# Modeling of the Steam Chamber Growth During SAGD*

**Eric Bathellier[1], Olivier Lerat[2], Axelle Baroni[2], and Gerard Renard[2]**

Search and Discovery Article #41380 (2014)**
Posted July 7, 2014

*Adapted from oral presentation given at Pacific Section AAPG, SEG and SEPM Joint Technical Conference, Bakersfield, California, April 27-30, 2014


[1]CGG, Houston, TX (eric.bathellier@cgg.com)
[2]IFPEN, Rueil-Malmaison Cedex, France

## Abstract

This paper presents an integrated workflow for the interpretation of 4D seismic data to monitor the steam chamber growth during the steam-assisted gravity drainage recovery process (SAGD). Superimposed on reservoir heterogeneities of geological origin, many factors interact during thermal production of heavy oil and bitumen reservoirs, which complicate the interpretation of 4D seismic data: changes in oil viscosity, fluid saturations, pore pressure, and so on. The workflow is based on the generation of a geological model inspired by a real field case of the McMurray formation in the Athabasca region. The approach consists of three steps: 1. Construction of an initial static model at the field scale, 2. Simulation of thermal production of heavy oil with two coupled fluid-flow and geomechanical models, 3. Computation of synthetic seismic data at different stages of steam injection. Production scenarios are run to obtain pore pressure, temperature, steam and oil saturations on a detailed reservoir grid around a well pair at several stages of production. Direct coupling with a geomechanical model produces volumetric strain and mean effective stress maps as additional properties. These physical parameters are used to compute new seismic velocities and density for each stage of production. A new synthetic seismic image of the reservoir is generated for each stage of production. The impacts of heterogeneities, production conditions and reservoir properties are evaluated for several simulation scenarios from the beginning of steam injection to 3 years of production. Results show that short-term seismic monitoring can help in anticipating early changes in steam injection strategy. In return, long-term periods allow the behaviour of the steam chamber to be monitored laterally and in the upper part of the reservoir. This study demonstrates the benefit of 4D seismic data in the context of steam-assisted heavy oil production.

# Modeling of the Steam Chamber Growth During SAGD

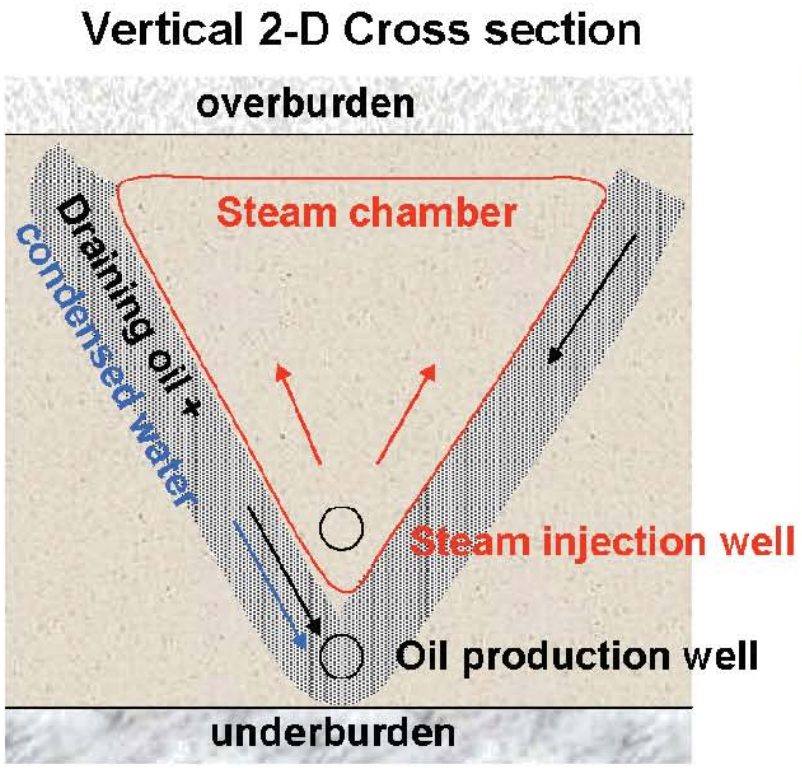
Eric Bathellier (CGG), Olivier Lerat, Axelle Baroni, Gérard Renard (IFPEN)

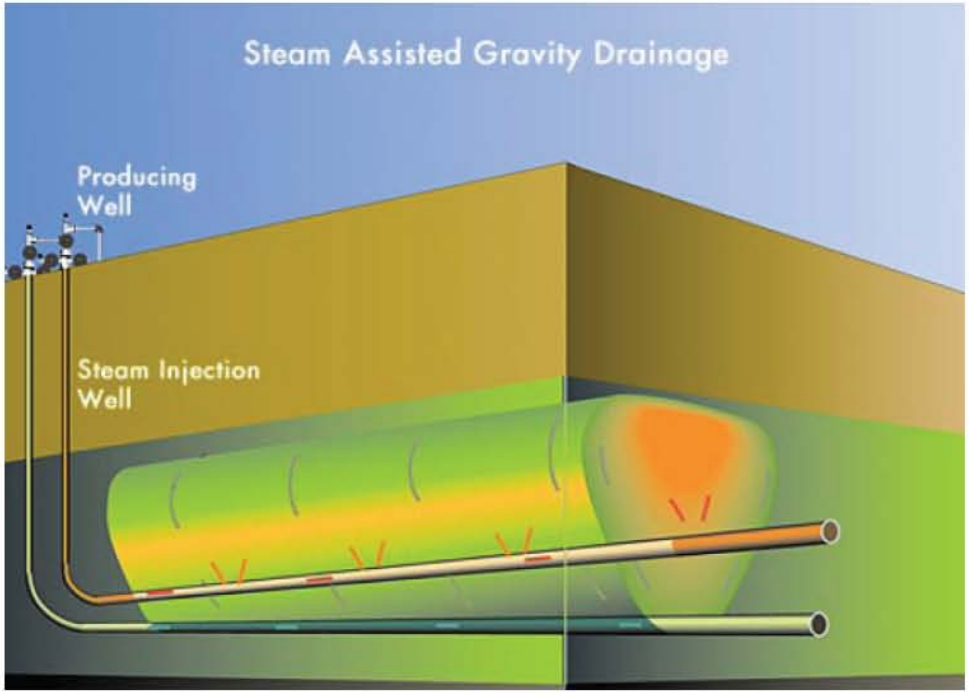
2014 PS-AAPG Meeting - April 29 - Bakersfield, CA

