Utilization of a Regional Water Chemistry Database to Improve Formation Evaluation and Reservoir Simulation in Low Permeability Reservoirs of Southwest Wyoming

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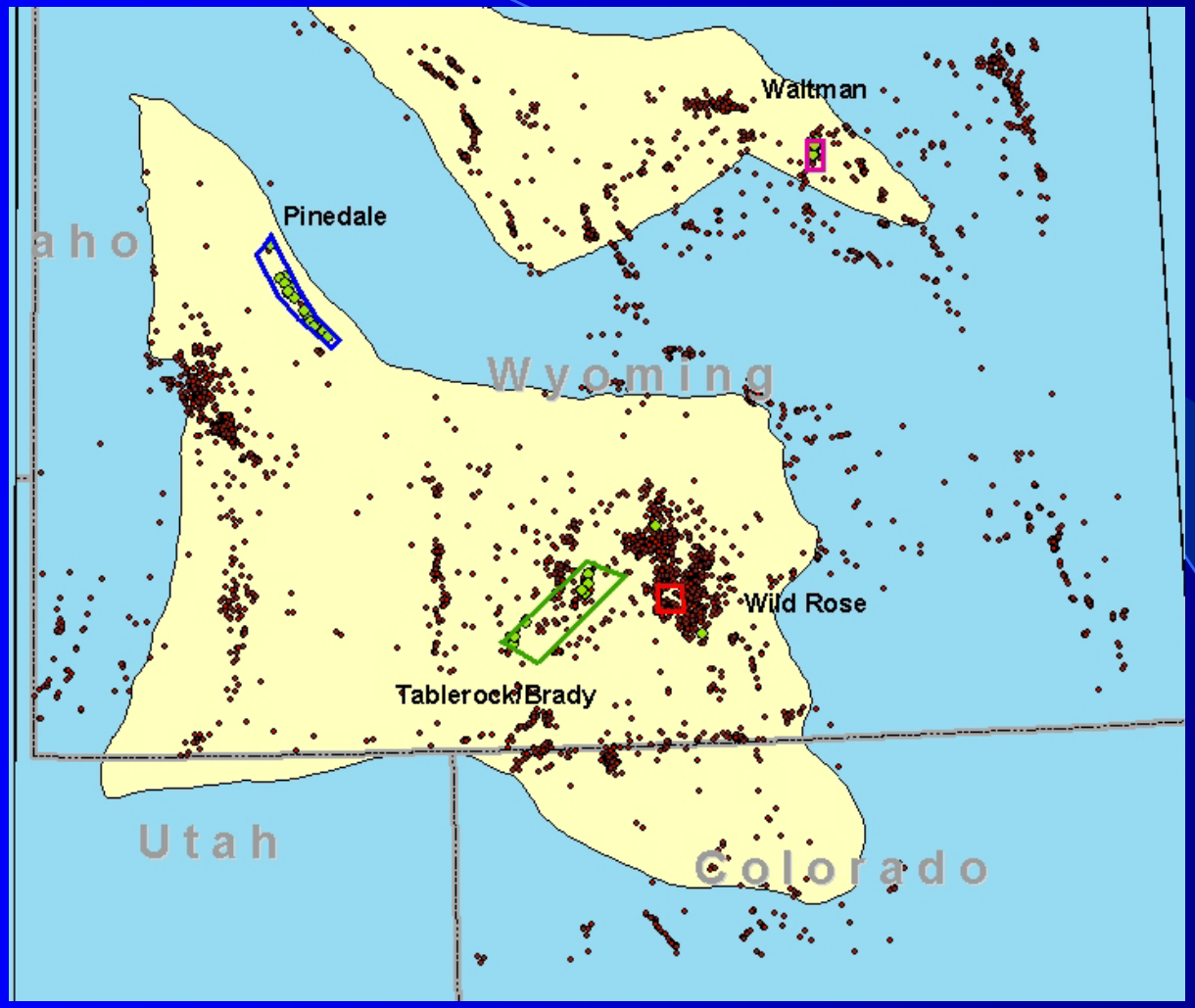
Presentation Outline

- Database Overview
- Field Study
  - Eastern Green River Basin
- Conclusions
  - High Quality Water Chemistry has Improved Formation Evaluation in the Field Study Area
  - SP Used to Determine Gas-Water Boundary
  - Gas-water Boundary Usually Found Near Base of Significant Almond Coals (a local source for gas?)
  - Sands are a Series of Discontinuous Lenses

Database Overview

- Historical Data
  - 3200 Well Locations/GGRB and WRB
  - 8000 Chemical Analyses
- Current Study
  - 86 new samples with full analyses and isotopes
  - Waltman/Cave Gulch, Pinedale, Tablerock, Wamsutter
  - 7 component “Stiff” Analyses
  - Strontium, Oxygen Isotopes
- Highly Accessible
  - Quality Screened
  - Access/Excel Formats

