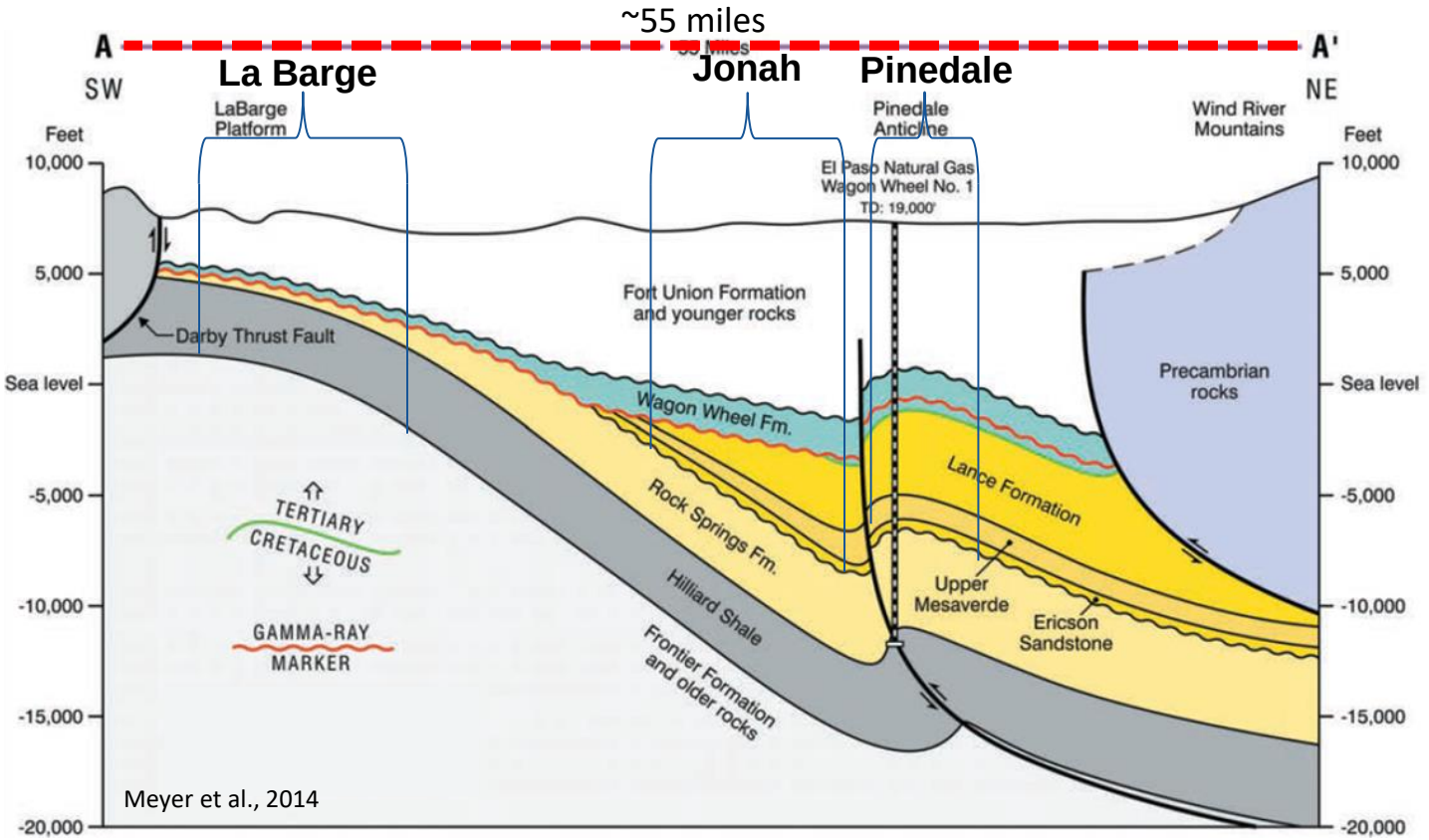


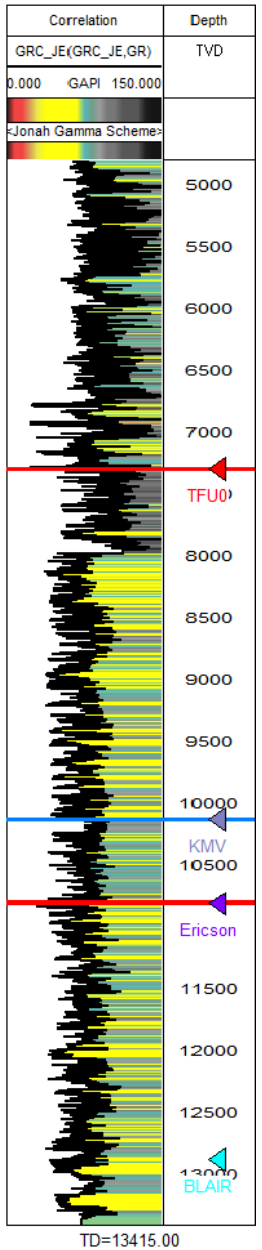
Montgomery and Robinson, 1997

- Lance Formation
  - Sediment sources
    - WY Thrust Belt
    - Wind River Range
  - Braided and meandering fluvial system
    - Draining northwest to southeast
    - Sand bodies range from 10'-150' total thickness
    - Lateral continuity estimated 200'-3000'

Formation of Pinedale Anticline

- Laramide Orogeny: Pinedale anticline formation
  - Northeast of Jonah Field
    - › Syncline on forelimb of anticline, lowest portion of Jonah Field
- Primary target: Lance Formation
  - Below Wasatch and Fort Union (Tertiary and Upper Cretaceous) above and Ericson and Rock Springs below (Lower Cretaceous)
  - Hilliard and Rock Springs source (1.5 -2.1 Ro)
  - 8-12% porosity, .01-.9 mD permeability





