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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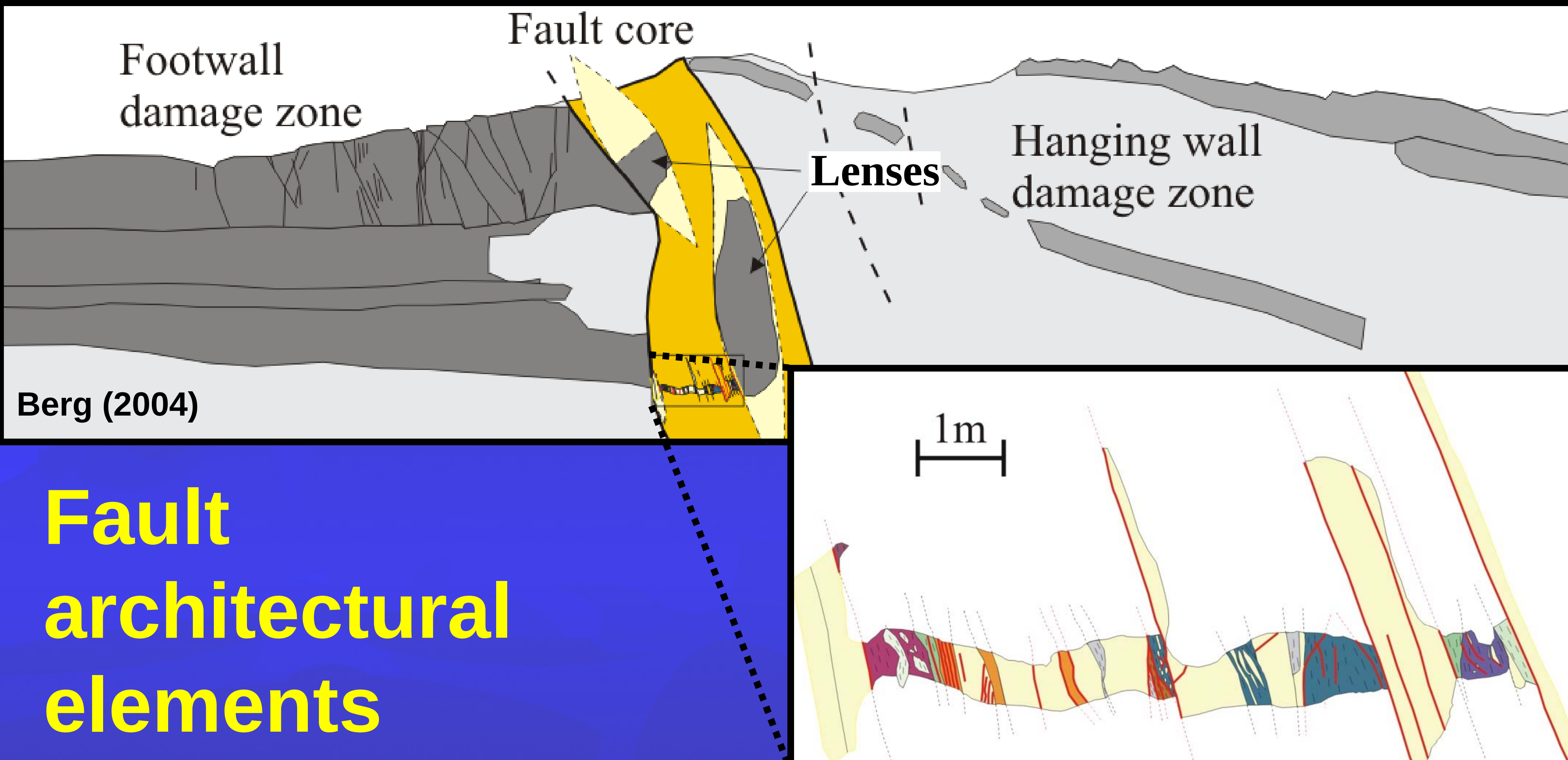
Centre for Integrated Petroleum Research (CIPR)
University of Bergen, Norway

Outline

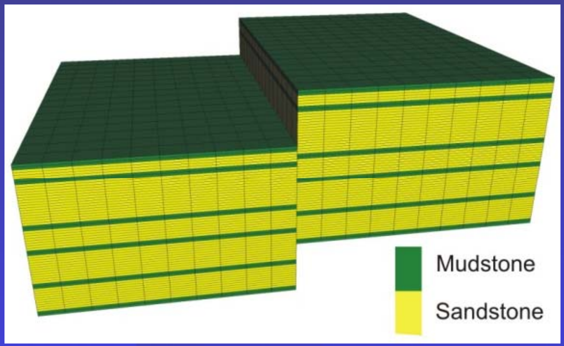
- Introduction
- Workflow and modeling aspects
- Results and analysis
- Conclusions

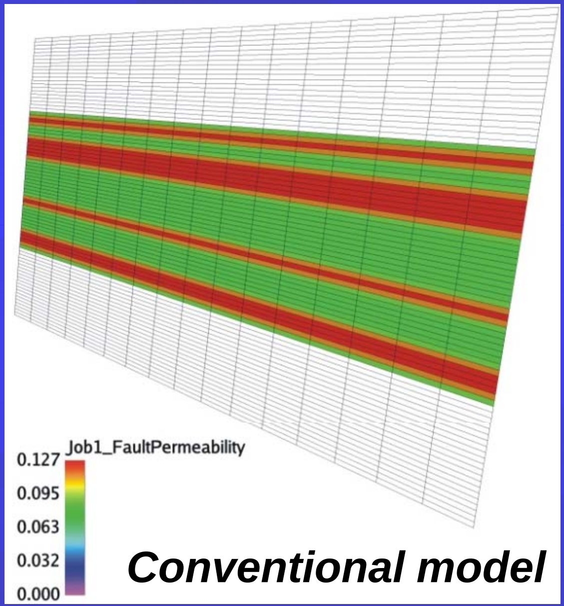


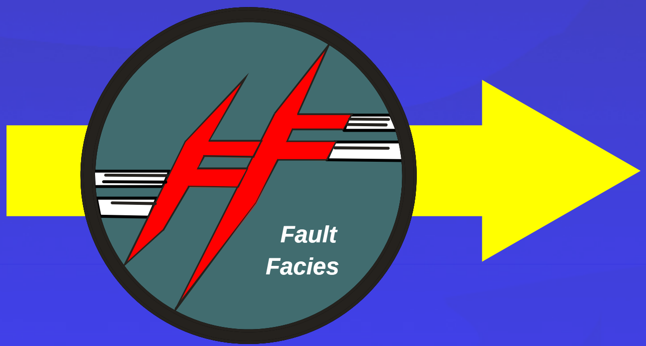
Fault architectural elements

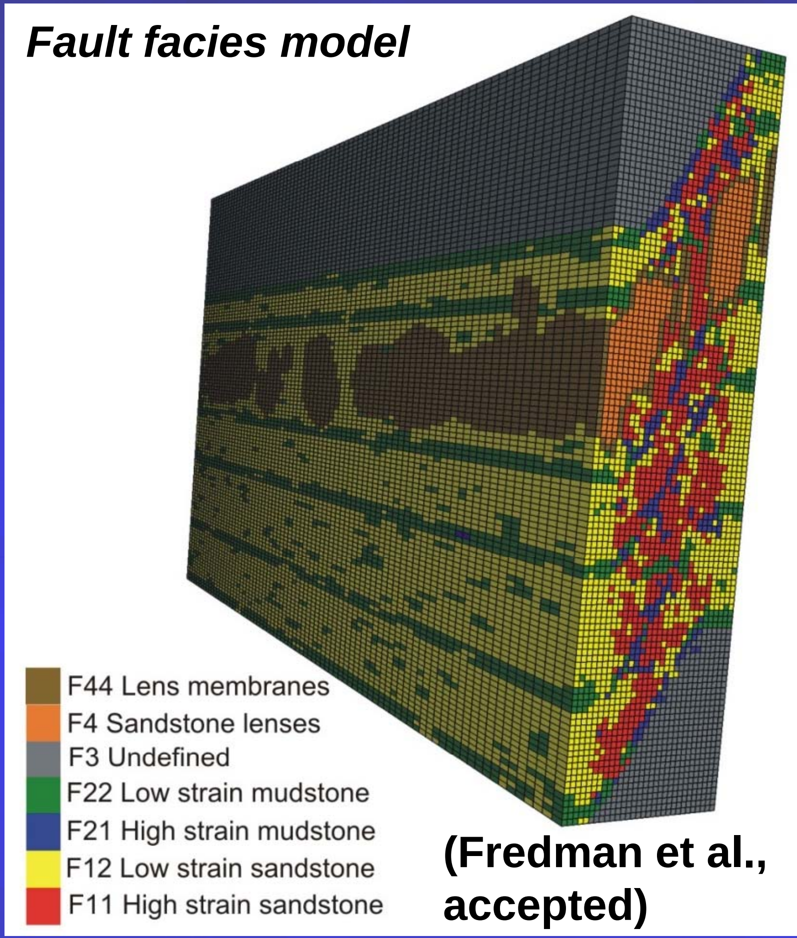
Fault Facies Project (Tveranger et al., 2005)

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



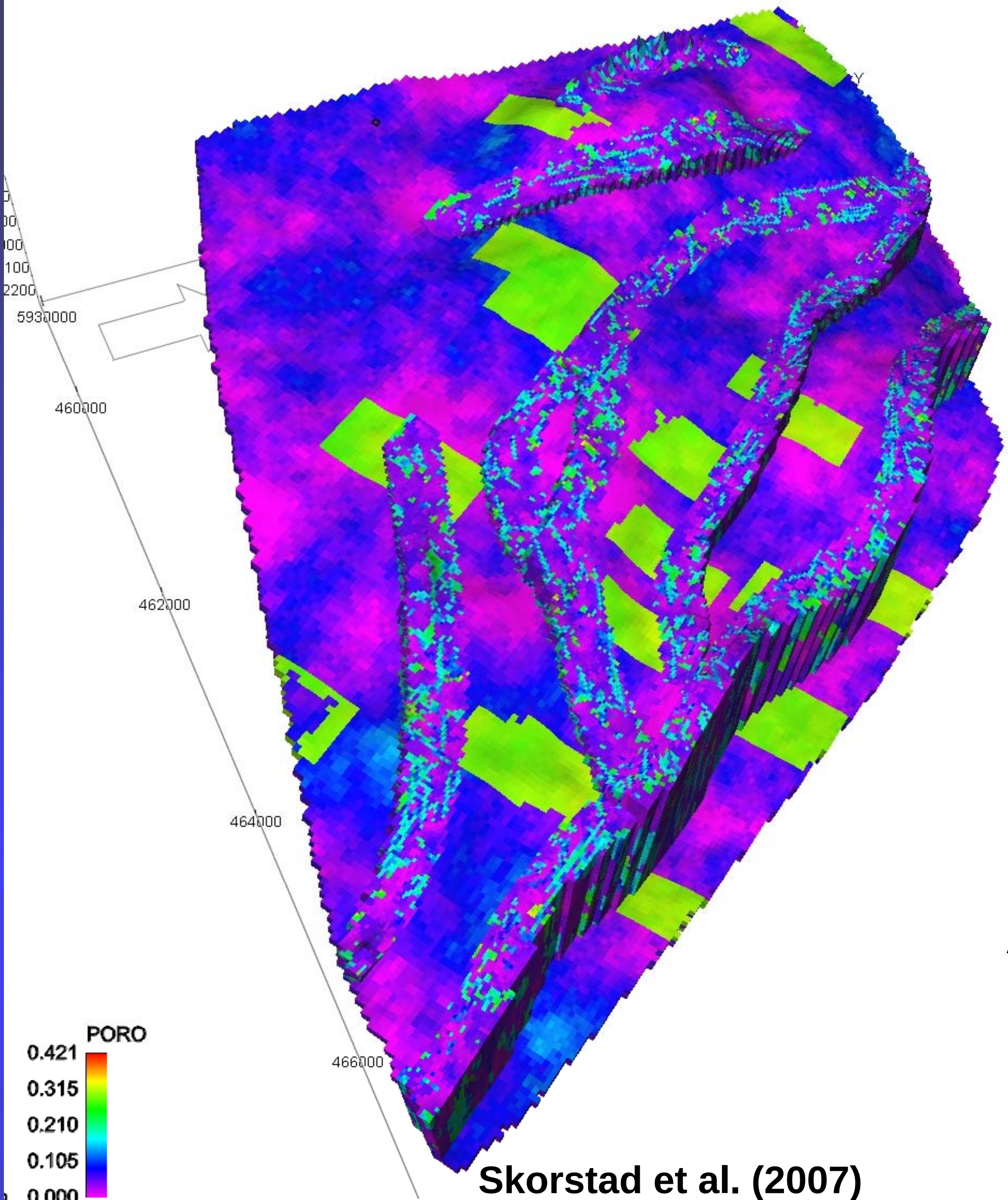




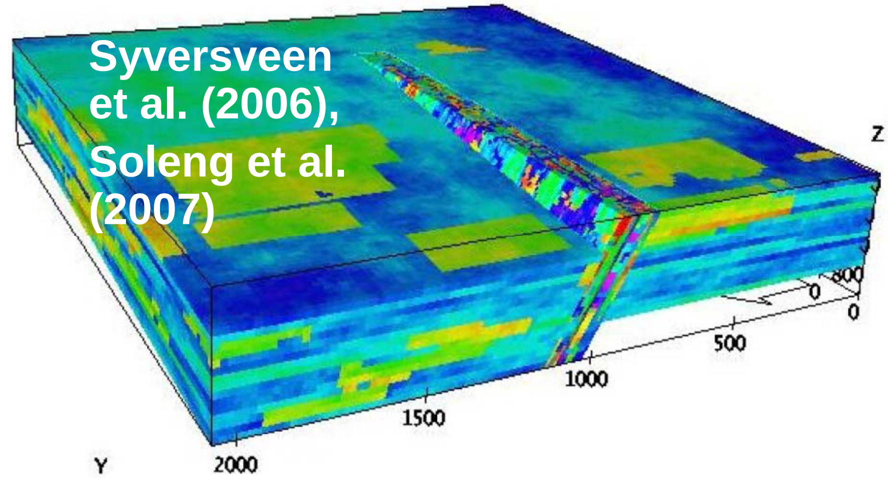


(Fredman et al., accepted)

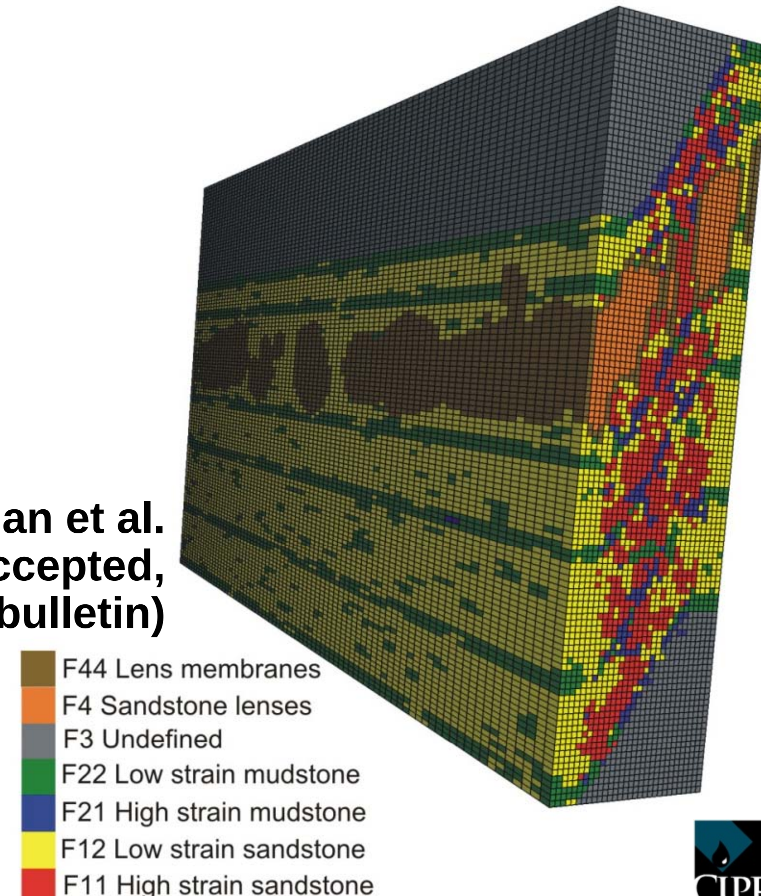
Previous studies



Skorstad et al. (2007)



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



Fredman et al. (accepted, AAPG bulletin)

Objectives

- Improvements
- Reproducing meso-scale observations
- Modeling input vs. resulting geo-model configurations

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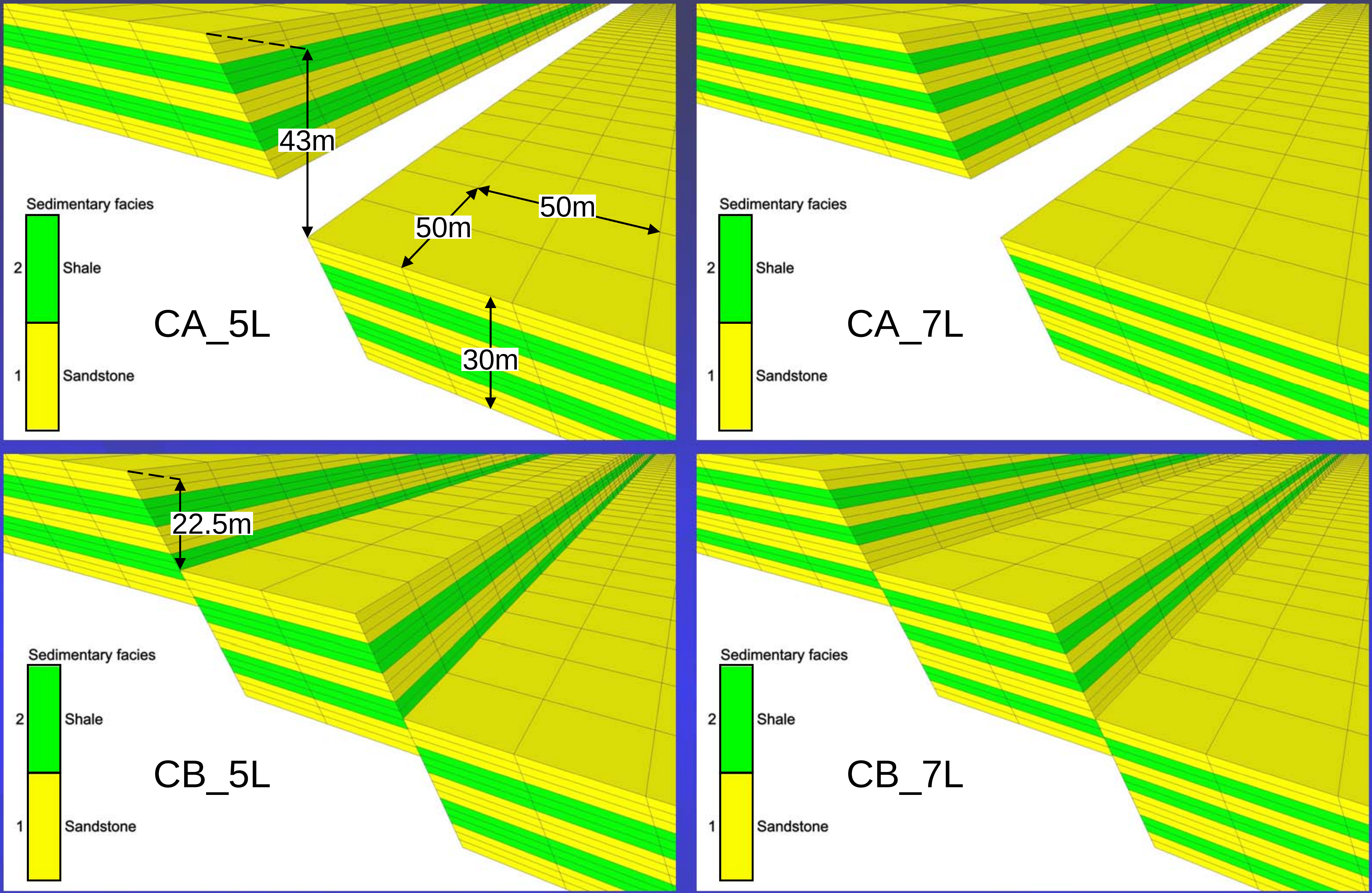
- Workflow and modeling aspects
- Results and analysis
- Conclusions

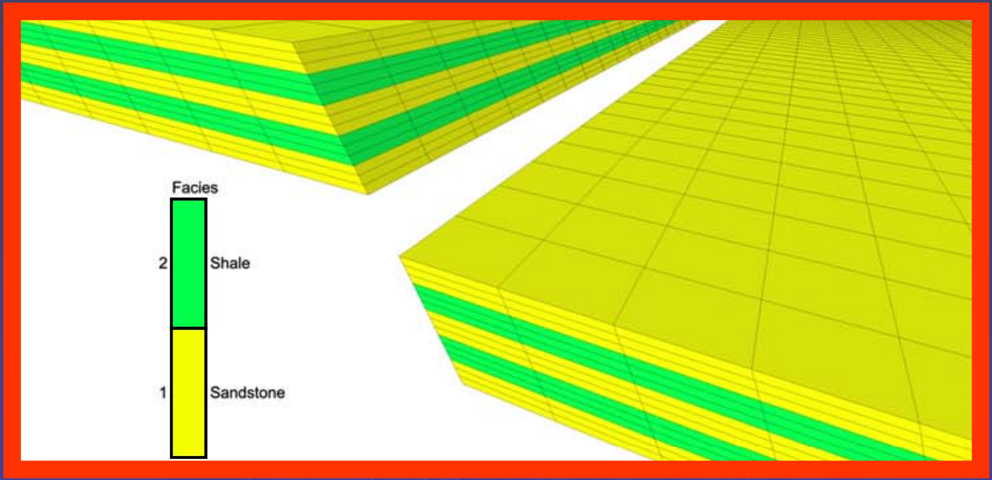
Conventional geo-cellular models

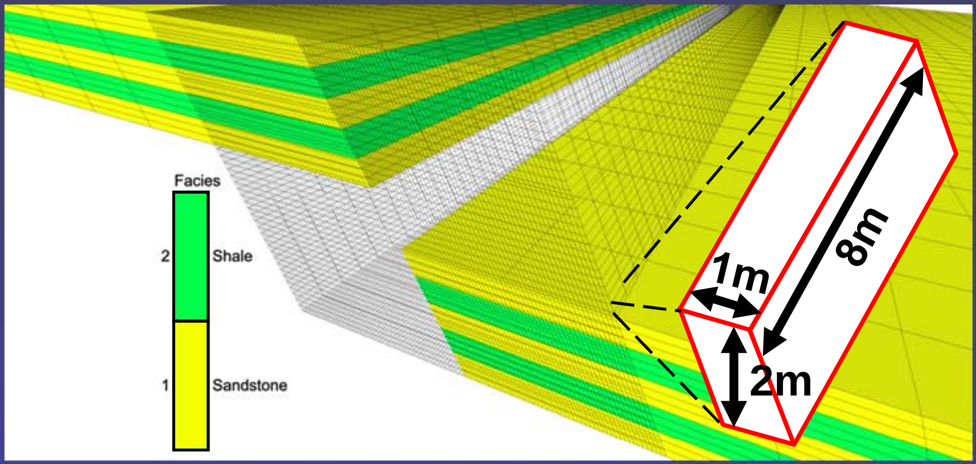


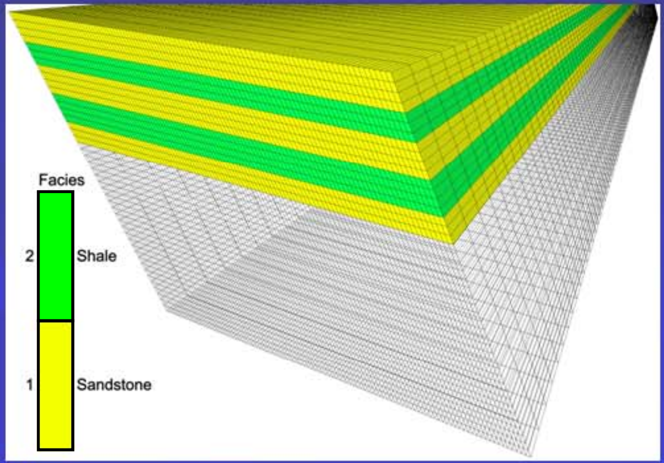
Workflow: - Syversveen et al. (2006)

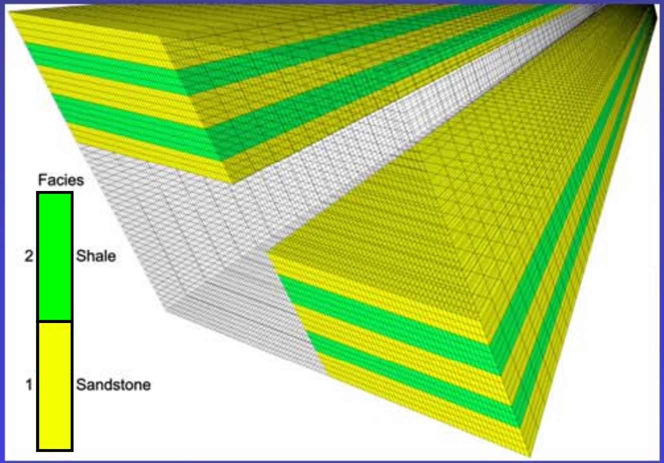
- Fredman et al. (accepted, AAPG Bulletin)