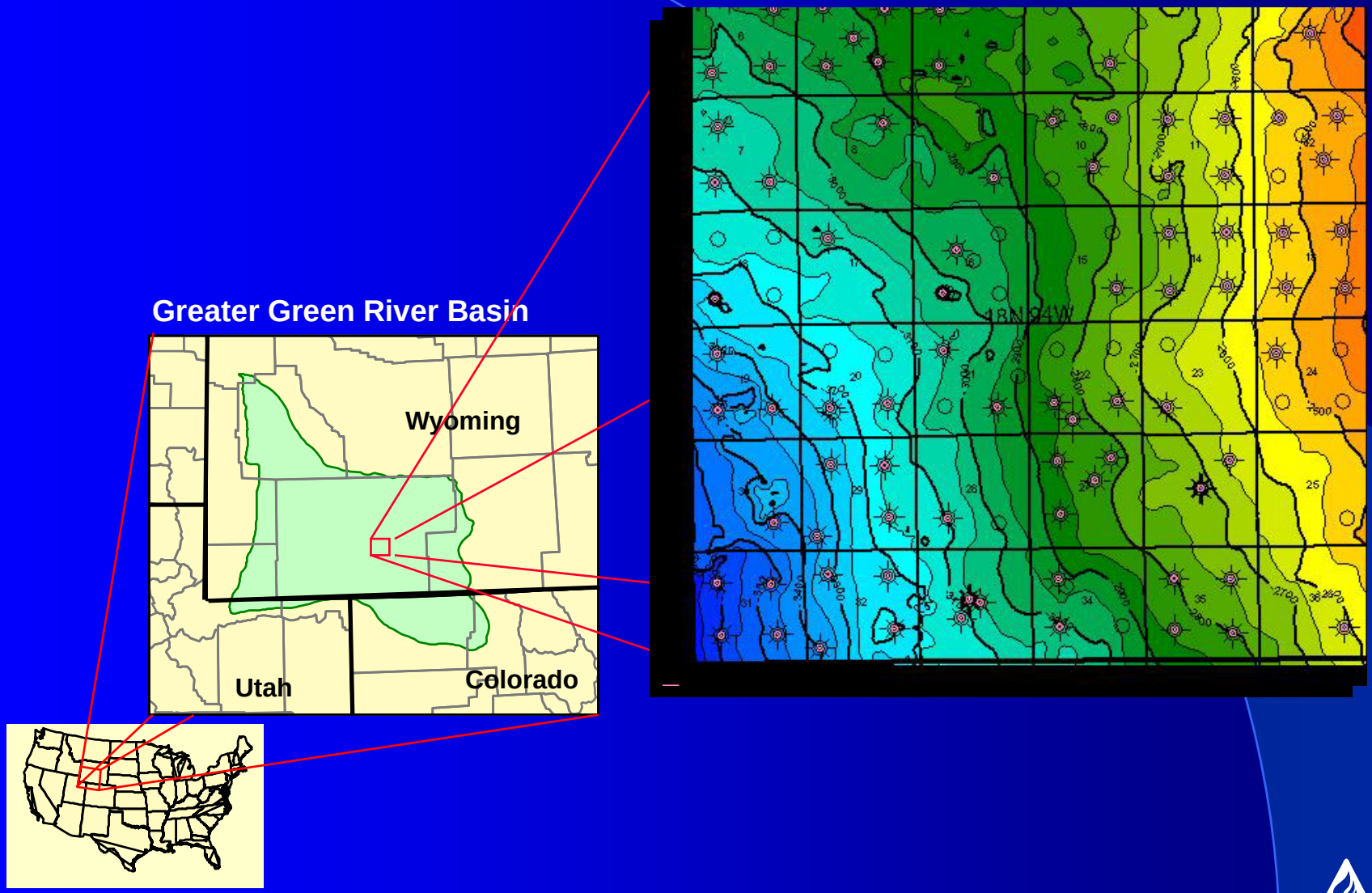
Database Coverage



Water Database Value

- Catalogue of Water Resistivity (RW)
  - Improved Formation Evaluation
    - Critical for delineating gas from fresh water
- Provide Source Point for Water Chemistry Ideas and Technology
    - Areas of Diagenetic Porosity Enhancement
    - Potential Flow Paths
    - Hydrologic Compartments
- Basin Modeling Data
- Database facilitates organization, mapping and analysis of large amounts of water chemistry data

