Fault Facies Modeling: Applications in Various Sedimentary and Fault System Configurations*

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Abstract

Fault facies modeling is the process of generating 3D geological objects in the fault envelope in reservoir grid. The modeling is performed to capture reservoir heterogeneity caused by faulting. The conditioning factors for fault facies modeling are a fault product distribution factor (FPDF, a parameter describing the distribution of lithologies in the fault envelope) and a shear strain parameter.

FPDF is generated based on the following variables:

1. Pre-faulting sedimentary facies configuration in the fault envelope.
2. Fault displacement model, which is constrained based on the following input variables:
   - Fault core thickness as a function of fault throw.
   - Footwall and hanging wall damage zone widths as functions of fault throw.
   - The displacement percentage accommodated by fault core and damage zones.
   - The type of displacement function.

The strain parameter is generated based on the fault displacement model. The strain parameter, together with the FPDF, is used for creating the probability distribution that serves as an input in stochastic modeling of the fault facies. The fault facies volumetric proportion and spatial distribution in the resulting models can be partly controlled by applying simple manipulations to the fault facies probability distribution.

The modeling technique allowed many synthetic fault envelope models to be built easily by varying the modeling input variables constrained by field data. The resulting models were systematized in matrix form, capturing the variation of both sedimentary and fault system configurations. Currently 64 models have been implemented, each executed in 10 stochastic realizations. Quantitative analysis of the implemented models shows that the application of the modeling technique is able to reproduce natural fault envelope configurations formed under various sedimentary and structural configurations.
Fault facies modeling: Application in various sedimentary and fault system configurations

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Bartlett fault, Utah

Fault core

Footwall damage zone

Hanging wall damage zone

Lenses


Fault architectural elements
Fault Facies Project (Tveranger et al., 2005)

- Structural heterogeneities implementation in reservoir models
- Fault impact on fluid flow in petroleum reservoirs
- Development within the framework of existing industrial modeling tools
Previous studies

Syversveen et al. (2006), Soleng et al. (2007)

Fredman et al. (accepted, AAPG bulletin)

Skorstad et al. (2007)
Objectives

• Improvements

• Reproducing meso-scale observations

• Modeling input vs. resulting geo-model configurations
Outline

• Introduction
• Workflow and modeling aspects
• Results and analysis
• Conclusions
Conventional geo-cellular models
Workflow:
- Syversveen et al. (2006)
- Fredman et al.
(accepted, AAPG Bulletin)
Workflow: geo-cellular modeling
Workflow: FZ gridding (in Havana)
Workflow: SF resampling
Workflow: SF restoring

- Facies 2: Shale
- Facies 1: Sandstone

Dimensions: 1m x 2m x 8m
Workflow: create lithologic distribution
Workflow: create shear strain
Workflow: FF probability distribution
Workflow: FF pixel-based modeling
Workflow: grid merging (in Havana)
Displacement model (FPDF)
Displacement model – variables

FPDF variables:

1. FC thickness & DZ width
2. Throw accommodated by FC & DZ
3. Type of displacement function
FPDF variables:

1. FC thickness & DZ width
2. Throw accommodated by FC & DZ
3. Type of displacement function

Antonellini and Aydin (1995)
Displacement model – subsurface data

FPDF variables:
1. FC thickness & DZ width
2. Throw accommodated by FC & DZ
3. Type of displacement function

Hesthammer and Fossen (2001)
Displacement model – variable modification

FPDF variables:
1. FC thickness & DZ width
2. Throw accommodated by FC & DZ
3. Type of displacement function
Displacement model – variable modification

FPDF variables:

1. FC thickness & DZ width

2. Throw accommodated by FC & DZ

3. Type of displacement function
Lithologic distribution parameter

CA/7L/86/12/90/Q2-C

CB/5L/86/12/90/Q4-Q2
Shear strain
Shear strain

\[ Shear \ strain \ = \ \gamma \ = \ tan \ \psi \ = \ \frac{\Delta X}{Y} \]

\[ \gamma_i = tan \ \psi_i = \frac{t_i - t_{i-1}}{dx_i . \sin \theta} \]

Davis and Reynolds (1996)
Shear strain

CA/7L/86/12/90/Q2-C

CB/5L/86/12/90/Q4-Q2
Fault facies probability distribution
Fault facies probability distribution