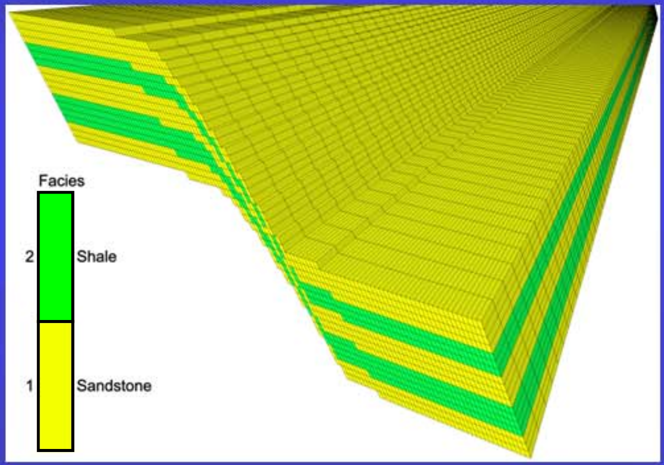
Workflow: geo-cellular modeling

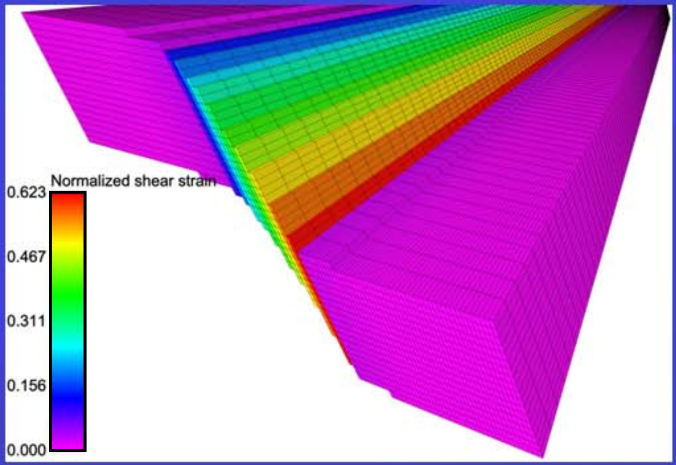




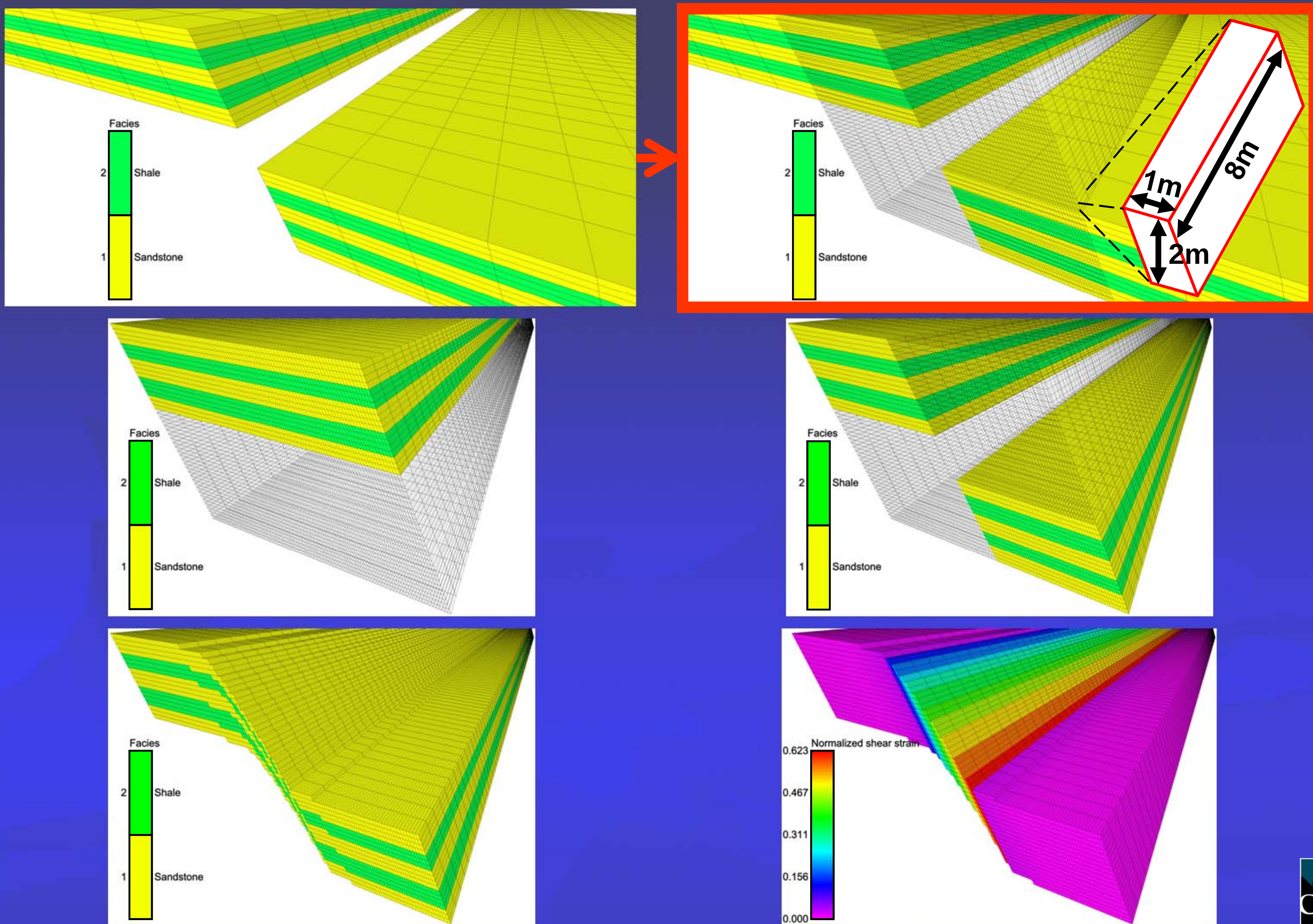




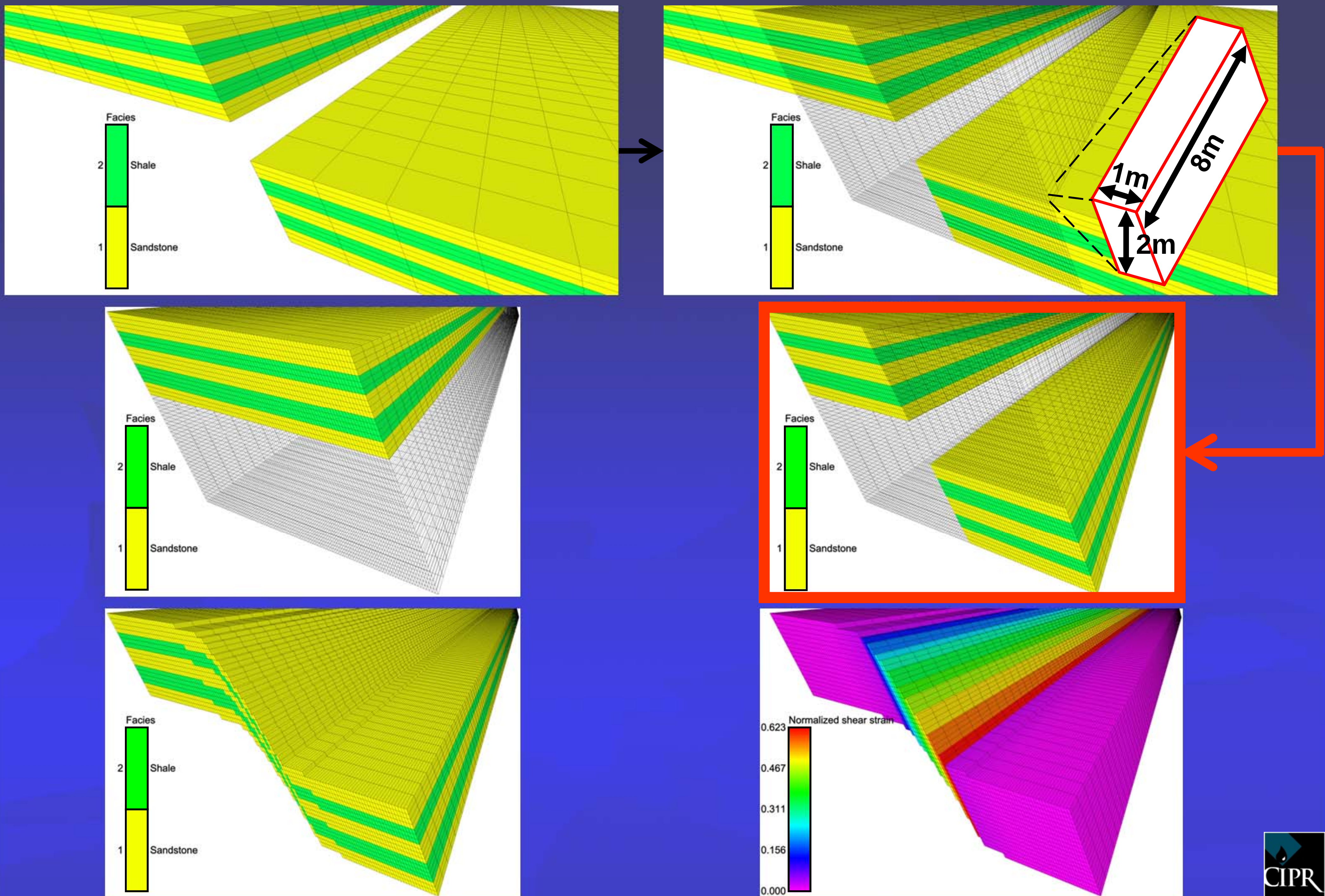




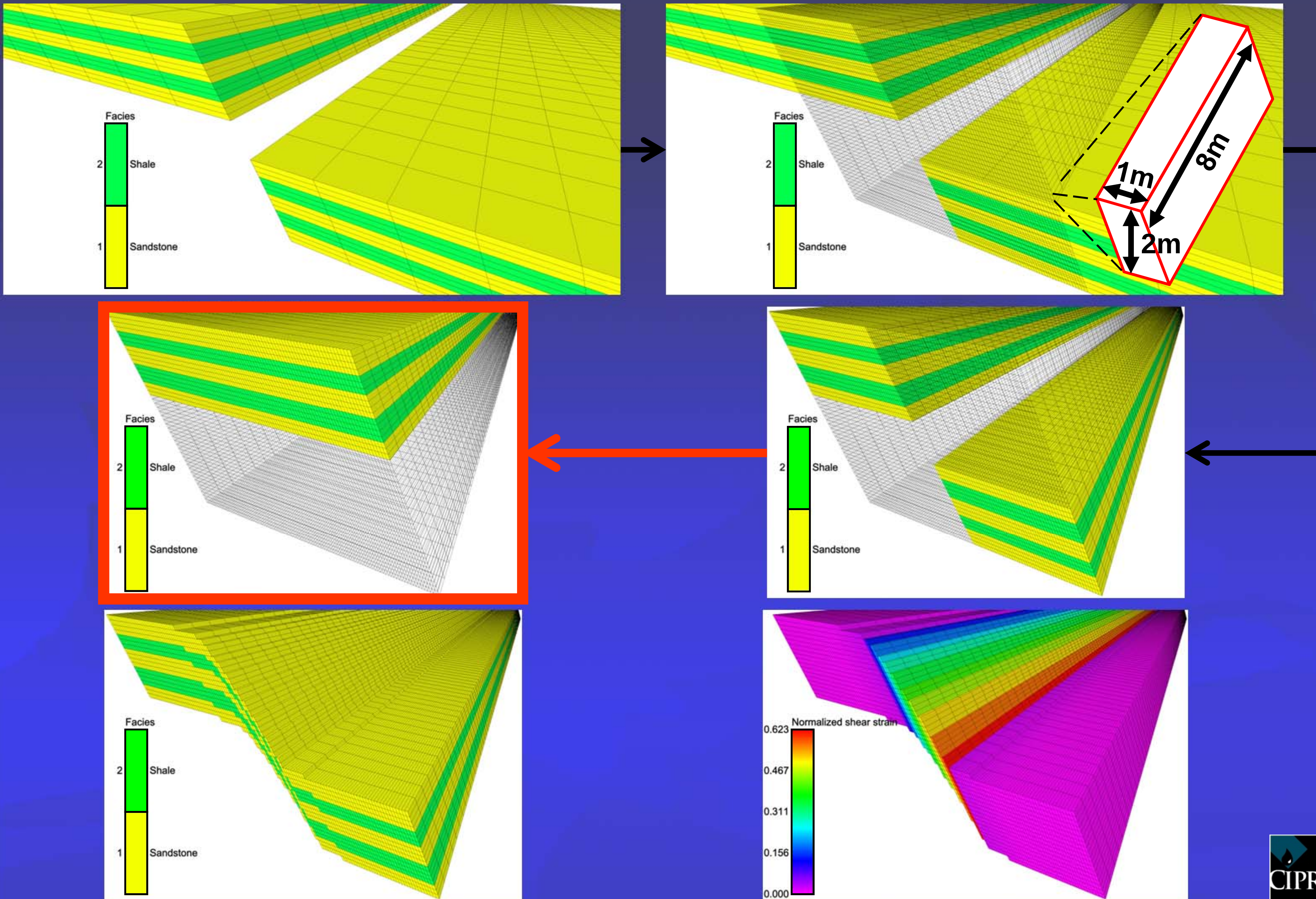
Workflow: FZ gridding (in Havana)



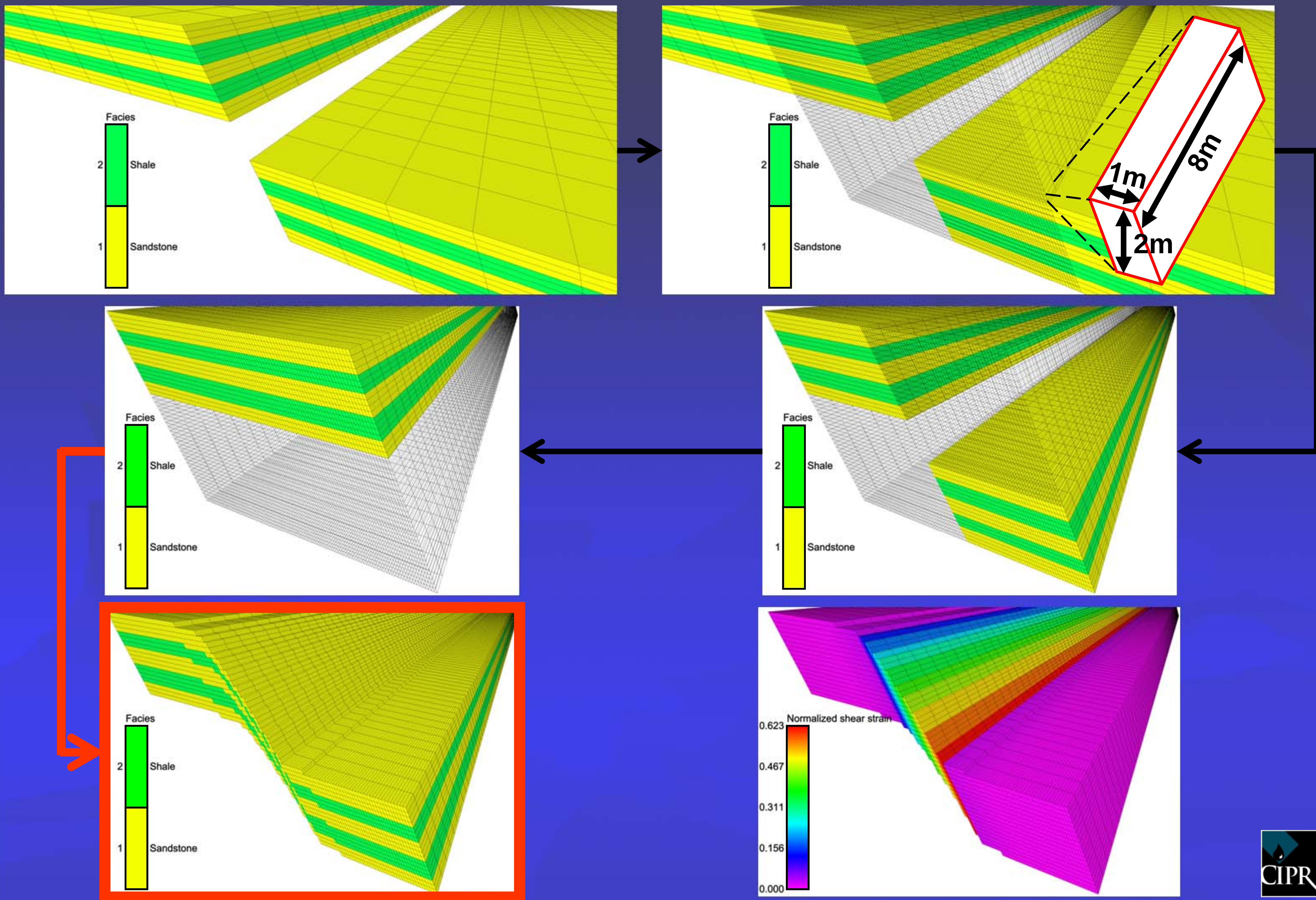
Workflow: SF resampling



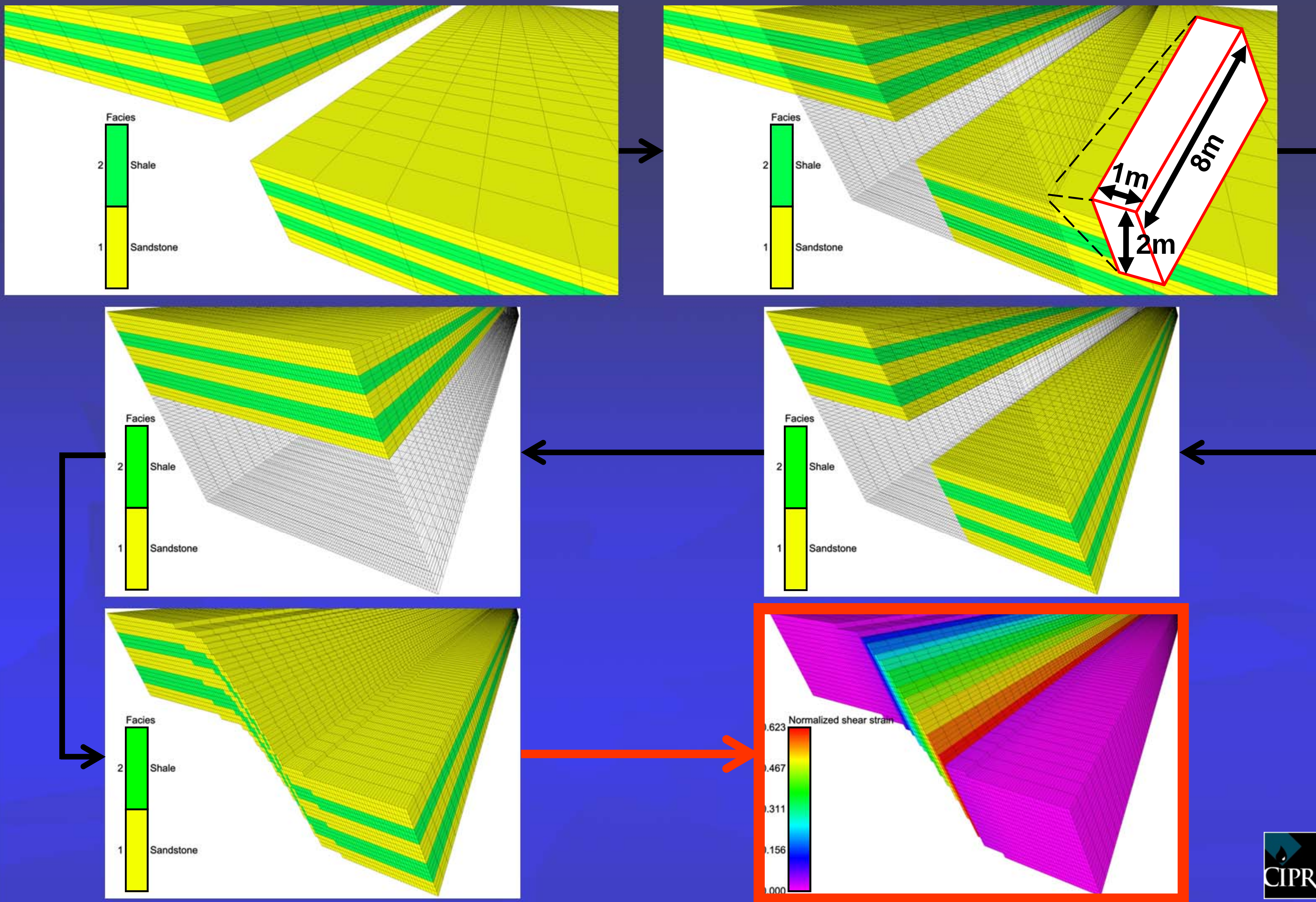
Workflow: SF restoring



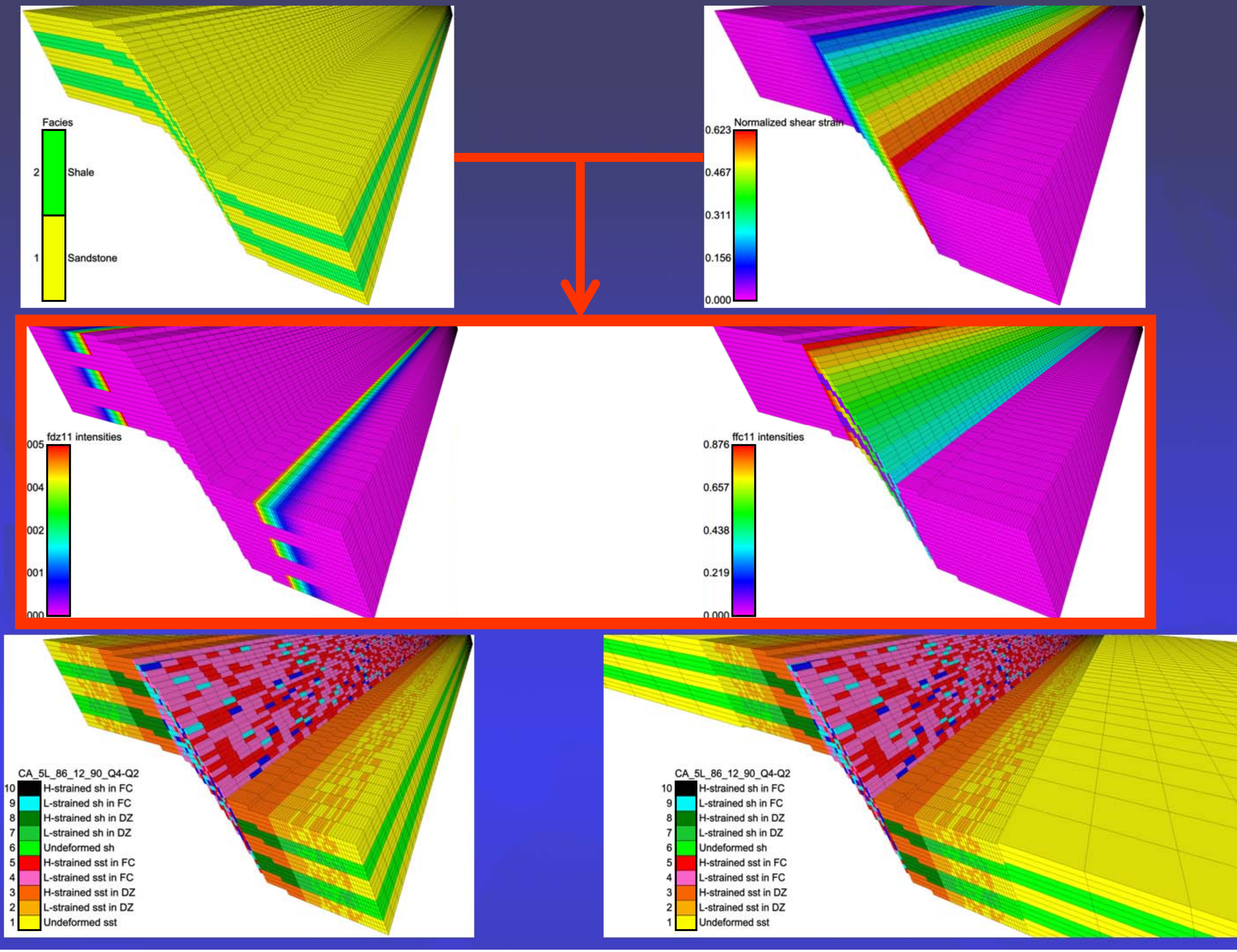
Workflow: create lithologic distribution