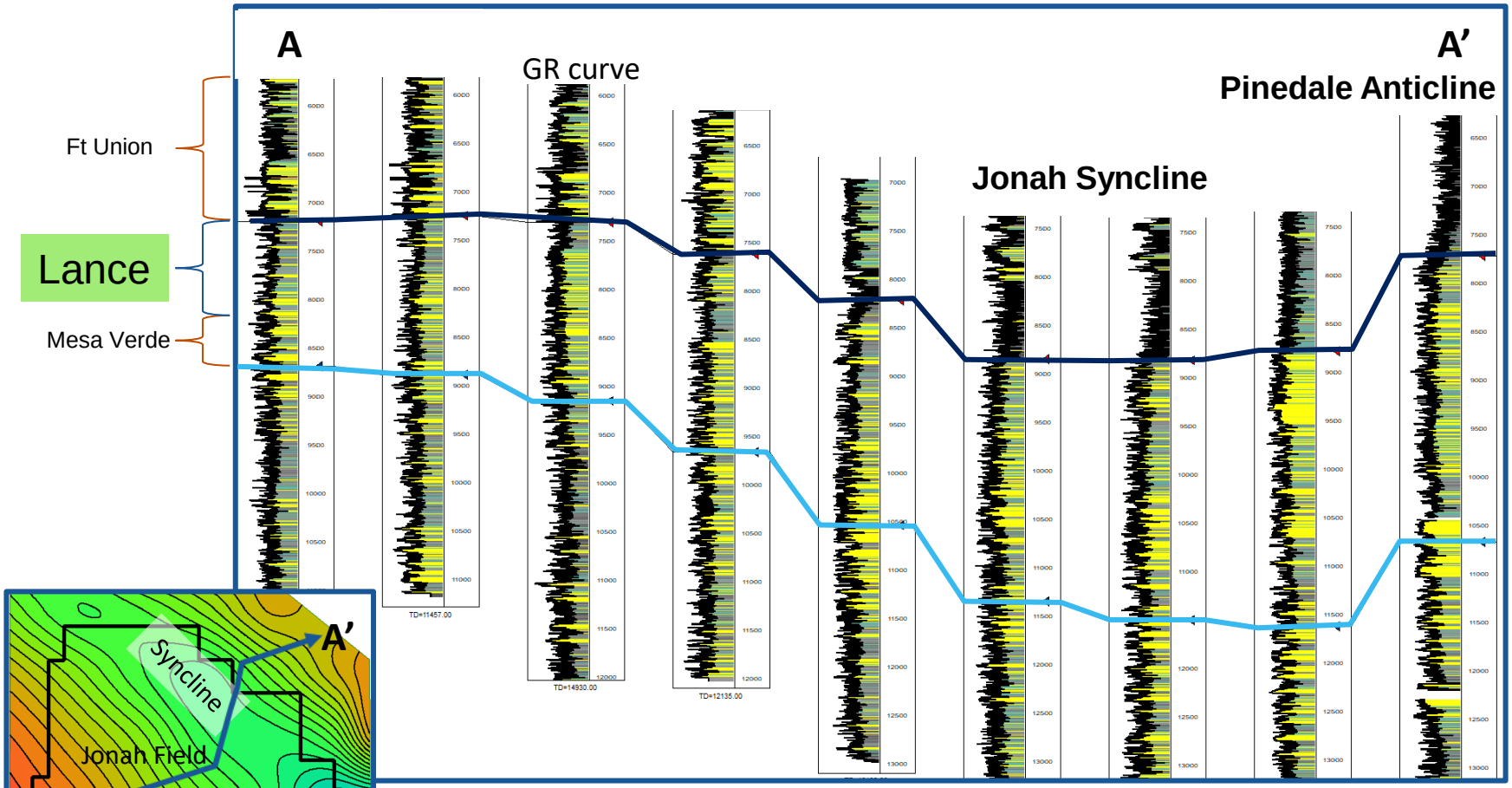
Wasatch and Fort Union

Lance and Mesa Verde

Ericson, Rock Springs, Hilliard

Jonah Field Stratigraphic Architecture

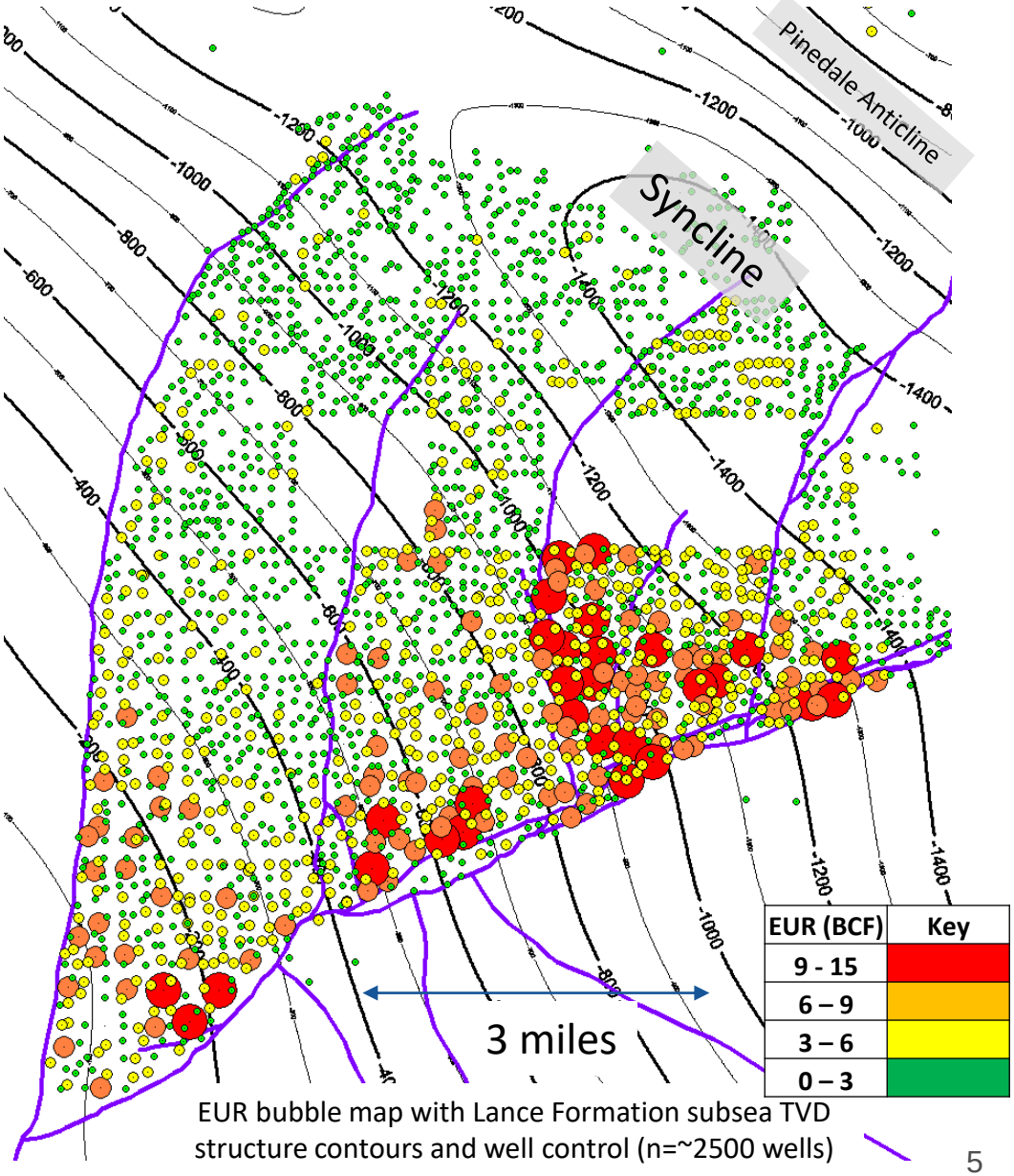
- Southwest to northeast cross section across Jonah Field to Pinedale Anticline (~10 miles)
- Gas productivity starts below the top of the Lance fluvial sands



Top of Lance Formation structure
(100' SSTVD contours)

