Reservoir Characterization for Geological Static Modeling

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Acknowledgments

State Legislature of Wyoming

EORI
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External

Software and Technology

Optech
InnovMETRIC
Schlumberger
BLUEBACK Reservoir
MADAGASCAR

EORI
Aims

• The problem.
• Data.
• Modeling framework.
• The use of analogs.
• Integration of regional data.
• Modeling decision tree.
• Modeling for faults and fractures.
• Conclusions.
Characterization and modeling of a subsurface reservoir is typically carried out using sparse data-sets:

- **Wells**
  - *Typically on a 20-40 acre (200-400 m) spacing in Wyoming.*
  - *Wire-line logs – ~1-2’ vertical sample rate and radial penetration.*
  - *Core – width of well (not all wells are cored).*

- **Seismic**
  - *2-D or 3-D, if lucky. Many old fields do not have these data.*
  - *Spatial resolution varies, but generally poor.*
    - ~20 m at 30 Hz vertical – frequency sweep and recovery;
    - 11-33 m horizontal – bin spacing.
The Problem

- E&P phases typically reliant on subsurface information derived from wells and seismic to delineate reservoirs and development.
- Trying to characterize a 3-D object with a series of widely spaced 1-D scan lines and seismic images.
The Problem

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

Element Scales for Stochastic Modeling

Reservoir Model

High-Resolution Outcrop Geological Model

Seismic Forward Model

Upscaling

Traditional- and Lidar-based Outcrop Interpretation and Characterization

Compare Known Outcrop Features at Seismic Scale to Original Seismic Image
The Problem
Sources of Data for Modeling

- Standard sources of data used in modeling are from wells and, ideally, seismic.

- Wire-line logs:
  - Either raster or digital (LAS).
  - If getting digitized, QC against the raw images.

- Core:
  - Essential for building a rigorous facies model; not always available.
  - Core analyses for petrophysics; compare to wire-line logs.

- Seismic:
  - Provides spatial information not delivered by wells.
  - Vertical and lateral resolutions not always great - lack of information on detailed heterogeneity.

- Production data:
  - Not always available digitally (e.g. pre-1974 in WY).
Sources of Data for EOR

- In WY, fields have been developed since c. 1915, leading to specific data issues when undertaking characterization.
- Wire-line logs:
  - Vintage logs (GR etc) need to be converted.
  - Mostly raster; need to digitize for maximum benefit.
- Core:
  - Not always available (check USGS/ BEG/ other sources).
  - Core analyses for petrophysics (USGS); compare to wire-line logs.
- Seismic:
  - Generally not available.
- Production data:
  - Many parts mis-recorded or not recorded (e.g. gas production when flaring in the early days of the field).
- In general, the older the field is and the more times it has passed through different companies, the less data available.
Modeling Framework

Data acquisition and digitization

- Top picks, mapping
- Structural framework
- Stratigraphic framework
- Model resolution?
- Modeling type (kriging, SGS, MP statistical)?
- Facies model
- Flow units
- Petrophysical model

Core, wire-line logs

Wells, seismic

Core, wire-line logs, production data, analogs

Geology, number of wells

Element scaling, well spacing

Core, wire-line logs
Modeling Framework: Structure

• A structural framework forms the main background to the model.
• Best accuracy comes from structural interpretation of 3-D data.
• Can use wire-line log picks integrated with production data to build a less-robust model.
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Modeling Framework: Structure

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- Can use wire-line log picks integrated with production data to build a less-robust model.
- Contour top surface and run structural attributes on this, e.g. structural dip.

Structural dip attribute of wire-line log constrained Top Newcastle Sandstone, Fiddler Creek Field, Weston County, WY.

From Tomasso & Wo, 2009.
Modeling Framework: Facies

- Ideally core available - only real rock from the reservoir.
- Integrate with wire-line logs - neural networking?
- If no core, relate facies/ depositional environments from wire-line log shapes.
Modeling Framework:

- Ideally core available - only real rock from the reservoir.
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Modeling Framework: Facies

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- Integrate with wire-line logs - neural networking?
Generalized depositional model, vertical sequences and electric log profiles of a meander belt sand body produce by a high sinuosity channel.