Eastern Green River Basin Field Study



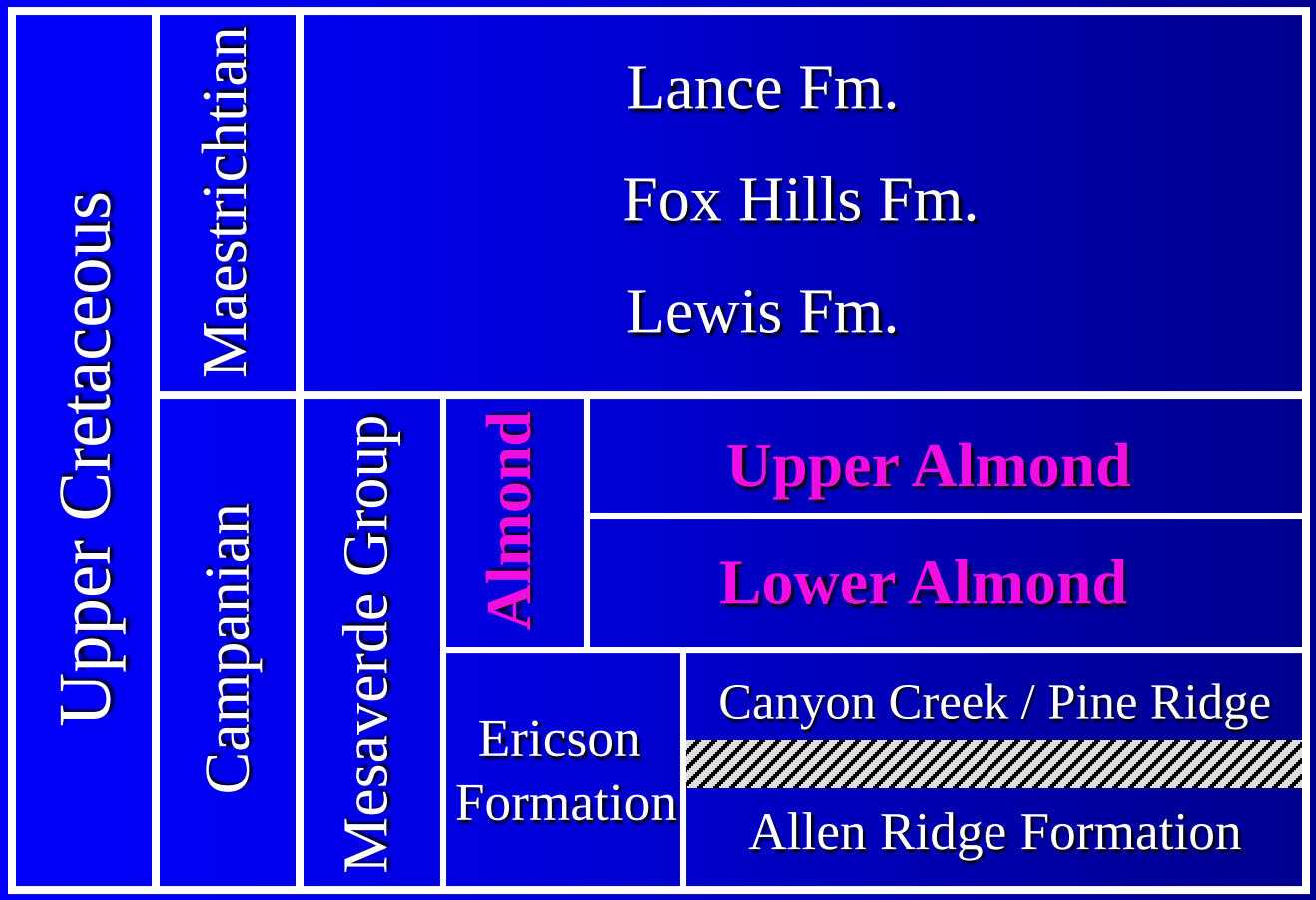
Eastern Green River Basin Field Study

Operator Issue: How to minimize water while capturing additional resources?

- Long-lived historical production area
- 88 wells
- 40 BCF Cumulative Production
- Water production problems
- Available data
  - Well logs, core, 3D seismic, production data
  - Water chemistry data

Technical Strategy: Improve formation evaluation, simulate reservoir to understand bulk permeability/water production.

Stratigraphic Column
Washakie Basin, Wyoming

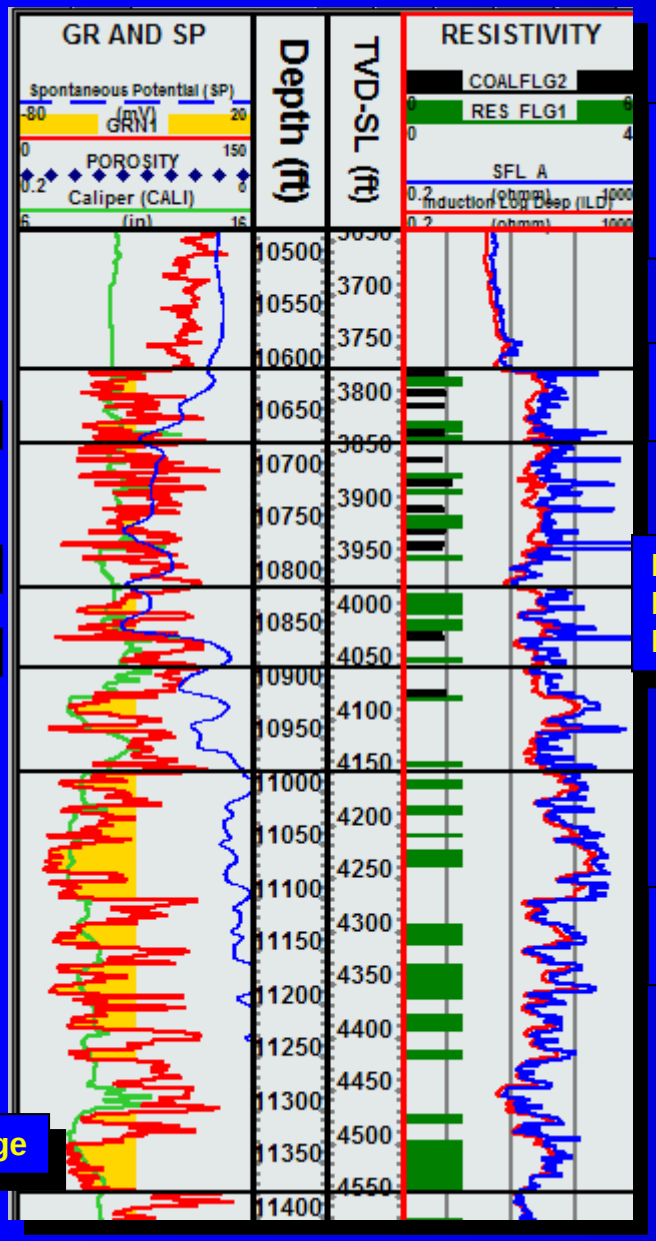


Modified from Roehler, 1990

Work Flow

- Build Stratigraphic Correlation Framework
- Interpret 3D Seismic for Structure
- Perform Base Petrophysical Study for Reservoir Characterization
  - Emphasized Produced Water Chemistry for High Quality Formation Water Resistivity (Rw)
- Assembled 23 Unit Dual Permeability Reservoir Model
  - Discrete Fracture Network Permeability Grid
    - Constrained by Geomechanical Simulation of Basement Faulting
  - Matrix Porosity and Permeability From Petrophysics
- Production History Match/Forward Simulation