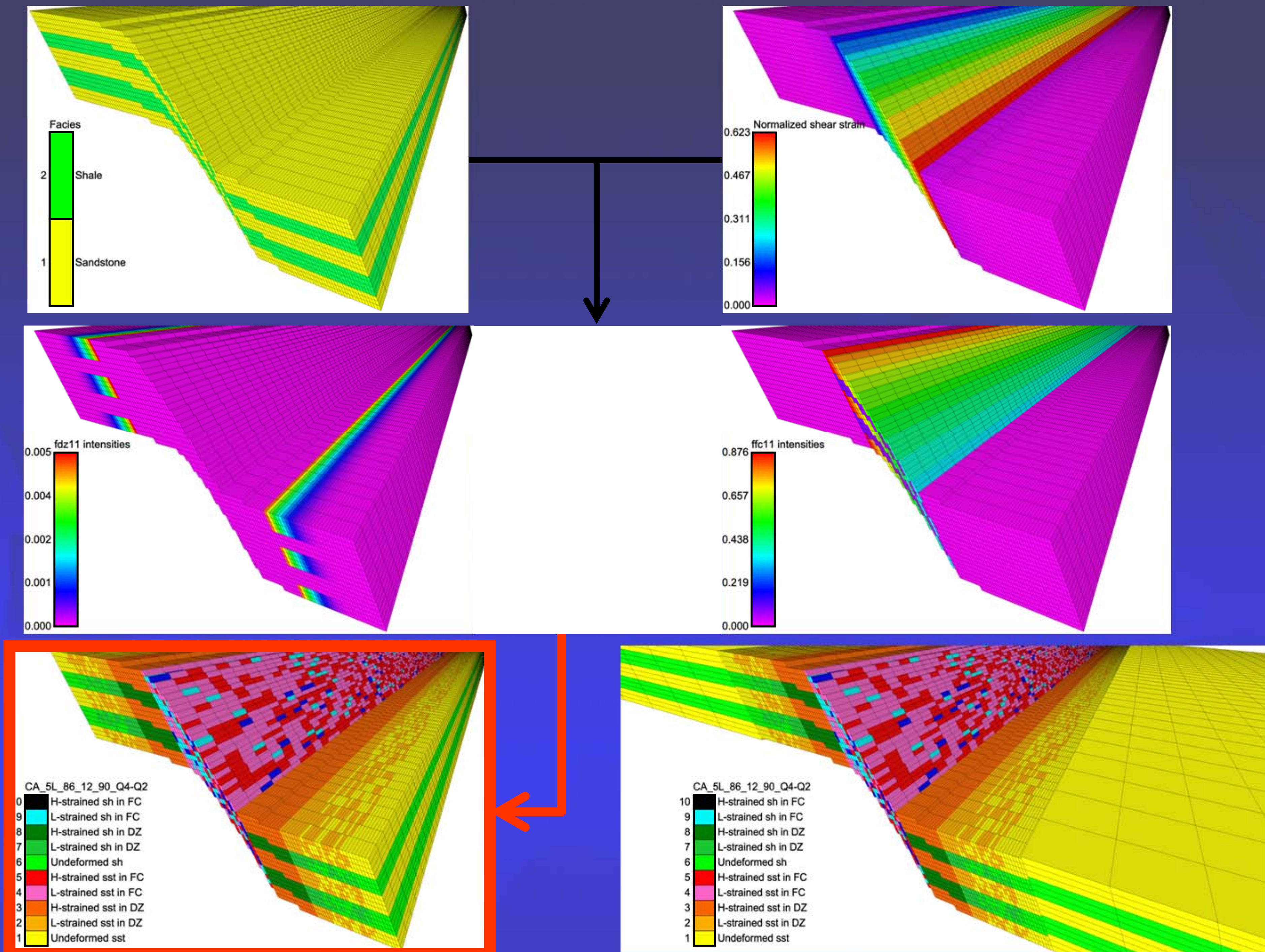
Workflow: create shear strain



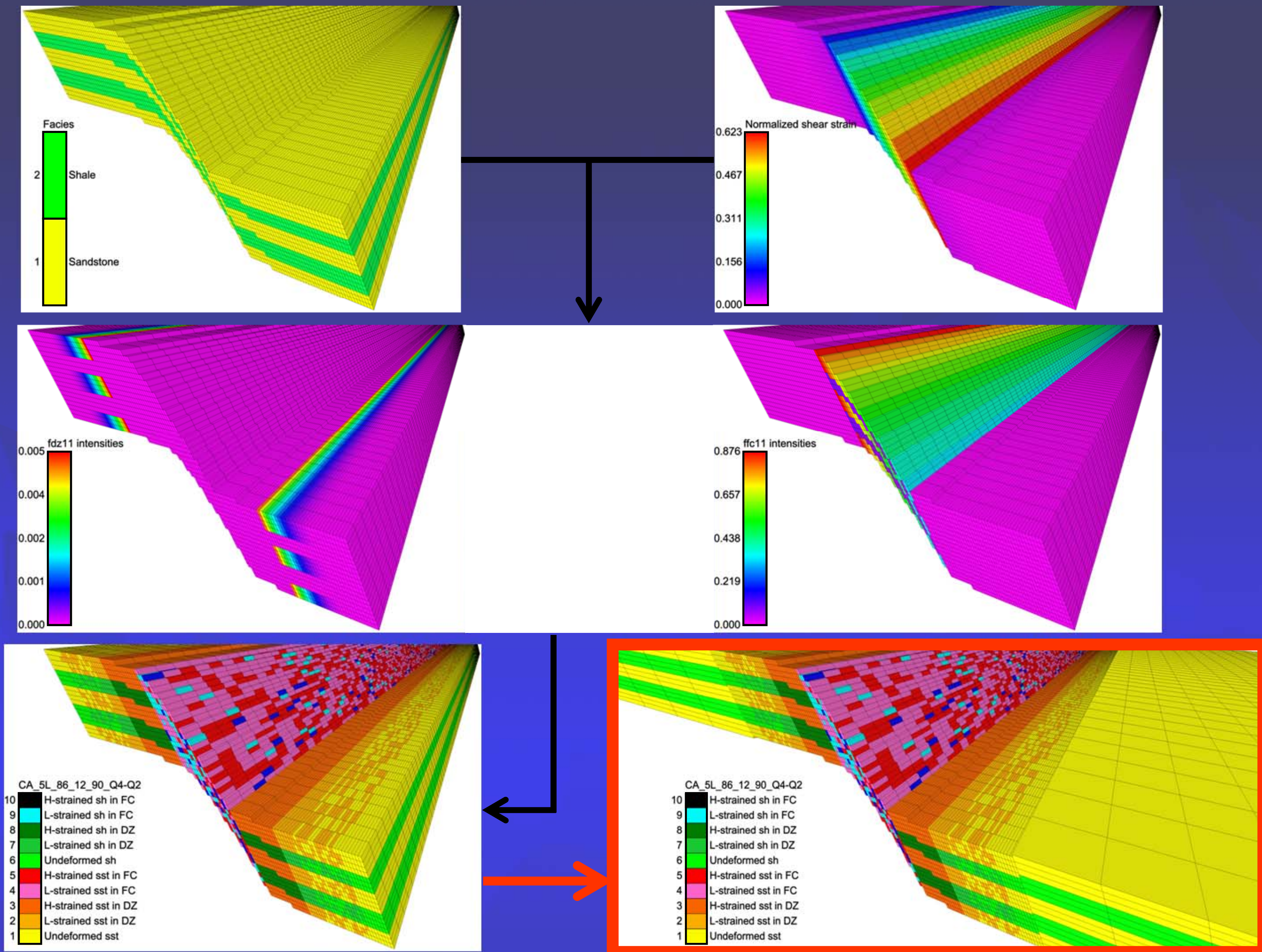
Workflow: FF probability distribution



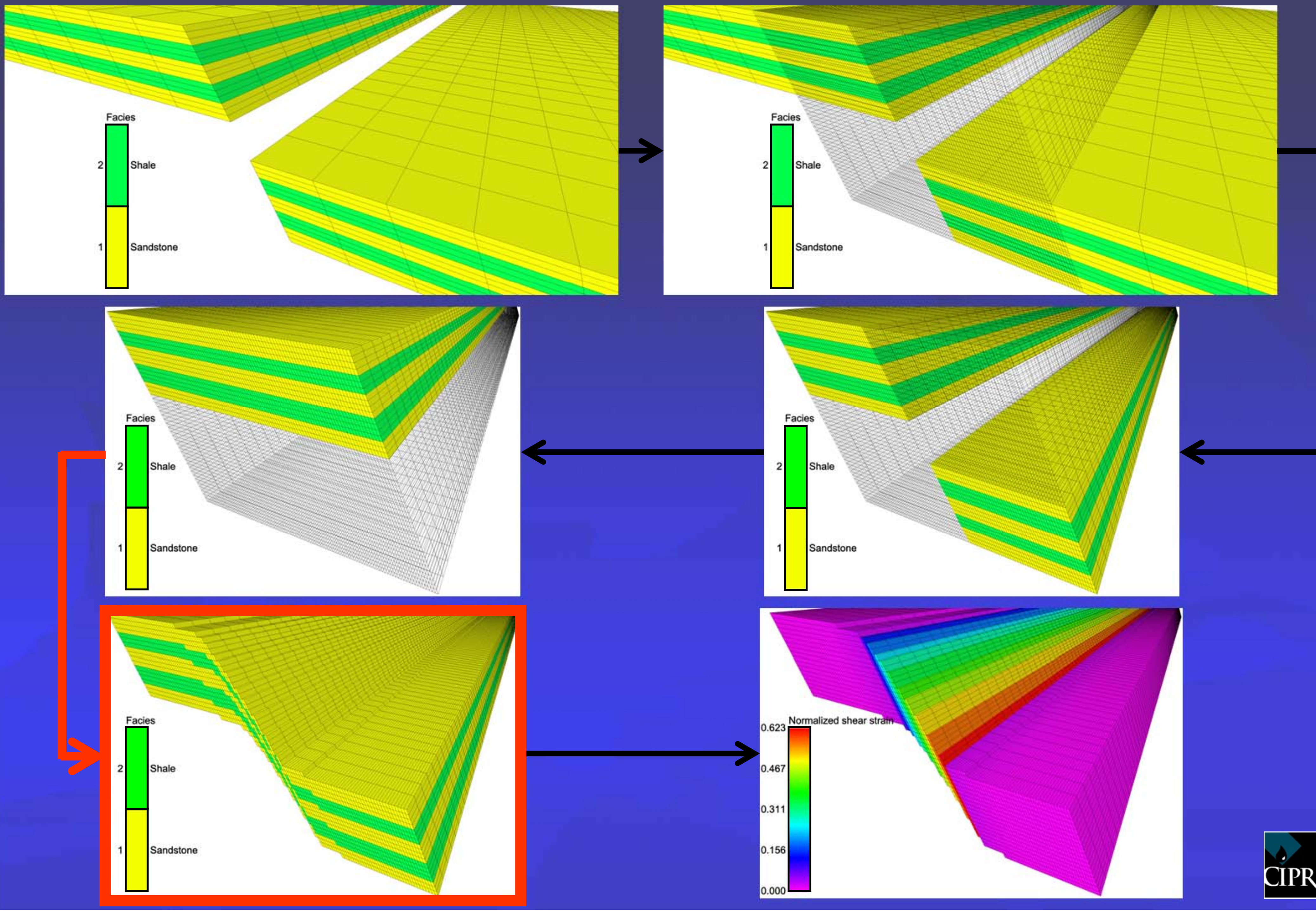
Workflow: FF pixel-based modeling



Workflow: grid merging (in Havana)



Displacement model (FPDF)



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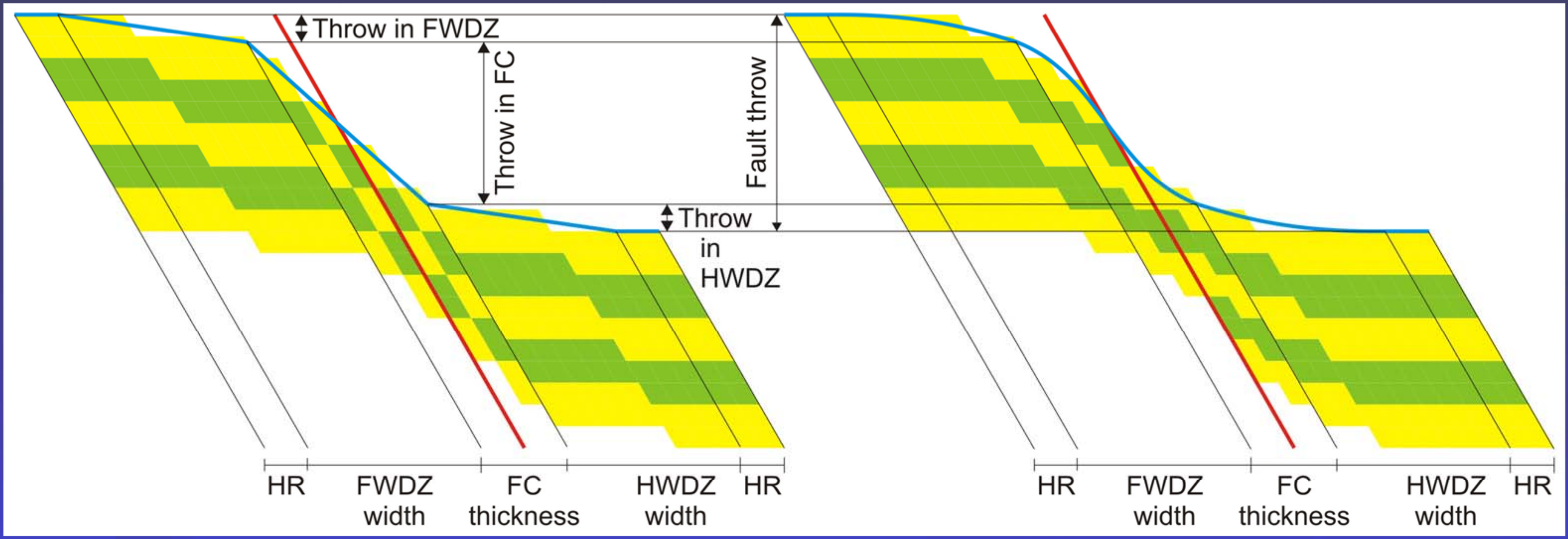
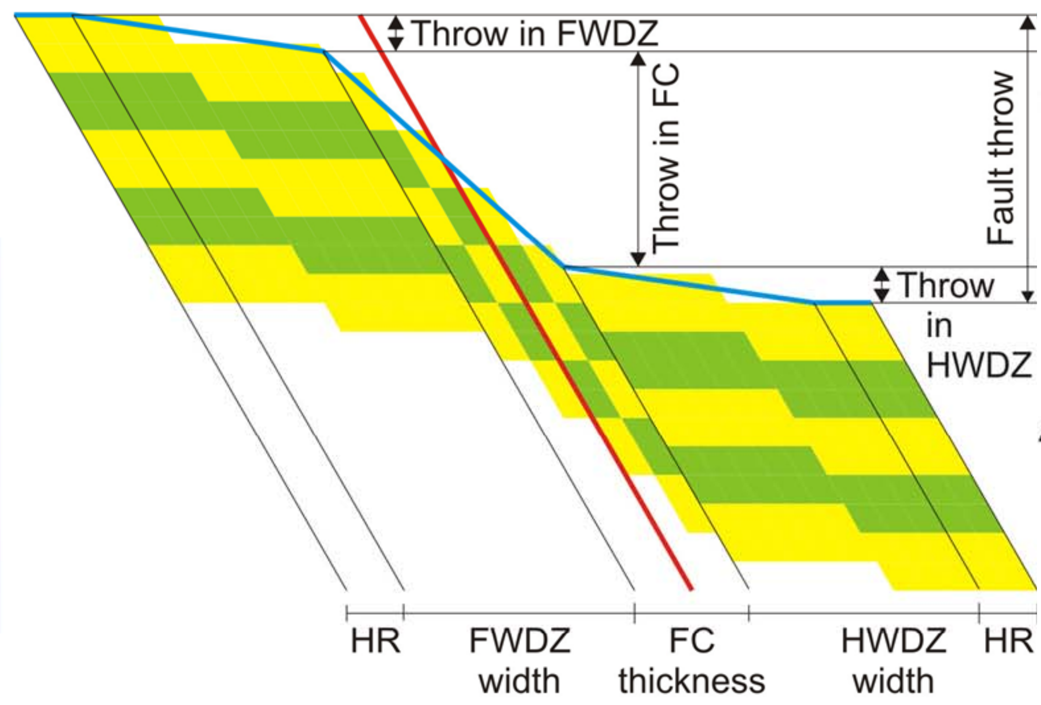
Displacement model – variables



FPDF variables:

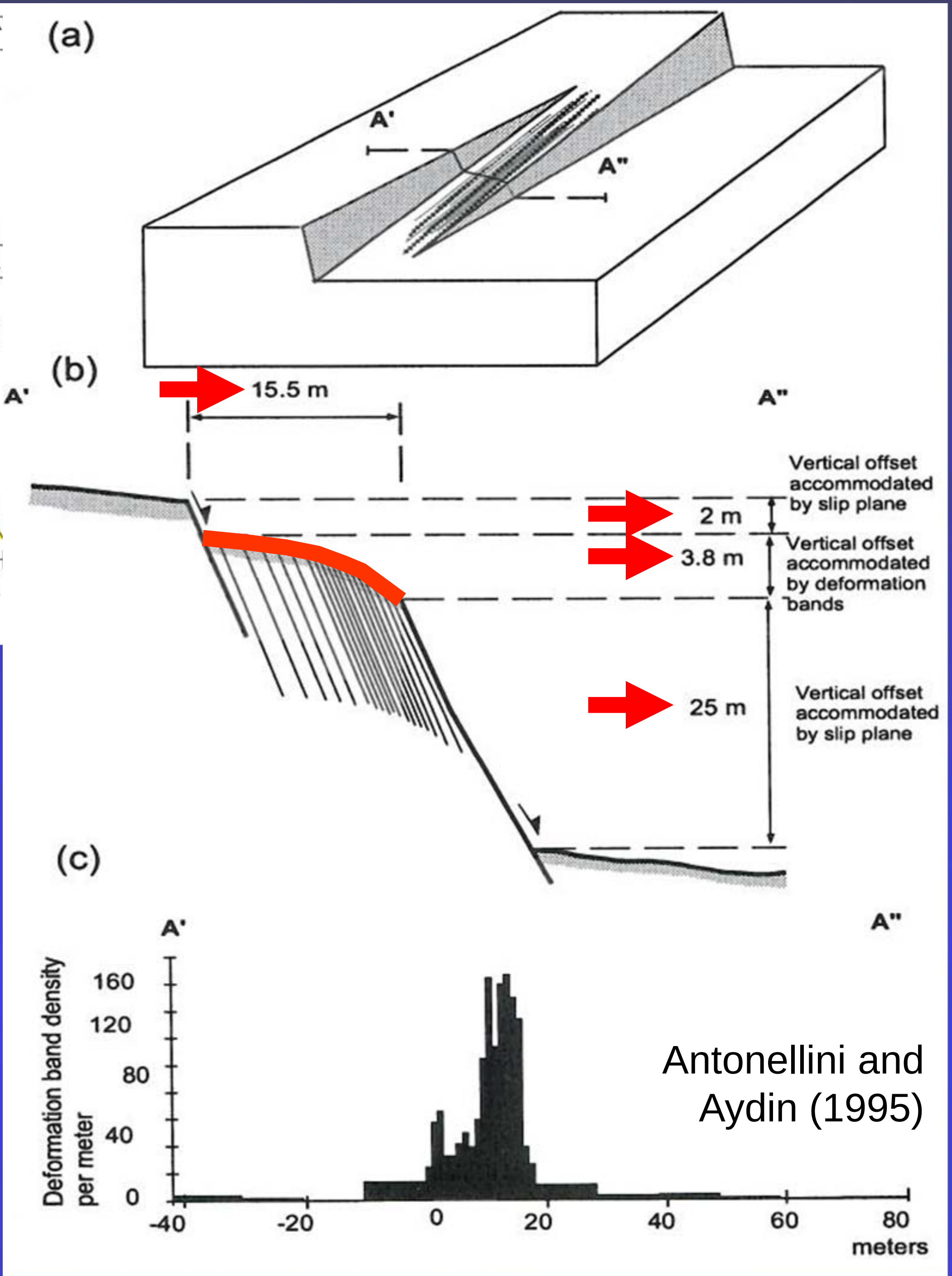
1. **FC thickness & DZ width**
2. **Throw accommodated by FC & DZ**
3. **Type of displacement function**

Displacement model – field data



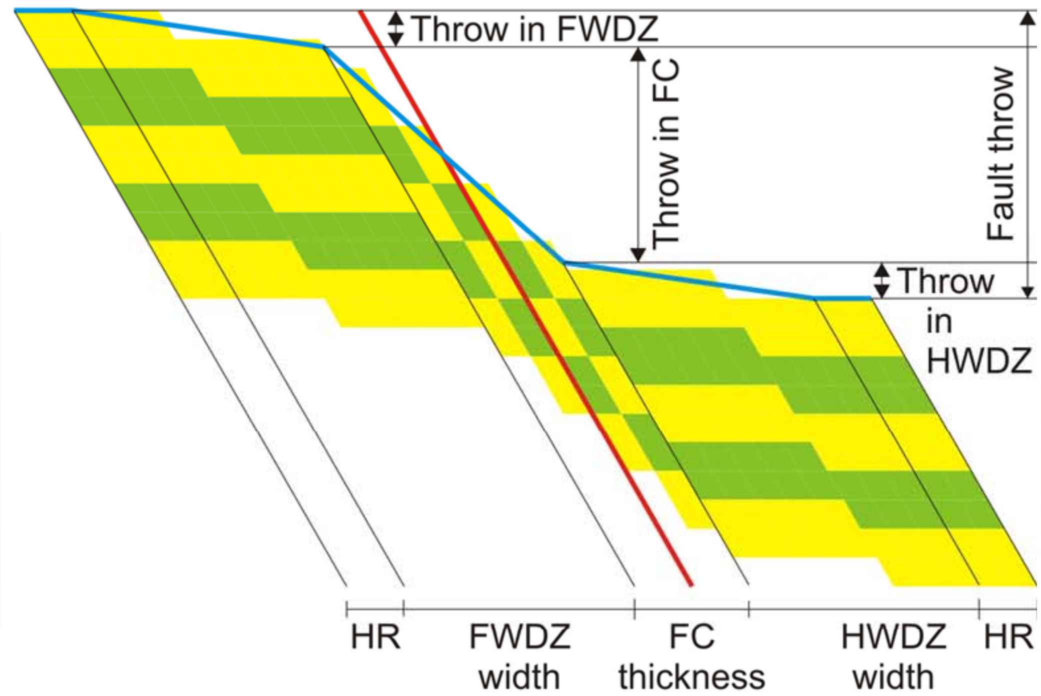
FPDF variables:

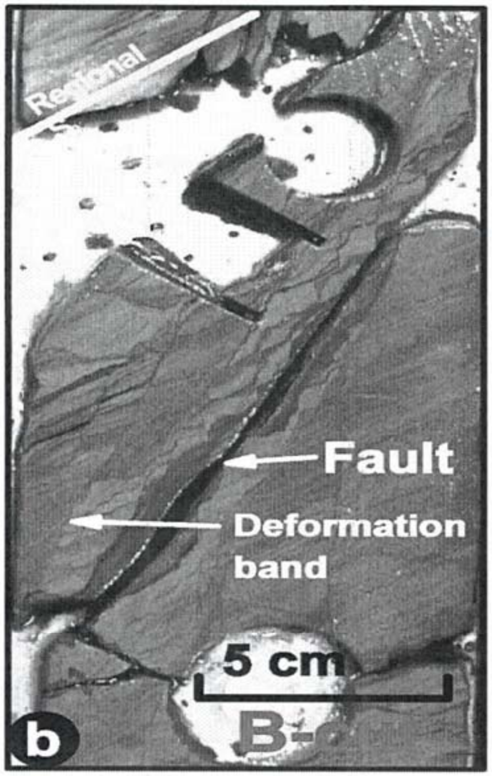
1. FC thickness & DZ width
2. Throw accommodated by FC & DZ
3. Type of displacement function

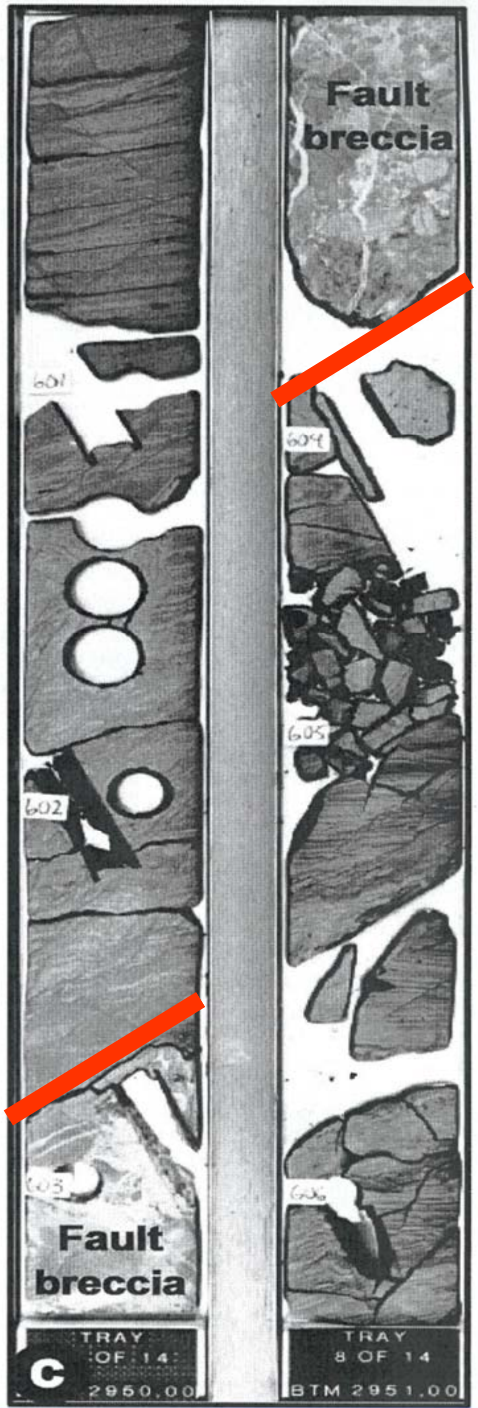


Antonellini and Aydin (1995)

Displacement model – subsurface data





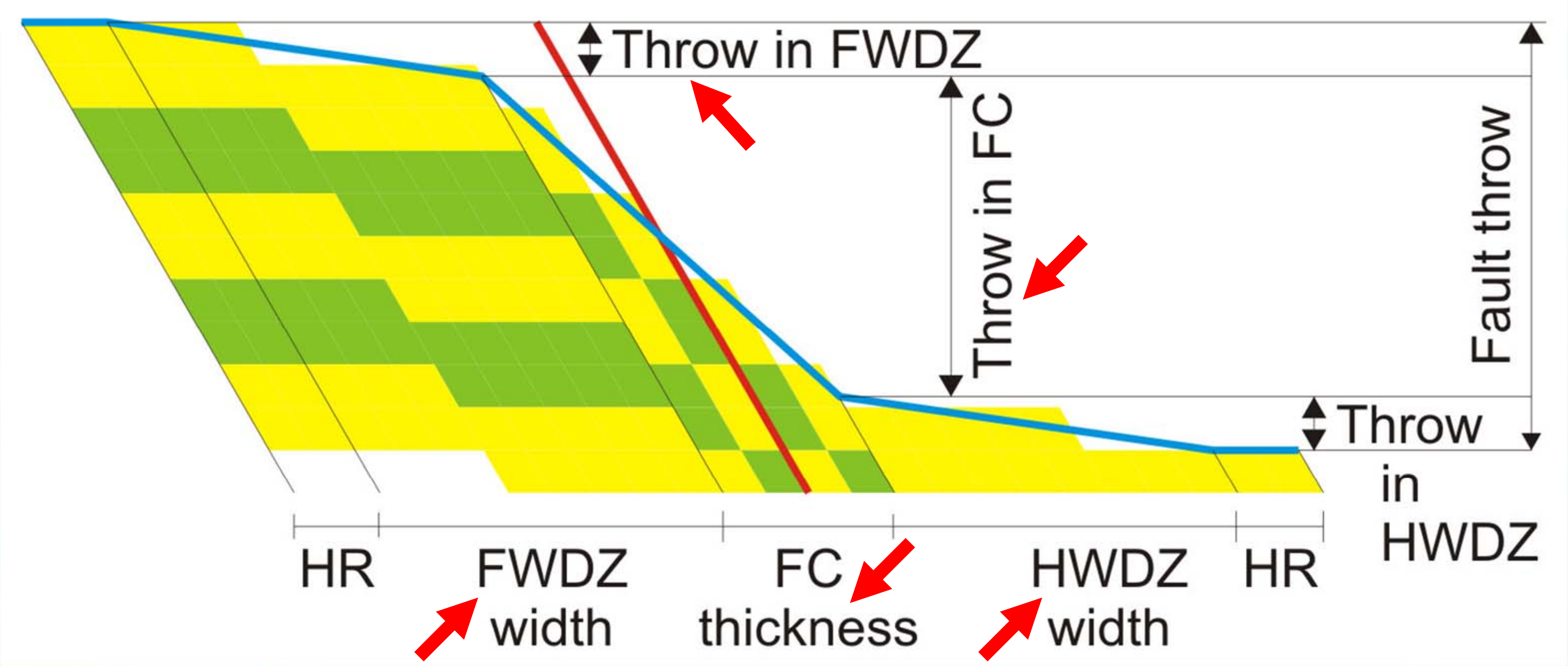


Hesthammer and Fossen (2001)

FPDF variables:

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

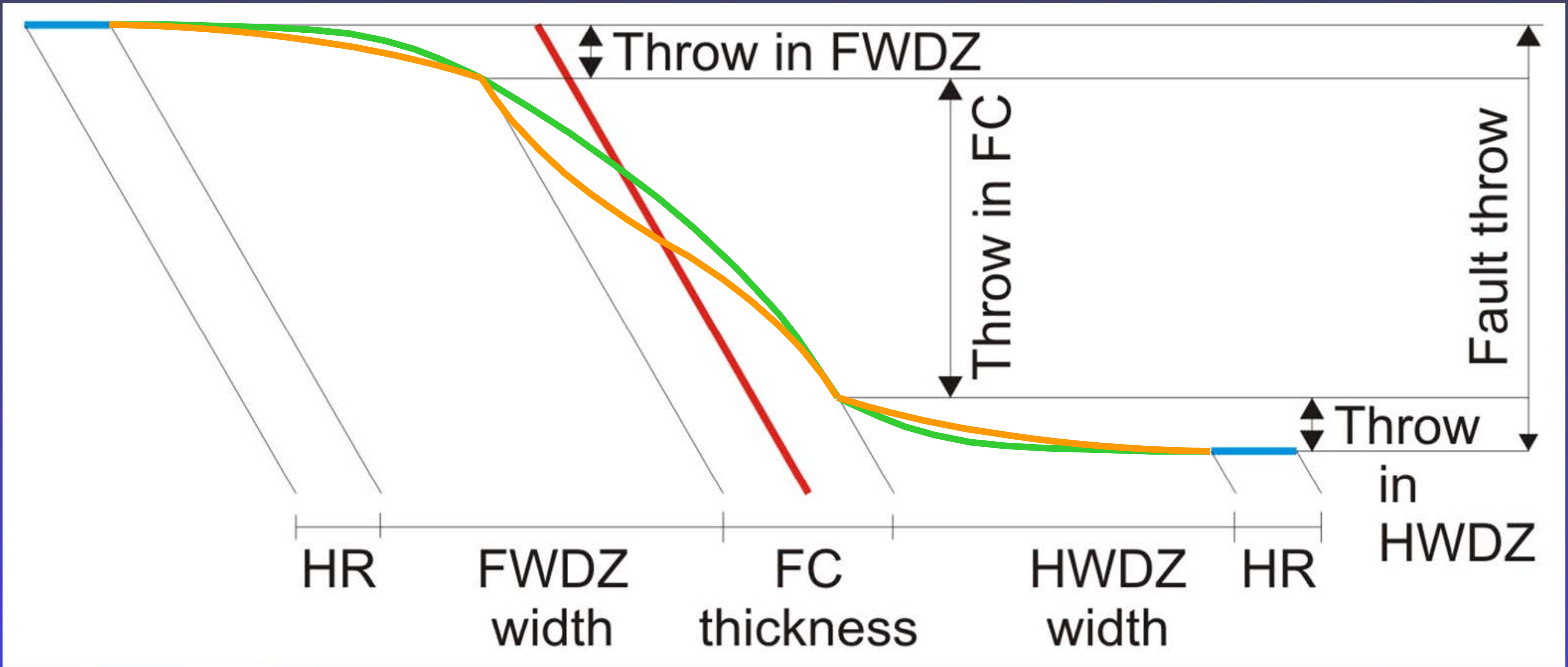
Displacement model – variable modification

