Reservoir Characterization for Enhanced Oil Recovery: From Outcrop to Subsurface

Mark Tomasso

1 Enhanced Oil Recovery Institute, University of Wyoming, Laramie, Wyoming 82071, USA
Presentation Objectives

- 2008 project summary by research theme.
- The 3D paradigm.
- Examples from each research theme:
  1. Reservoir characterization - Fiddler Creek Field (Muddy Sst).
  2. Outcrop characterization - Sand Creek (Casper Sst).
  4. Developing research - Minnelusa database query.
- Future work.
1. Reservoir characterization, assessment, and/or static geological modeling:
   - Fiddler Creek (Underwood Oil and Gas) - May 2008.
     - Muddy/Newcastle Sandstone.
   - Multiple other field studies completed or ongoing.
     - Tensleep, Minnelusa, Wall Creek, Lakota.

2. Outcrop characterization:
   - Casper Sandstone, Sand Creek, Albany County - ongoing.
     - Phase 1 outcrop characterization (stratigraphy, structure, lidar).
3. Subsurface geophysical interpretation and modeling:

- **Teapot Dome (EORI / RMOTC Pilot) - August 2008.**
  - Modeling seismic response to CO$_2$ injection at the well.
  - Basic seismic survey design parameters, interaction with seismic acquisition vendors.

- **Tensleep field study - August 2008.**
  - Seismic interpretation and attribute analysis to define fracture pathways.

- **Forward seismic modeling - ongoing.**
  - Developing new techniques for quick and accurate 3D forward seismic modeling of outcrop analogs and subsurface reservoir models.
4. Developing research:

- Integrate EORI database (Murrell) and GIS capability (Reyes) to analyze data - ongoing.
  - Come up with and answer research questions in a spatial context.
  - Ties into other EOR options - chemical flooding, etc.
- **Tensleep-Minnelusa-Casper regional framework - ongoing.**
  - Development of an updated gross depositional framework model.
The 3D Paradigm

• Geology is 3D!
• Address sub-surface uncertainty in correlation and distribution using 3D seismic and outcrop studies.

Sinuous slope channel complex, Beacon Channel
Pyles et al. (in press)

Tidal channel, Dry Wash
Dalia “Green Channel Complex”,
Abreu et al. (2003)
The 3D Paradigm

Subsurface Interpretation and Characterization
Seismic and Well data (wire-line logs, core, etc.)

Element Scales for Stochastic Modeling

Reservoir Model

Upscaling

High-Resolution Outcrop Geological Model

Seismic Forward Model

Compare Known Outcrop Features at Seismic Scale to Original Seismic Image
1) Reservoir Characterization

Fiddler Creek Example
• 212 wells with SP log data.
  • Use to define stratigraphic framework.
  • Characterization of SP log shape to facies and depositional regime.
• 49 wells with other data (other logs, information from well files, etc).
• 68 wells (at minimum) with no data.
• 85 wells with core porosity and/or permeability.
• 0 wells with currently available core in reservoir interval.
• Associated maps and production data.

Fiddler Creek: Location and Data

• On eastern margin of Powder River Basin.
• Lower Cretaceous Muddy/Newcastle Sandstone incised-valley fill reservoir.
• Underpinned by major basement lineaments (Fiddler Creek and Weston/Hat Creek).

Modified from Martinsen (2003), Marrs & Raines (1984)
*Top Newcastle Formation = transgressive surface of erosion (TSE)*

- Fiddler Creek: SP Log Picks
- Mowry Shale datum
- Shell Creek Shale
- Springen Ranch Mbr?
- Ute Mbr?
- Skull Creek Shale
- Sequence B
- Sequence A
- 0) Incomplete
- 1) Rounded/Cylinder
- 2) Bell
- 3) Funnel
- 4) Inverse Serrate
- 5) Serrate
- 6) Modified
- 7) Flat
- Blocky
- Upward-fining
- Upward-coarsening
- Spikey
- Serrate
- Upward coarse/fine
- Sand-poor
- Unknown; probably channel
- Channel fill, axis
- Channel fill, off-axis/point-bar
- Crevasse splay
- Levee
- Floodplain
- Modified channel fill; possible OWC?

Newcastle Sandstone isopach: Thicks should indicate good sand, and may illustrate channel meander patterns.

Top Newcastle Sandstone, dip attribute: Possible Weston/Hat Creek basement lineament.

Probable Weston/Hat Creek basement lineament: Linear features in East Unit parallel to NNW-SSE basement trend.

Isolated structures?:
Fiddler Creek: Facies Modeling

Representative facies model

- Object-based stochastic modeling:
  - Rule-based modeling of individual channels, crevasse splay, and levees.
  - Based on channel aspect ratio, sinuosity, channel probability mapping.
Significant challenges:
- Large field with many wells.
- Significant reservoir heterogeneity - channel compartmentalization.
- Significant structural heterogeneity - fractured vs. non-fractured sectors.