Type Log



ALMD

ALMD_SH1

ALMD_SH2

ALMD_SH3

ERCS

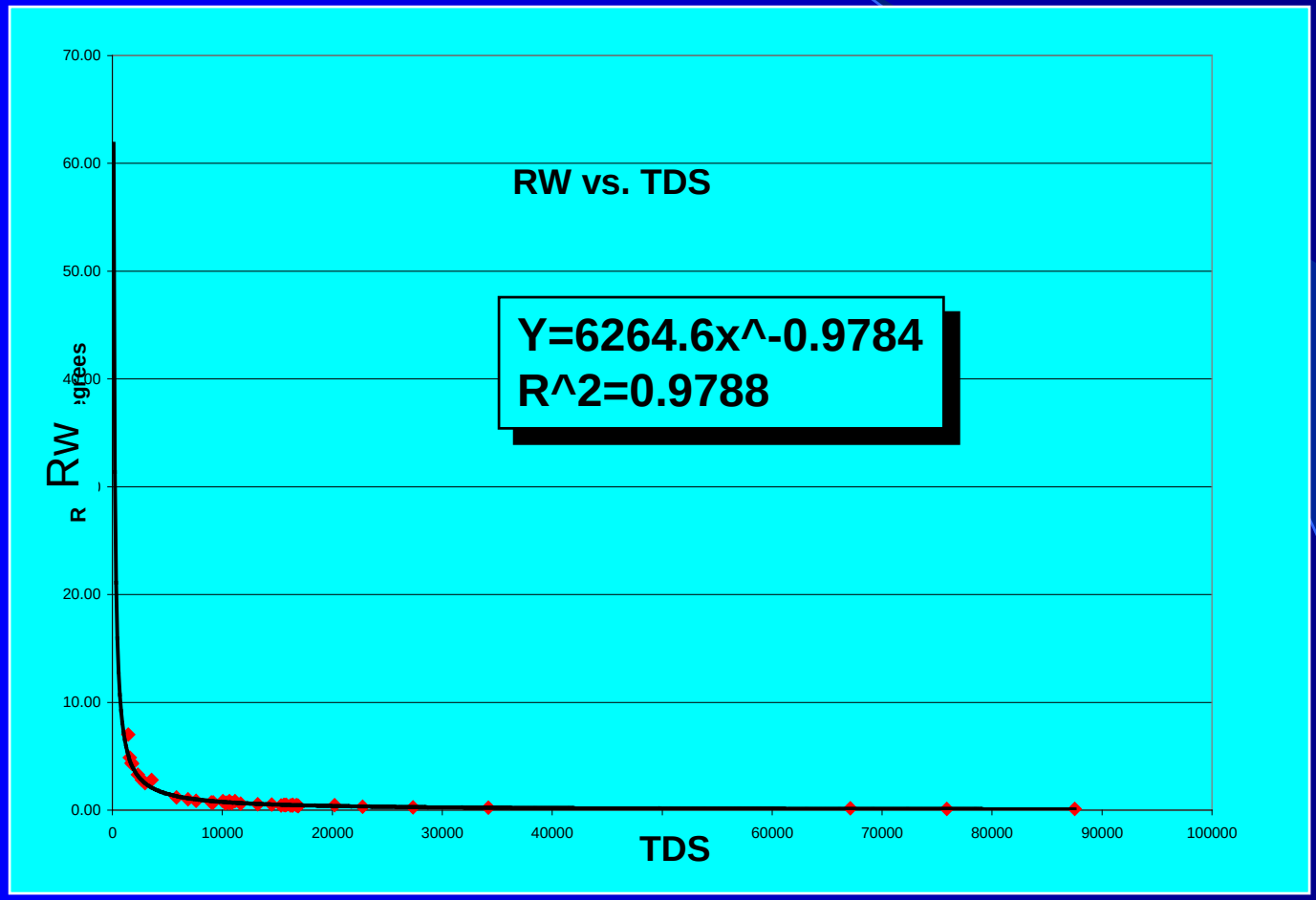
Allen Ridge

Environments of Deposition	Regional Water Chemistry Data
Upper Almond Marine to Marginal Marine	TDS Range 1,700 to 50,000 ppm Average 19,000 ppm
Middle/Lower Almond Marginal Marine to Coastal Plain	TDS Range 7,000 to 18,000 ppm Average 13,000
Ericson Coastal Plain/Fluvial	