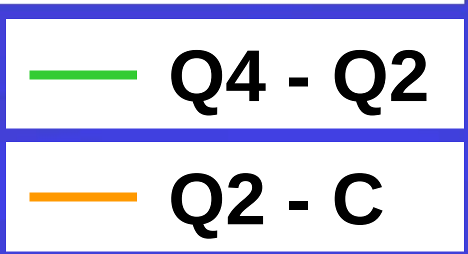


FPDF variables:

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

Displacement model – variable modification



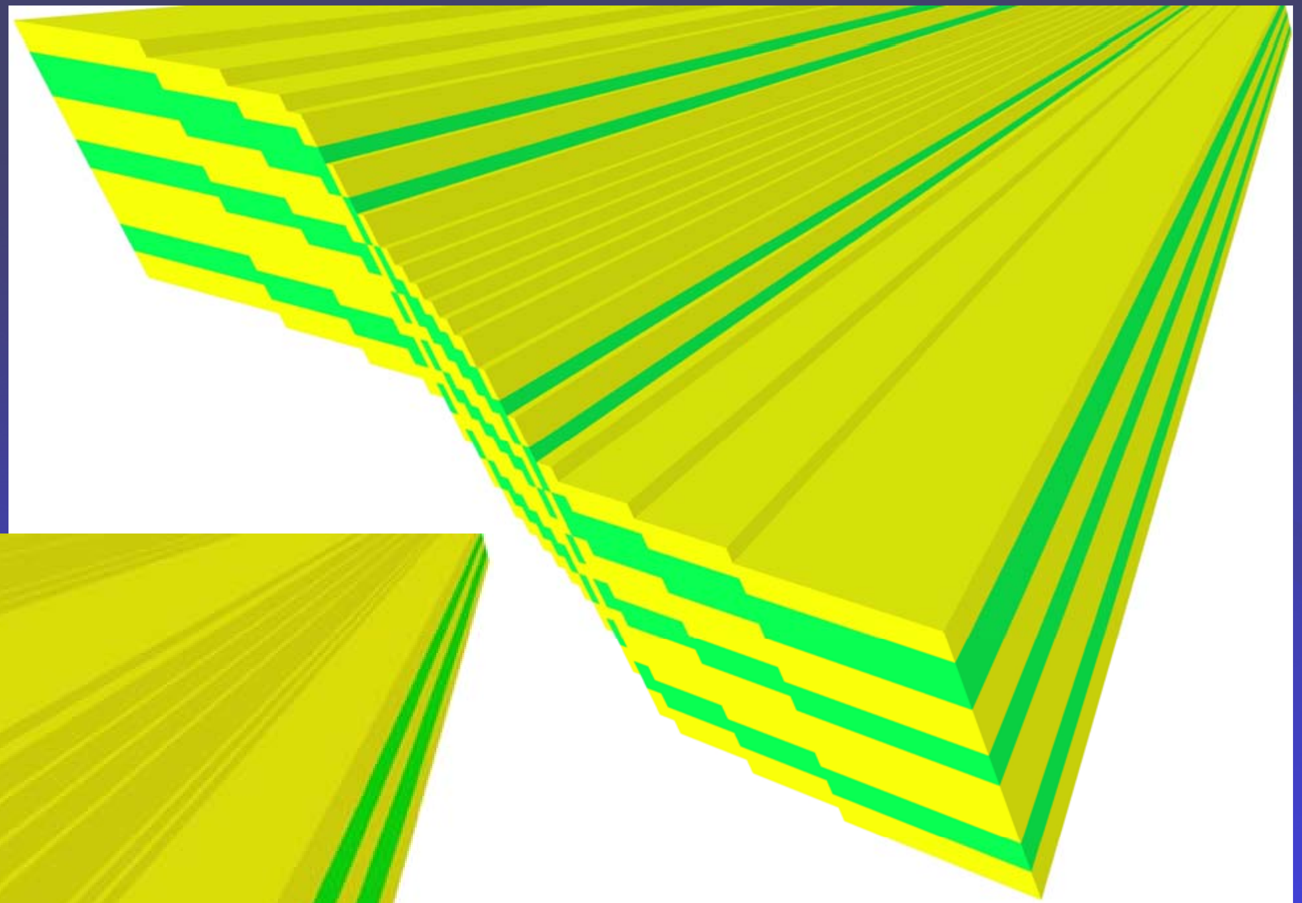


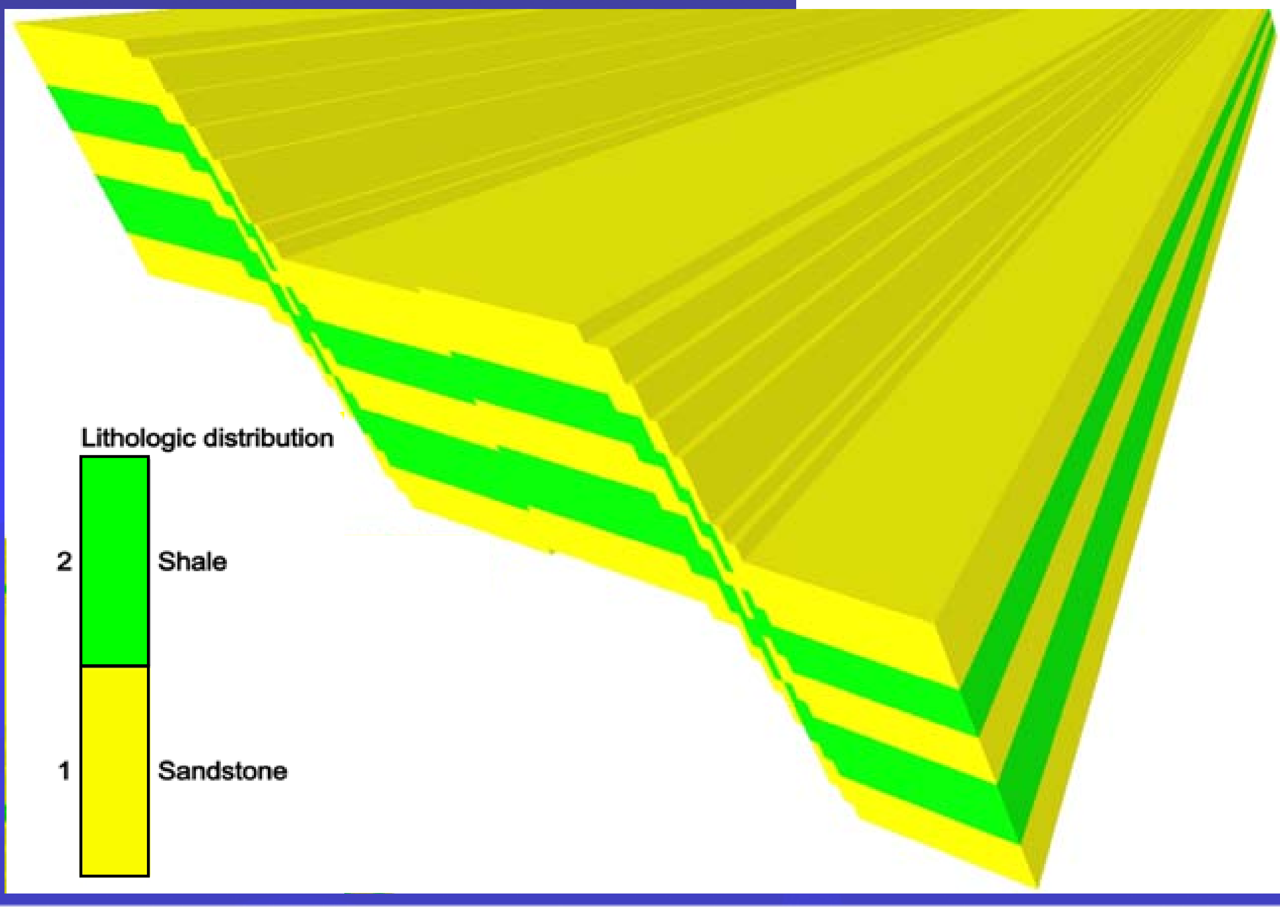
FPDF variables:

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

Lithologic distribution parameter

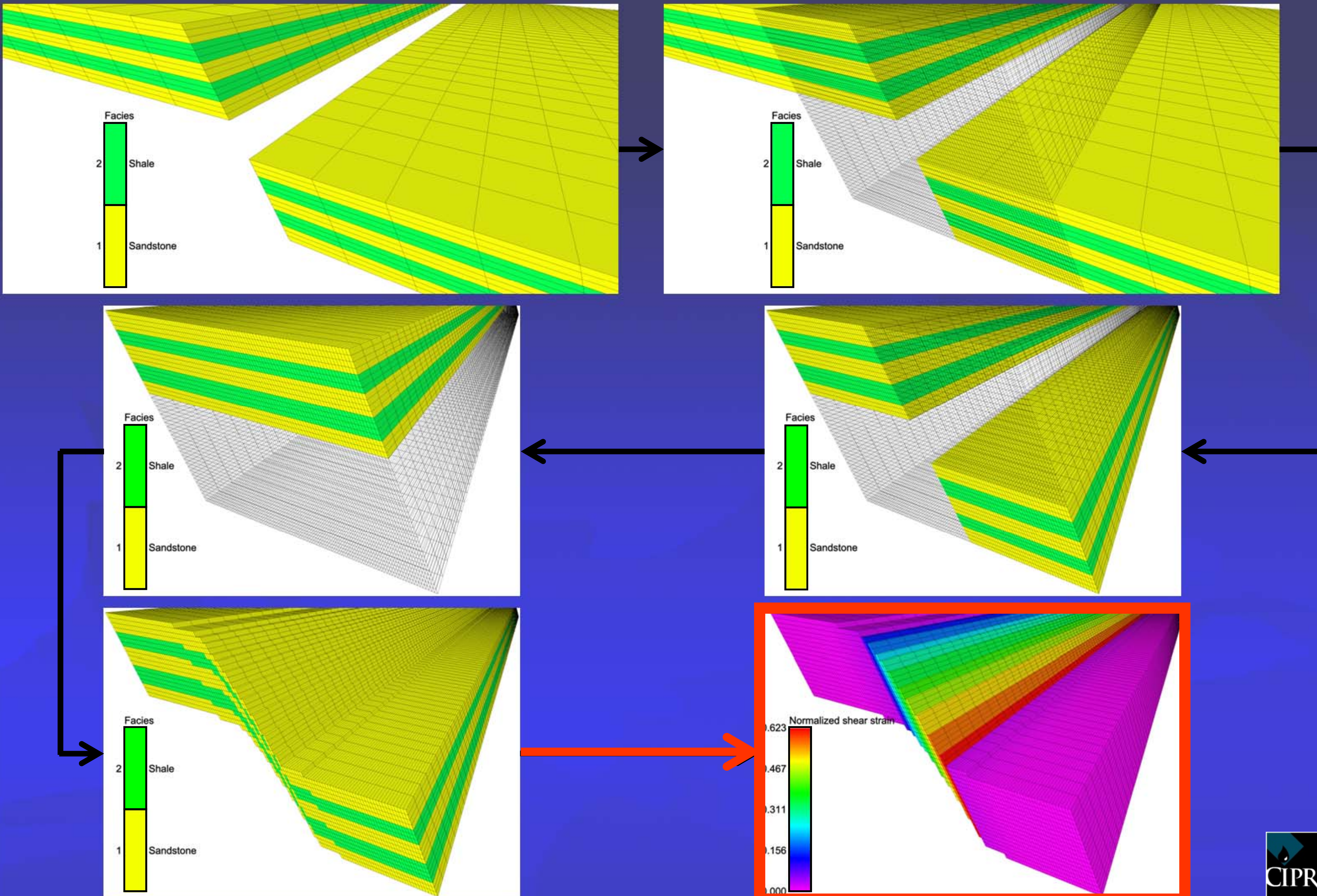
CA/7L/86/12/90/Q2-C



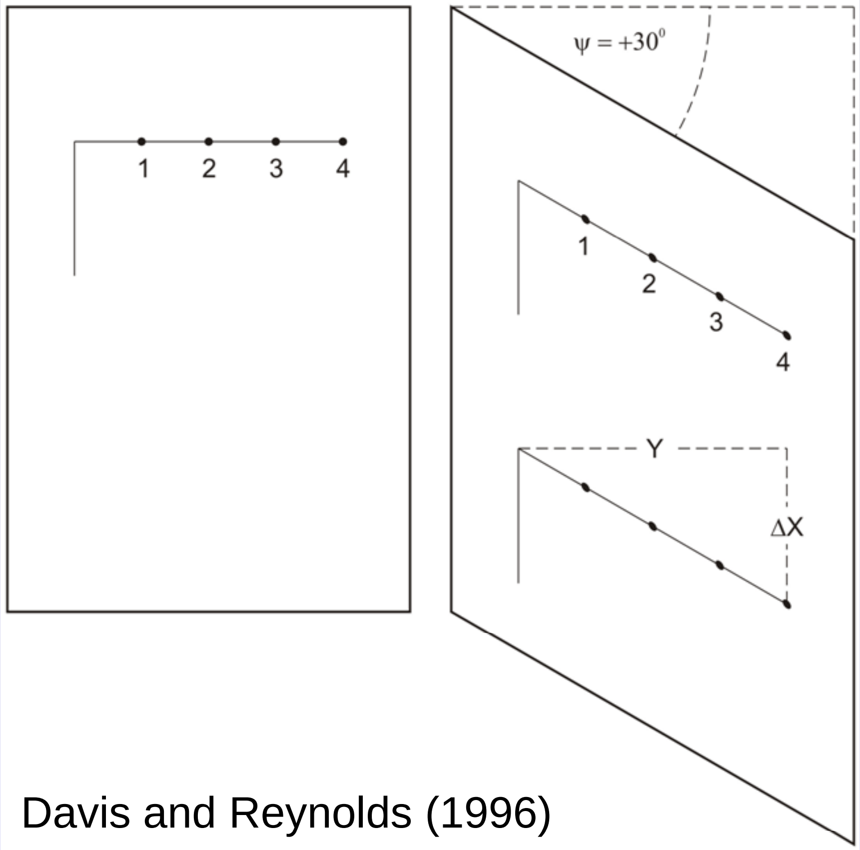


CB/5L/86/12/90/Q4-Q2

Shear strain



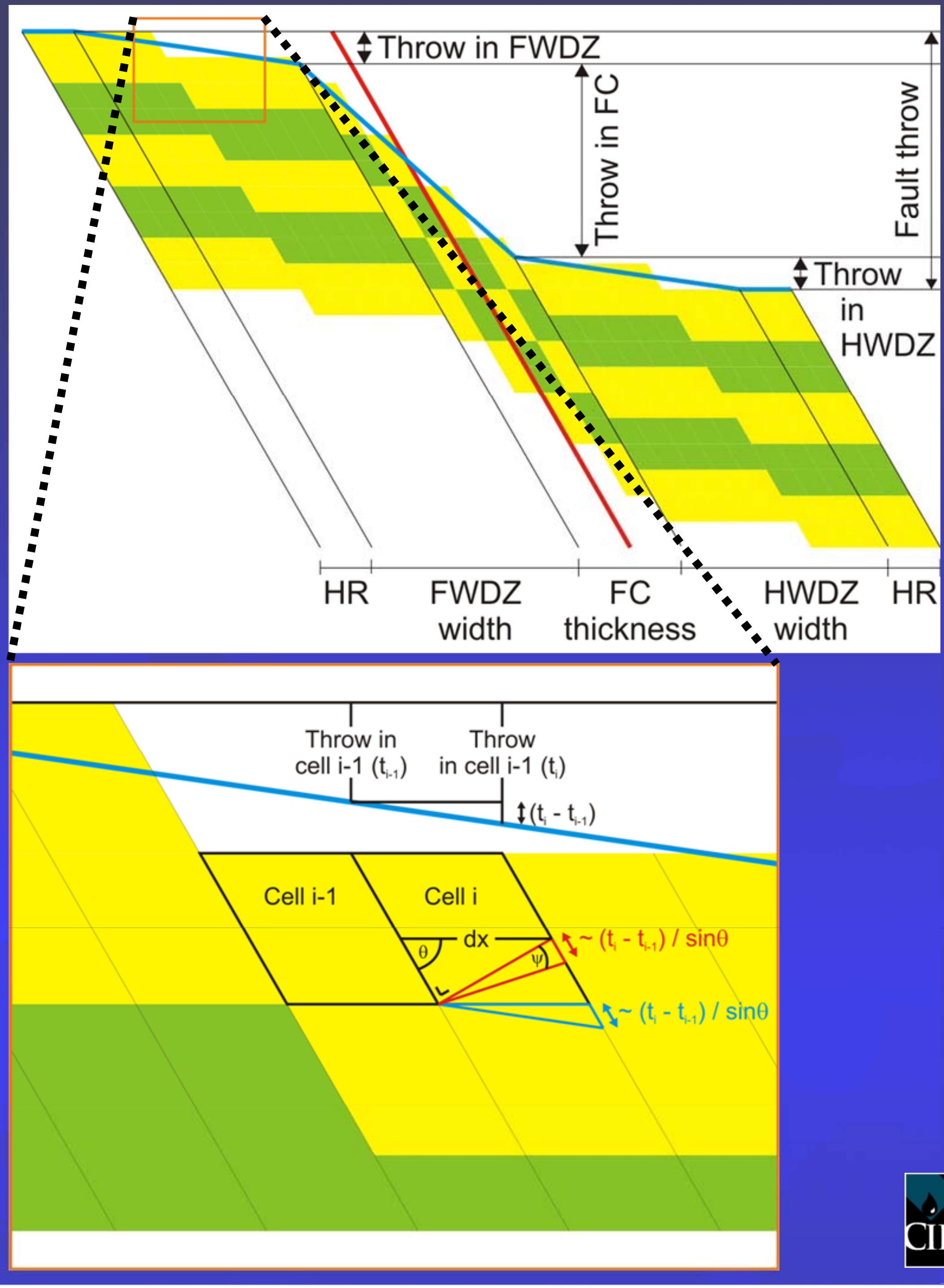
Shear strain



Davis and Reynolds (1996)

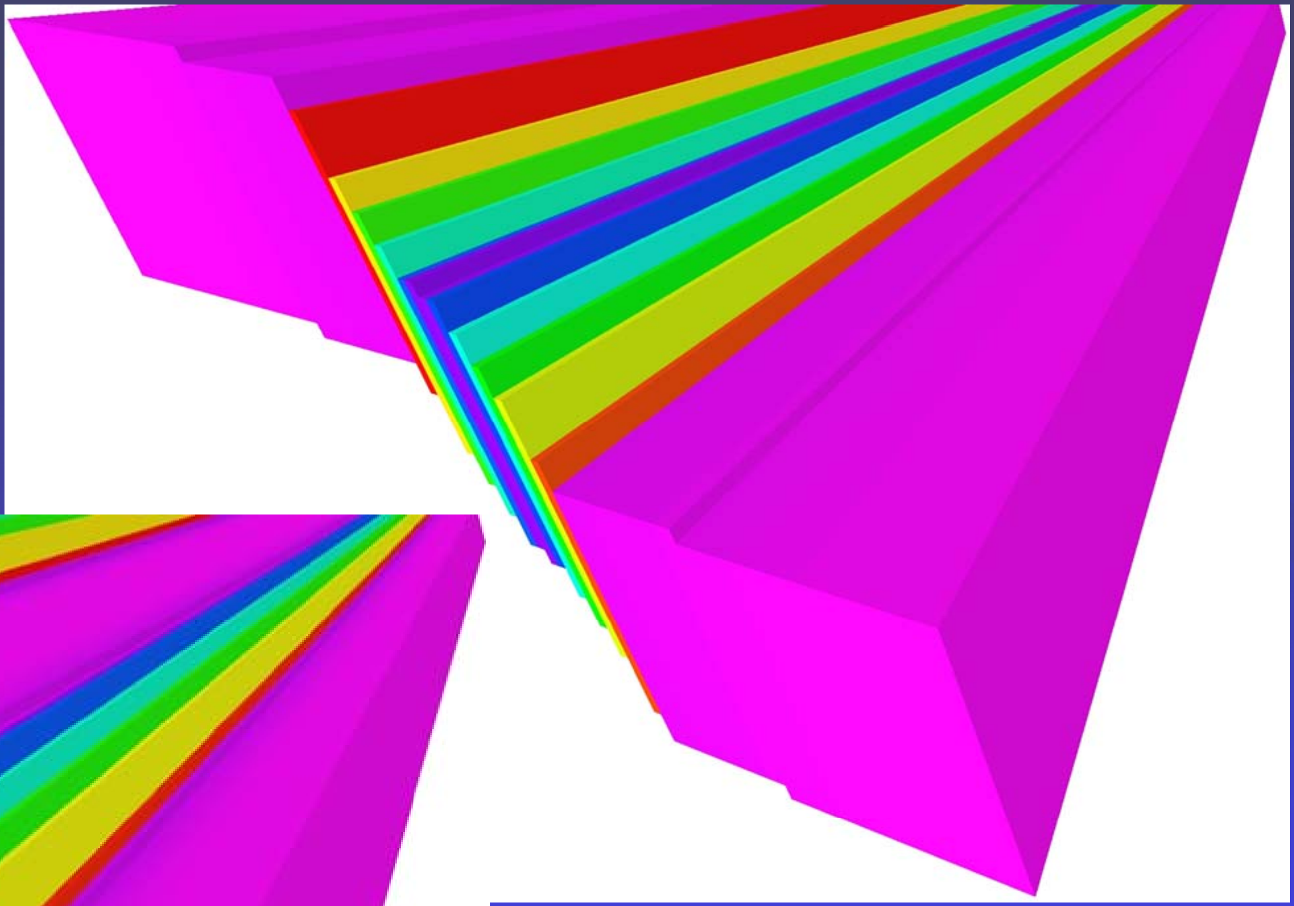
$$\text{Shear strain} = \gamma = \tan\ \psi = \frac{\Delta X}{Y}$$

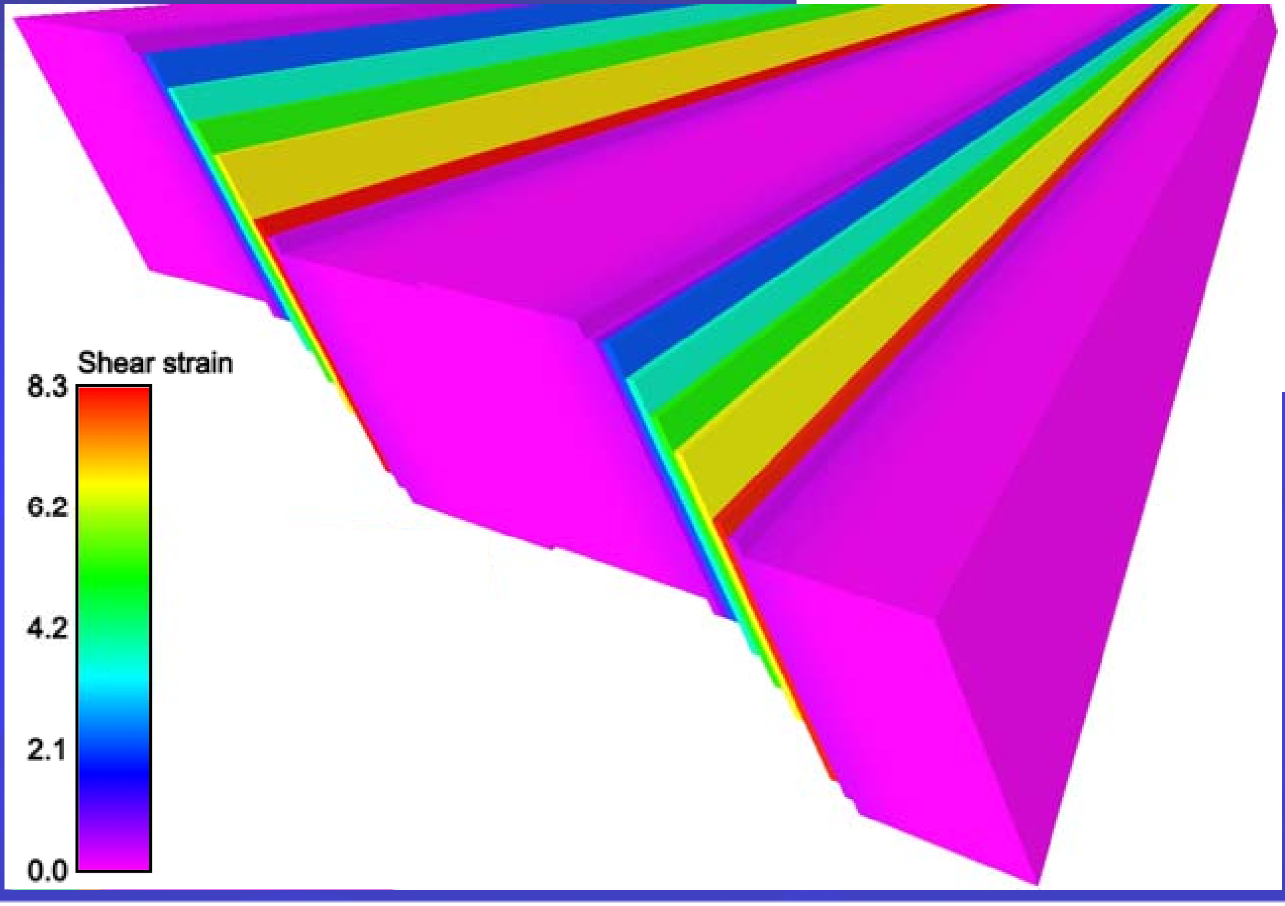
$$\gamma_i = \tan\psi_i = \frac{\dfrac{t_i - t_{i-1}}{\sin\theta}}{dx_i.\sin\theta}$$