Jonah Field Vertical Development

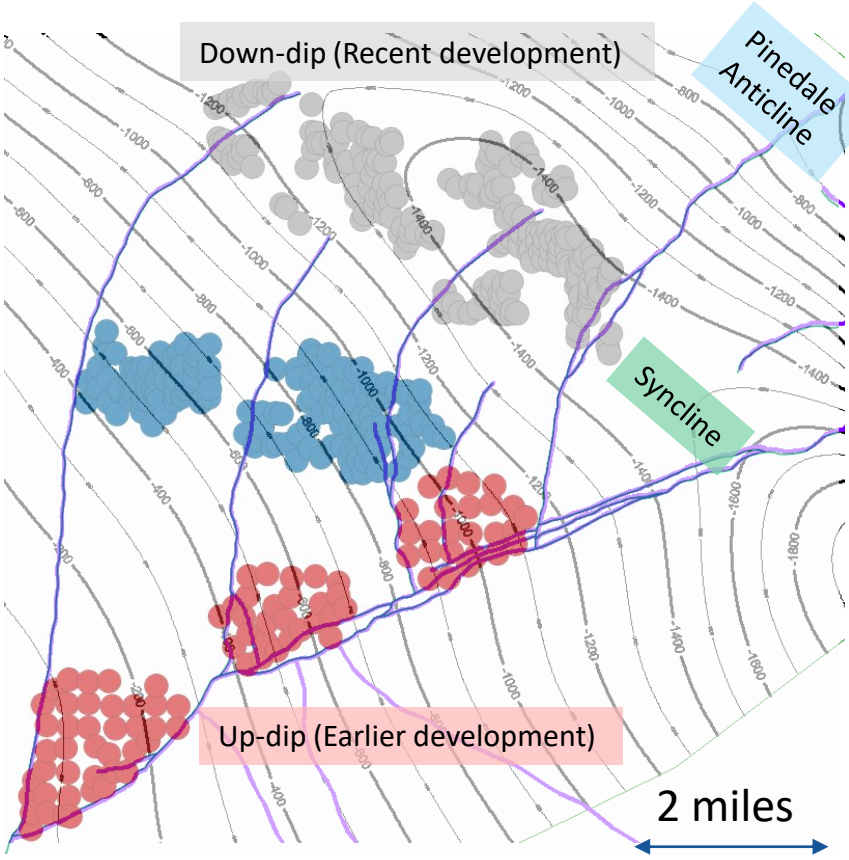
- Wells up-dip, near shallow strike-slip faults performed better
  - 4-10+ BCF
- Structurally down-dip, towards basin axis and away from faults
  - 2 - 3 BCF

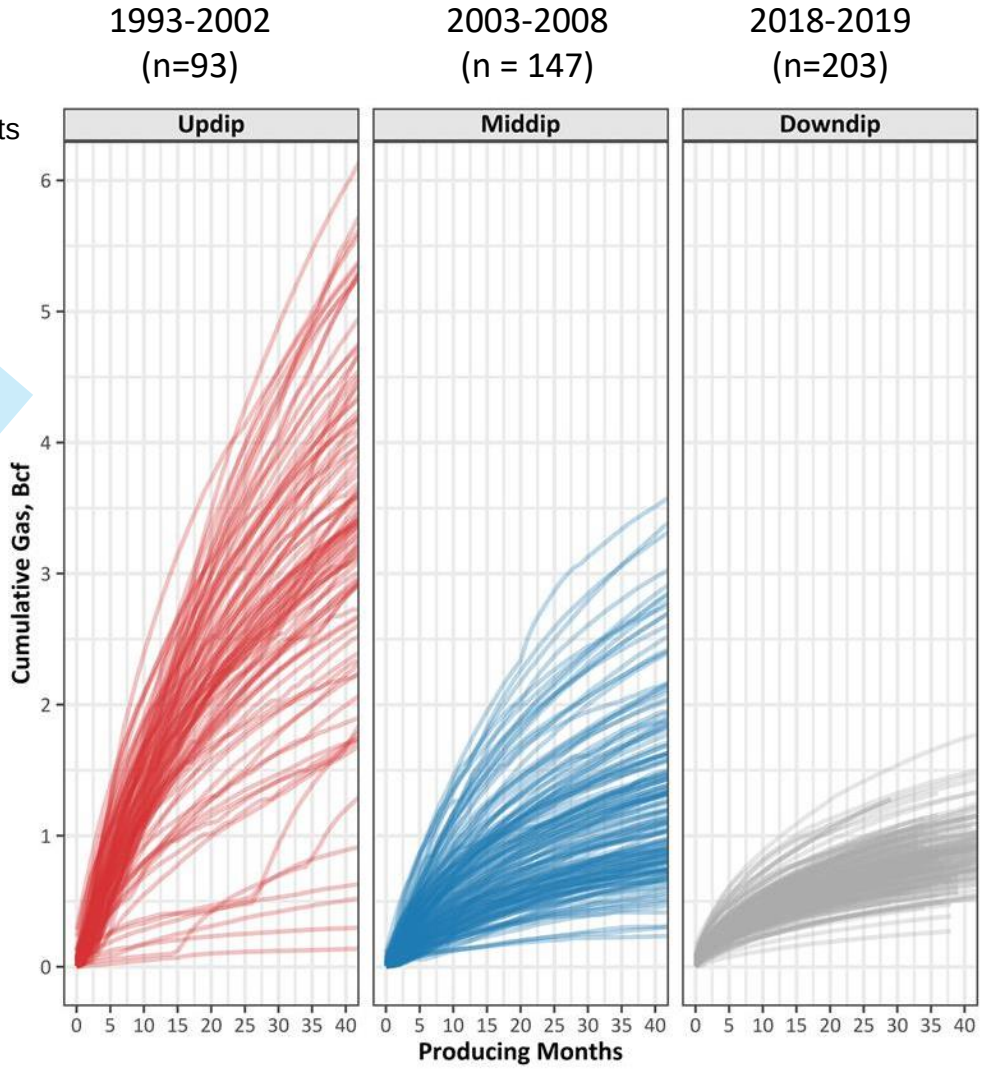


EUR bubble map with Lance Formation subsea TVD structure contours and well control (n=~2500 wells)