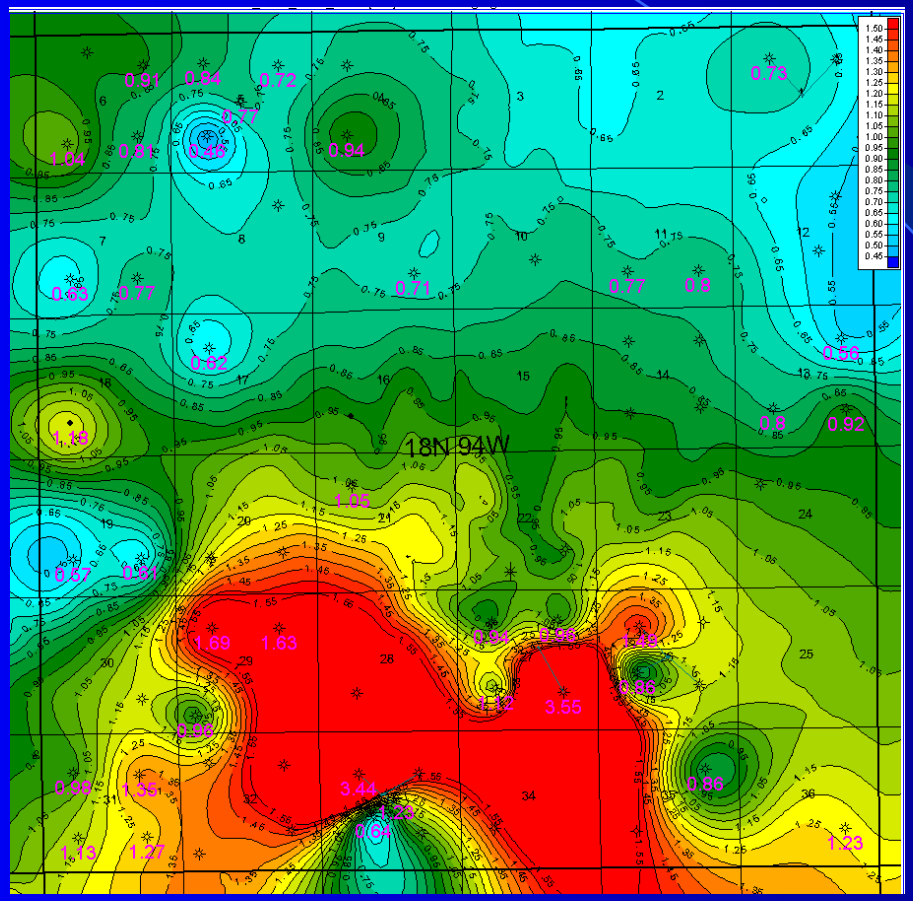
Water Resistivity (Rw) and Petrophysics

- **Evaluated Regional Almond Rw Trends**
  - **Variable Rw influenced by Depositional Environments**
- **9 Township Focused Area**
  - **Vertical and Horizontal Variation**
  - **Established Rw-Total Dissolved Solids (TDS) Relationship**
- **Established Rw by Zones for Saturation Calculations**
  - Aquifer water is so fresh (<5000 ppm NaCl) that it is difficult to distinguish from gas invaded by a fresh water filtrate
  - Porous and permeable Ericson has high resistivity, although it only produces water
  - Used water chemistry, fluids and logs in Upper and Middle Almond to calibrate Rw in gas zone, and the Ericson to calibrate Rw in the aquifer

TDS/Rw Cross-Plot 68 degrees F
9 Township Area



AVERAGE PRODUCED WATER RESISTIVITY

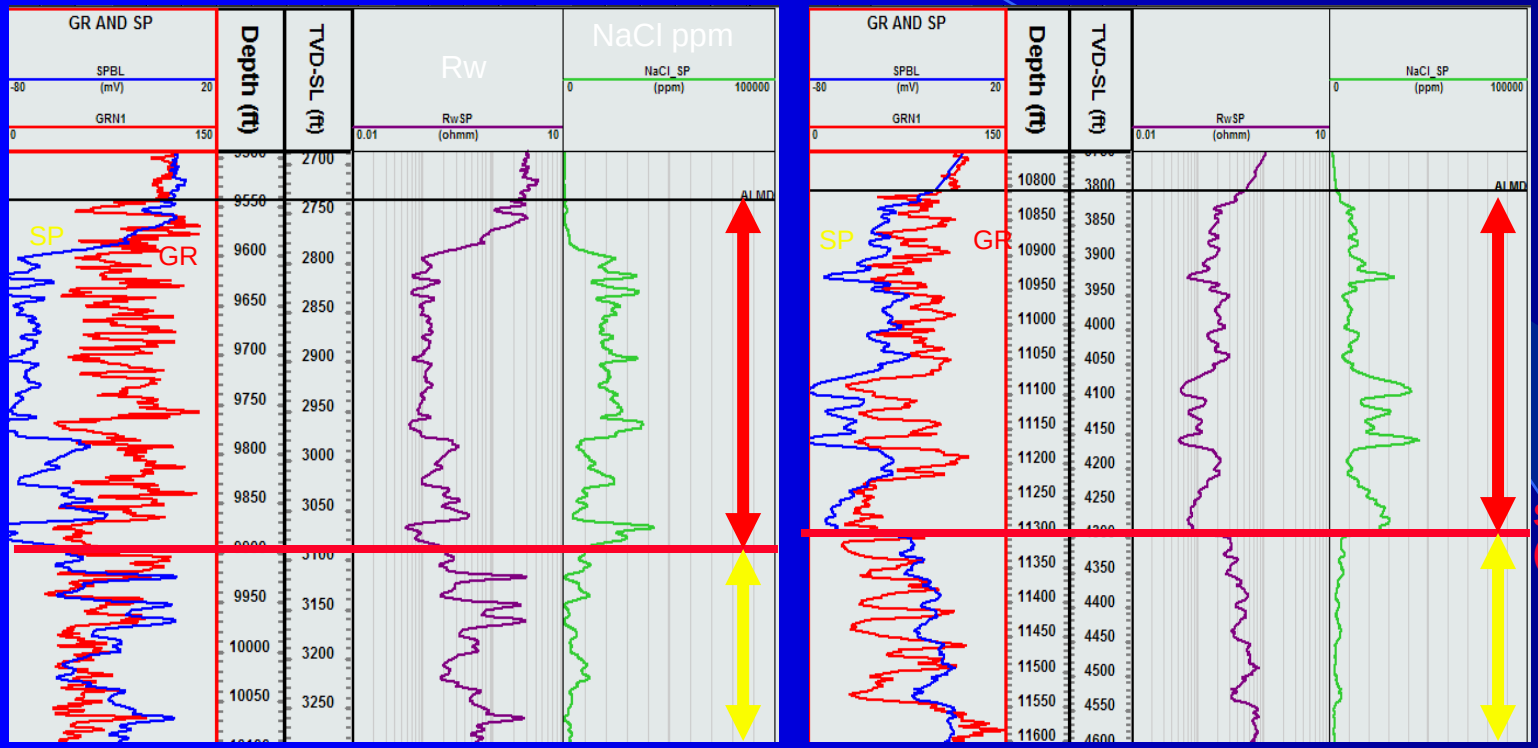


Red Shades indicate High Rw, Blue indicate Low Rw (@ 68 F)