Passion for Geoscience

CGG

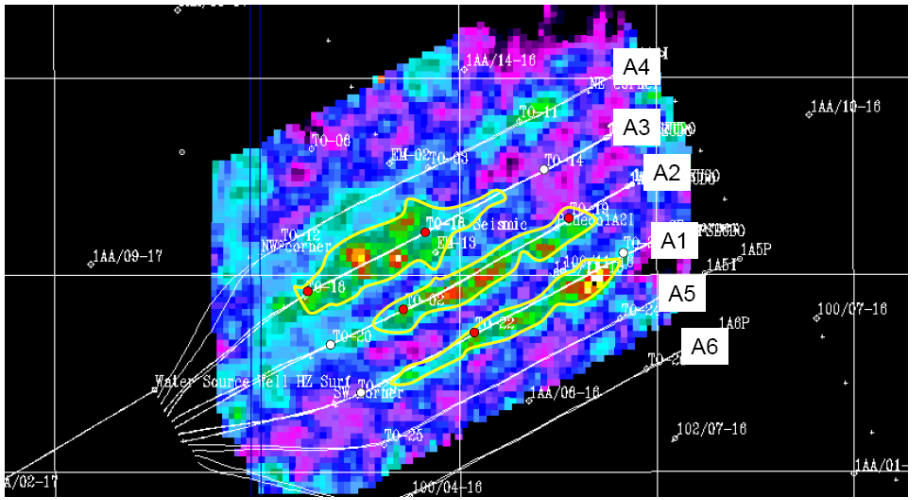
# Steam Assisted Gravity Drainage



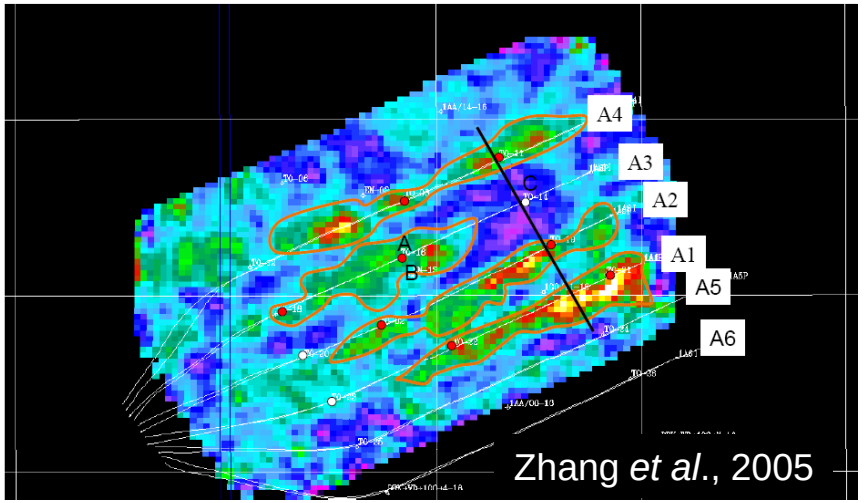



# Conventional 4D Seismic Data

between 2001 and 2004 surveys




between 2001 and 2005 surveys




**Map views of 4D seismic amplitude difference**

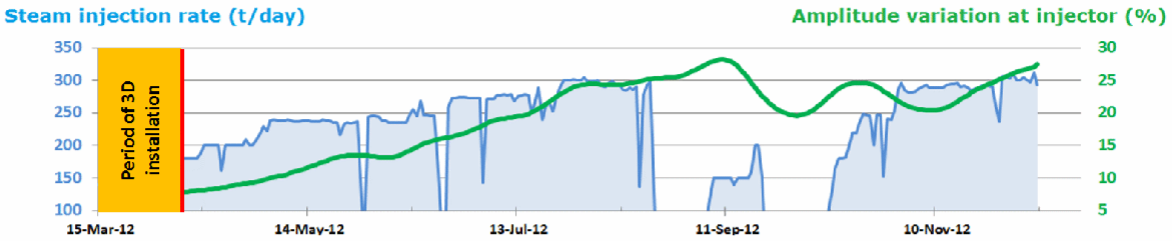
*Steam injection*

➔ *reduction of viscosity and mobility ratio*

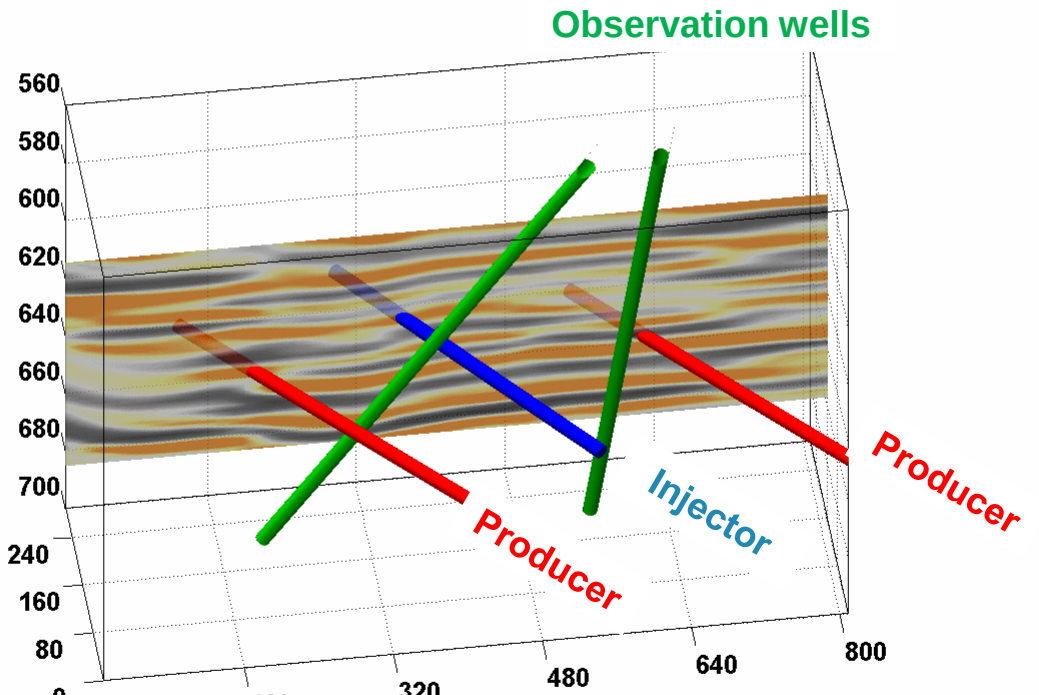
➔ *But also: rock and fluid expansion, compaction, oil vaporization,…*

# Continuous and Permanent Seismic Monitoring (SeisMovie™)

## Injected steam rate




07-Apr-2012



# Project Objectives

- Imaging of the steam chamber evolution from 4D seismic data at early times of SAGD steam injection phase

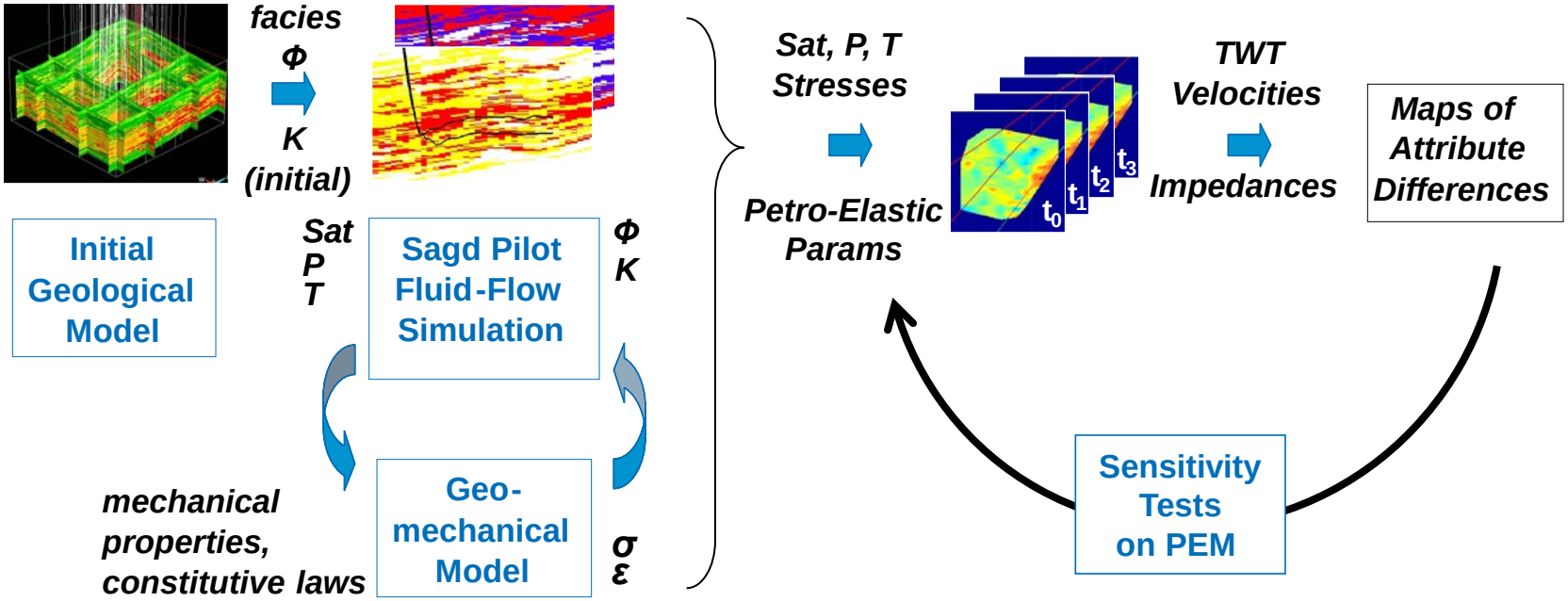
- Demonstration and promotion of the SeisMovie™ technology in heavy oil and bitumen production