Vertical Well Development Phases and Production

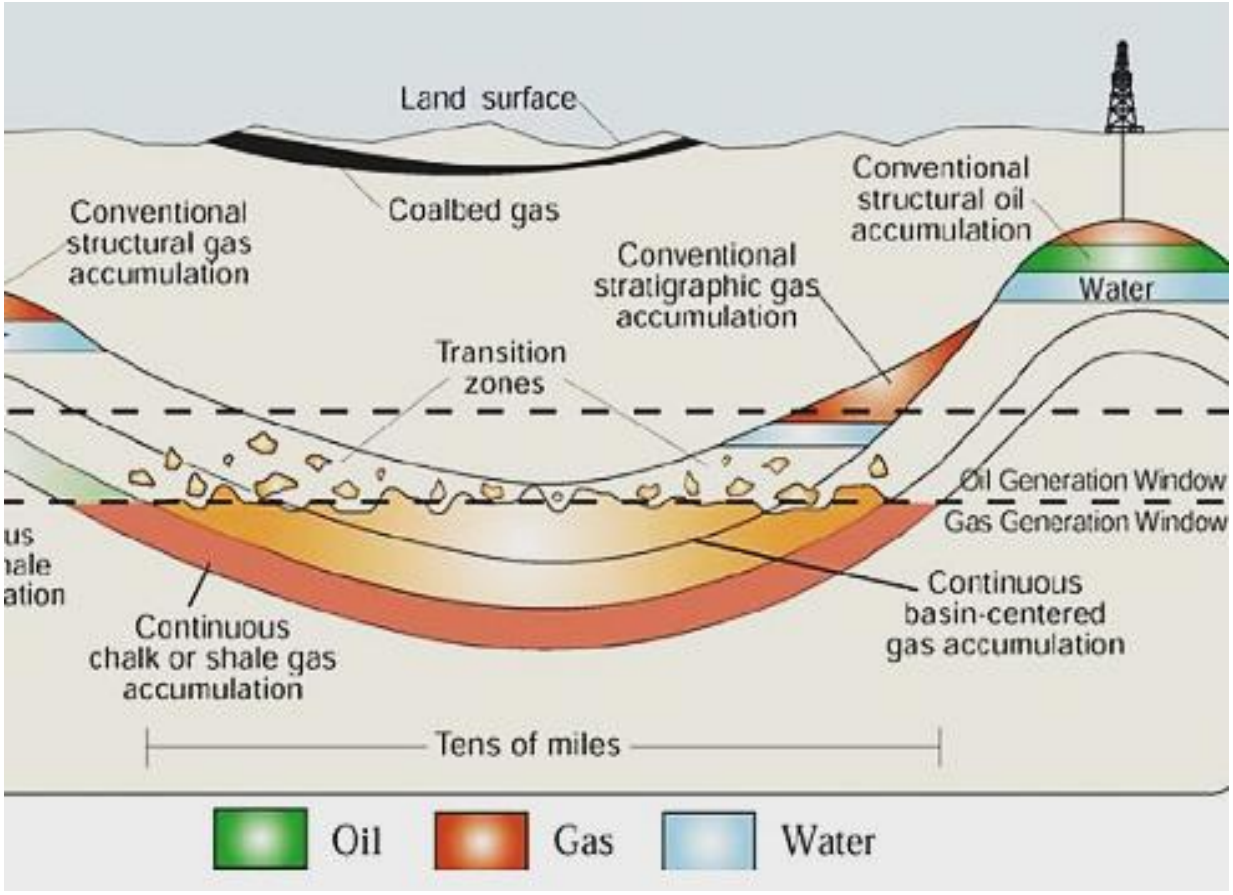
- Early vertical development
  - Up-dip targets close to faults
- Recent vertical development
  - Down-dip development away from Jonah Field faults
  - Reduced production
  - Tighter spacing
  - Increased depletion potential





Jonah Field Basin-Centered Gas

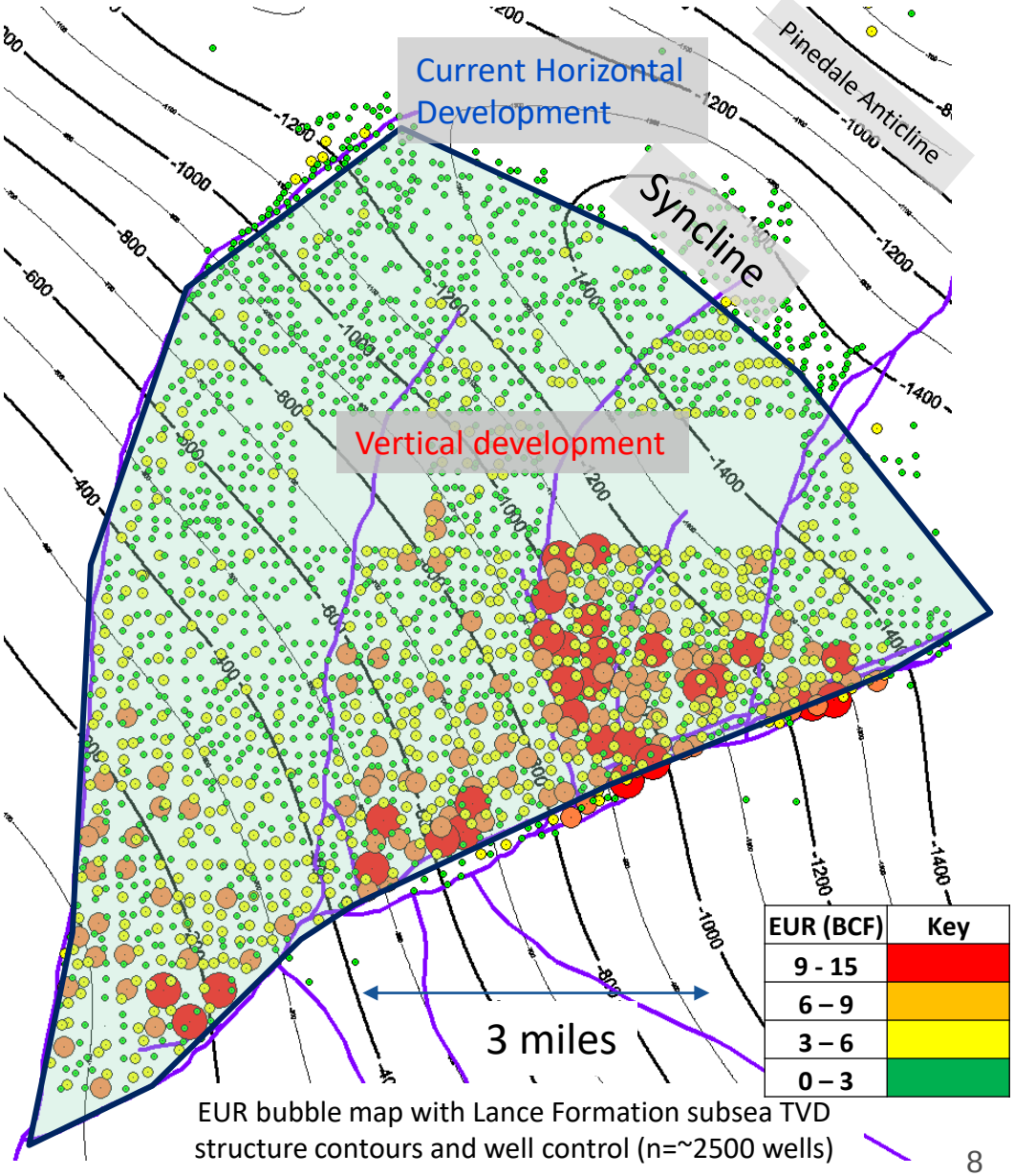
- Basin-Centered Gas Model
  - Proposed by Law (2002)
  - Mature hydrocarbon system
  - Structurally low areas near sources that are productive
  - Some liquids
  - Structural and stratigraphic traps
- Jonah's basin-centered gas attributes
  - Stratigraphic and structural traps
    - › Sandstone reservoir made of braided and meandering stacked channel complexes impeding up-dip migration
    - › Shallow faulting truncating channel complexes
  - Discontinuous seals
  - Has structural low (syncline) with hydrocarbon saturation