Shear strain

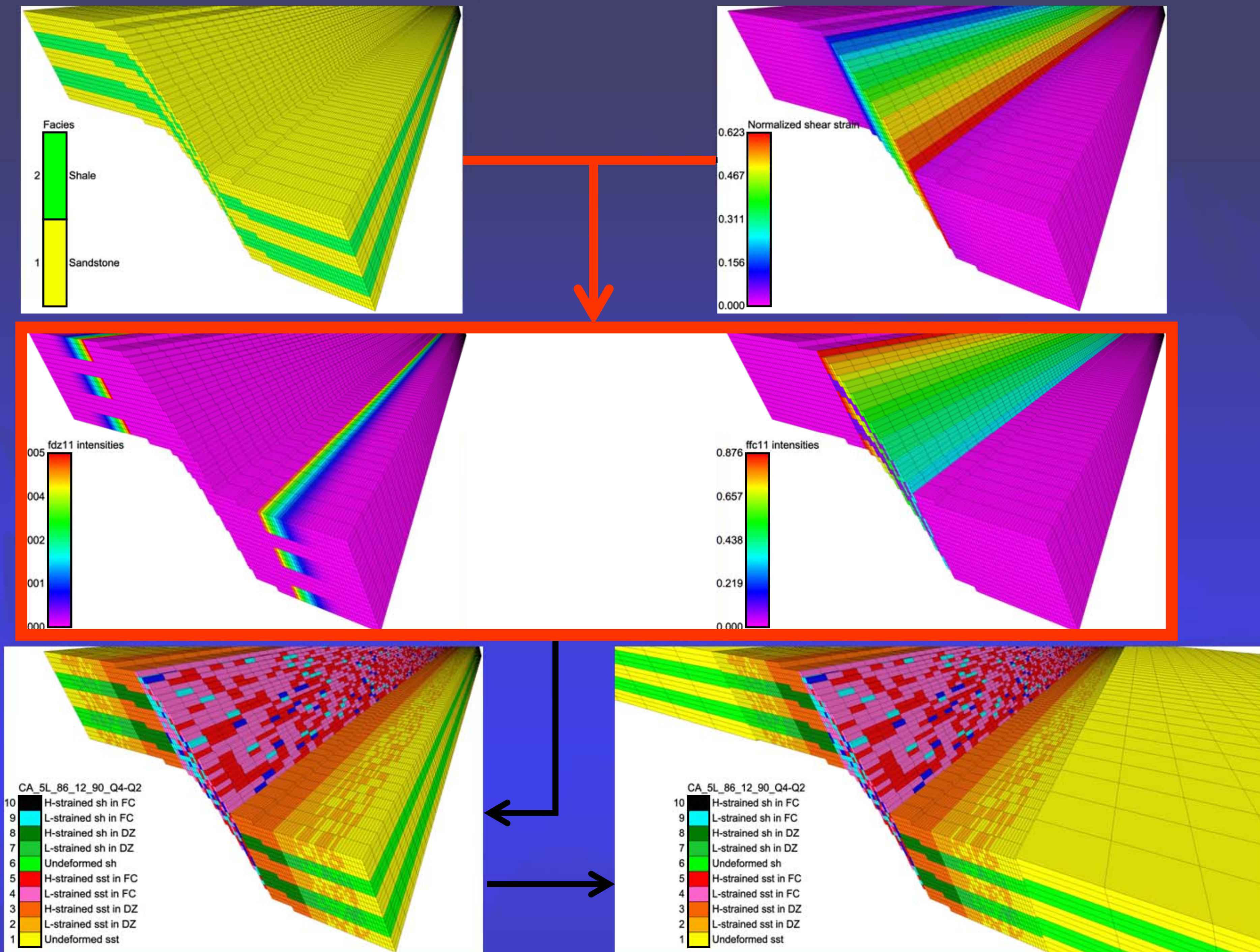
CA/7L/86/12/90/Q2-C



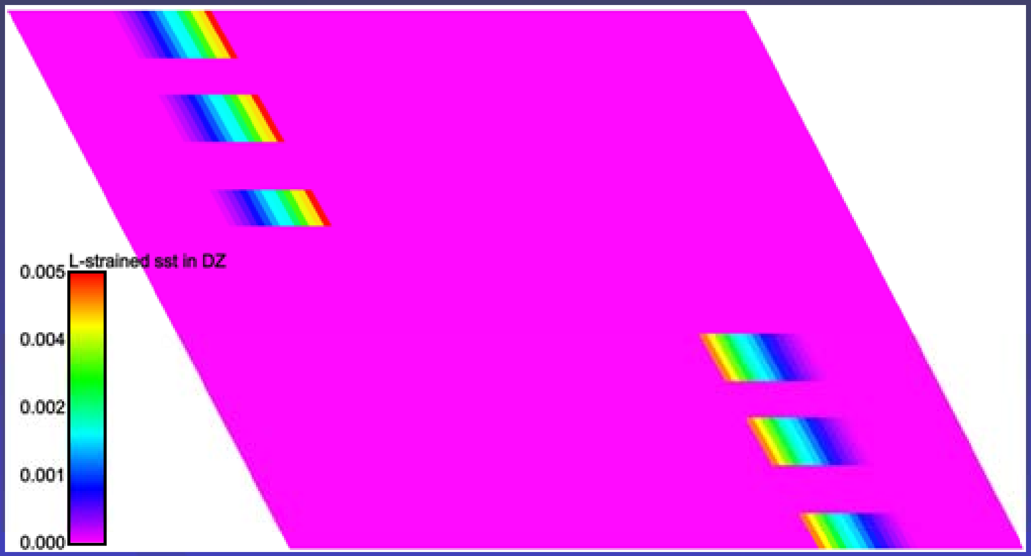


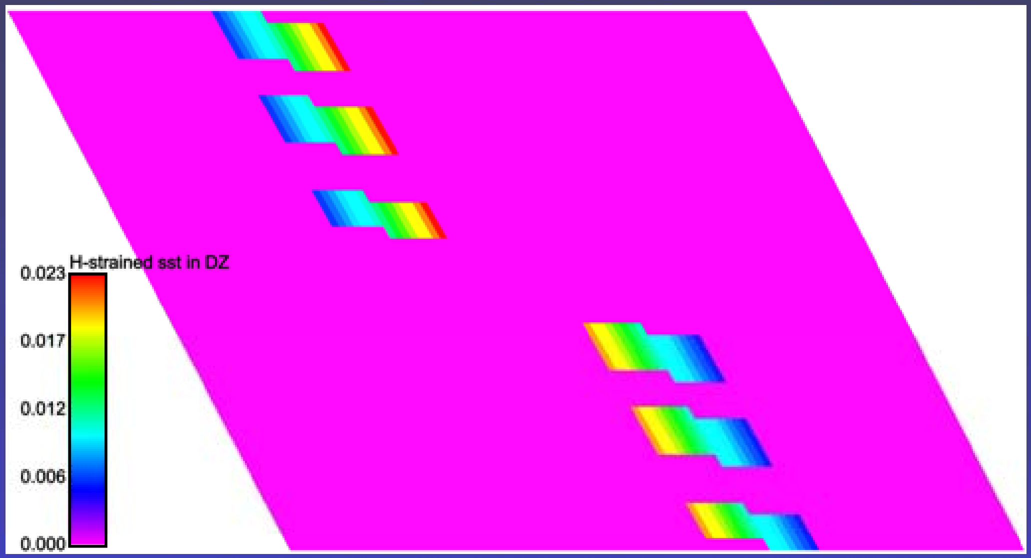
CB/5L/86/12/90/Q4-Q2

Fault facies probability distribution

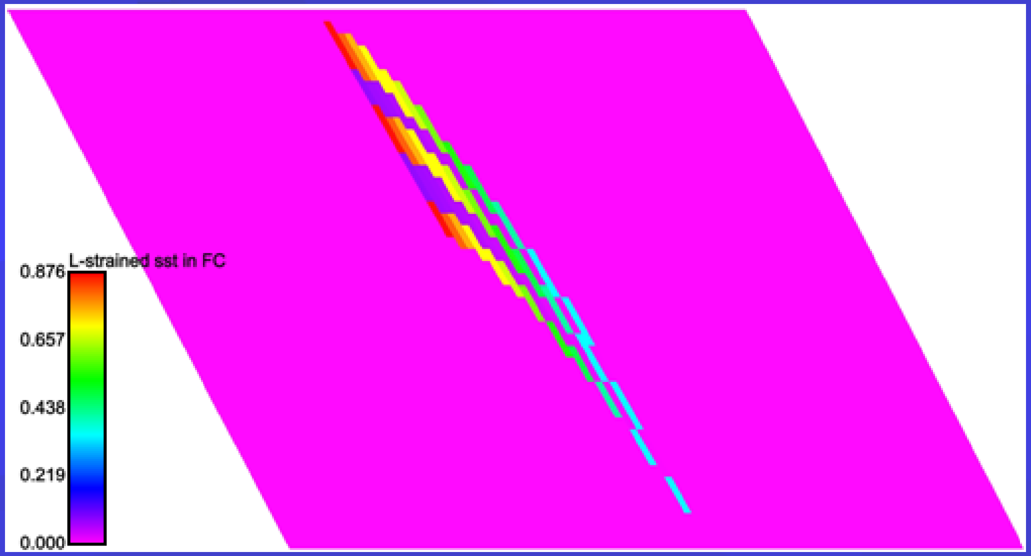


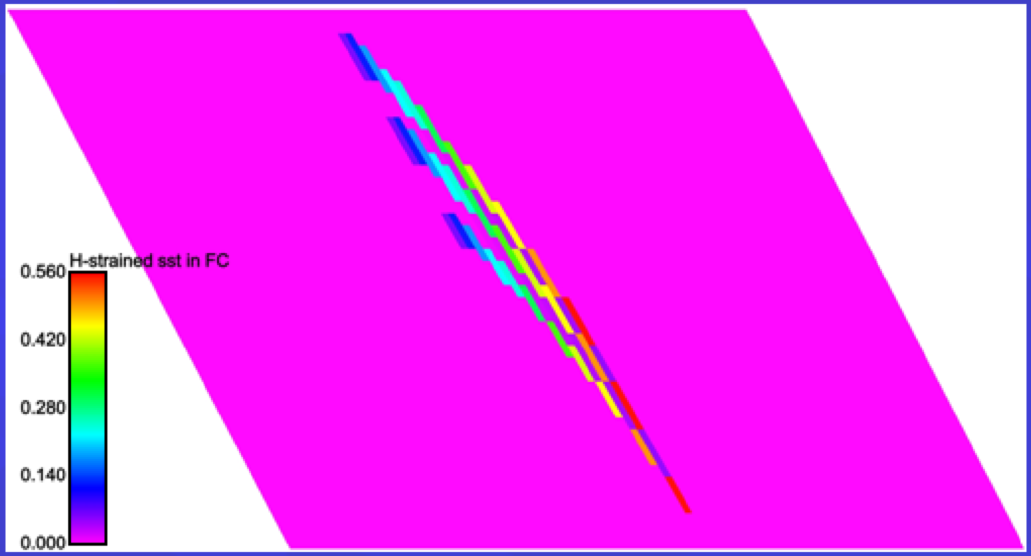
Fault facies probability distribution



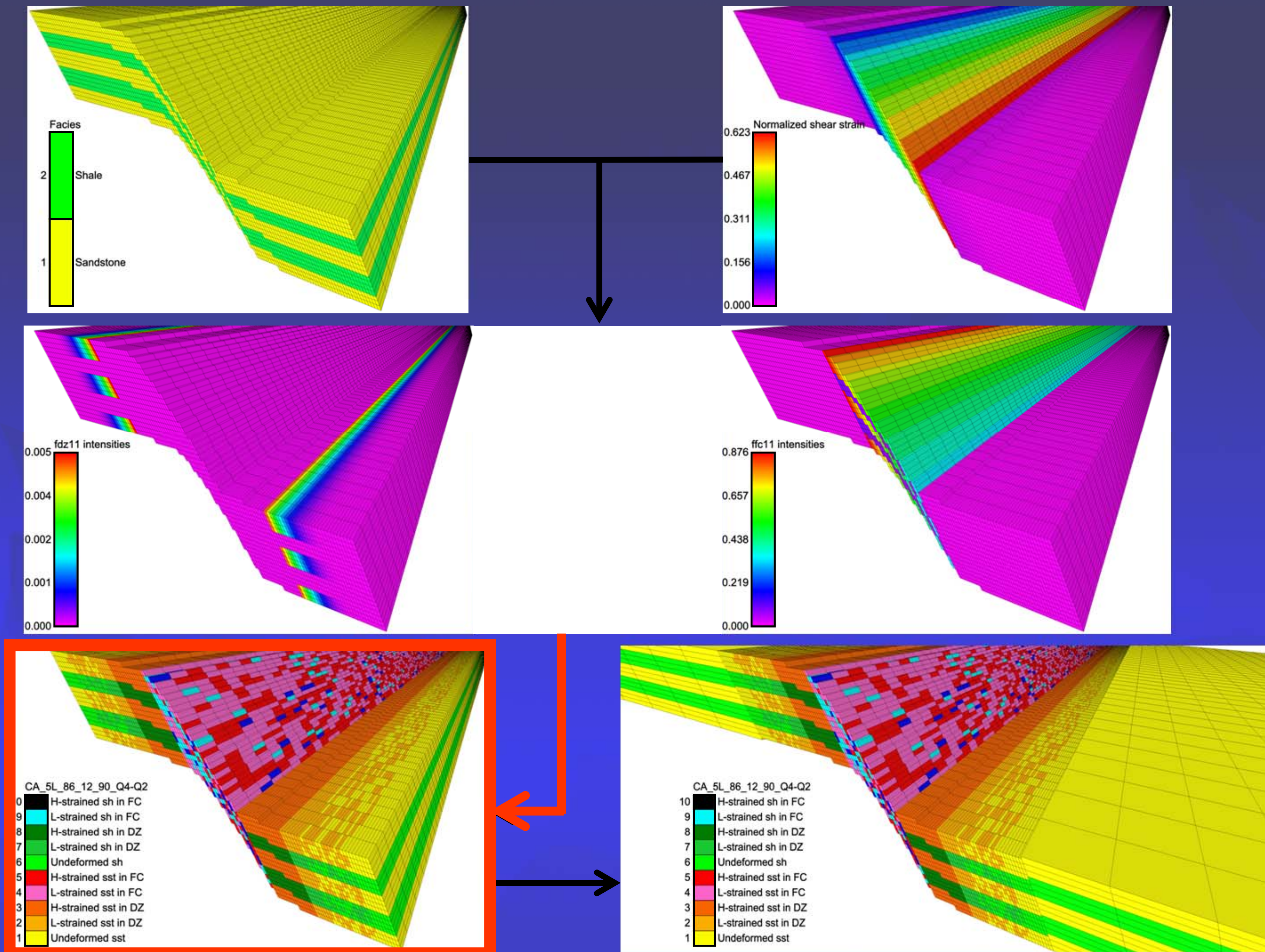


Cross sections perpendicular to fault plane

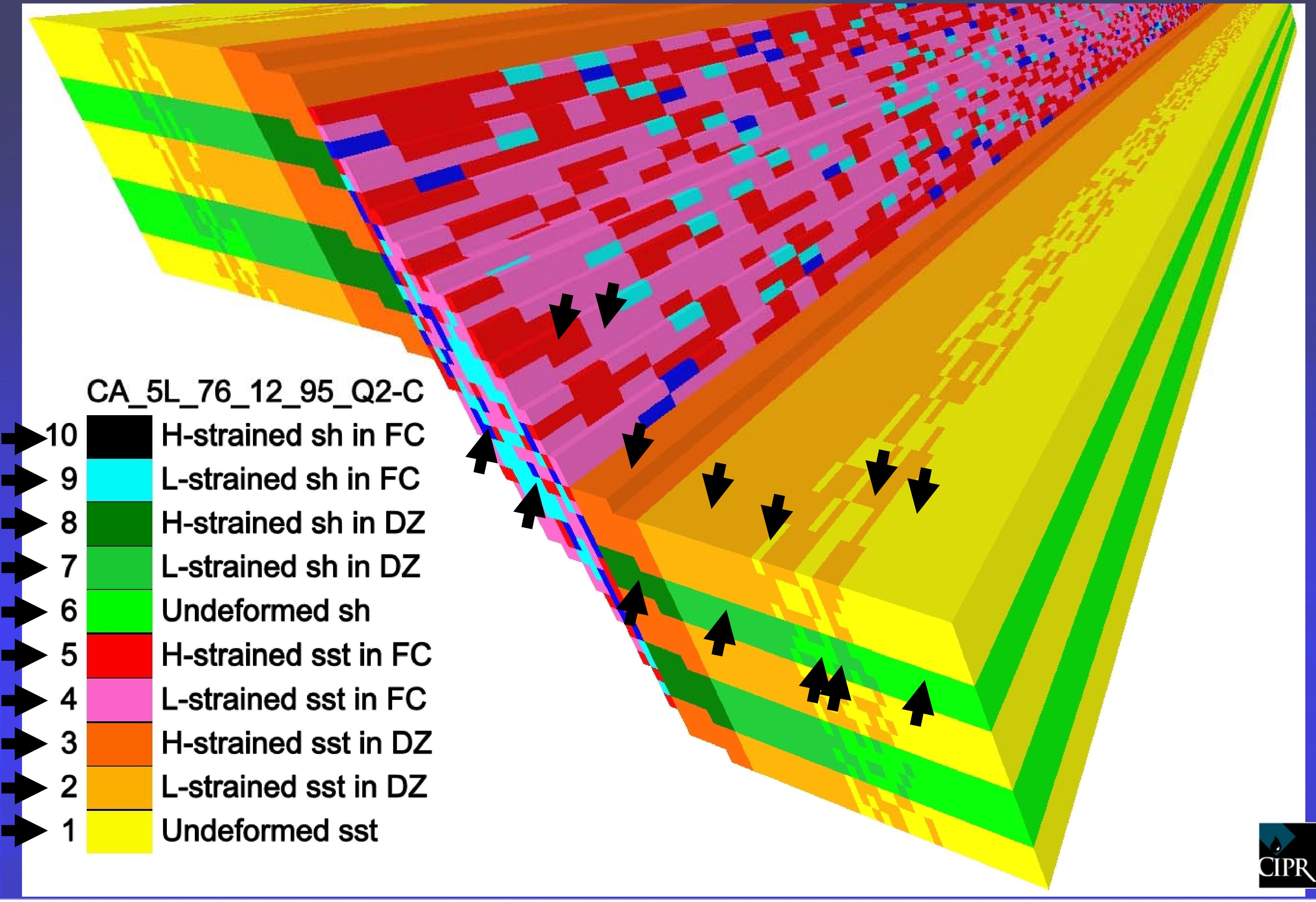




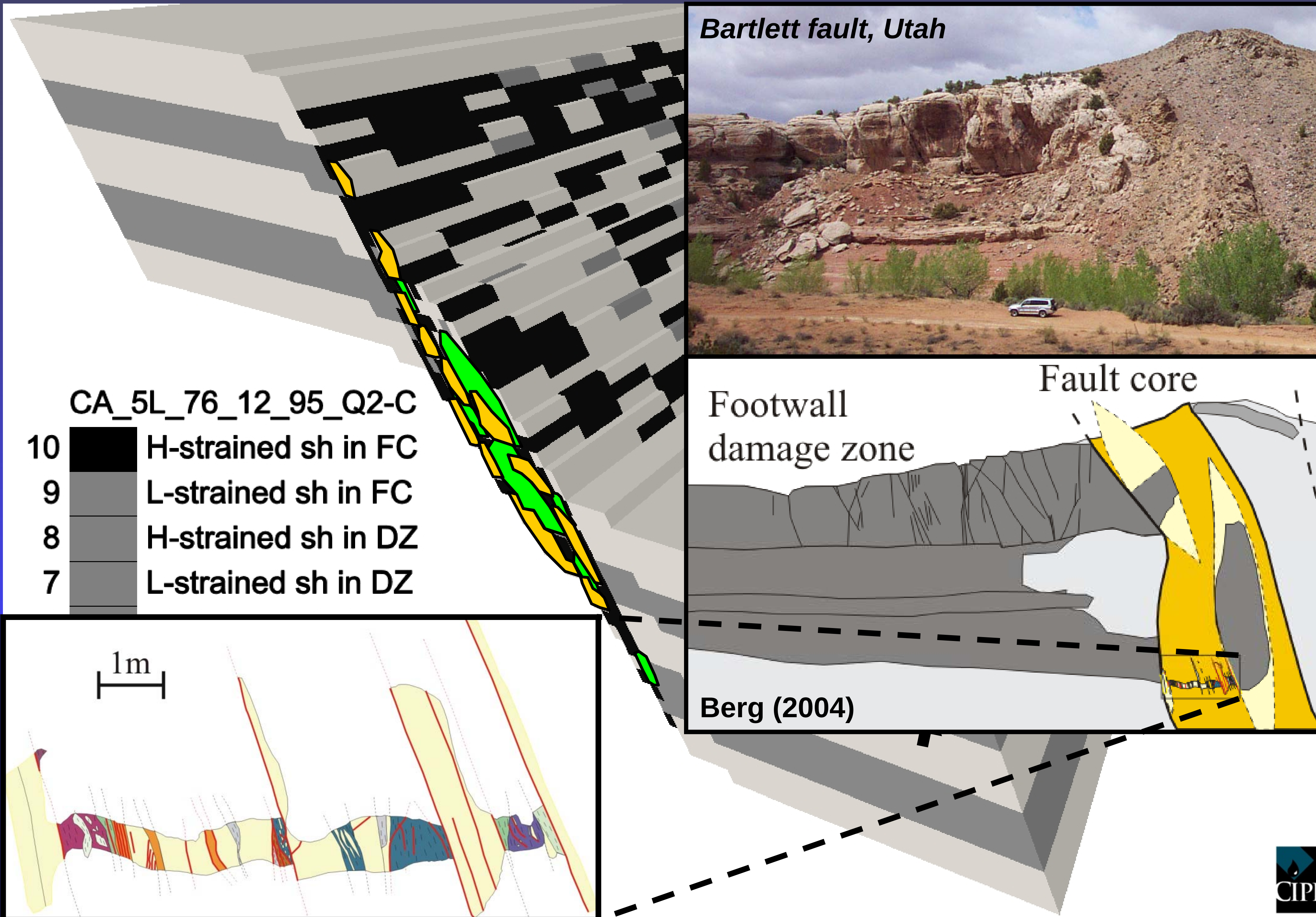
Fault facies probability distribution



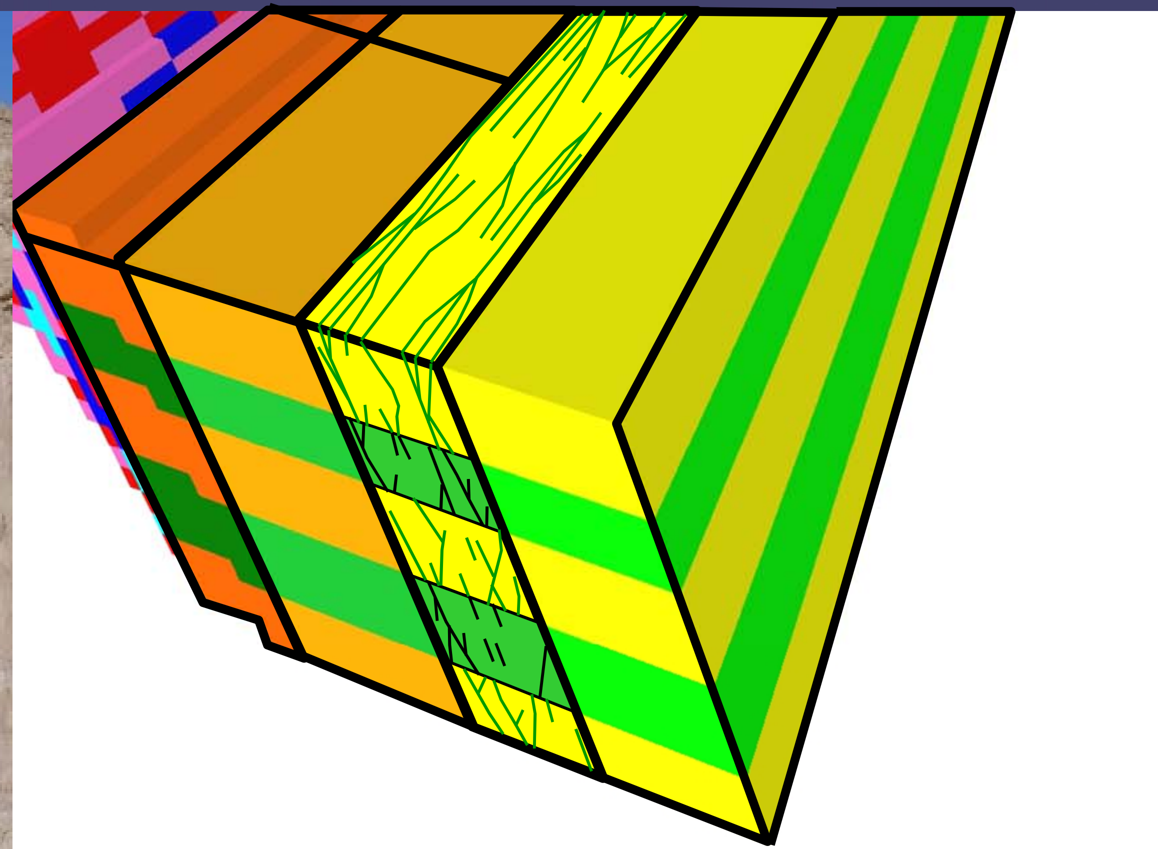
Fault facies

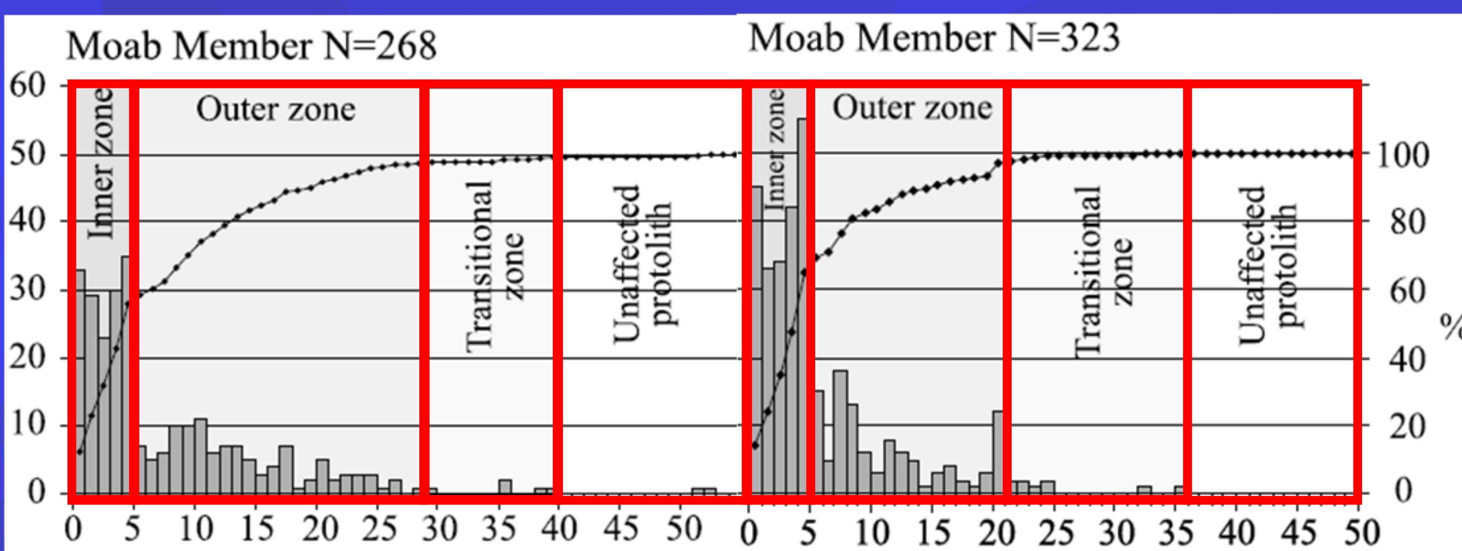


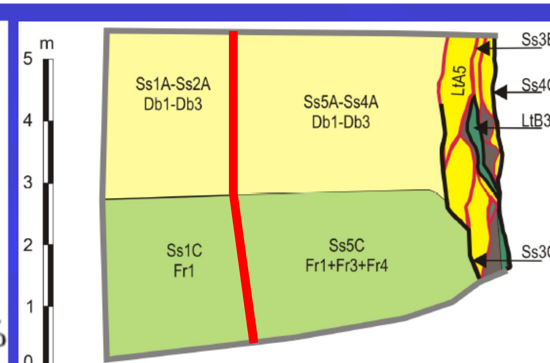
Fault facies – fault core



Fault facies – damage zones







Braathen et al (in prep.)