SP-Rw

Mungo Federal 1-14

Champlin 221C



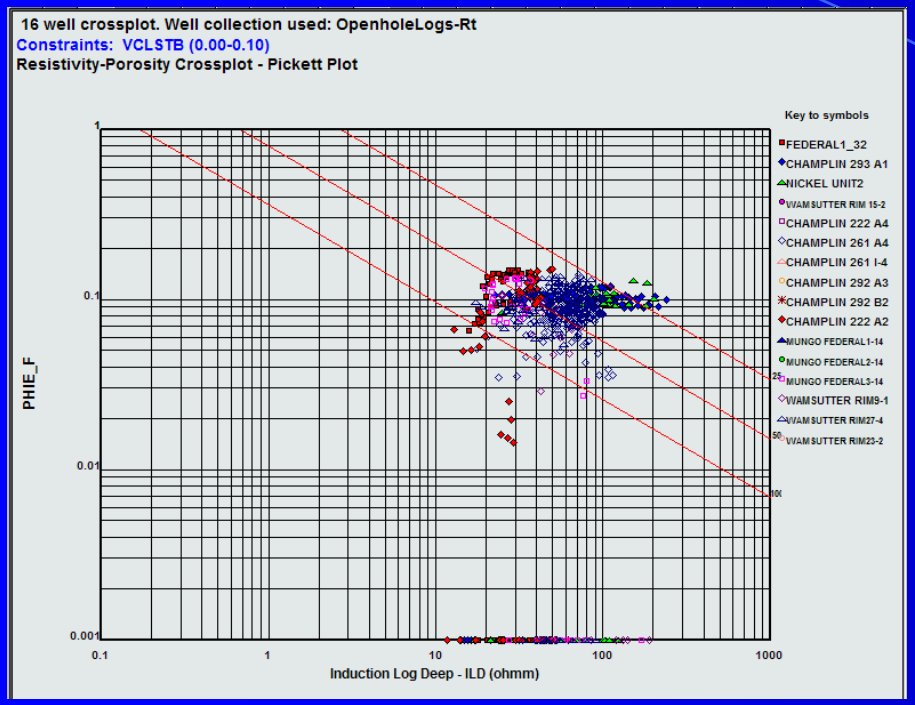
Medium salinity water in gas zone

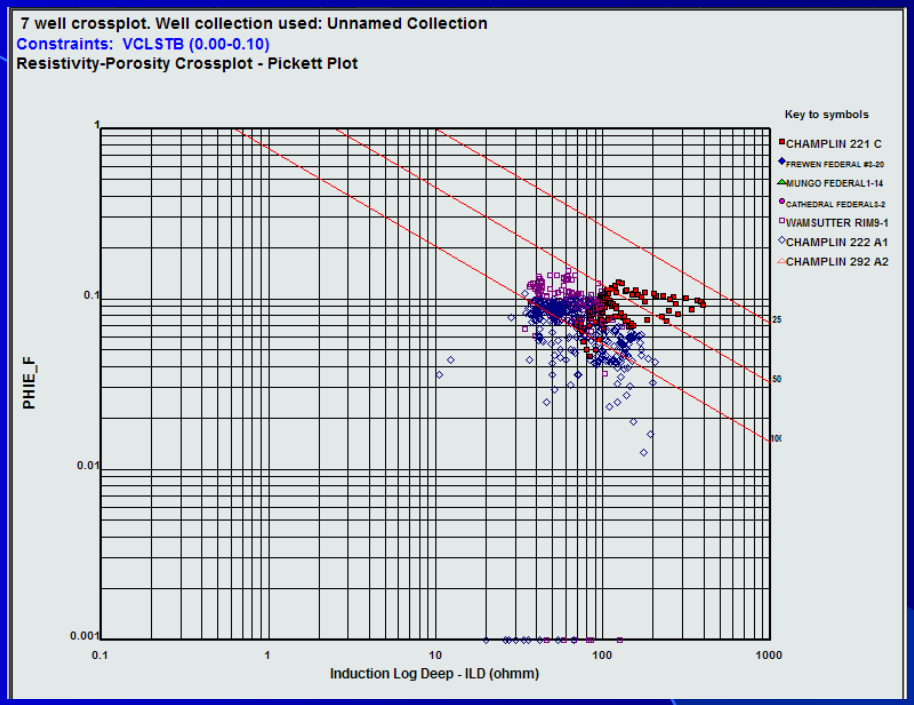
SP Change (Gas-Water Boundary)

Low salinity water in aquifer

Despite difficulties, SP to Rw calculations show a dramatic shift in formation water salinity in the upper (more saline) and lower (fresher) parts of the formation.