USGS, 2008

Horizontal Development (2020-Present)

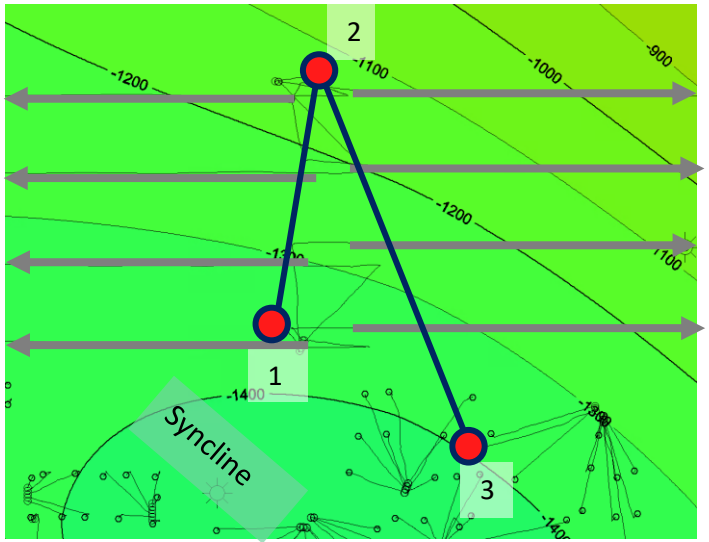
- Objective:
  - Target sand-rich horizons of the Lance with horizontal drilling and completion techniques
- Methods:
  - Leverage new vertical delineation wells and existing wells to identify continuous stacked sand bodies
    - › Production test for saturation and deliverability
    - › Map horizontal targets with seismic where well control is lacking
  - Where possible, drill vertical section near vertical well control and drill horizontal portion away from existing development
  - Steer wells using type logs of existing verticals



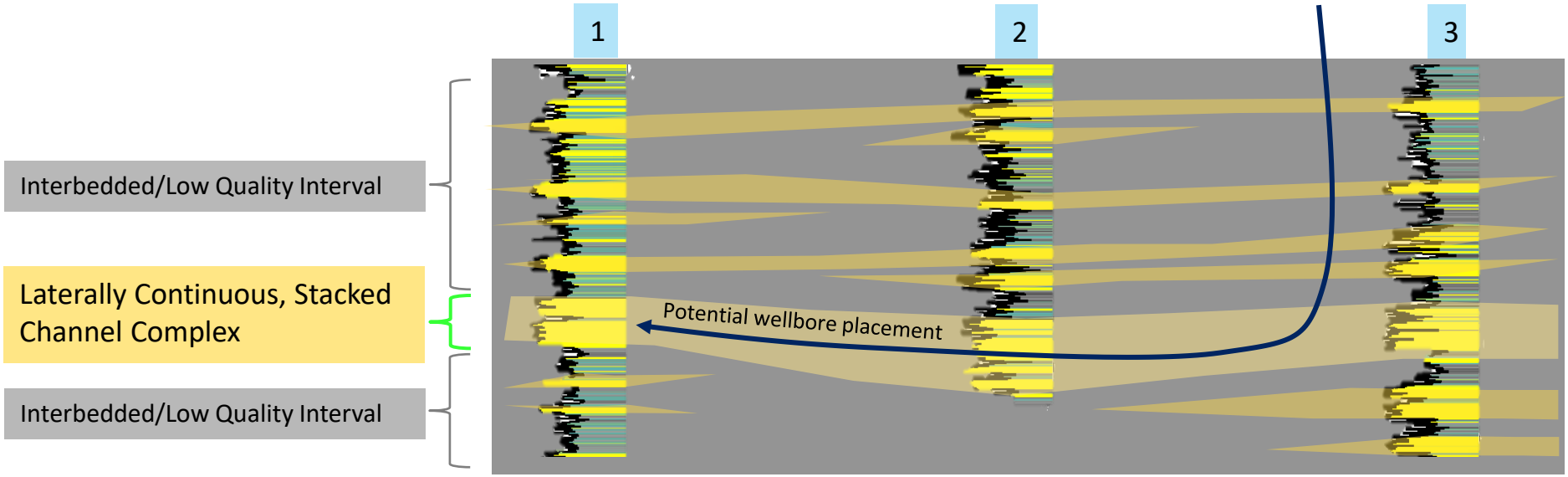
EUR bubble map with Lance Formation subsea TVD structure contours and well control (n=~2500 wells)

Horizontal Play Concept

- Delineation wells
  - 2018-2019 spud dates
  - Identified and characterized prospective sand rich intervals encountered in penetrations
  - Zone of interest is production-tested for saturation and deliverability
  - Mapped to prove correlation to other vertical penetrations
  - Bound above and below by shalier intervals
- Wells will encounter some low-quality reservoir rock
  - Expect 60-75% net to gross reservoir vs non-reservoir