- Improvement of the understanding of physical laws driving the petro-elastic model during steam injection

# Presentation Outline

- Workflow
- Construction of the full-field static model
- Coupled modeling
- Seismic modeling
- Summary

# Workflow



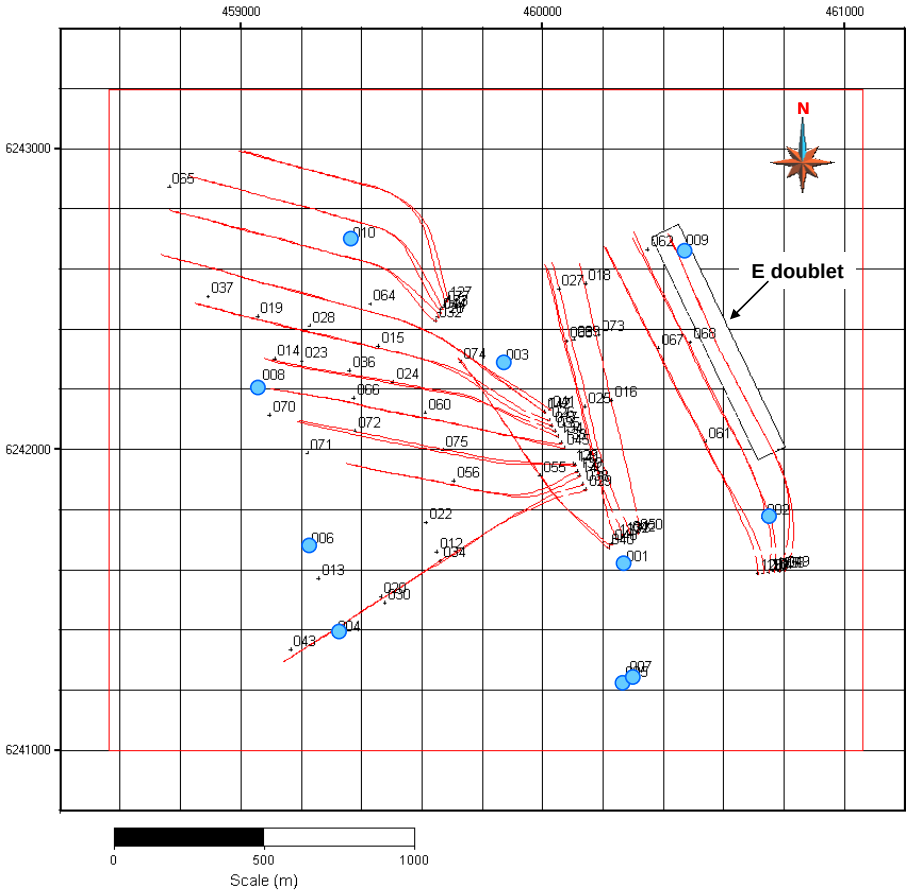

- One-way coupling of reservoir and geomechanical models
- Short to long periods of steam injection (weeks -> 6 years)
- Sensitivity study

# 1.
# Construction of the Full-field Static Model

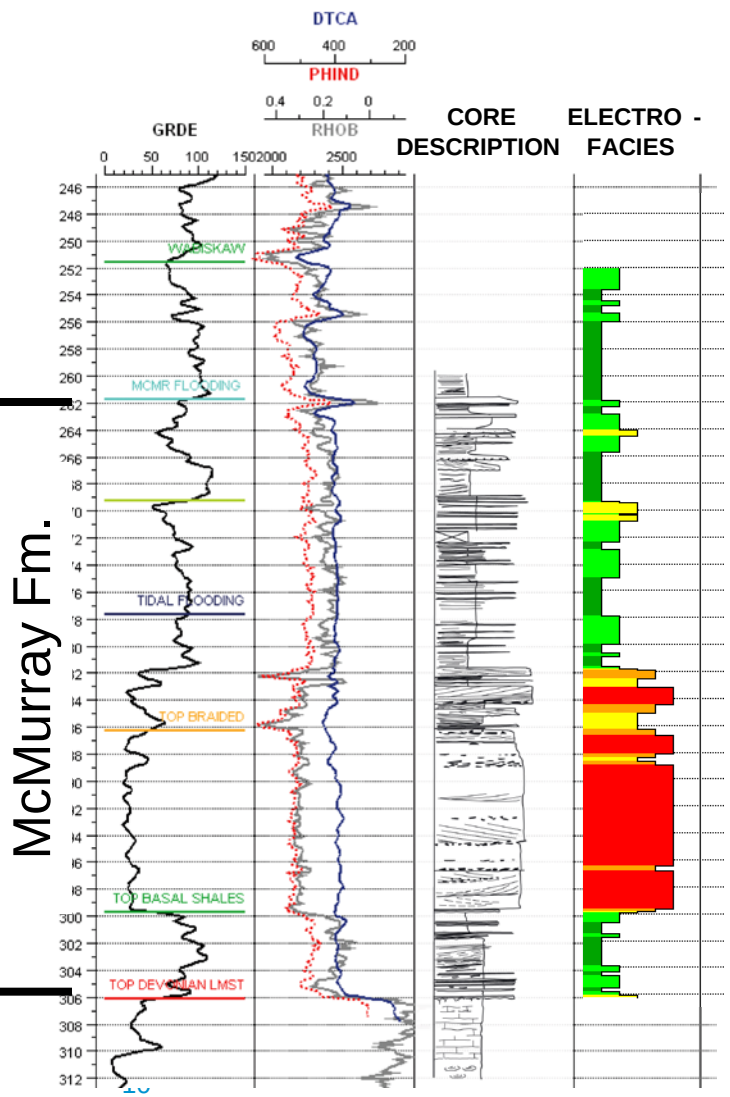
➔ *Geological Model and Static Properties*

# Hangingstone Field Data

- Athabasca region (Alberta, Canada)
- McMurray Formation
- Oil viscosity 1 000 000 cp
- Oil density 8° API
- 32 horizontal wells
- 50 vertical wells
- 10 cored wells
- Production data (90 months)