Pickett Plot Gas Zone & Aquifer





Gas Zone
Upper & Middle Almond
Vclay<10%

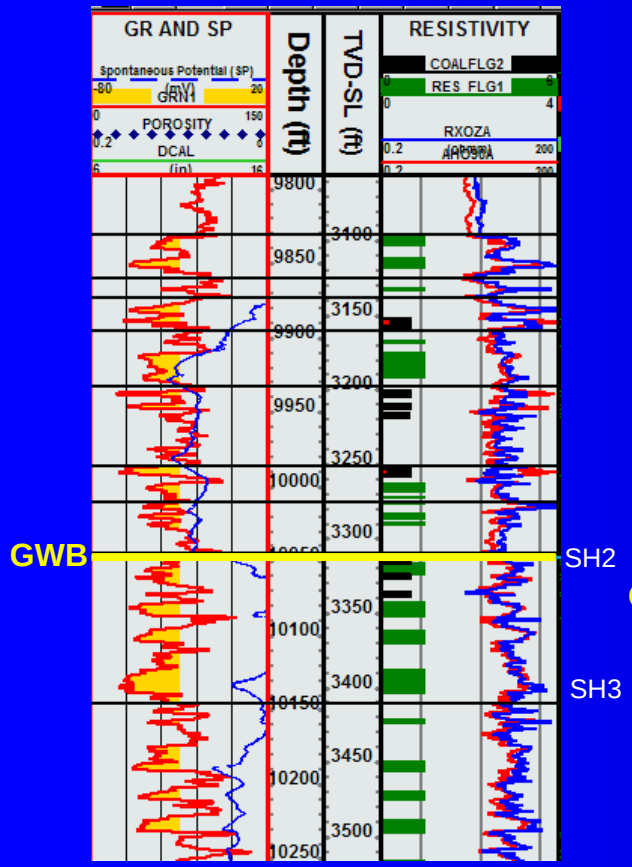
a=1.0, n=2.00, m=1.74
Rw=0.17 @ 200F
NaCl=13,000 ppm

Water
Lower Almond & Ericson
Vclay<10%

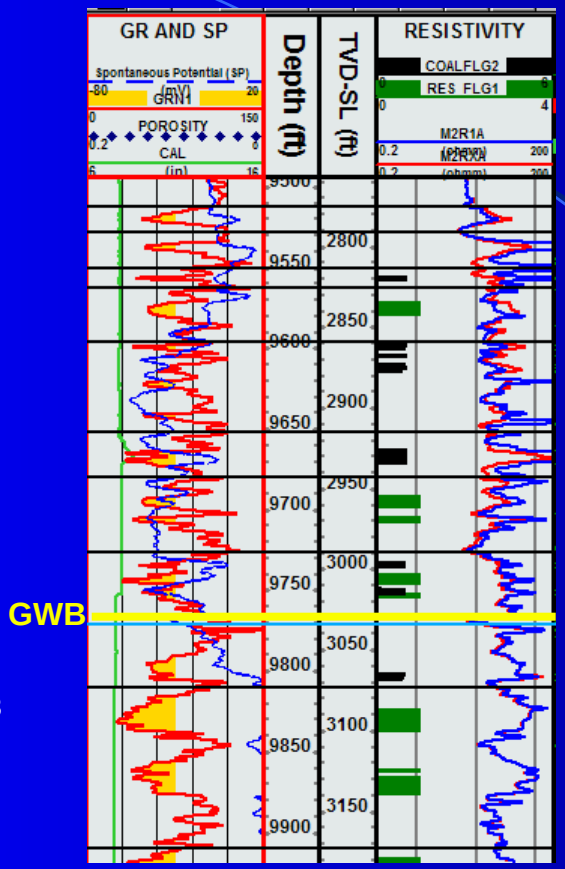
a=1.0, n=2.00, m=1.74
Rw=0.63 @ 200F
NaCl=3,500 ppm

Gas-Water Boundary & Coal & Wells

Wamsutter Rim 17-1



Cathedral Federal 3-2



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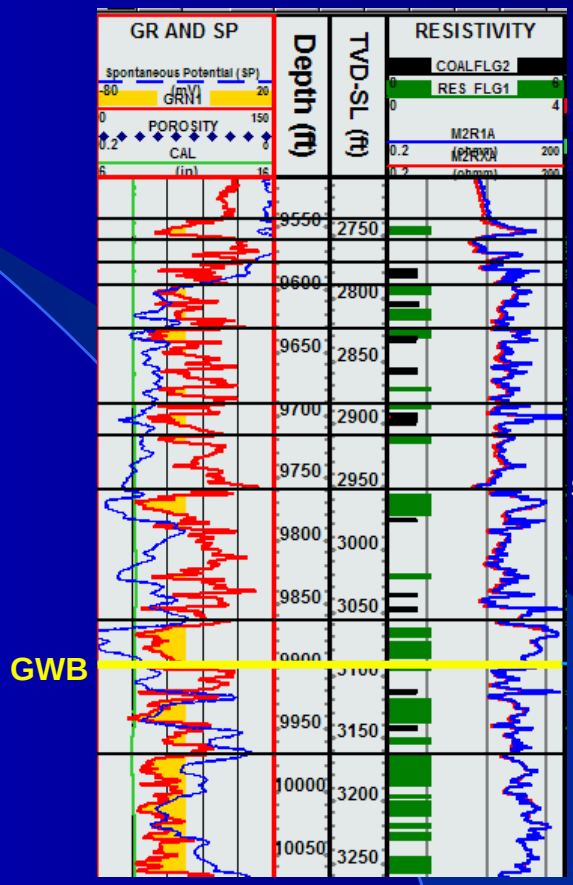
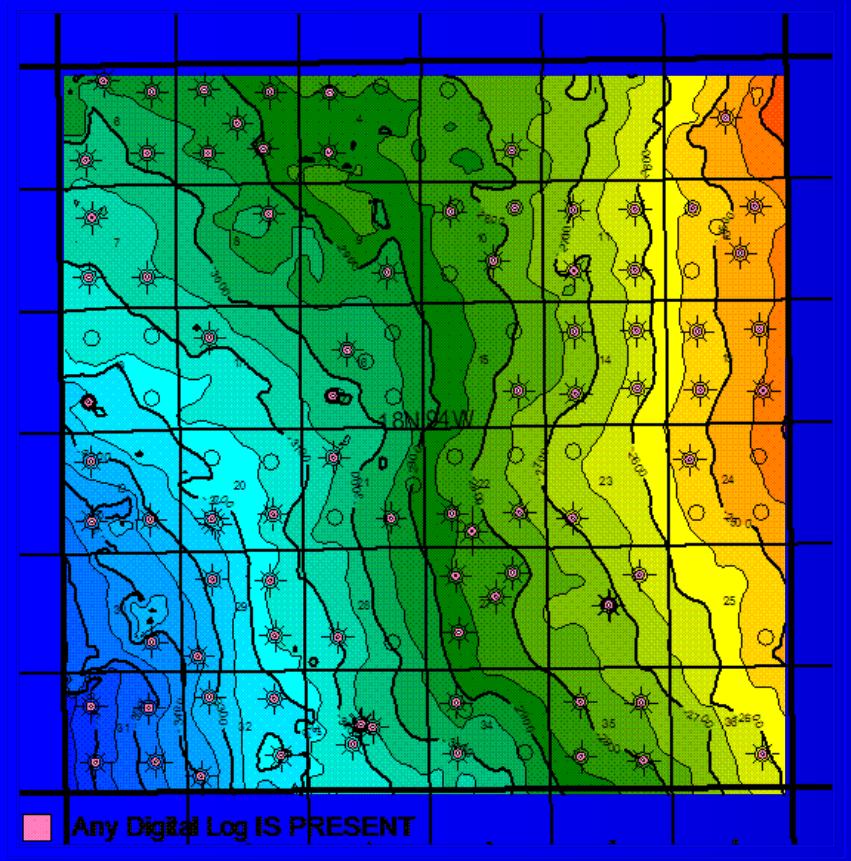