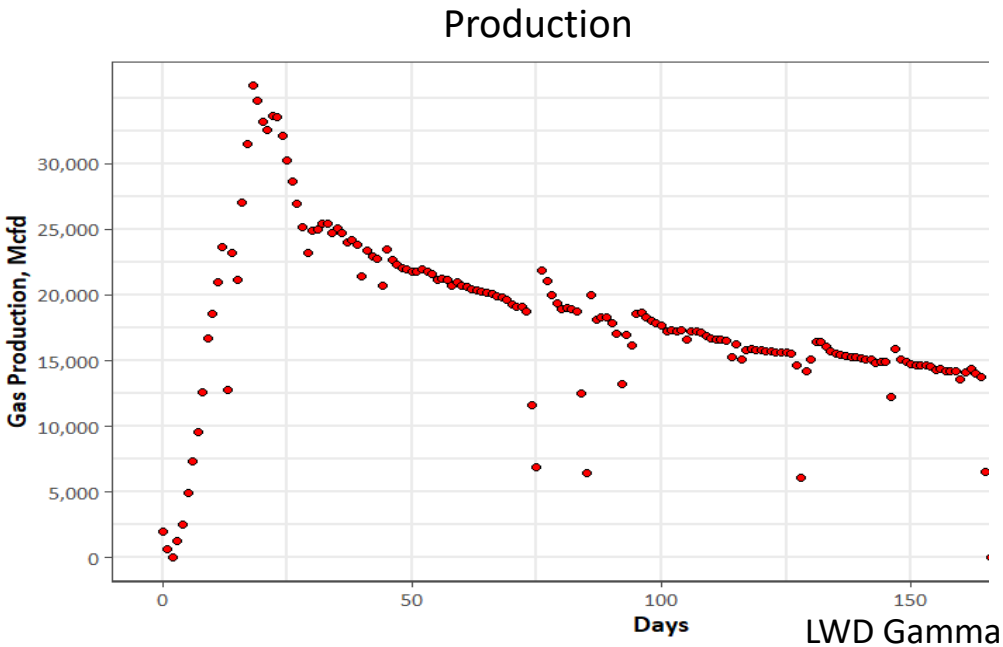
~1 mile

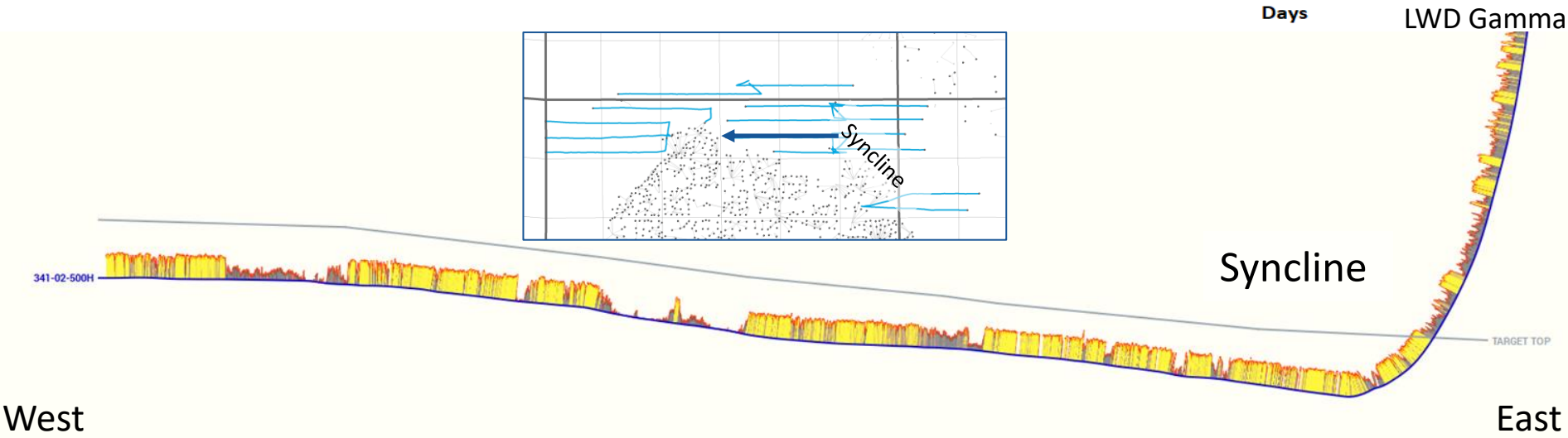


Horizontal Test Example: Curiosity 341-02-500H

- **Objectives:**
  - Avoid previously developed acreage
  - Test syncline development concept
  - Avoid major faults
  - Establish well spacing with microseismic

- **Results:**
  - ~10K lateral
  - Steered by using vertical control at heel and other existing producers in main part of Jonah Field
  - Proved target deliverability and development concept for area
  - IP: ~35+ MMcfd



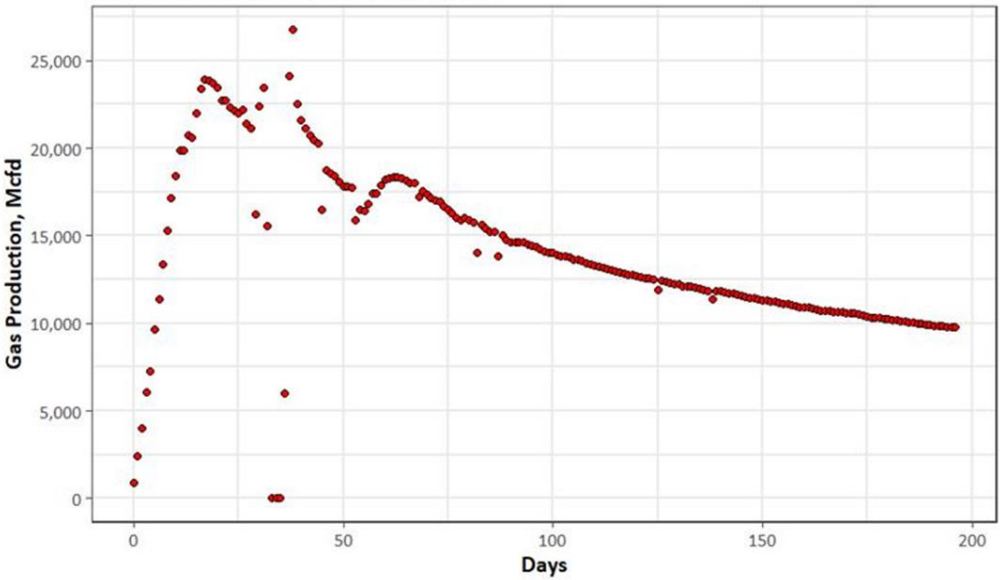


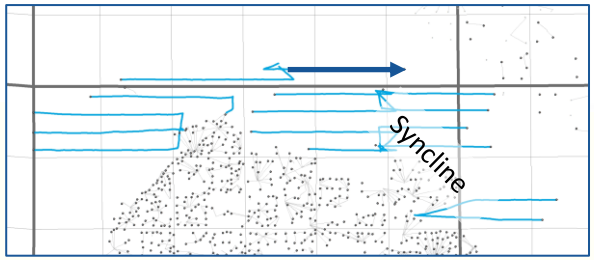
Horizontal Test Example: Falcon 341-34-500H

- **Objectives:**
  - Drill further from proven horizontal development in syncline
  - Cross major thrust fault to prove production on both sides

- **Results:**
  - 9K lateral
  - Successful landing and crossing of syncline
  - Establish fault offset at this location (~50') and increased confidence in seismic interpretations
  - Challenging to regain target interval on eastern half of lateral
  - Proved development potential for area and across major structural feature