# Facies and Logs – Core Calibration




**RESERVOIR UNIT**

Lithofacies 1
Lithofacies 2
Lithofacies 3
Lithofacies 4
Lithofacies 5

***Open bay shales***

Unit 4

***Stacked tidal flats, Channels and bars***

***Tidal ravinement***

Unit 3

***Stacked meandering channels With tidal influence***

Unit 2

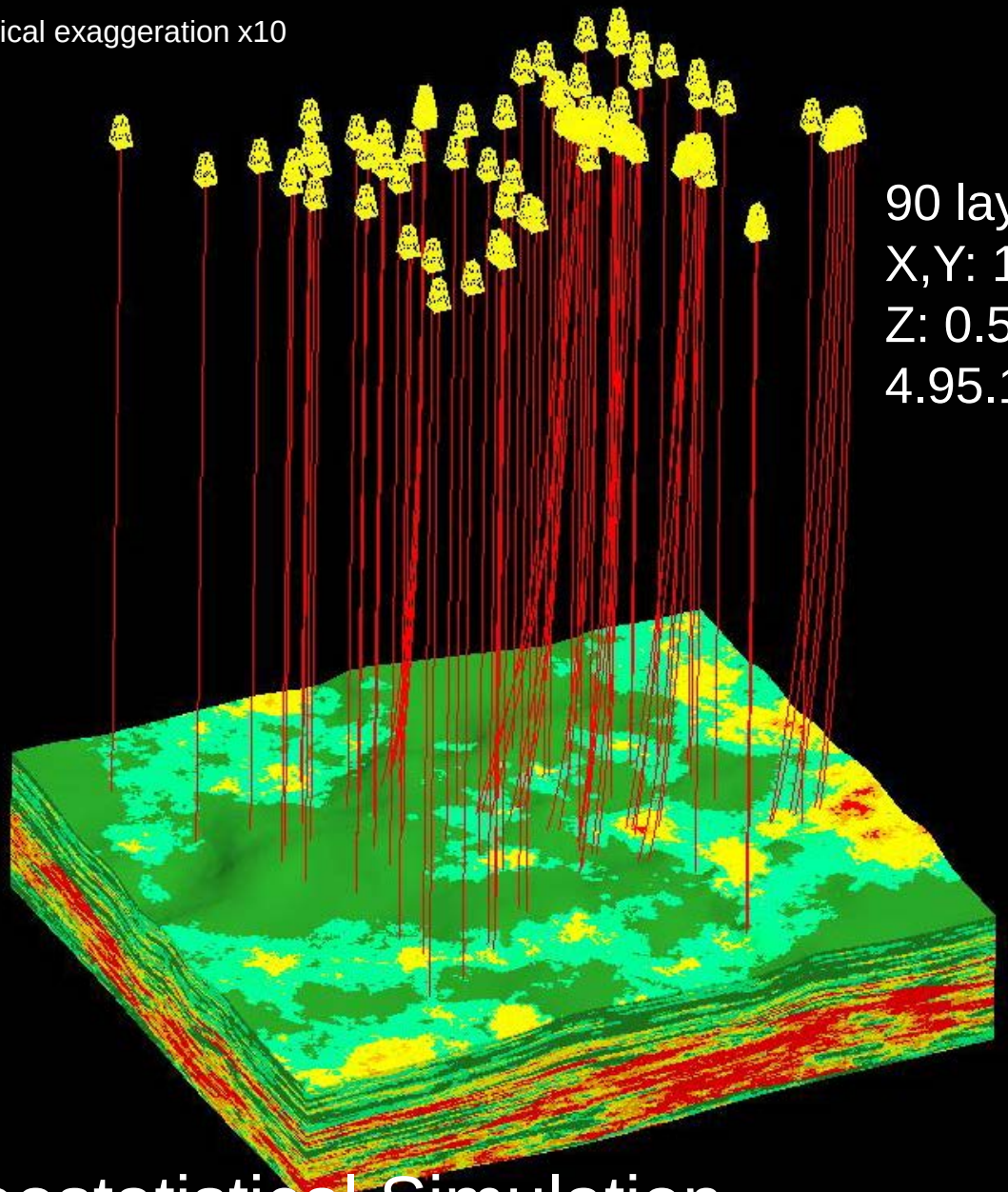
***Amalgamated fluvial Braided channels***