(A) and (B) illustrates a complete fining-upward sequence typical of the mid or down-stream point bar.

(C) illustrates the truncated vertical sequence commonly found in the upstream end of the bar.

Modeling Framework: Facies

- If no core, relate depositional environment and facies from wireline log shapes.

Depositional environments from SP log shape, Fiddler Creek Field, Weston County, WY.

From Tomasso & Wo, 2009.
Modeling Framework: Petrophysics

- Best case workflow is to integrate core with log data.
  - Need an accurate core-to-log shift.
- Need to choose correct parameters to be used in any calculation.
- Seismic inversion.
Modeling Framework: Petrophysics

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- Minnelusa Fm. core-measured porosities with core-to-log shift applied.
Modeling Framework: Petrophysics

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- Time-averaged Wyllie equation - good fit for sonic porosity vs. core.
Modeling Framework:

- Need to choose correct parameters to be used in any calculation.

Composite density porosity for Madison Fm., SW Wyoming. Using integrated core analysis data combined with density log cut-offs, model density porosity for a composite sequence of porous dolomites and tight limestones.

From Thyne et al., in press.
From Thyne et al., in press.
Modeling Framework: Petrophysics

- Seismic inversion integrates wire-line log data with seismic volume to extract petrophysical properties from the volume.

- Amplitude volume of a Wyoming reservoir.

Seismic image courtesy of True Oil LLC.
Modeling Framework: Petrophysics

- Seismic inversion integrates wire-line log data with seismic volume to extract petrophysical properties from the volume.

Seismic image courtesy of True Oil LLC.
The Use of Analogs

• Even with good well correlation, knowledge of the stratigraphic heterogeneity away from the wells is limited.
• Study of modern, outcrop and field analogs allows us to examine inter-well and sub-seismic scale heterogeneities in order to provide rules for reservoir modeling.

Field analogs:
• Look for fields with similar architecture.
• WGA field sheets - show reservoirs with similar framework and petrophysical/reservoir parameters.
• Published studies - AAPG, SPE, Marine & Petroleum Geology, etc.

Outcrop and modern analogs:
• A combination of traditional and novel techniques.
• Quantitative characterization and measurement.
• Direct input into 3-D geologic models.
• Provide a test of new modeling techniques.
• Forward seismic modeling provides analogs for seismic interpretation.
The Use of Analogs: Fields

(A) Isopach of fine-grained sandstone, siltstone and mudstone, constituting the fill of the abandoned channel overlying the Q Sandstone at Little Creek Field, LA, and underlying a regional marker that defines the top of the fluvial interval.

(B) Cross sections through the Q Sandstone and overlying beds in Little Creek Field, LA. From Werren et al. (1990).

Use of field analog data for a channelized reservoir, Fiddler Creek Field, Weston County, WY.

From Tomasso & Wo, 2009.
The Use of Analogs: Modern

- Early example of tripartite estuarine sedimentation zonation, Yaquina Bay, Oregon (original from Kulm and Byrne, 1967). From Boyd et al. (2006).

Use of modern analog data for a channelized reservoir, Fiddler Creek Field, Weston County, WY. From Tomasso & Wo, 2009.
The Use of Analogs: Modern

Google Earth image of Upper Minnelusa relative lowstand analog, eastern Qatar.

From Tomasso et al., 2010a, 2010b.
The Use of Analogs: Modern

Google Earth image of Upper Minnelusa relative highstand analog, northern Brazil.

From Tomasso et al., 2010a, 2010b.
The Use of Analogs: Outcrop

Quantification of reservoir heterogeneity and element scaling by characterizing outcrop analogs.
The Use of Analogs

Integration of traditional and modern field data acquisition, Chimney Rock Mbr., Rock Springs Fm., SW Wyoming.
From Tomasso et al., 2010c.