Production





LWD Gamma

Anticline forelimb

Original Seismic Interpretation Main Thrust Fault

Main Thrust Fault

-54.7

-5.6

-21.9

-0.5

Syncline

Target Sand

Target Base Shales

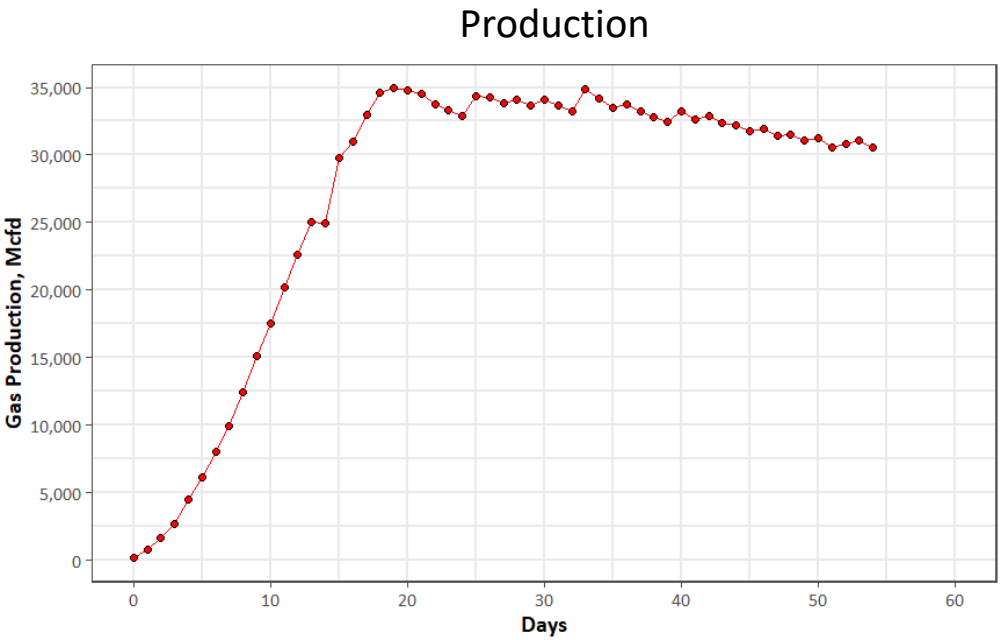
West

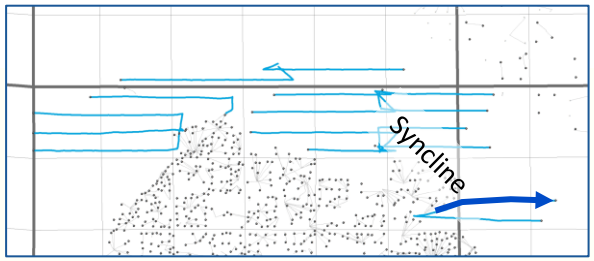
East

1 mile VE: 3x

Horizontal Test Example: Wildhorse 03-500H

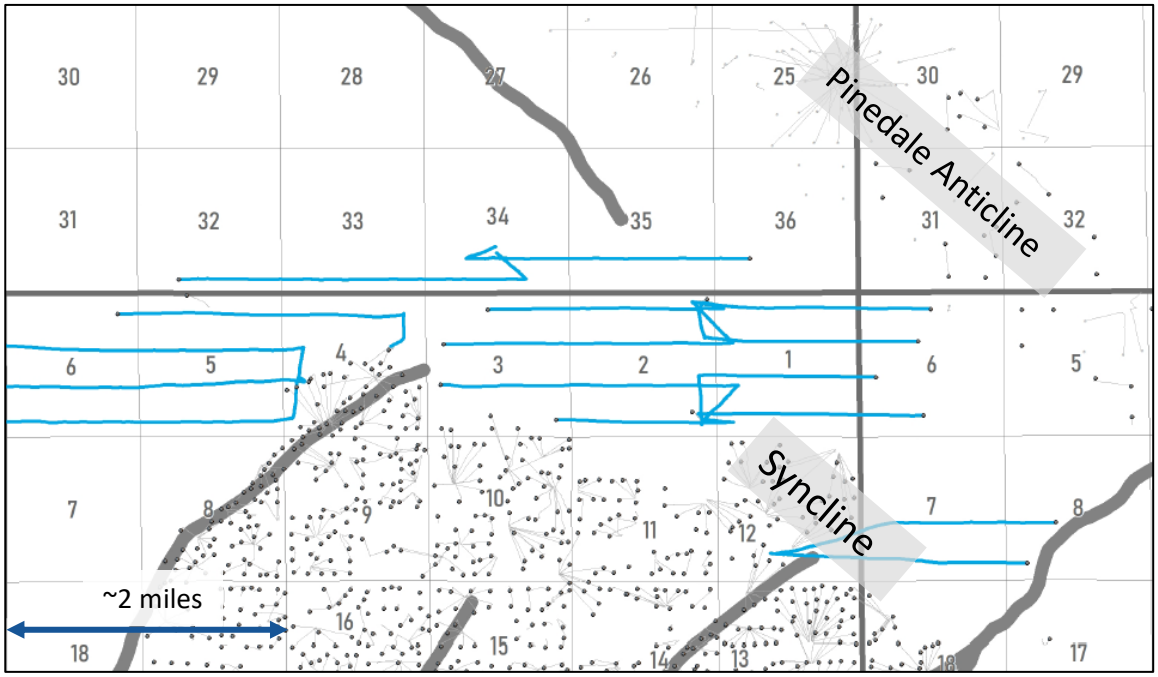
- **Objectives:**
  - Drill and land closer to vertical development and further SE into syncline plunge
  - Cross into structurally complex zone near toe
    - › Test development potential near Antelope Fault
- **Results:**
  - Drilled lateral portion away from vertical wells and into new acreage
  - Climbed from the syncline and up the forelimb of the Pinedale Anticline
  - Excellent production: ~30-35+ MMcfd for nearly 2 months



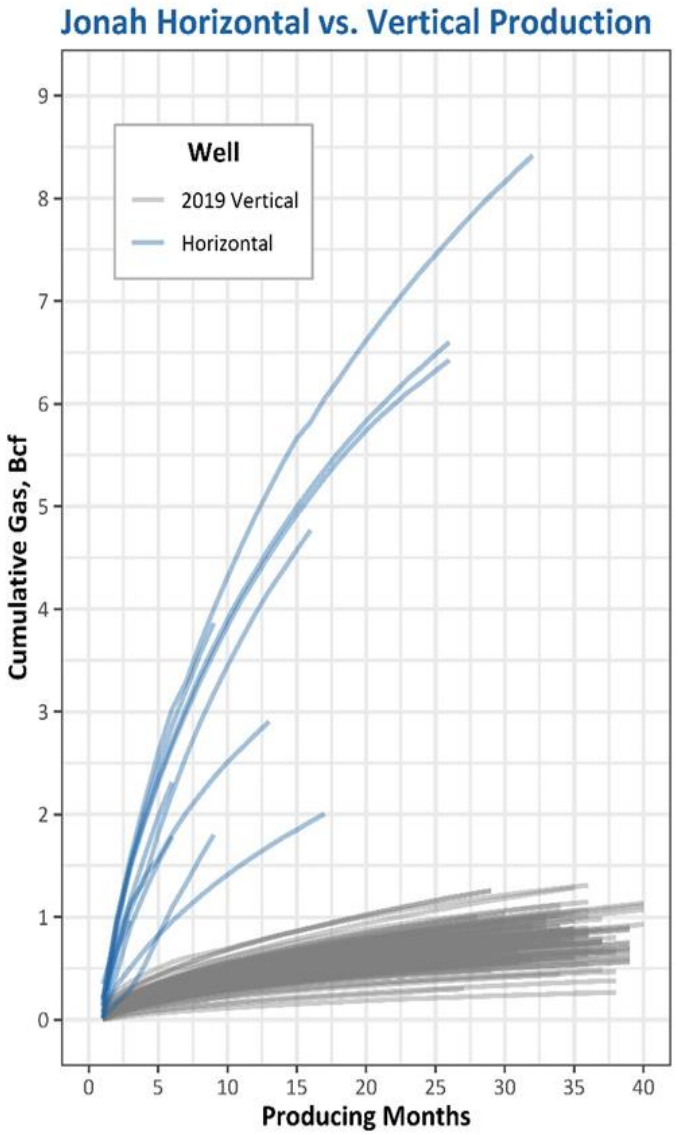


Horizontal vs Vertical Well Results

- To date: 17 horizontal wells spud in current program
- Early cumulative production of a single horizontal well is 6-10x that of a vertical well in the down-dip region of the Jonah Field