Cross sections perpendicular to fault plane
Fault facies probability distribution
Fault facies

- CA_5L_76_12_95_Q2-C
- H-strained sh in FC
- L-strained sh in FC
- H-strained sh in DZ
- L-strained sh in DZ
- Undeformed sh
- H-strained sst in FC
- L-strained sst in FC
- H-strained sst in DZ
- L-strained sst in DZ
- Undeformed sst
Fault facies – fault core

Bartlett fault, Utah

Footwall damage zone

Fault core


H-strained sh in FC
L-strained sh in FC
H-strained sh in DZ
L-strained sh in DZ

10
9
8
7

1m

CA_5L_76_12_95_Q2-C
Fault facies – damage zones

Tayeba Mines fault, Western Sinai

Braathen et al (in prep.)
Berg and Skar (2005)
Complete workflow

- Fault plane modeling
- Horizons modeling
- Zone gridding
- Sedimentary facies (SF) modeling
- SF petrophysical modeling
- Fault zone gridding
- Fault facies modeling
- FF petrophysical modeling
- Grid merging

- Resample SF
- Restore SF
- Set up input variables for displacement model
- Apply displacement model: lithologic distribution
- Apply displacement model: shear strain
- Create FF probability distribution
- Pixel-based FF modeling
- Change input variables of displacement model
- Change fault system configuration
- Change sedimentary facies configuration
Outline

- Introduction
- Workflow and modeling aspects
- Results and analysis
- Conclusions
Matrix of geo-models

<table>
<thead>
<tr>
<th>Configuration A, fault throw (FT) = 43 m</th>
<th>Configuration B, @ FT = 22 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>DZ width = 2 FT</td>
<td>DZ width = 1.7 FT</td>
</tr>
<tr>
<td>FC thick. = 0.27 FT</td>
<td>FC thick. = 0.27 FT</td>
</tr>
<tr>
<td>FCDP = 90%</td>
<td>FCDP = 90%</td>
</tr>
<tr>
<td>FC thick. = 0.18 FT</td>
<td>FC thick. = 0.18 FT</td>
</tr>
<tr>
<td>FCDP = 95%</td>
<td>FCDP = 95%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 sedimentary facies</th>
<th>5 layers</th>
<th>16 geo-models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion: 0.6 sst, 0.4 sh</td>
<td>7 layers</td>
<td>16 geo-models</td>
</tr>
<tr>
<td>CA_5L_86.12_90_Q4-Q2</td>
<td>Q4-Q2</td>
<td></td>
</tr>
<tr>
<td>CA_5L_86.12_95_Q2-C</td>
<td>Q2-C</td>
<td></td>
</tr>
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<td>CA_5L_86.12_90_Q4-Q2</td>
<td>Q4-Q2</td>
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<td>CA_5L_76.8_95_Q4-Q2</td>
<td>Q2-C</td>
<td></td>
</tr>
</tbody>
</table>

- 64 models
- 640 realizations
Modifying fault system configuration

Geo-model characteristics

**Configuration A**

**Configuration B**
Modifying sedimentary facies configuration

Geo-model characteristics

Distance along the fault envelope (m)
Distance in perpendicular-fault direction (m)

5 layers

7 layers

5 layers

7 layers
Modifying DZ width and FC thickness

Geo-model characteristics

Wide DZ or FC

Narrow DZ or FC

Volumetric proportion

Distance in perpendicular-fault direction (m)
Modifying FC throw

Geo-model characteristics

Displ. %: Low in FC
High in DZ

Displ. %: low in FC, high in DZ

Displ. %: high in FC, low in DZ
Modifying the type of displacement function

**Geo-model characteristics**

Function: Q4 in DZ, Q2 in FC

Function: Q2 in DZ, C in FC
Conclusions

• Improvements
  – Displacement models

• Reproducing meso-scale observations
  – Sequential indicator simulation

• Modeling input vs. resulting geo-model configurations
  – Fluid flow
  – Faulted reservoir performance
  – Upscaling procedure
Flow characteristics

PermX - Day 0
Flow characteristics

Oil saturation - After 1 month
Flow characteristics

Oil saturation - After 2 months
Flow characteristics

Oil saturation - After 3 months
Flow characteristics

Oil saturation - After 4 months
Flow characteristics

After 5 months

Oil saturation - After 5 months
References


Thank You!