***Channel belt incision***
*Coastal plain ?*

Unit 1

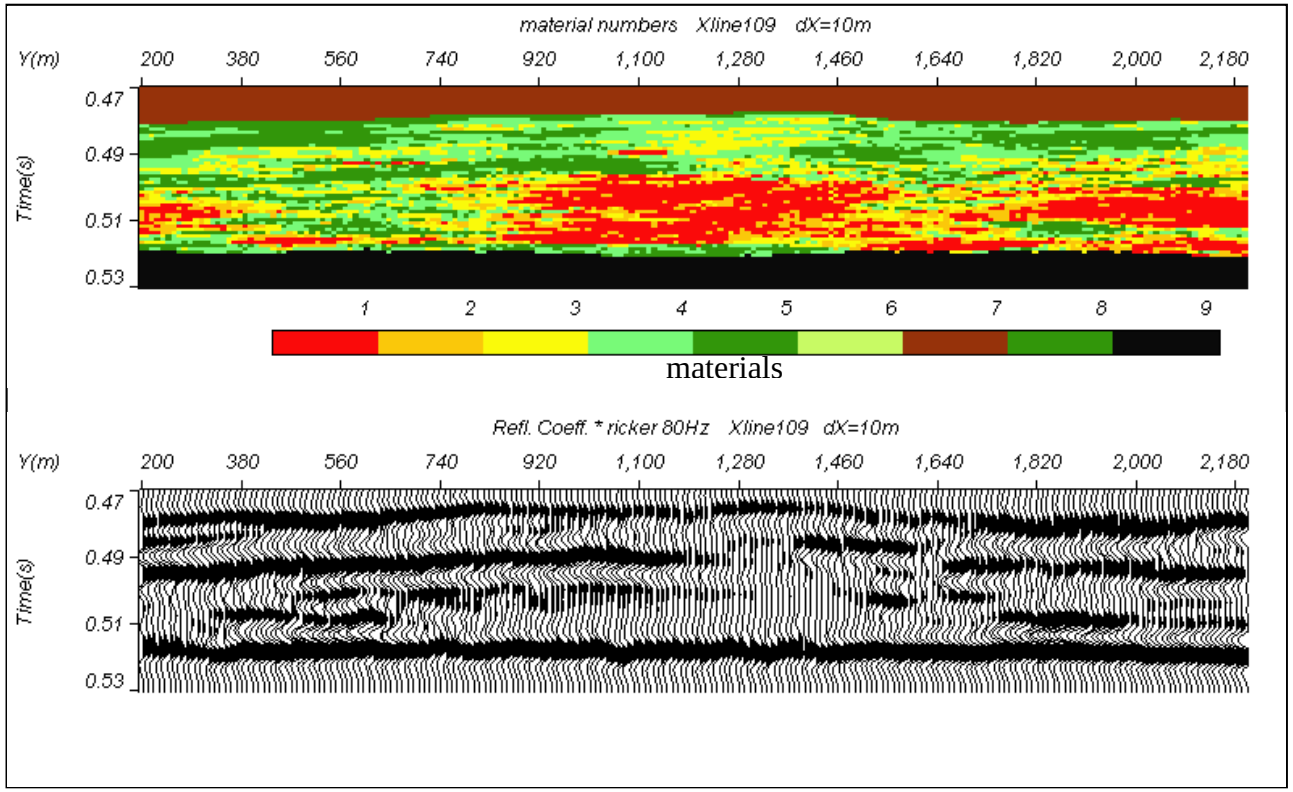
***Base Cretaceous unconformity***

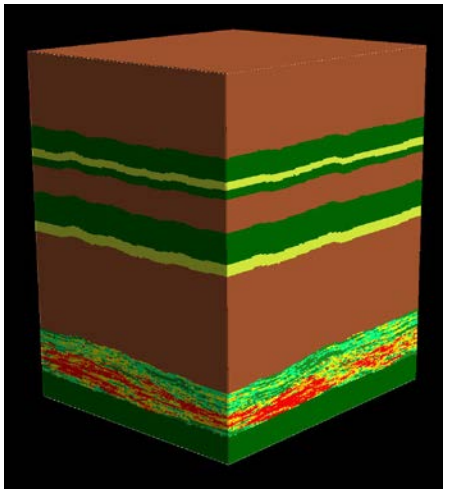
*Devonian Carbonates*

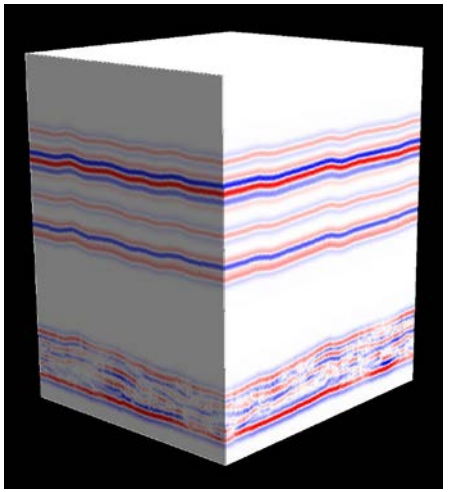



# Geostatistical Simulation of Facies Distribution

# Seismic Modeling Before Production



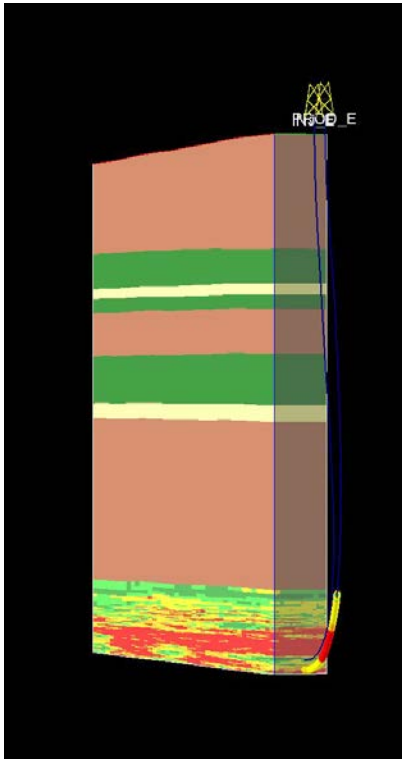


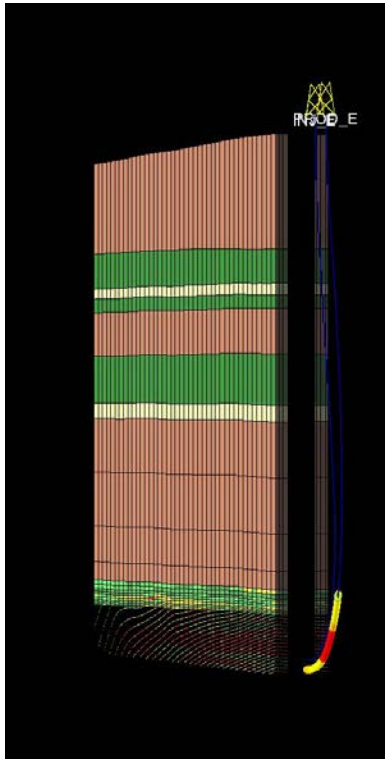
**1D seismic modeling (reservoir zone)**:
**Lithofacies (top), reflectivity coefficients convolved by a 80Hz Ricker wavelet (bottom)**