Berg and Skar (2005)

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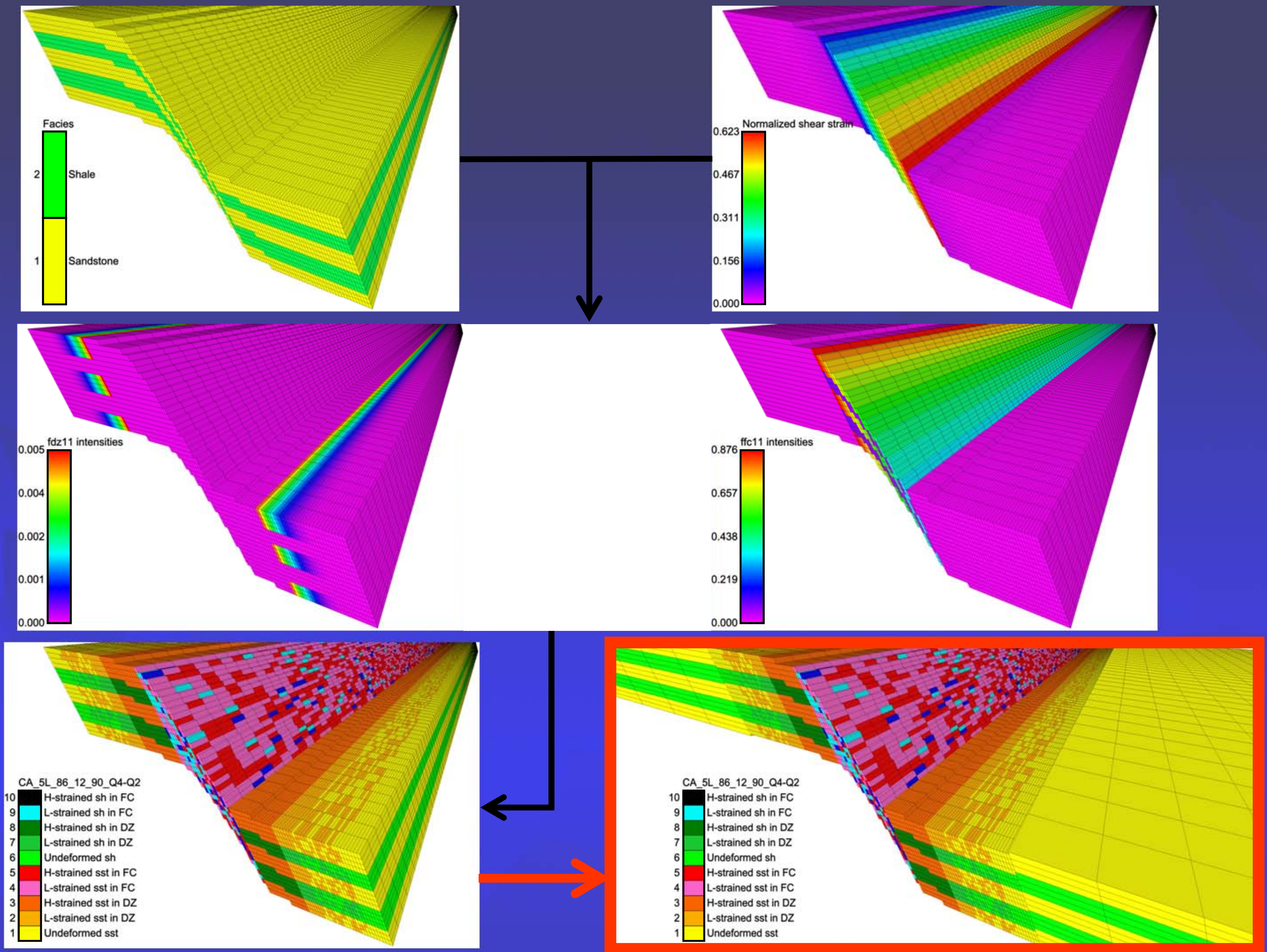
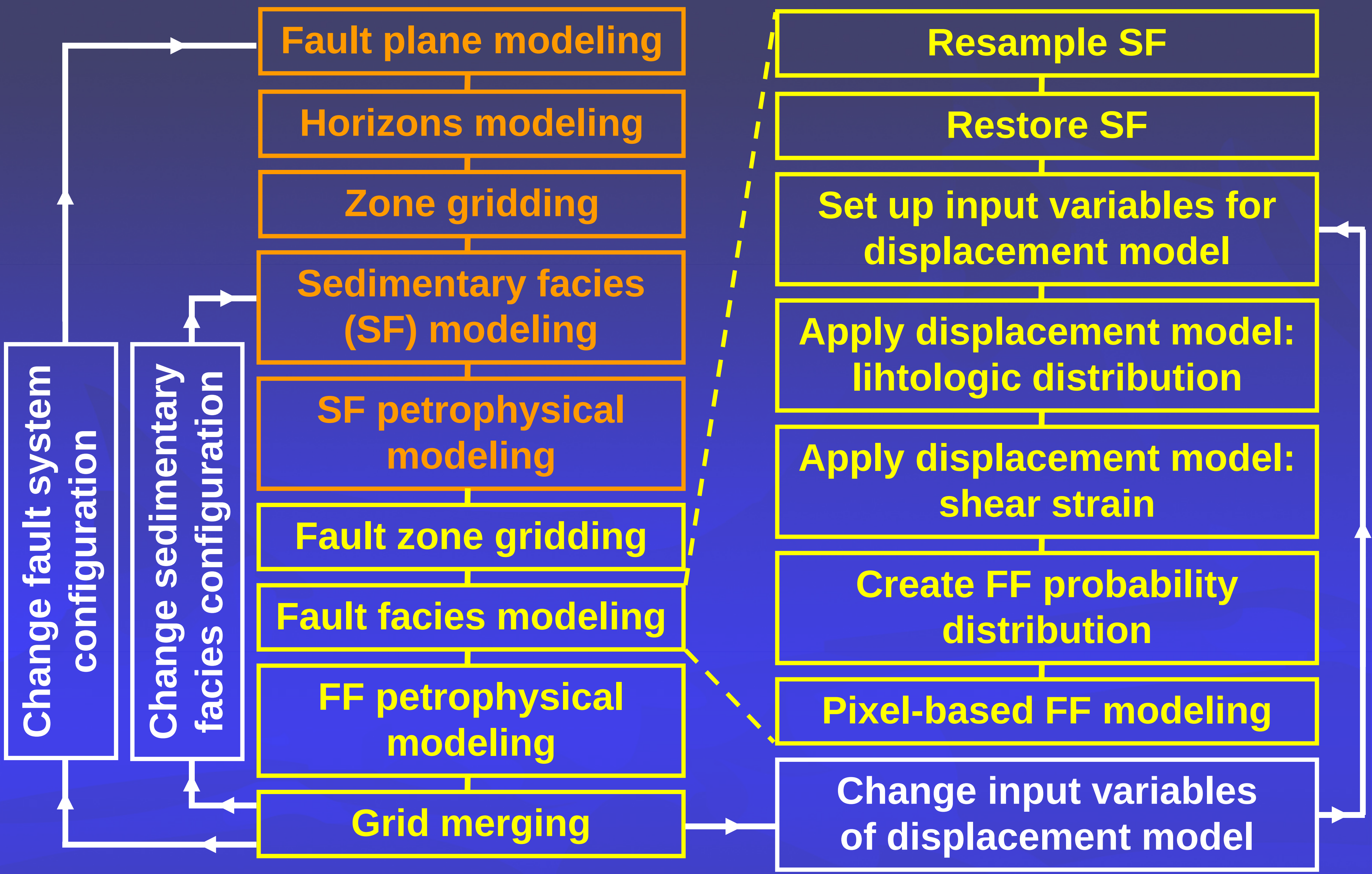
Fault facies probability distribution



Complete workflow



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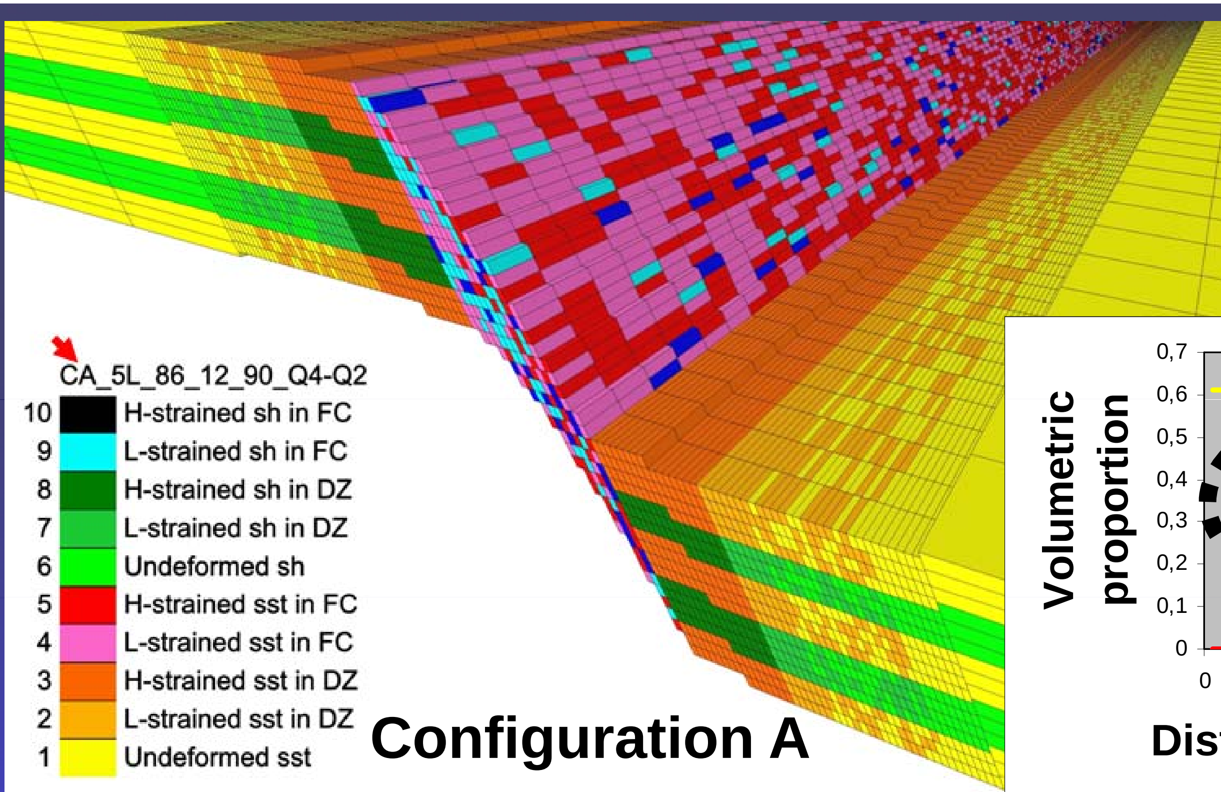
Matrix of geo-models

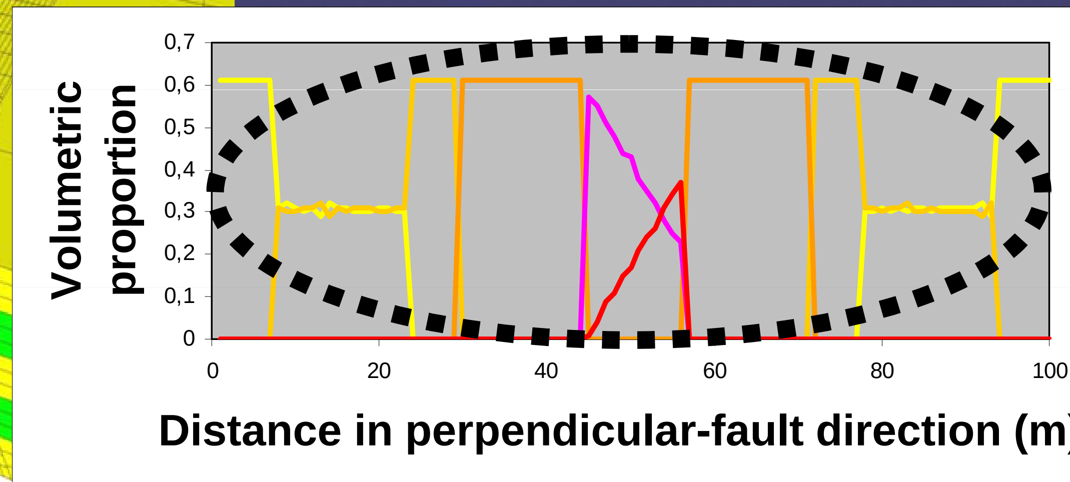
			Configuration A, fault throw (FT) = 43 m																Configuration B, @ FT = 22 m
			DZ width = 2 FT								DZ width = 1.7 FT								
			FC thick. = 0.27 FT				FC thick. = 0.18 FT				FC thick. = 0.27 FT				FC thick. = 0.18 FT				
			FCDP = 90%		FCDP = 95%		FCDP = 90%		FCDP = 95%		FCDP = 90%		FCDP = 95%		FCDP = 90%		FCDP = 95%		
			Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	Q4-Q2	Q2-C	
2 sedimentary facies	Proportion: 0.6 sst, 0.4 sh	5 layers	CA_5L_86_12_90_Q4-Q2	CA_5L_86_12_95_Q2-C	CA_5L_86_12_95_Q4-Q2	CA_5L_86_12_95_Q2-C	CA_5L_86_8_90_Q4-Q2	CA_5L_86_8_90_Q2-C	CA_5L_86_8_95_Q4-Q2	CA_5L_86_8_95_Q2-C	CA_5L_76_12_90_Q4-Q2	CA_5L_76_12_90_Q2-C	CA_5L_76_12_95_Q4-Q2	CA_5L_76_12_95_Q2-C	CA_5L_76_8_90_Q4-Q2	CA_5L_76_8_90_Q2-C	CA_5L_76_8_95_Q4-Q2	CA_5L_76_8_95_Q2-C	16 geo-models
		7 layers	16 geo-models																16 geo-models

- **64 models**
- **640 realizations**

Geo-model characteristics

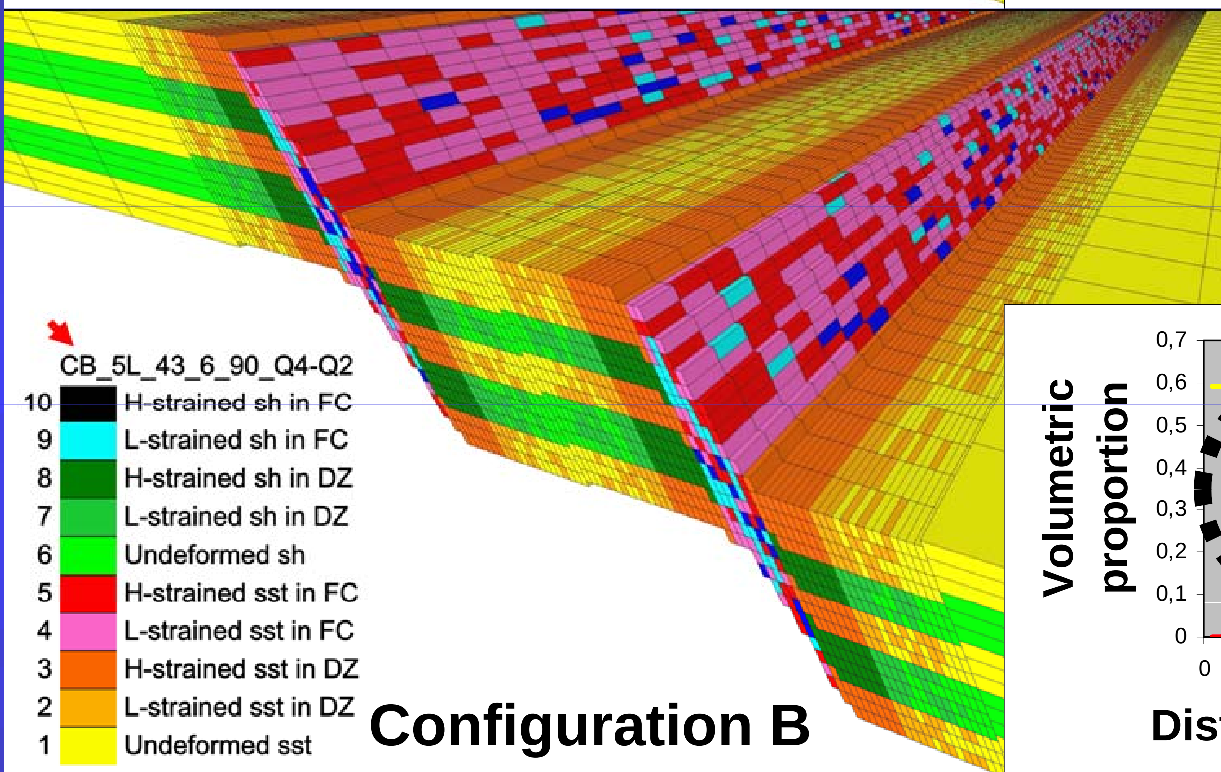
Modifying fault system configuration

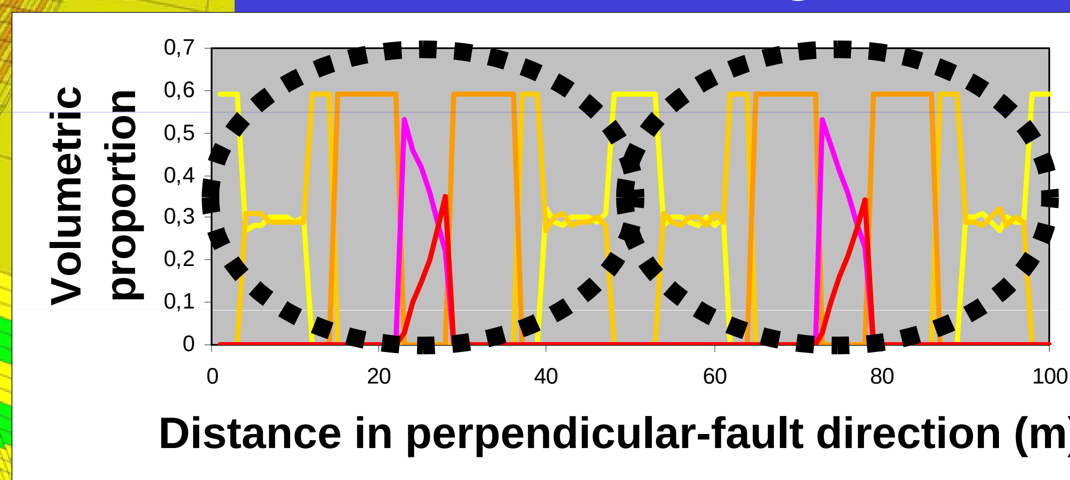




Configuration A

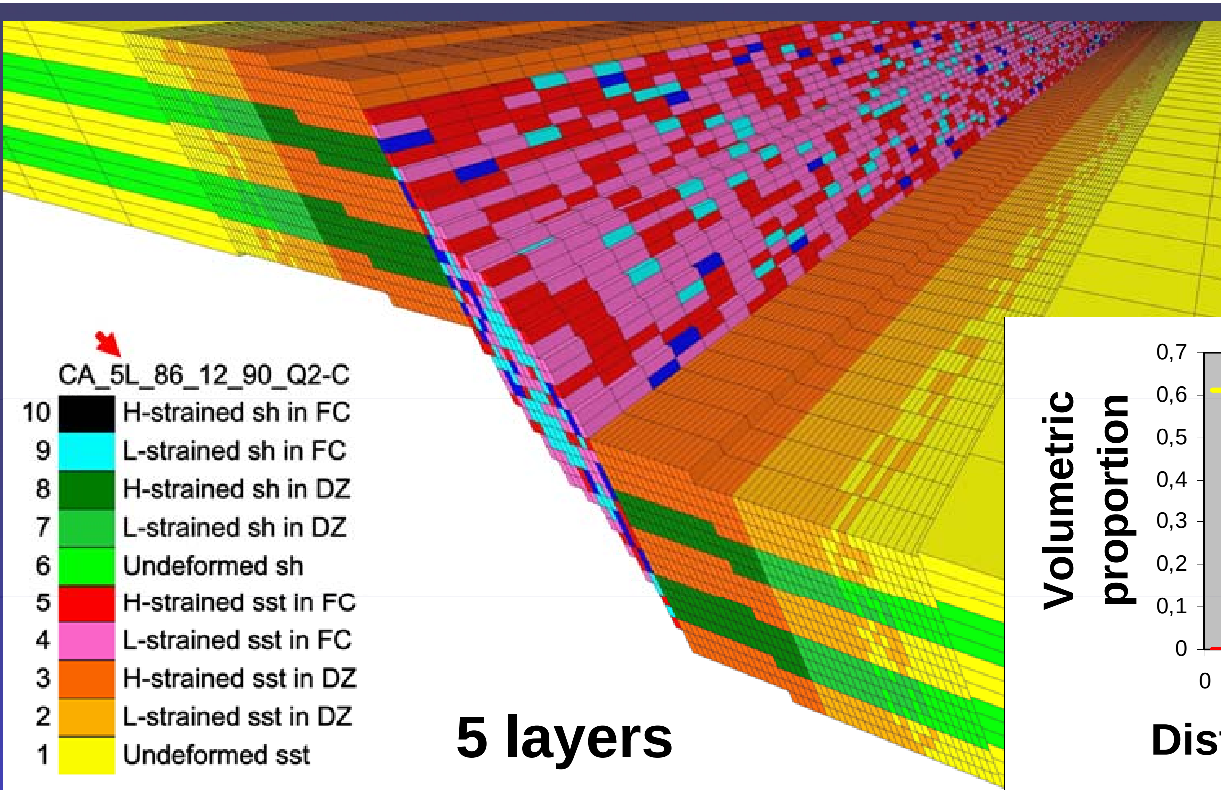
Configuration B

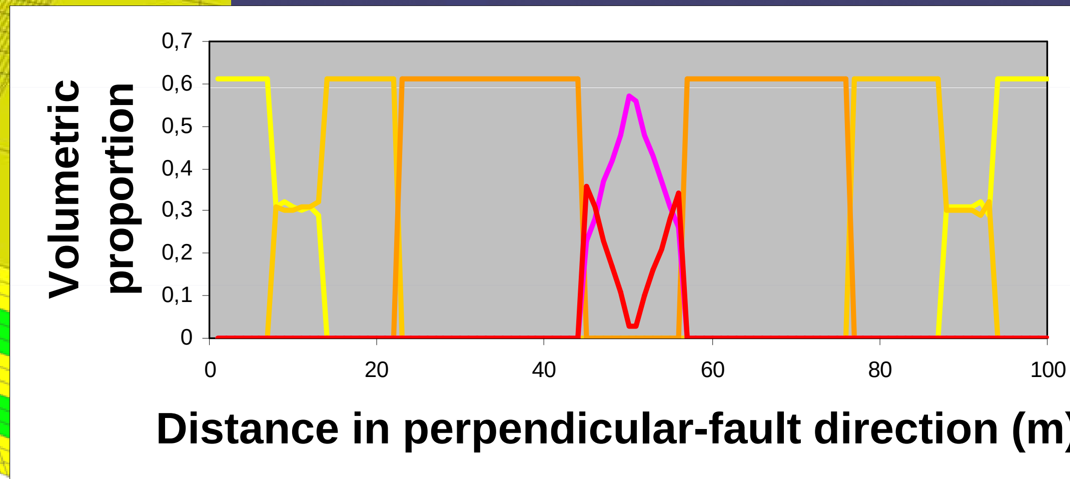




Geo-model characteristics

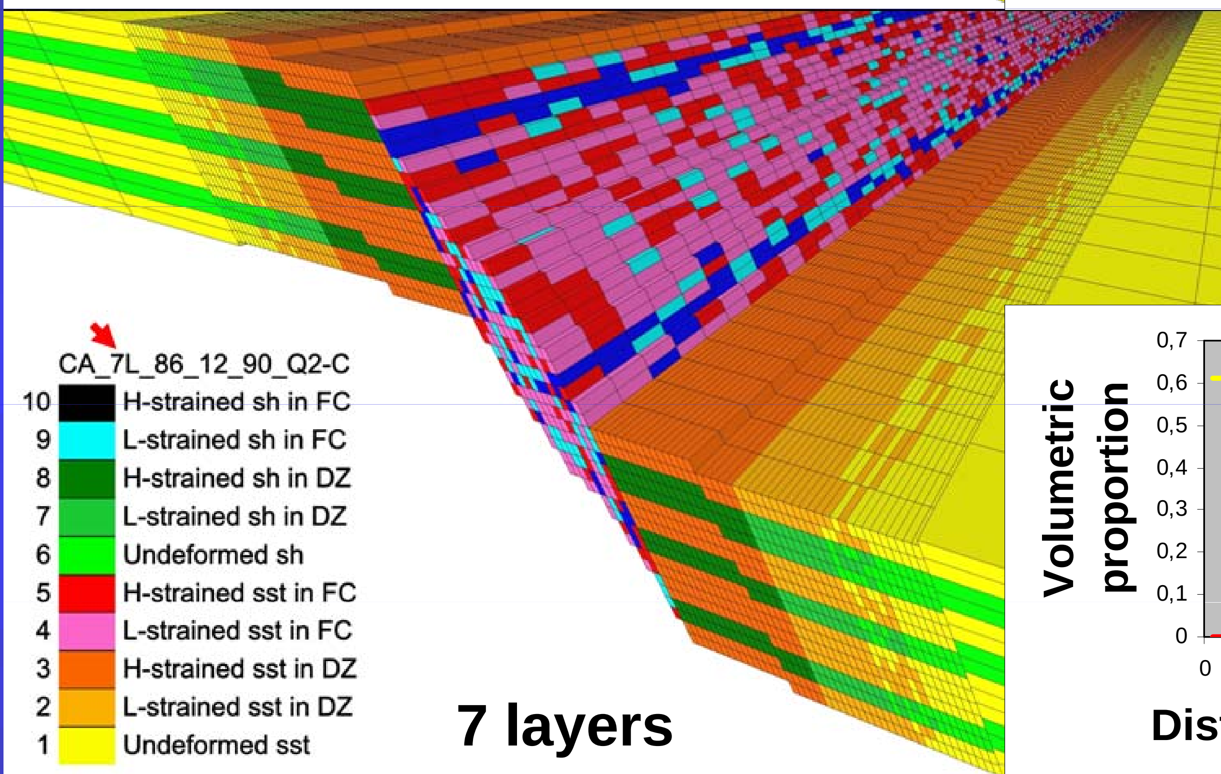
Modifying sedimentary facies configuration