	IP30, Mcfd	1-Yr. Cum, Bcf	5-Yr. Cum, Bcf	Stage Count	Total Proppant, MMlbs
2019 Vertical Avg.	3065	0.5	1.1	10.4	1.4
Horizontal Program Avg.	18549	3.5	8.3	26.8	9.2



1. Average of highest month's production 2. Based on actual plus forecasted production

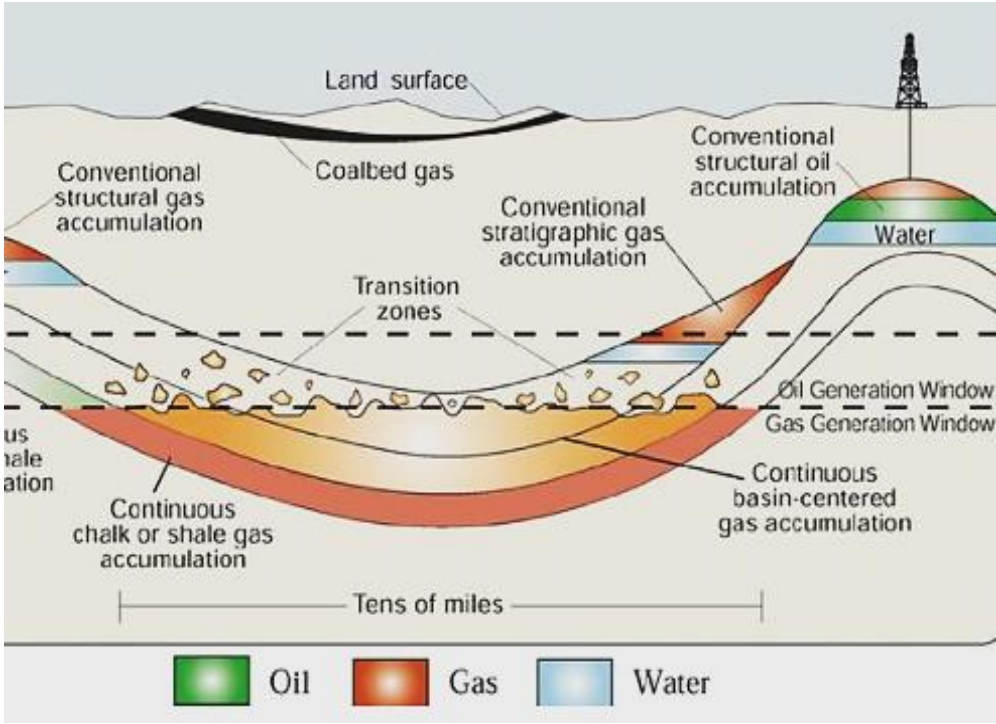
Summary of Early Horizontal Program

- New approach for development around Jonah Field
  - Addition of delineation wells
    - Identify laterally continuous, amalgamated sandstone complexes
    - Production test zones of interest
    - Map existing vertical wells and new delineation wells
    - Integrate well control with seismic to expand horizon prospect away from Jonah Field
  - Drilling vertical portions of horizontal wells near control
    - Steer with several type logs from nearby vertical wells
    - Attempt to forecast faults with seismic where wellbore may encounter them
  - Expectations for reservoir vs non-reservoir
    - Fluvial systems have mixtures of sand, silts and shales which can complicate lateral steering interpretations
    - Faults and facies transitions lead to variable net to gross sand encounters
    - Careful mapping of laterally continuous zones and their thicknesses can help improve amount of reservoir contacted

Discussion: Basin-Centered Gas at Jonah Field?

- Jonah Field basin-centered gas elements
  - Conventional sandstone reservoir
  - Structurally low compared to neighboring Pinedale Anticline and main Jonah Field
  - Gas saturation found in structurally low areas

- New observations
  - Productive sands in syncline axis
    - › Laterally continuous sand intervals encased in non-reservoir rock provide best horizontal targets
  - Reduced net to gross sand in the Lance at the syncline
    - › Diminishing production towards syncline due to less reservoir encountered in vertical wells
    - › Lack presence of fault blocks like up-dip Jonah Field
  - However, small scale faulting and fracturing likely contribute to the most prolific horizontal wells drilled
  - Note that horizontal wells are not in deepest part of the syncline or basin center



USGS, 2008

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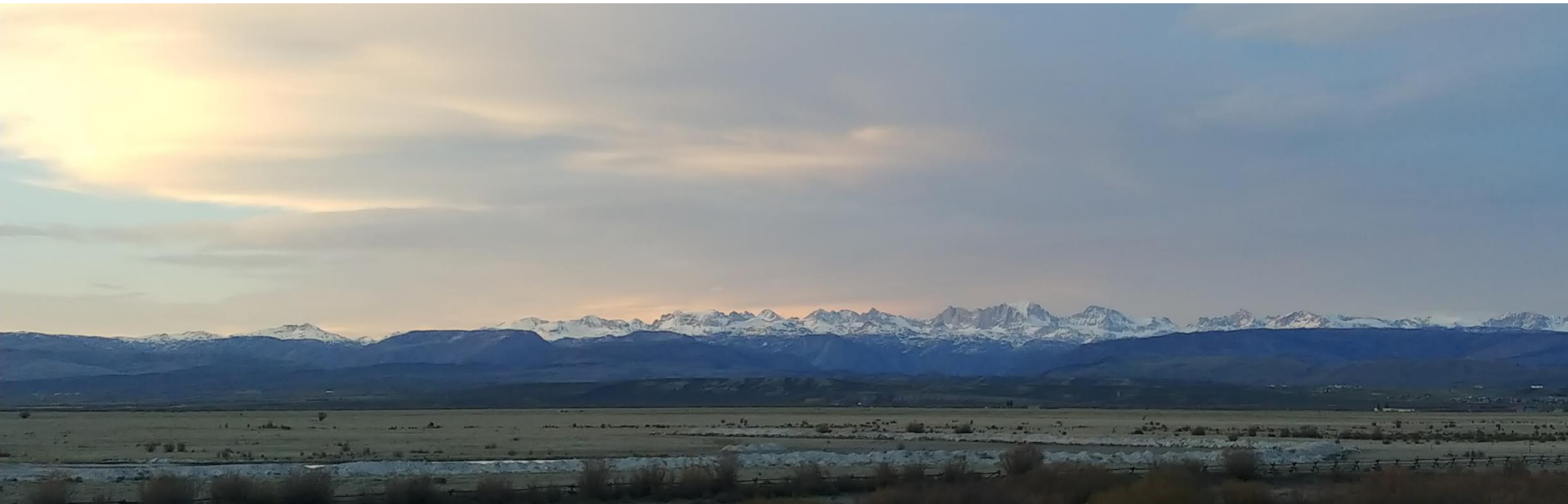

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