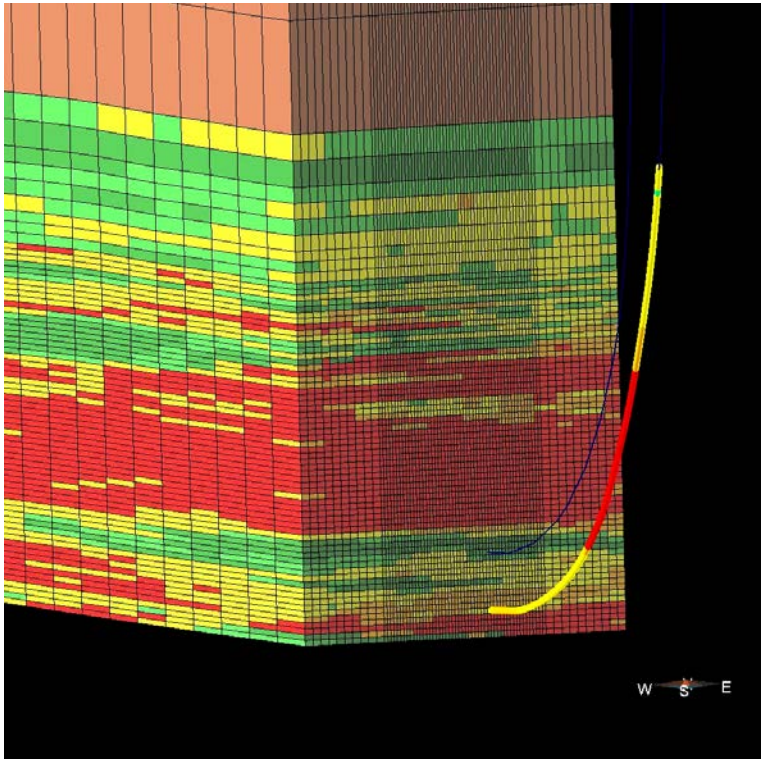
# 2.
# Coupled Modeling

- *Reservoir Simulation (Puma$^{flow}$)*
- *Geomechanical Modeling (Abaqus)*

# Definition of the Local SAGD Reservoir Model







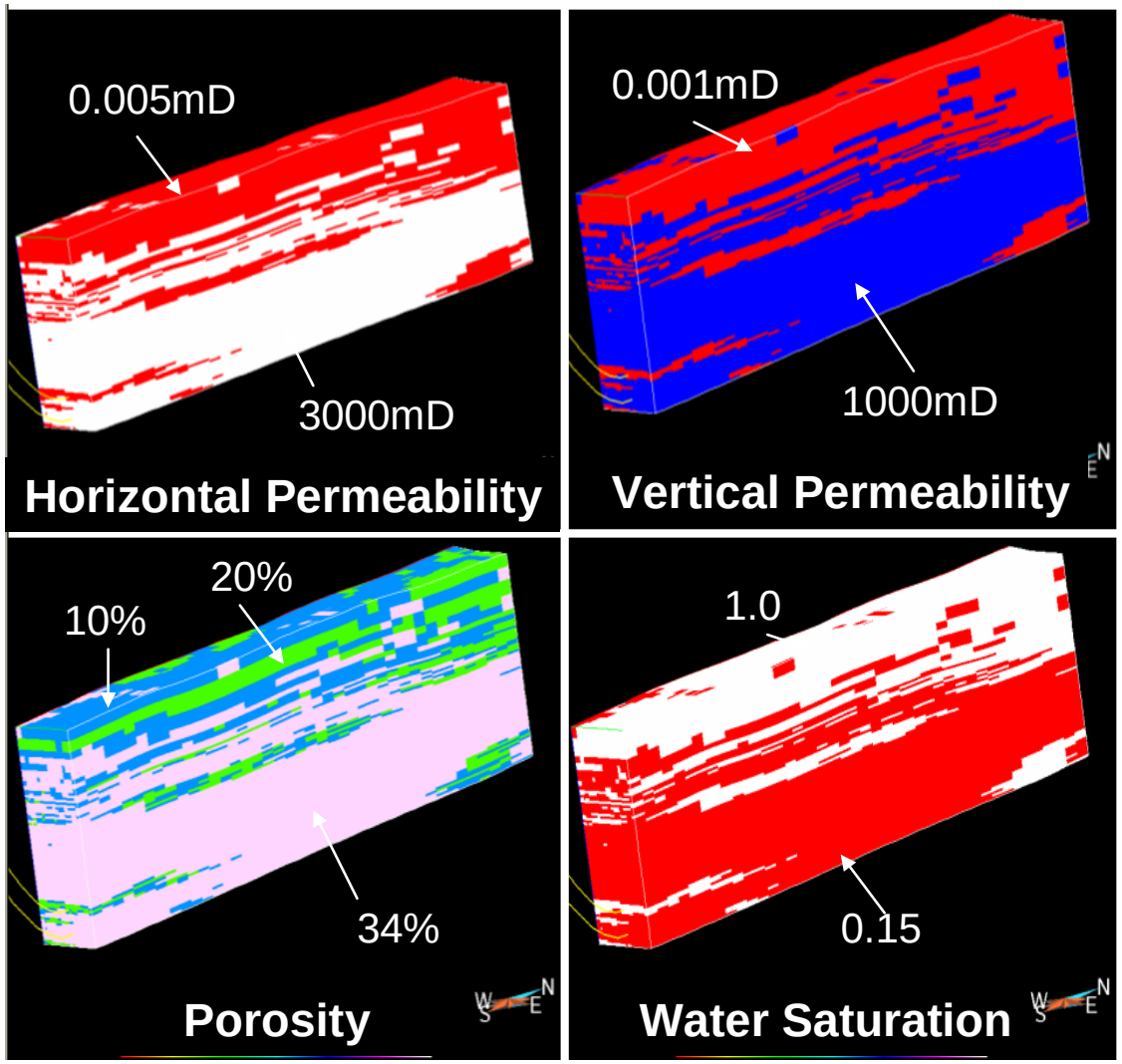

Mesh: 10x2.5m; 50x1m; 10x2.5m Y: 41x20m
(235,000 cells)

# Scenario for SAGD Modeling

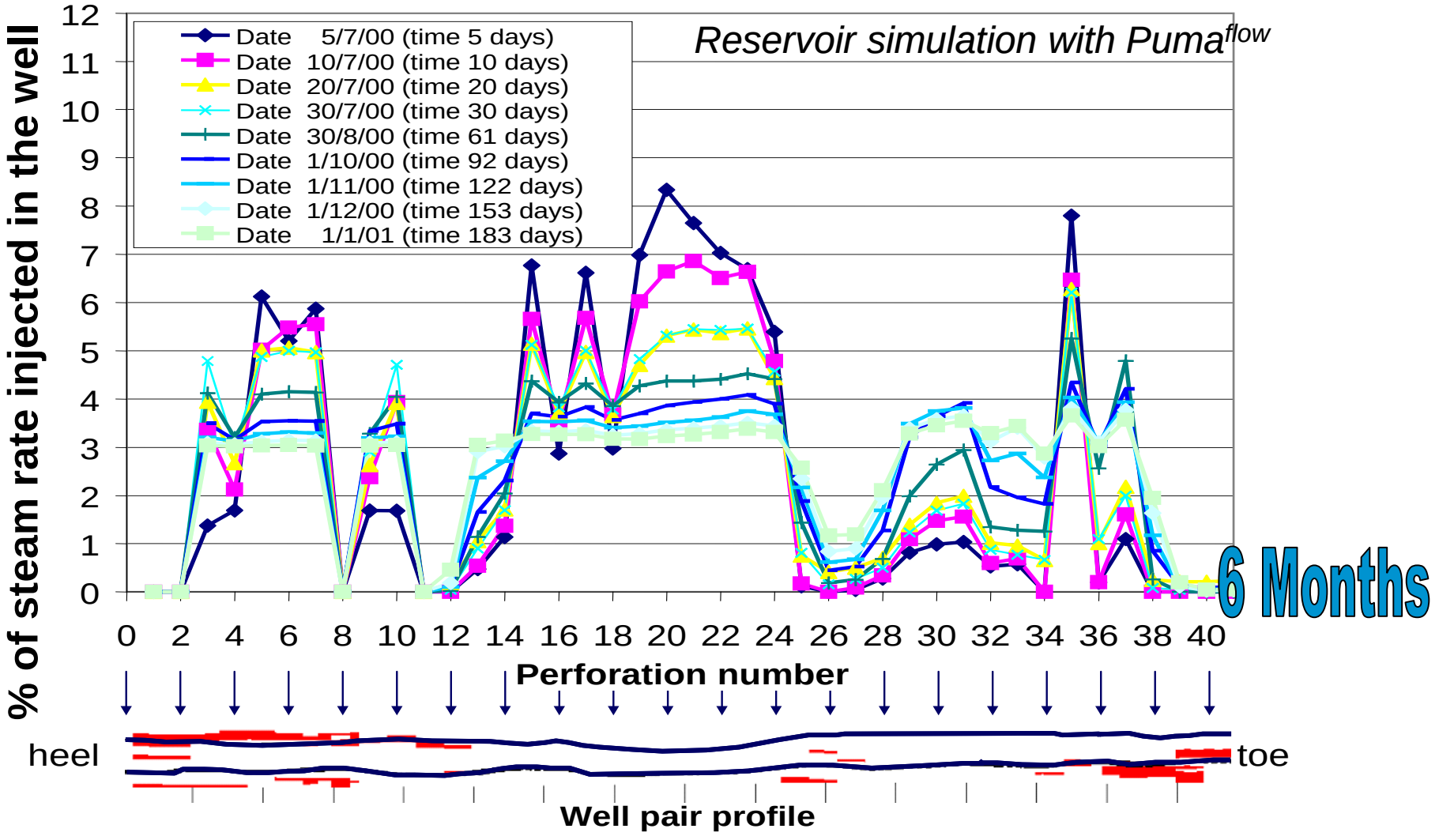
Operating conditions in the wells

- **Warm up phase**
  - **Four months @ constant T = 220°C**
- **Steam injection: up to 6 years**
  - **Real injection-production history at wells**
  - **Steam trap control implemented**