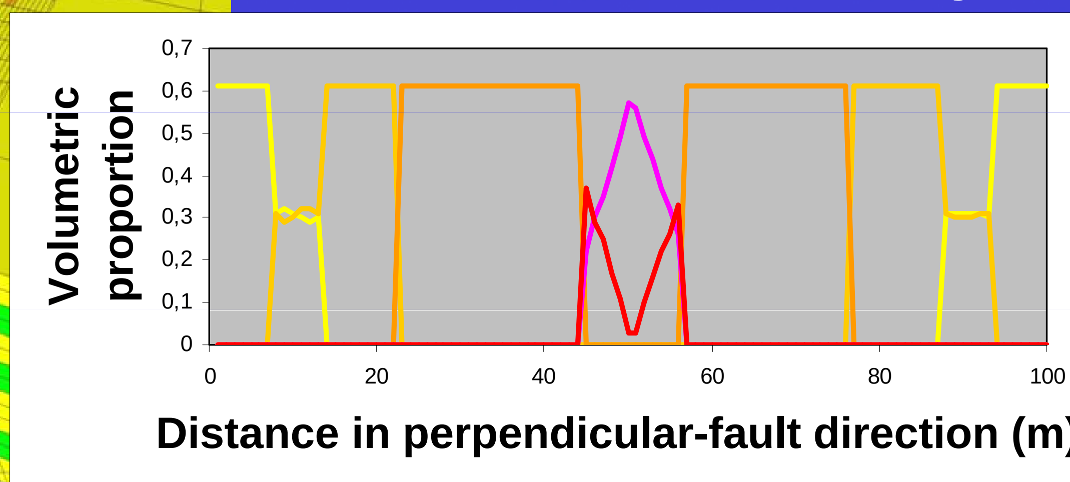




5 layers

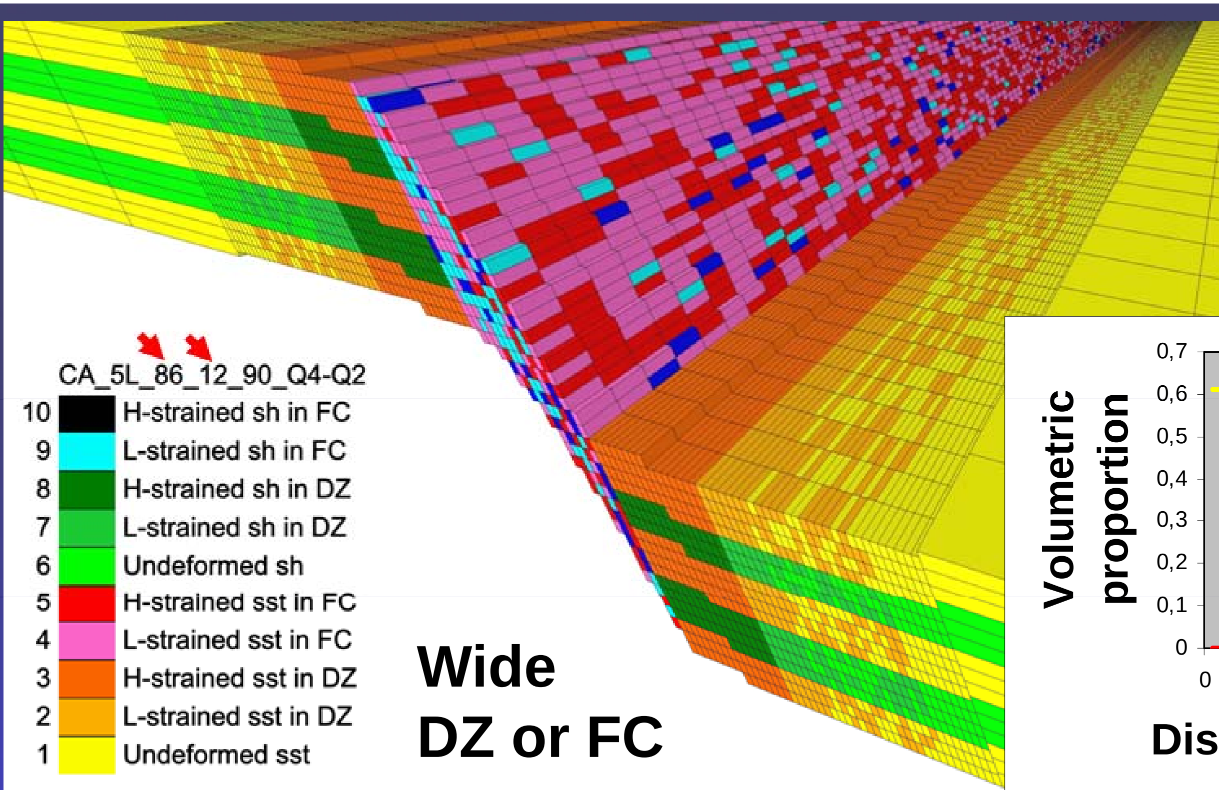
7 layers

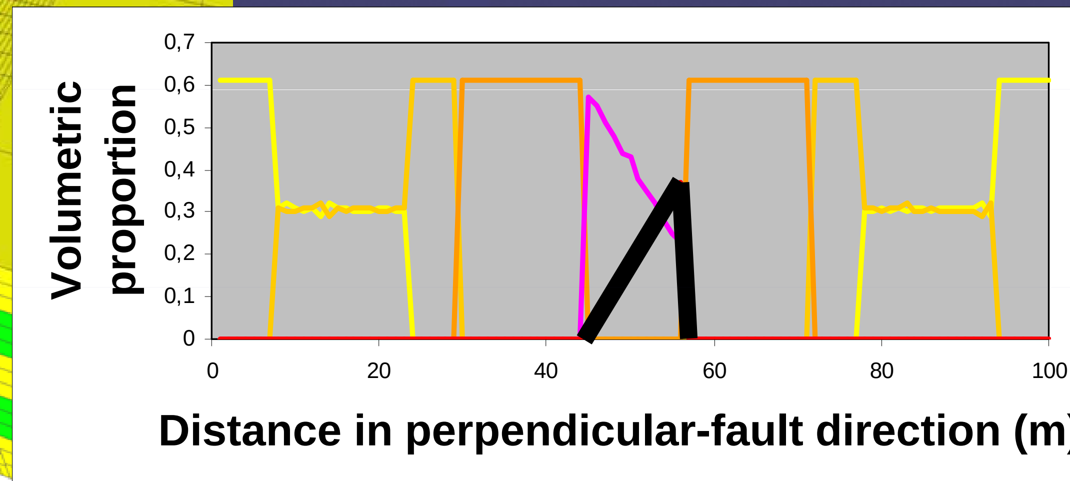




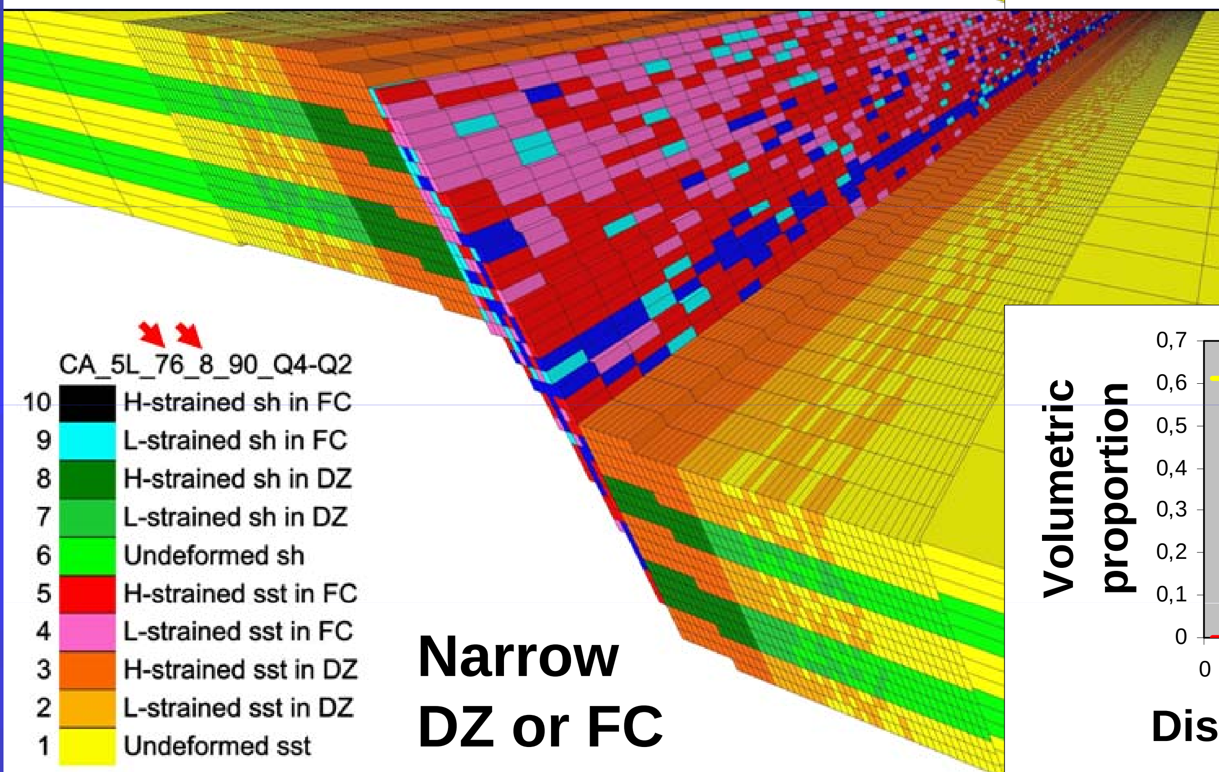
Geo-model characteristics

Modifying DZ width and FC thickness

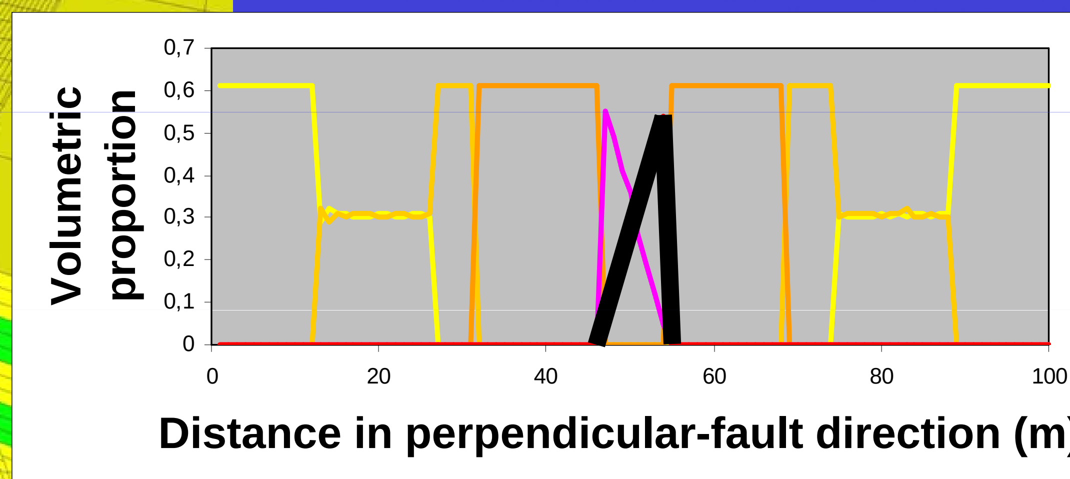




Wide DZ or FC

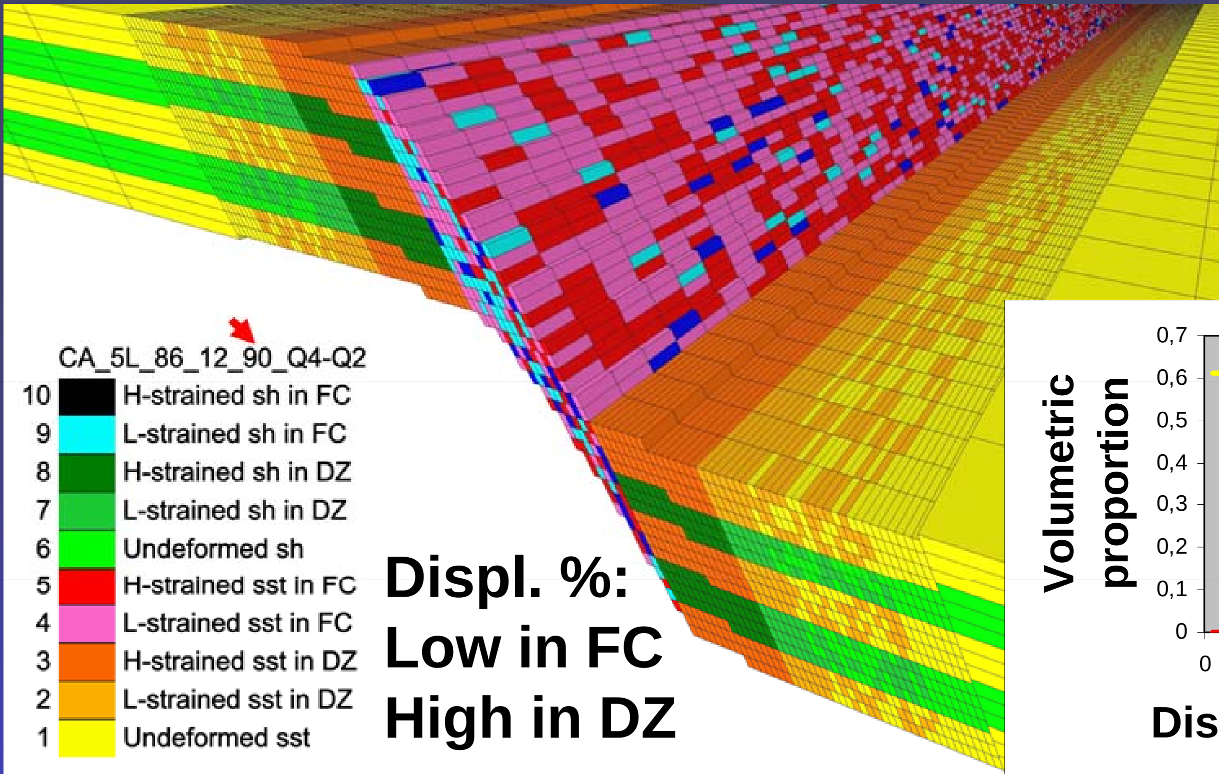


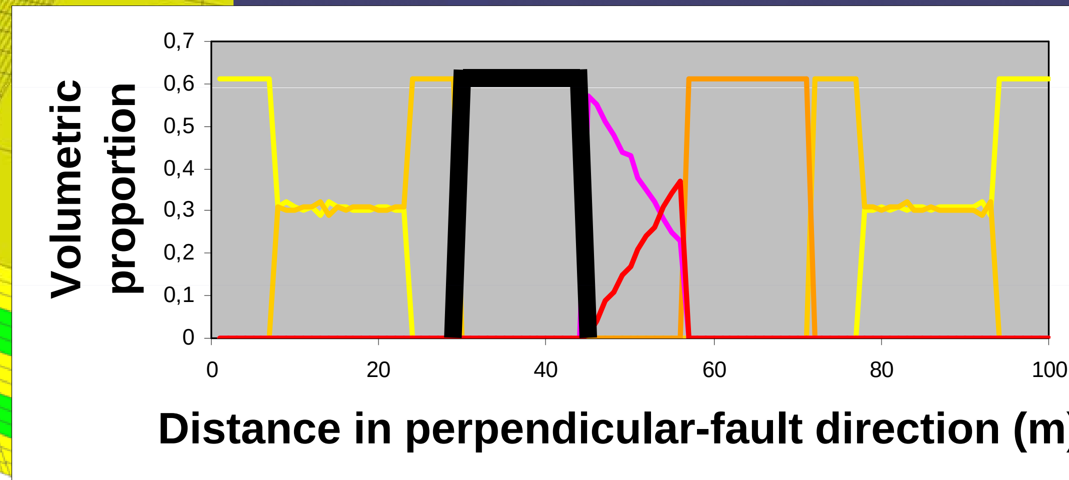
Narrow DZ or FC



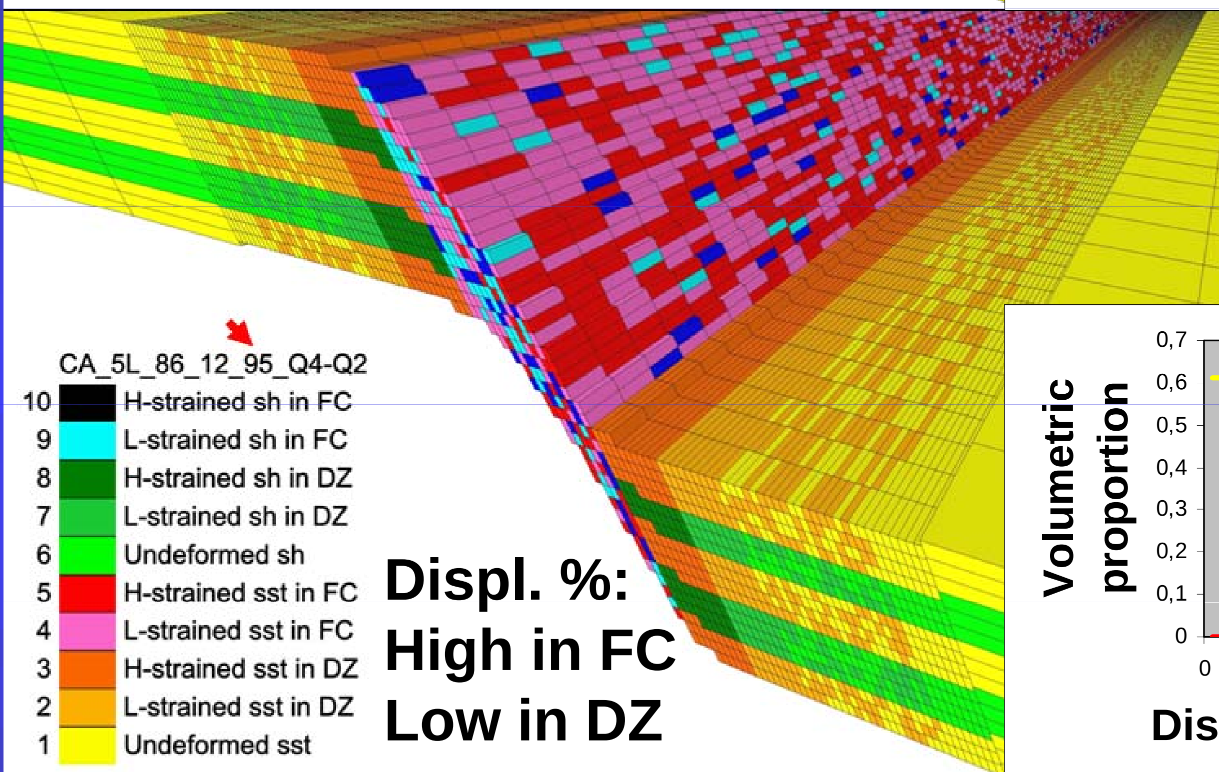
Geo-model characteristics

Modifying FC throw percentage

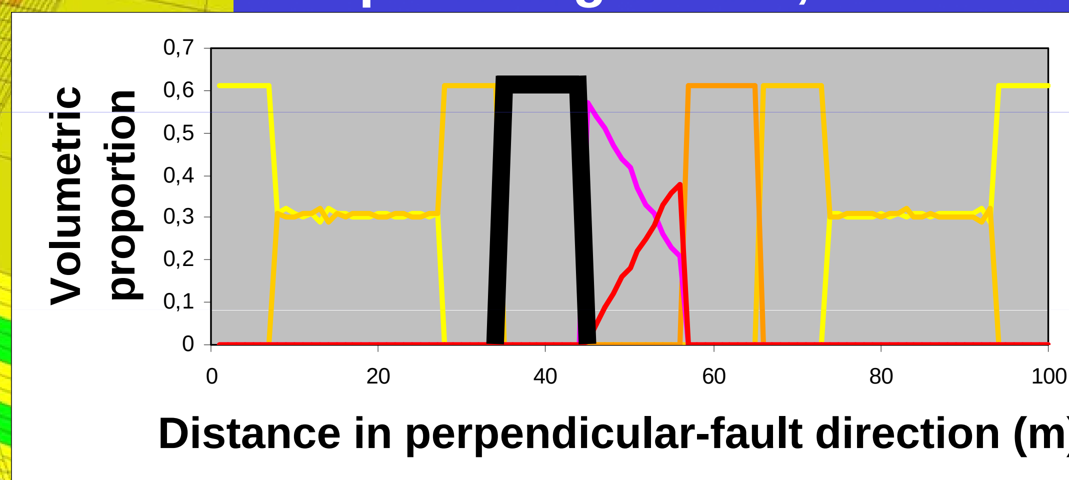




Displ. %: low in FC, high in DZ

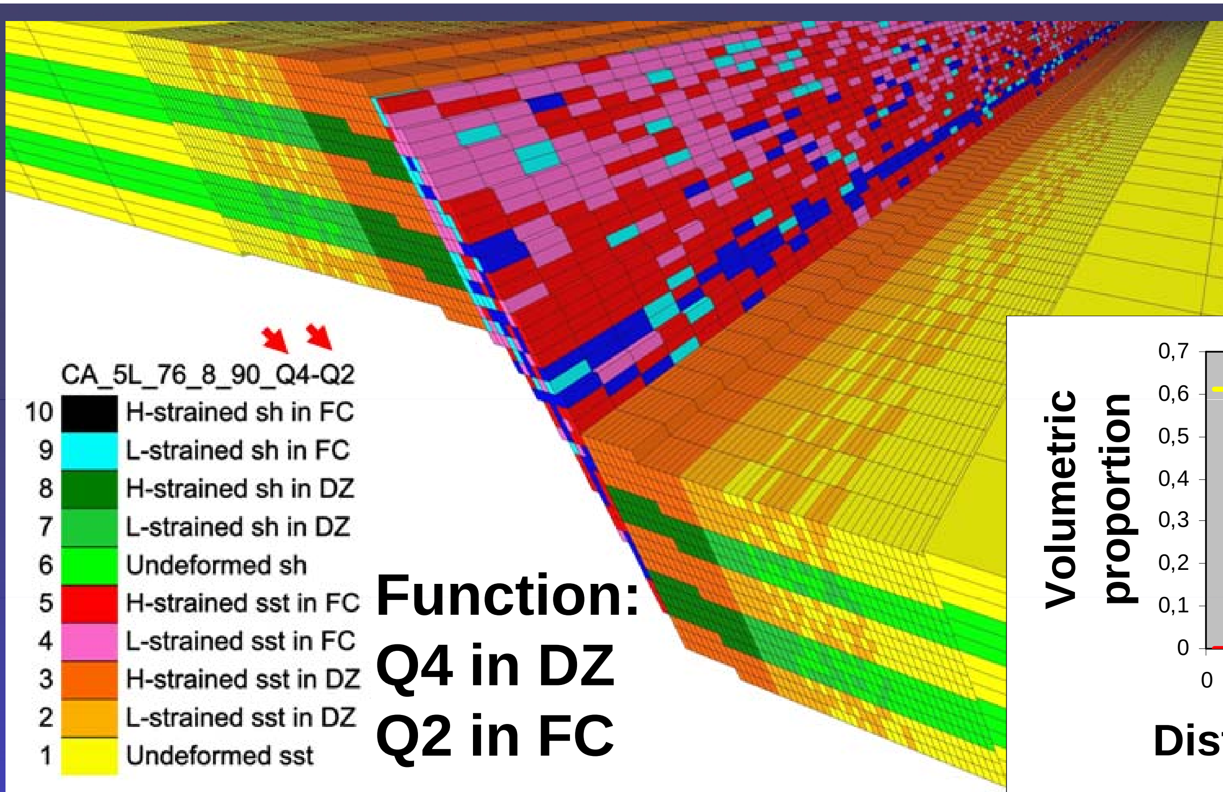


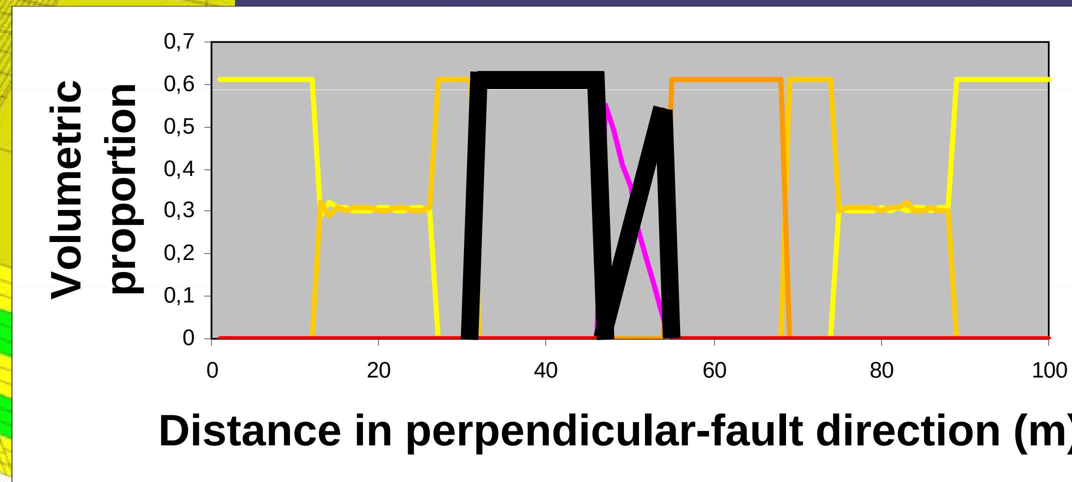
Displ. %: high in FC, low in DZ



Geo-model characteristics

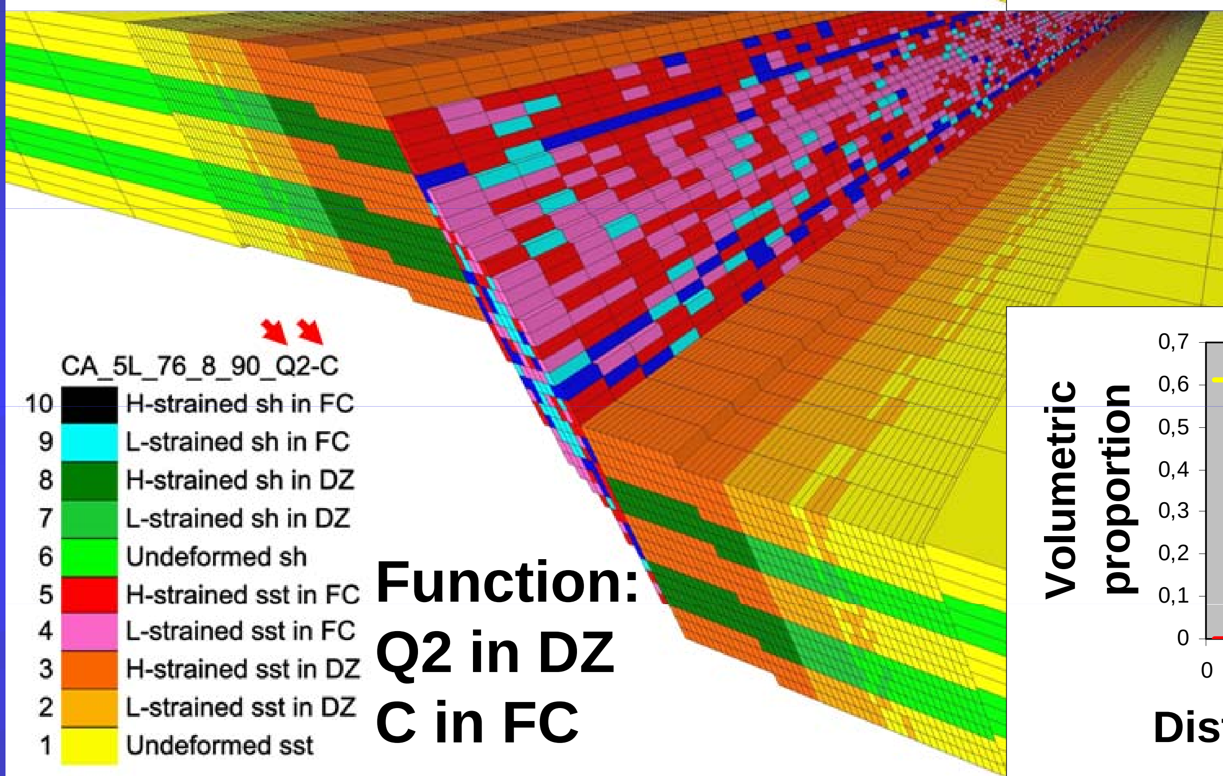
Modifying the type of displacement function