Carry out sector modeling for each unit (west, east).
- Approximates to reservoir structural zonation.
2) Outcrop Characterization

Sand Creek Example
Sand Creek: Casper Sandstone

- Crops out in a series of hoodoos to the SW of Laramie, WY.
- Formed the basis of the seminal work by Knight (1929).
- Deposited on top of fluvial sheet deposits of the Fountain Fm.
Sand Creek: Outcrop Dataset

- Interpreted photopan correlations.
- Multiple stratigraphic logs.
- Multiple paleocurrent data.
- Terrestrial lidar scanning.
Lower Casper Sandstone comprises small- to large-scale dune cross-bedding, interspersed with ripple-laminated damp interdune, sheet flood sediments, and dolomitic limestones.
Sand Creek: Upper Casper Sst

- Generally truncates underlying Lower Casper.
- Upper dunes heavily slumped and fractured.
• Casper Sandstone is fractured.
• 3 main fracture sets, orthorhombic to orthogonal:
• The aim of the study is to provide increased understanding of the effect of architectures that cannot be resolved using seismic or sparse well data.

• Build a detailed geological model:
  • Deterministic in architectural styles.
  • Stochastic for reservoir properties, derived from producing Wyoming reservoirs.

• Use the model as a test-bed:
  • Uncertainty in well-based correlations.
  • Flow modeling of matrix without/with known fractures.
  • Testing response of open, partially open, or closed fractures to well placement.
  • Testing upscaling effects.
  • 3D and 4D forward seismic modeling.
  • Use of seismic attributes in enhancing reservoir characterization
Forward Seismic Modeling Example
Spectral recomposition:

- A new technique in which 3D/4D forward seismic models are tailored to specific reservoirs and specific seismic images.
- Can be applied to both outcrop analogs and reservoir models.

Using full suite of frequencies found in the target seismic image, not just the dominant frequency.

Computationally cheap:

- 1D Ricker convolution, 3D exploding reflector modeling.
- A quick first-pass prior to advanced waveform techniques.
Forward Seismic Modeling

Tomasso et al., in review
Spatial delineation of API in Minnelusa reservoirs.

Developing: Minnelusa API, Structure


POWDER RIVER BASIN

Cartographer: B. Reyes

Legend
- County
- Basin
- Field
- Basement Fault
- Inferred Fault

Mean API
- 17.5 - 21.3
- 21.4 - 24.0
- 24.1 - 29.0
- 29.1 - 35.0
- 35.1 - 41.0

Kilometers
02.55 10 15 20
Developing: Minnelusa API, Structure


Satellite gravity data from Scripps Institution of Oceanography, UC San Diego; http://topex.ucsd.edu/cgi-bin/get_data.cgi

Gravity, mGals

- Basement Fault
- Inferred Fault

Mean API
- 17.5 - 21.3
- 21.4 - 24.0
- 24.1 - 29.0
- 29.1 - 35.0
- 35.1 - 41.0
Developing: Minnelusa API, Structure

Wyoming gravity data with interpolated basement lineament dividing high and low API Minnelusa oils

Gravity, mGals


Satellite gravity data from Scripps Institution of Oceanography, UC San Diego; http://topex.ucsd.edu/cgi-bin/get_data.cgi
1. Reservoir assessment, characterization, and/or static geological modeling:
   - Multiple field studies.
     - Tensleep, Minnelusa, Shannon, Wall Creek, Lakota.
   - Regional Minnelusa.

2. Outcrop characterization:
   - Casper Sandstone, Sand Creek, Albany County - ongoing.
     - Phase 2 outcrop characterization (strat., structure), static modeling.
     - Uncertainty analysis of well interpretation, effects of upscaling on flow modeling results.
   - Minnelusa Sandstone.
   - Muddy Sandstone.
3. Subsurface geophysical interpretation and modeling:
   - **Seismic interpretation for reservoir characterization.**
     - Obtain 3D seismic data over specific fields.
     - Interpretation of amplitude and attribute images.
   - **Forward seismic modeling.**
     - “Spectral recomposition” – production of forward seismic models tailored to a specific target real-world image; integration of noise; 4D modeling.

4. Developing research:
   - Integrate EORI database (Murrell) and GIS capability (Reyes) to analyze data.
   - **Tensleep-Minnelusa-Casper regional framework.**
     - Large-scale correlation of Tensleep-Minnelusa-Casper across Wyoming, with an updated gross depositional framework model.
Acknowledgements

State Legislature of Wyoming

EORI and Affiliated Researchers

Software & Technology
Ginger Paige (UW College of Agriculture)

Other
Bruce Lewis (Lewis Ranches)