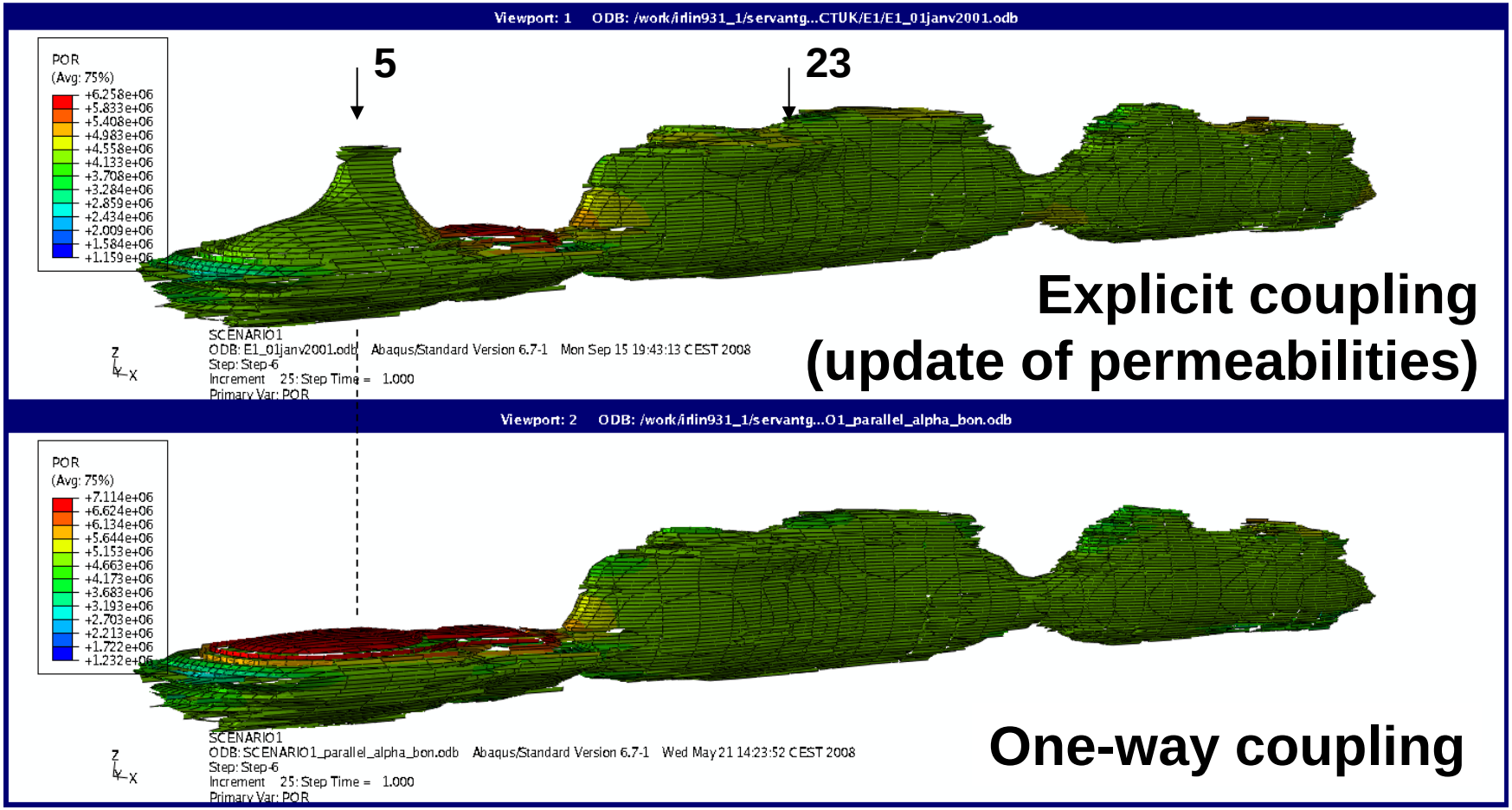
# Properties Exported to the Reservoir Model