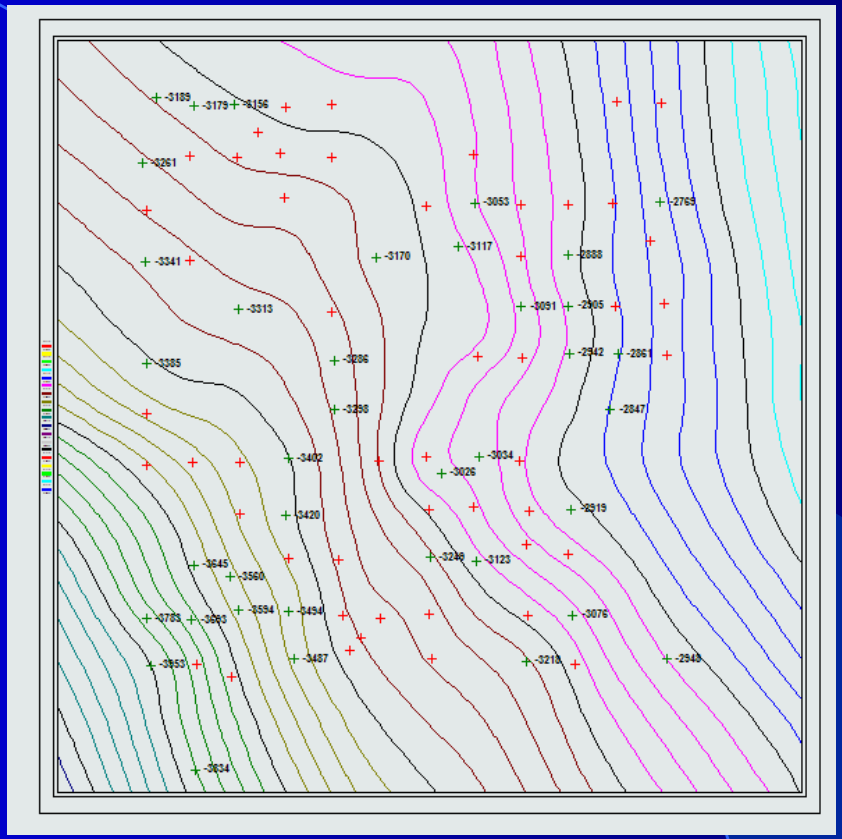
Gas-Water Boundary is picked based on SP and/or Resistivity curves.
Generally near Almd_SH2 and Almd_SH3 picks in this township.
Usually appears near first significant appearance of coals, which is a presumed local gas source.
Follows dipping structure, but not rigorously; therefore, is a boundary between discontinuous gas-charged
& aquifer sands rather than an actual contact.

SP-GWC Structure Map

Structure Map on Top Almond



Structure Map on Gas-Water Boundary



Gas-Water Boundary follows dipping structure, but not rigorously; therefore, this is a boundary between discontinuous gas-charged & aquifer sands rather than an actual contact.

Testing Gas-Water Boundary Hypothesis

The depth of the gas-water boundary was compared to the initial fluid production in 41 wells as reported in the Wyoming Oil and Gas Commission website.

Initial Production tests above gas-water boundary (15 wells)

< 10 BWPD	**17 tests**
11-20 BWPD	**3 tests**
21-30 BWPD	**2 tests**

Initial Production tests below gas-water boundary (26 wells)

<25 BWPD	**7 (4 not perf'd in permeable sand below GWB)**
25-50 BWPD	**2 tests**
>50 BWPD	**20 tests**

Conclusions

- High Quality Water Chemistry has Improved Formation Evaluation in the Field Study Area
  - SP used to determine gas-water boundary
  - Supported by initial production data (75% agreement)
  - Useful for perforation and completion strategy
- Gas-water Boundary Usually Found Near Base of Significant Almond Coals (a local source for gas?)
- Sands are a series of discontinuous lenses