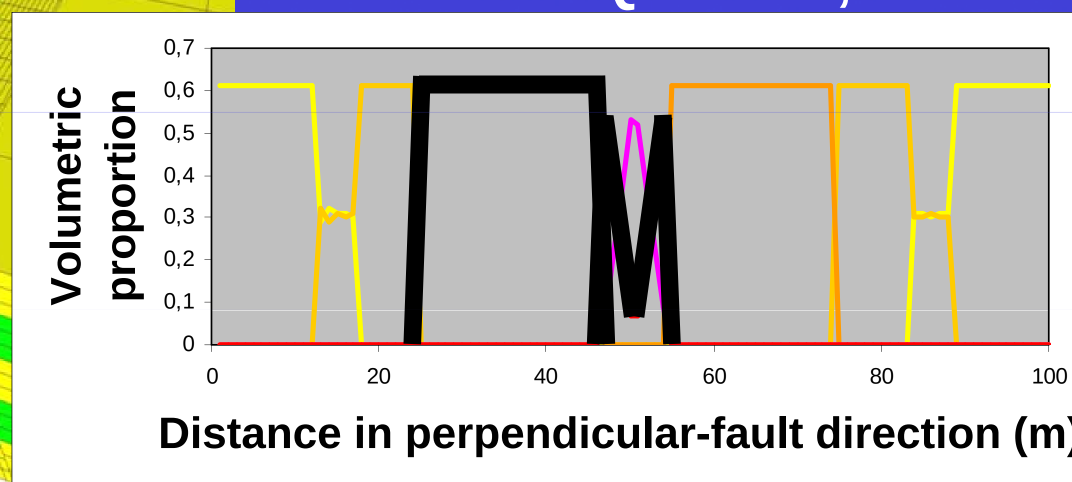




Function: Q4 in DZ, Q2 in FC

Function: Q2 in DZ, C in FC

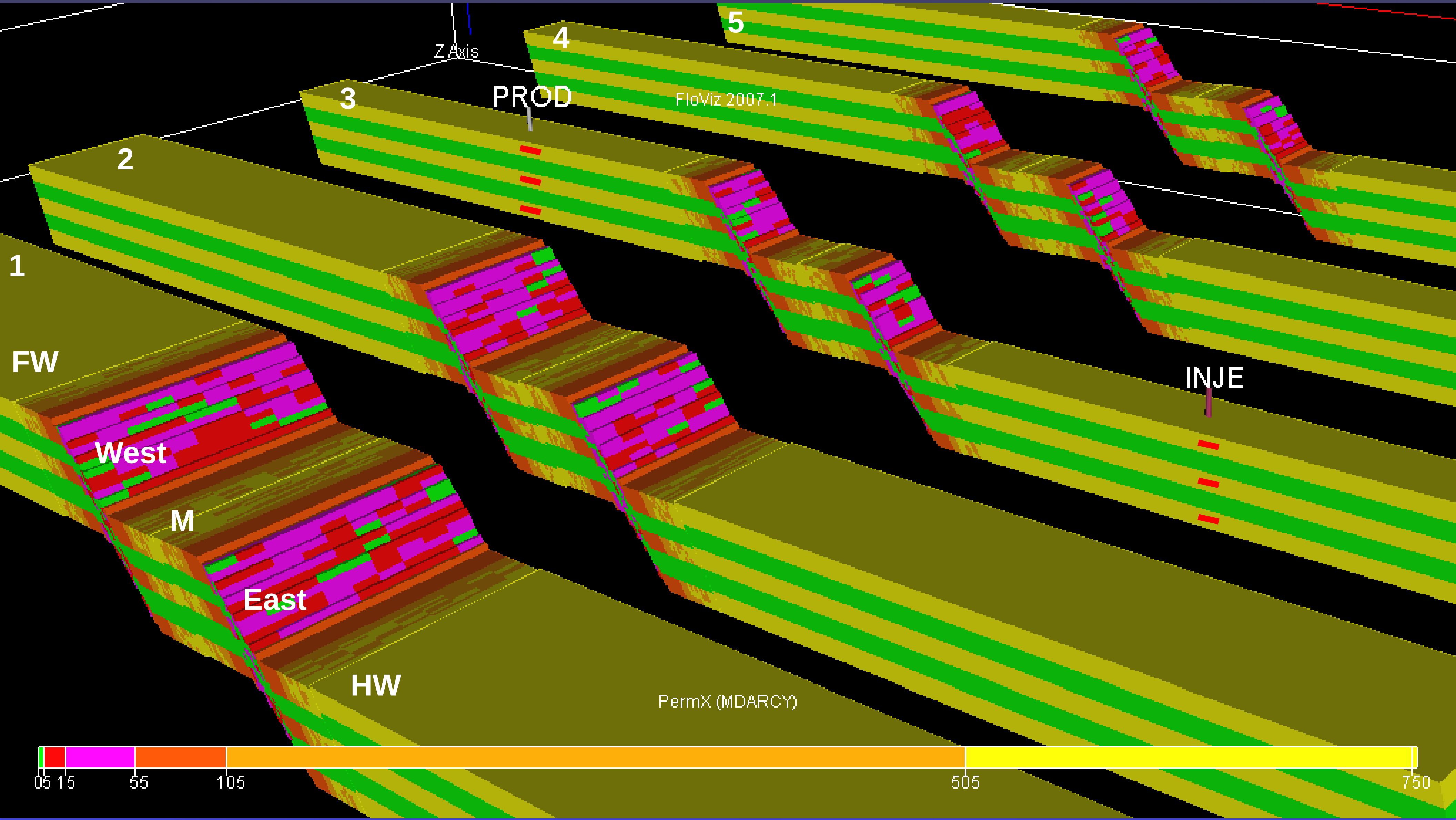




Conclusions

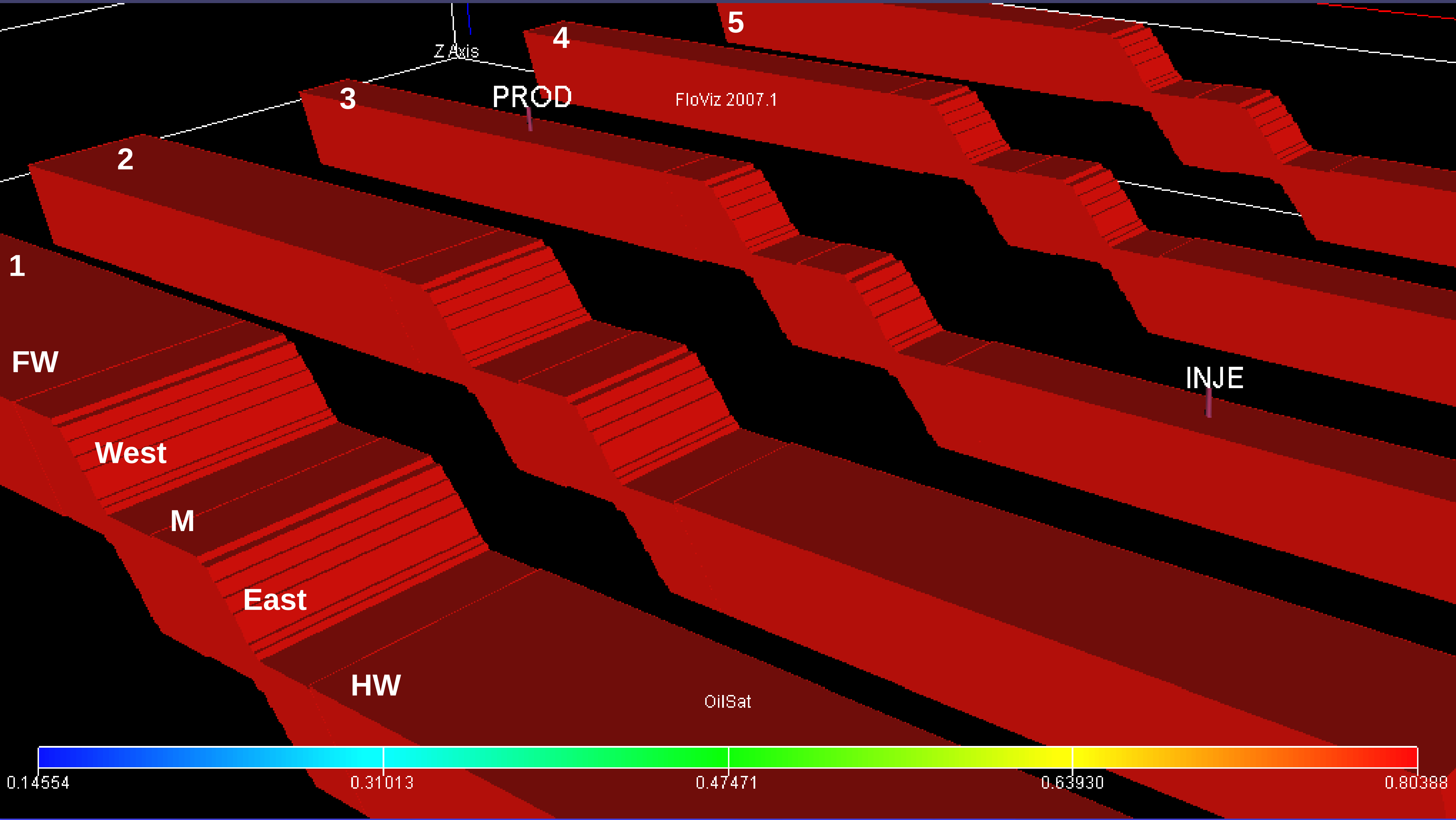
- Improvements
  - Displacement models
- Reproducing meso-scale observations
  - Sequential indicator simulation
- Modeling input vs. resulting geo-model configurations
  - Fluid flow
  - Faulted reservoir performance
  - Upscaling procedure

Flow characteristics



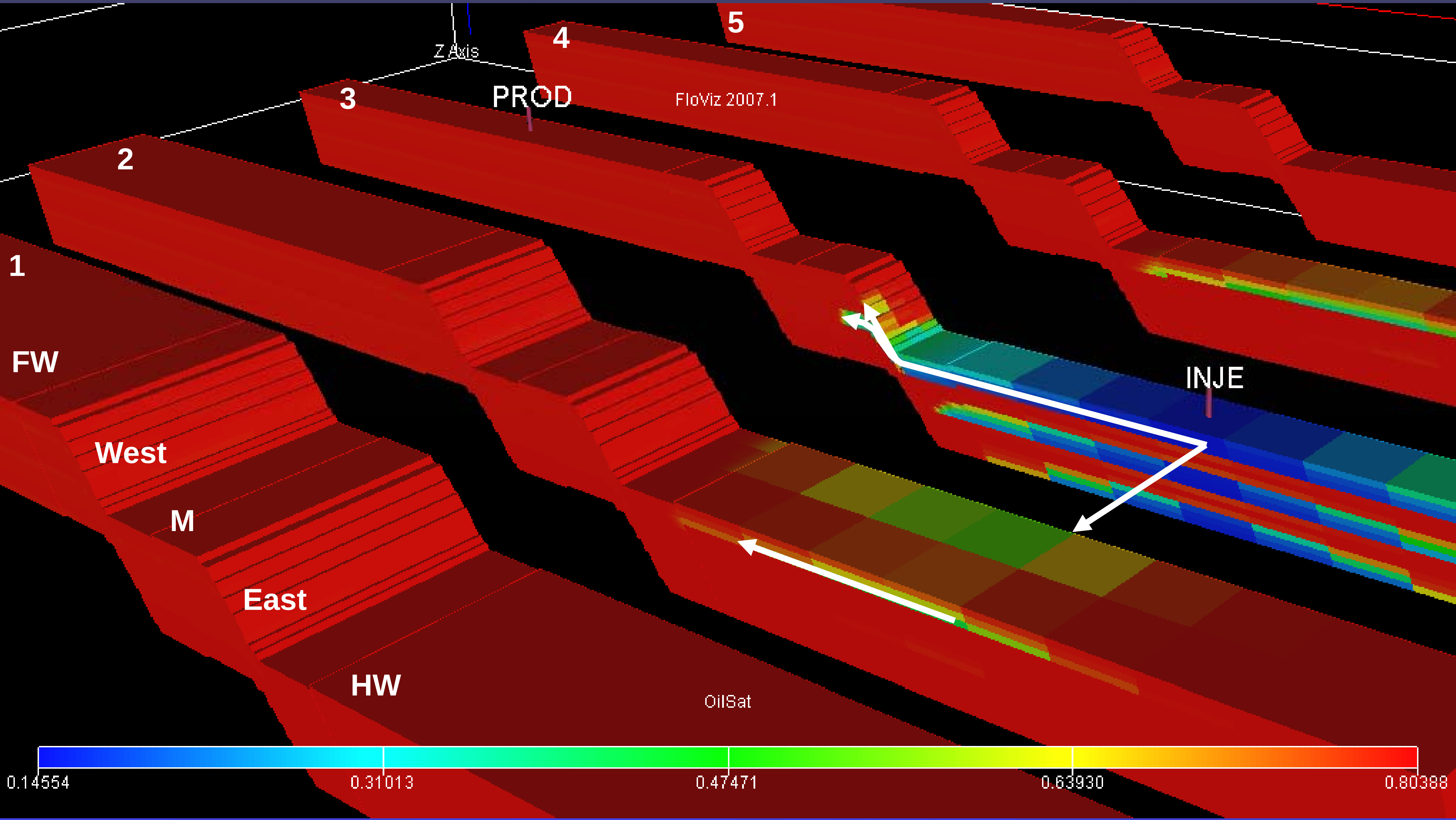
PermX - Day 0

Flow characteristics



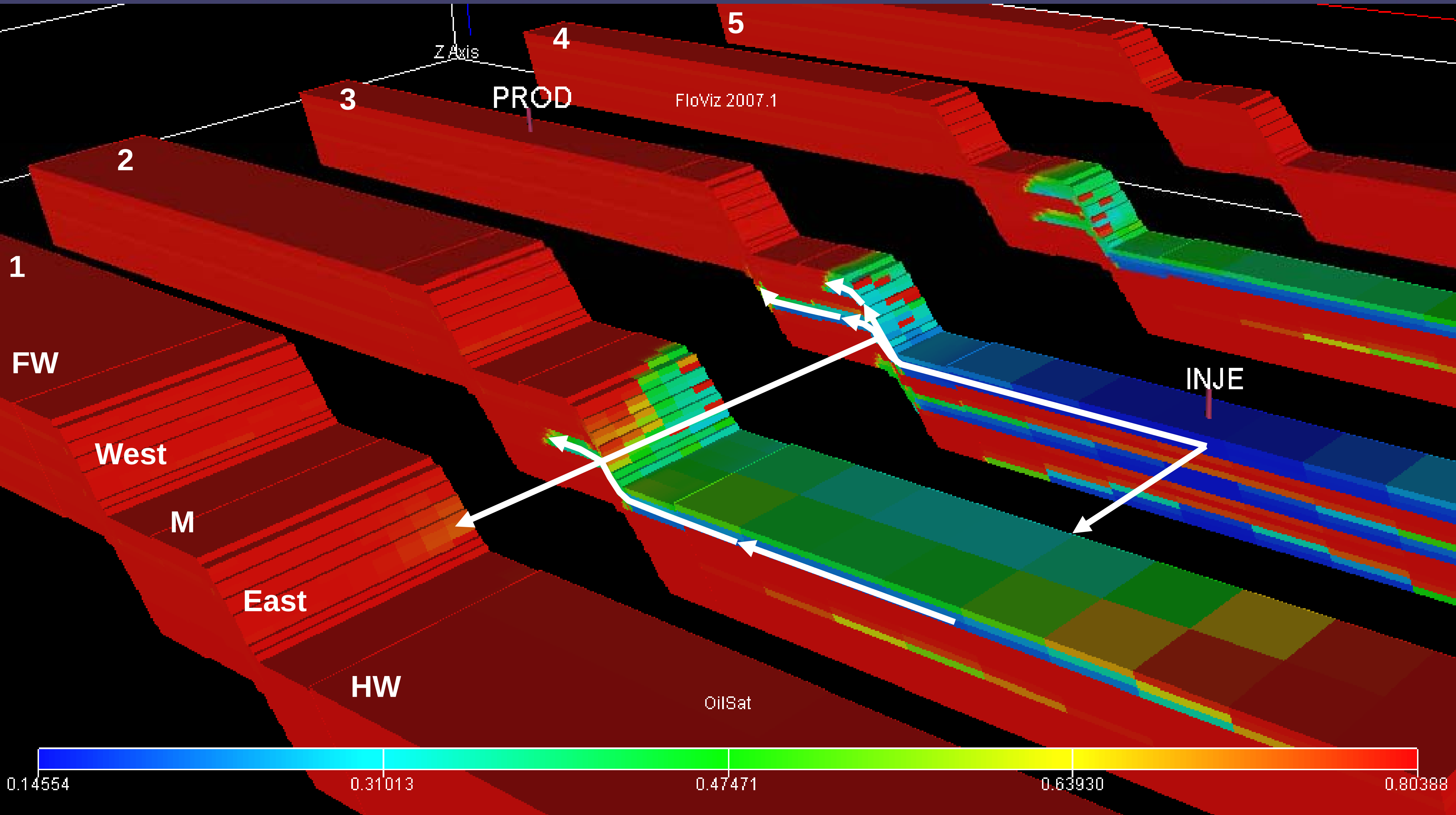
Oil saturation - Day 0

Flow characteristics



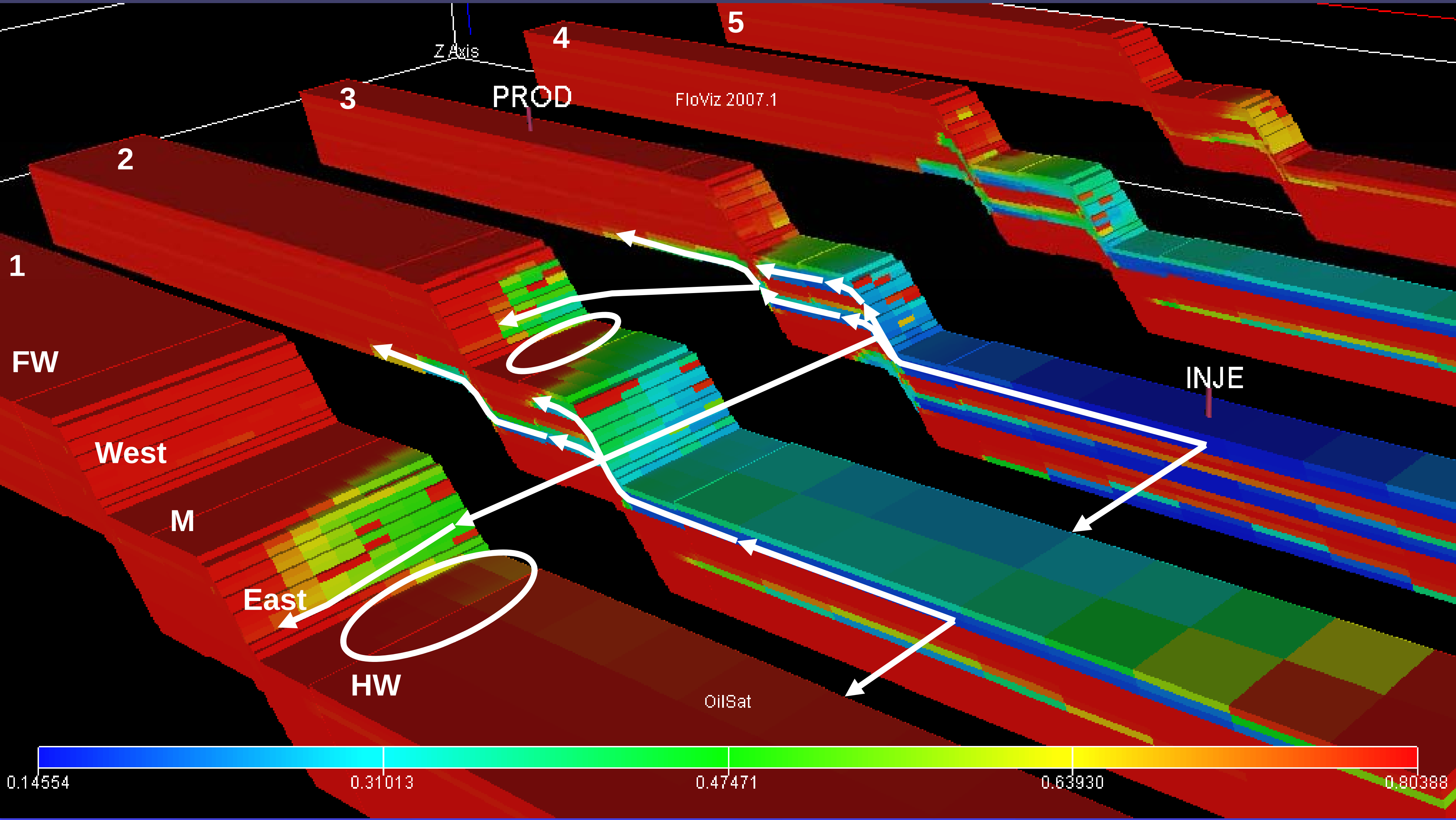
Oil saturation - After 1 month

Flow characteristics



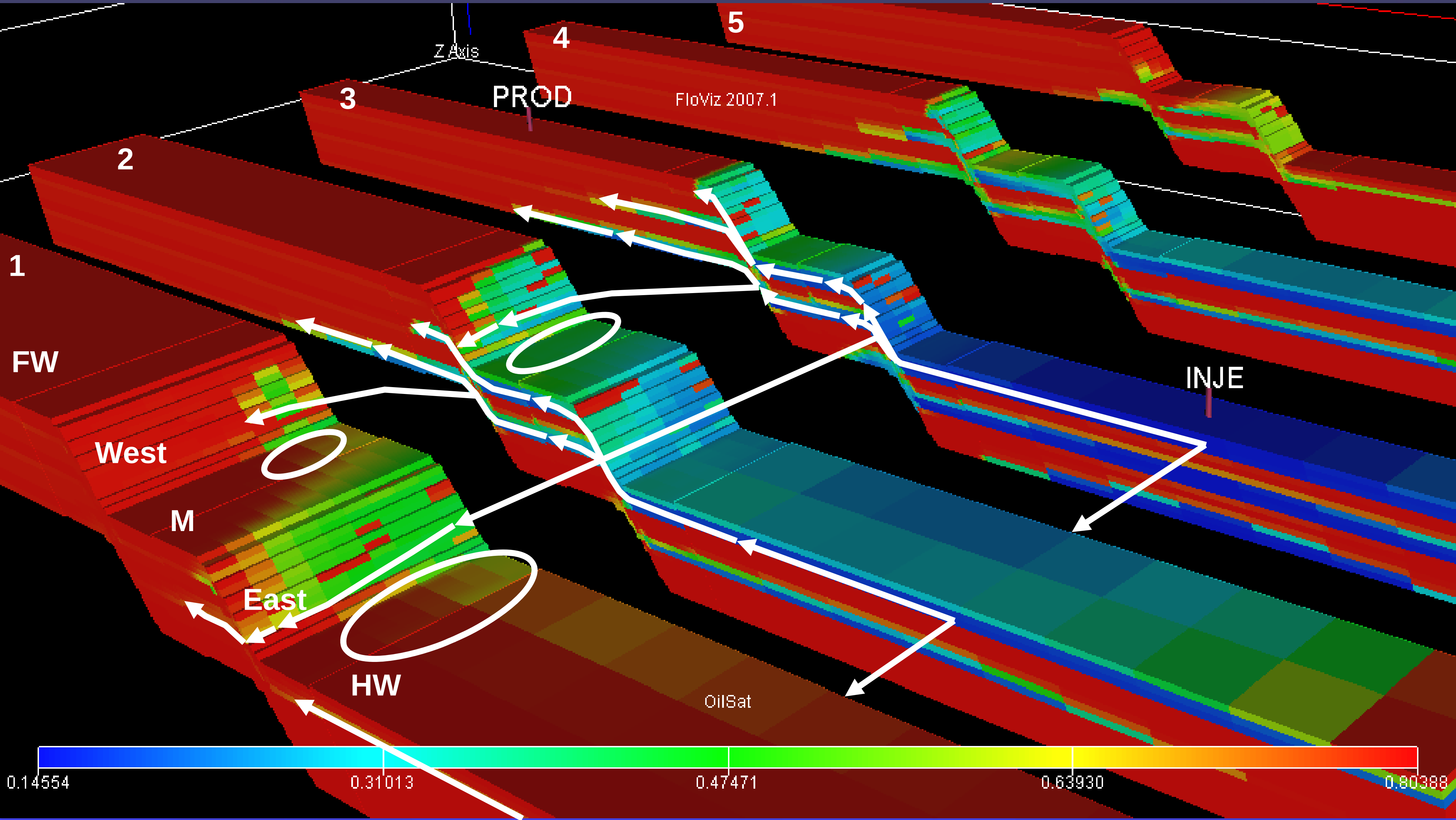
Oil saturation - After 2 months

Flow characteristics



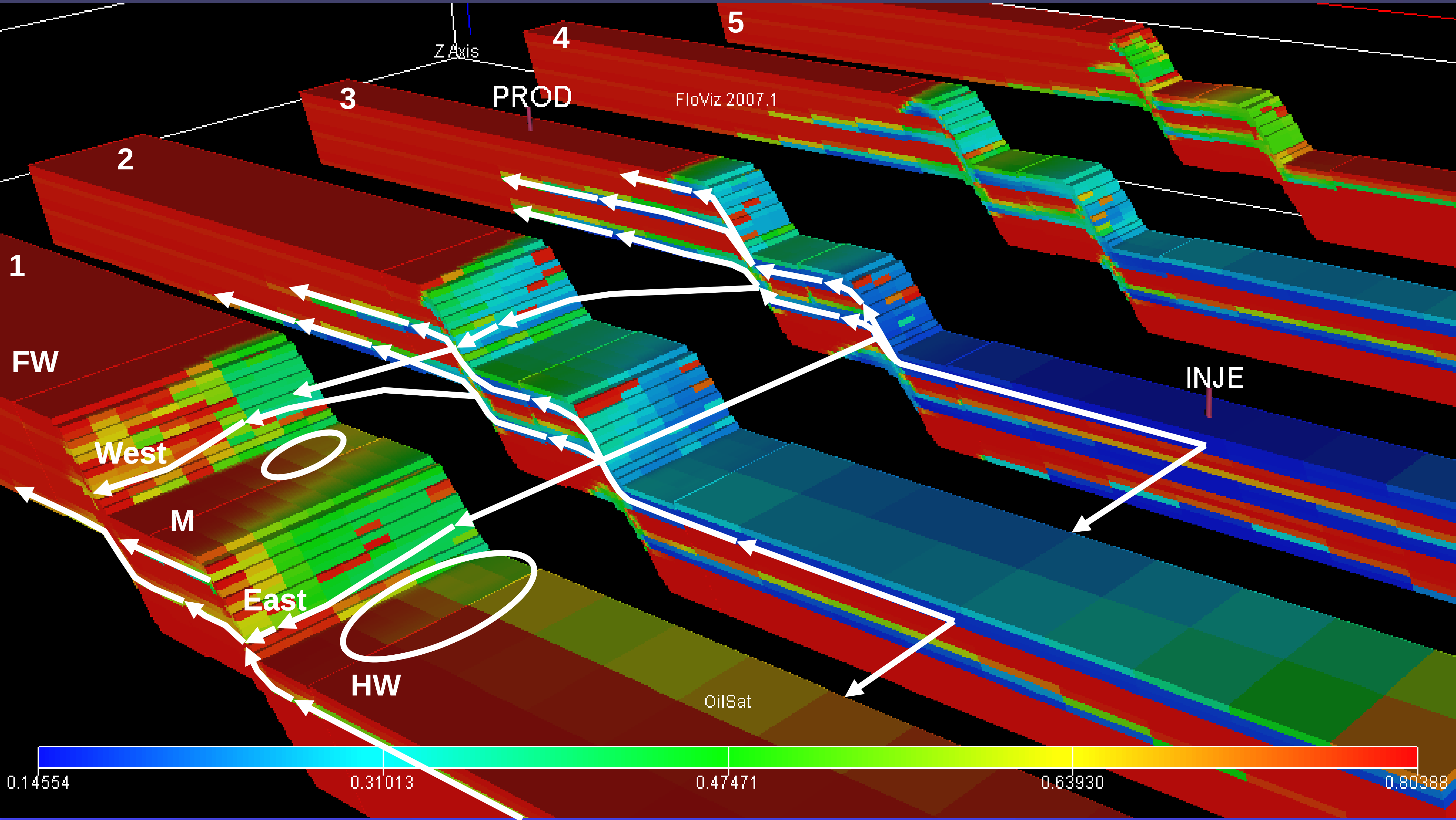
Oil saturation - After 3 months

Flow characteristics



Oil saturation - After 4 months

Flow characteristics



Oil saturation - After 5 months

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Thank You!