Martinsen et al., 1998.
The Use of Analogs: Forward Seismic Model

Forward seismic model of incised valley outcrop, Chimney Rock Mbr., Rock Springs Fm., SW Wyoming. This can be compared back to real-world seismic for analog interpretation purposes.

From Tomasso et al., 2010c.
The Use of Analogs: Forward Seismic Model

Forward seismic model of tidal channel outcrop, Ferron Sandstone, central Utah. This is compared back to real-world seismic from Teapot Dome, WY, for analog interpretation purposes of a sinuous channel in the uppermost Wall Creek Sandstone.

From Tomasso et al., 2010e.
Integration of Regional Data

• Although we typically deal with a single field at a time, knowledge of the regional geology can help inform the modeling process.
Integration of Regional Data

Recognition of high-resolution structural lineaments, which may indicate fracture zones, from regional analysis of the Upper Minnelusa Fm., Powder River Basin, WY.

From Tomasso et al., 2010a, b.
Modeling Decision Tree

• After assembling and integrating data, and making the subsurface interpretation, several decisions need to be made prior to modeling:
  • Model scaling - grid size in x, y, z to capture the relevant stratigraphic and elemental heterogeneity.
  • Modeling variograms and algorithms - choice of simple kriging, stochastic modeling, and object based modeling.
Modeling Decision Tree

- Model scaling - grid size in x, y, z to capture the relevant stratigraphic and elemental heterogeneity.
  - E.g. small enough to capture channel geometries.

![Modeling Decision Tree Diagram](image)

From Smith & Ecclestone, 2006.
Modeling Decision Tree

- Model scaling - grid size in x, y, z to capture the relevant stratigraphic and elemental heterogeneity.
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![Scales of Sedimentological Observations](image)

- Approximate seismic resolution
- What are the critical sub-seismic heterogeneities?
Modeling Decision Tree

- Model scaling - grid size in x, y, z to capture the relevant stratigraphic and elemental heterogeneity.

From Smith & Ecclestone, 2006.
Modeling Decision Tree

- Modeling algorithms - choice of simple kriging, stochastic modeling, and object based modeling.
Modeling Decision Tree: Variograms

- Quantitative description of variation of a property as a function of separation distance between data points.
- Based on principle that two points close together are more likely to have similar values than points far from each other.

From Schlumberger, 2009.

**Calculation process and setup:**
1. A **Search radius** and **Lag increment** must be defined => Decides the **Number of lags** and consequently the **Lag Distance**
2. All pairs of points in each **Lag** (bin) will be compared
3. For each Lag (with a given number of pairs), the average variation is calculated (squared difference)

**Variogram plot:**
1. The **Semi-variance** vs. **Lag distance** is plotted. These points (average variance per lag) make up the **Experimental Variogram** (black points)
2. A **Regression curve** (grey line) is made based on all plotted points
3. Fit a curve through the Experimental Variogram to create a 'best fit' **Variogram Model** (blue line)
Modeling Decision Tree: Variograms

- Primary data come from vertical heterogeneity in well logs.
- Wells often too far apart to calculate accurate horizontal variograms, so secondary data - seismic inversion, etc - can be used.

From Schlumberger, 2009.
Kriging is an interpolation of the data, honoring data inputs. If all parameters stay the same, the model result will be the same each time. Effects of modeling variability:

- Geologically accurate models come from variogram orientation with the conceptual model.
- Nugget values ~1 approximate the global mean at all sample points; low nugget values give higher heterogeneity or variability in the resultant model.
- Variogram range needs to be large enough to minimize localized well effects.
Kriging is an interpolation of the data, honoring data inputs.

If all parameters stay the same, the model result will be the same each time.

Effects of gridding algorithms:

- **Kriging**
  - Control over data influence range
  - Anisotropy handling
  - No extrapolation, fault boundaries
  - Not suitable for large input data/grids

- **Convergent**
  - Extrapolation control
  - Excellent fault handling
  - Suitable for large input data/grids
  - No anisotropy handling

- **Moving Average**
  - Suitable for any input data/grids
  - Anisotropy handling
  - No extrapolation, fault boundaries
  - Limited bulls-eye control

From Schlumberger, 2009.
Modeling Decision Tree: Gaussian Simln.

- Gaussian simulation honors the well data, input distributions, variograms and trends.
- Variogram and distribution used to create local variability, even away from input data.
- Stochastic - multiple representations to characterize uncertainty.

![Variogram Range](Range_500.png) ![Variogram Range](Range_5000.png) ![Nugget](Nugget_0.png) ![Nugget](Nugget_0.9.png)

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Nugget values ~1 approximate the global mean at all sample points; low nugget values give higher heterogeneity or variability in the resultant model.
Modeling Decision Tree: Gaussian Simln.

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From Schlumberger, 2009.

Variogram Model Type (Range: 5000m)

**Exponential** and **Spherical** models give quite similar results

**Gaussian** model gives smooth result
Stochastic Modeling Example

Representative facies model

Representative permeability model

Stochastic representation from a suite of facies and permeability models, Fiddler Creek Field, Weston County, Wyoming.

From Tomasso & Wo, 2009.
• Variograms from well data are a poor descriptor of geological heterogeneities.

Three different geological heterogeneities resulting in three similar variograms.

Multi-point statistics describes the spatial correlation from one-to-multiple points at the same time.

Variogram is replaced by a 2-D or 3-D training image which describes the geological facies in relative position to each other.

Patterns need to be stationary over the entire training image.

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**Modeling Decision Tree: Multi-Point Stats**

- Caers & Zhang, 2004
- Schlumberger, 2009
Modeling for Faults and Fractures

- Need to be able to incorporate effects of large- and small-scale faulting and fracturing into static model.
- Fault transmissibility - triangle plots (SGR), Allan diagrams.
- Sub grid-scale fault connectivity (e.g. Manzocchi et al., 2007).
- Development of dual phi/ k models if fracture permeability a big influence (e.g. Tensleep reservoirs in WY).
Modeling for Faults and Fractures

• Fault transmissibility - triangle plots (SGR), Allan diagrams.

Triangle diagram of depth vs. throw contoured for predicted permeability. This shows the area of juxtaposition of a stratigraphic sequence offset across a notional fault with a throw that varies between 0 and > sequence thickness. Heterolithic deep-water sequence, Mt. Messenger Fm., Taranaki, New Zealand.

From Childs et al., 2007.

Allan diagram drawn looking from the footwall side of a fault. Shale layers on the hanging wall are dark gray, on the foot wall are pale gray. Sand-on-sand juxtaposition are colored by SGR connectivity.

From Manzocchi et al., 2007.
Conclusions

• Developing accurate geological models depends on a holistic approach to the reservoir.
  • Stratigraphic heterogeneity, structure, etc.
• Data is of primary importance, especially with old fields.
• Well data provide the primary information for the reservoir.
  • Core and wire-line log based facies and petrophysics.
  • Vertical variograms - heterogeneity and cyclicity.
• Secondary data can be obtained from seismic images, conceptual models, regional data, and outcrop and modern analogs.
• Care should be taken to model at a grid scale that is appropriate for the level of reservoir heterogeneity that should be captured.
• Different modeling techniques can have markedly different results, even using the same data.
  • Newer techniques such as MPS can apply more accurate modeling of geological heterogeneity.
• Golden rule - QC, QC, then QC some more.
Recent discussion - “My model is good, your model is bad.”

Synopsis by Tim Wynn, AGR Petroleum Services (TRACS):

- Define modeling objectives as tightly as possible - fit for purpose.
- Volumetrics are not a universal criteria for a “good” model.
- Review quality and relevance of implicit assumptions and default practices - can have significant impact.
  - *E.g. are wells in the right place?*
- Models may contain errors of both conceptualization and implementation. Conceptual errors are harder to find and fix as concepts are subjective. Implementation errors easier to spot and fix.
- Well data do not always need to be honored in the sense of whole model histograms. If well sampling is biased and there are robust concepts and/ or good quality seismic data control there may be significant divergence.
- Iterate as often as possible between all geoscience disciplines. The result will nearly always be better.