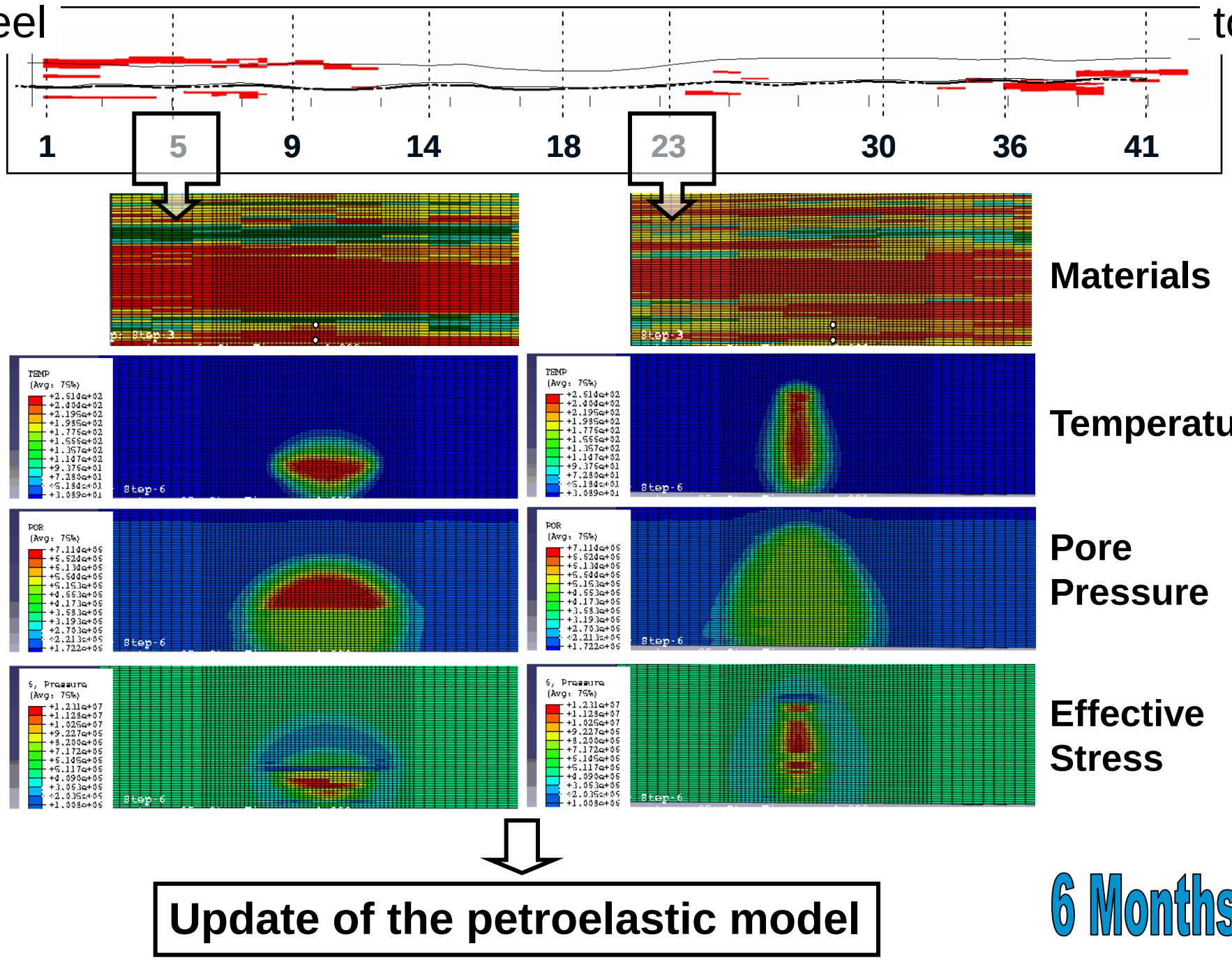
# % of steam rate in the injector



# Mechanical Behavior of Shale Materials?



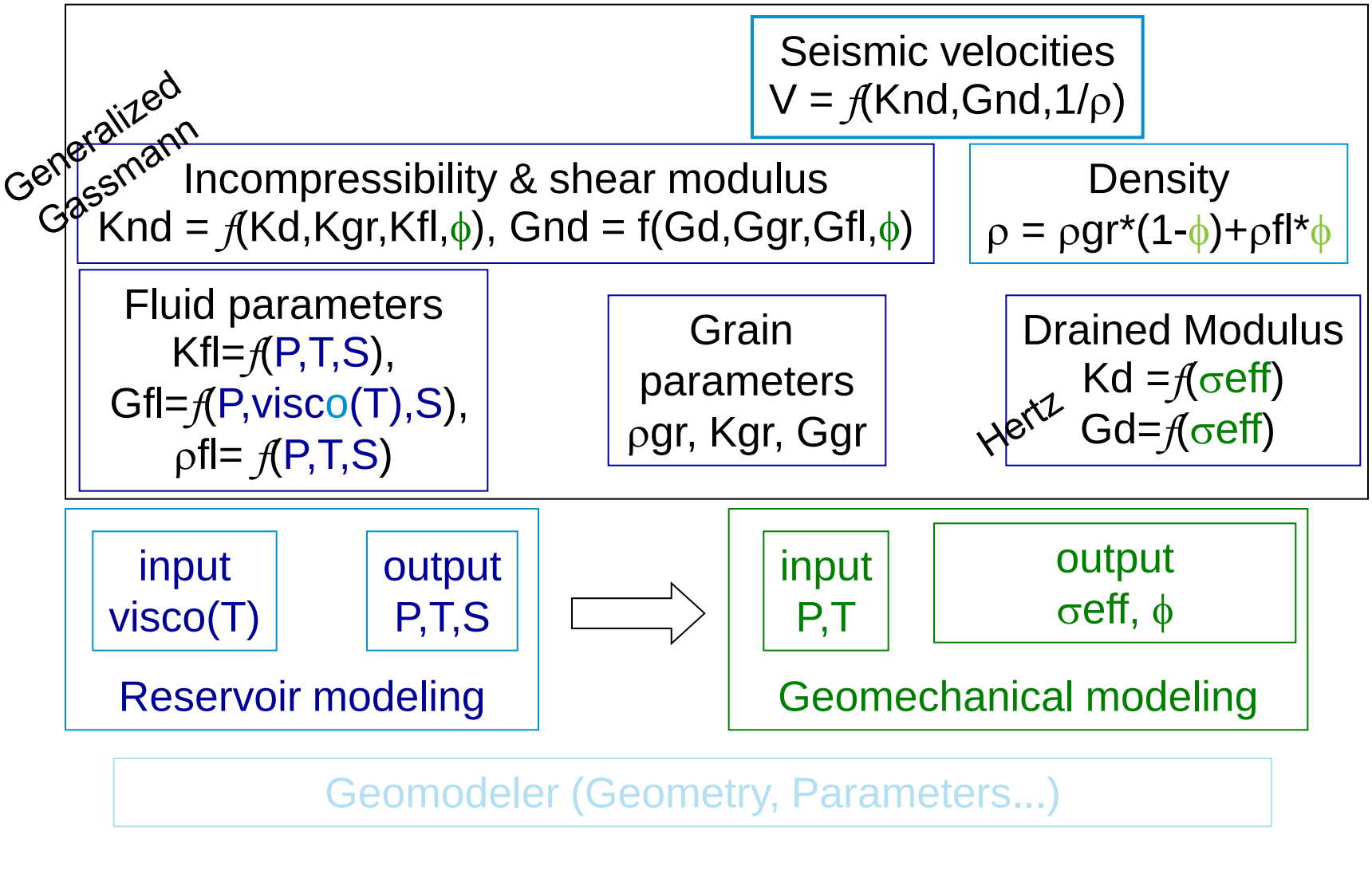

**6 Months**


heel
toe
1
5
9
14
18
23
30
36
41
Materials
Temperature
Pore Pressure
Effective Stress
Update of the petroelastic model
6 Months

# 3.
# Seismic Modeling

- *Impact of Thermal Production on PEM (Petro-Elastic Model)*

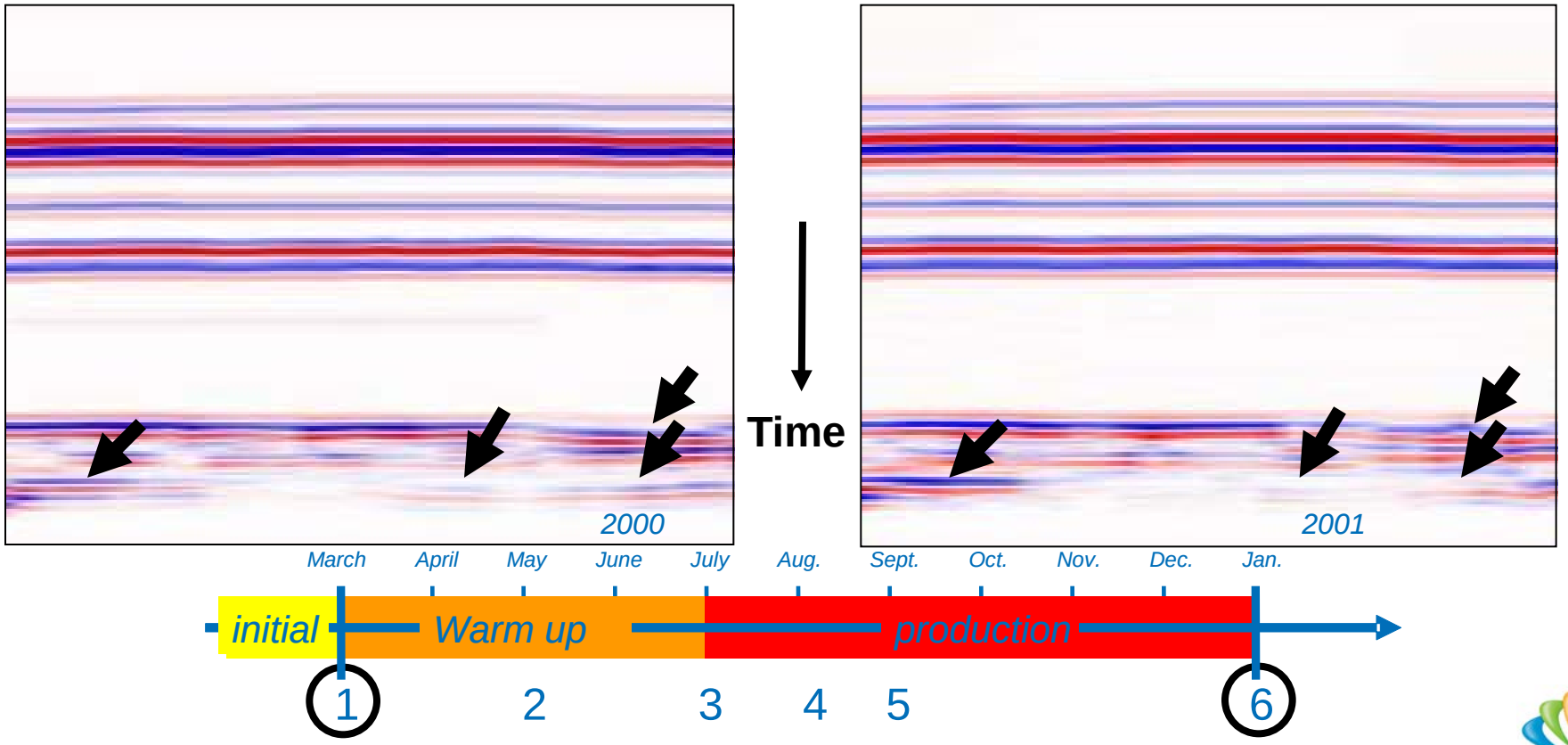
# Velocities Sensitivity



# Synthetic Seismogram in Time

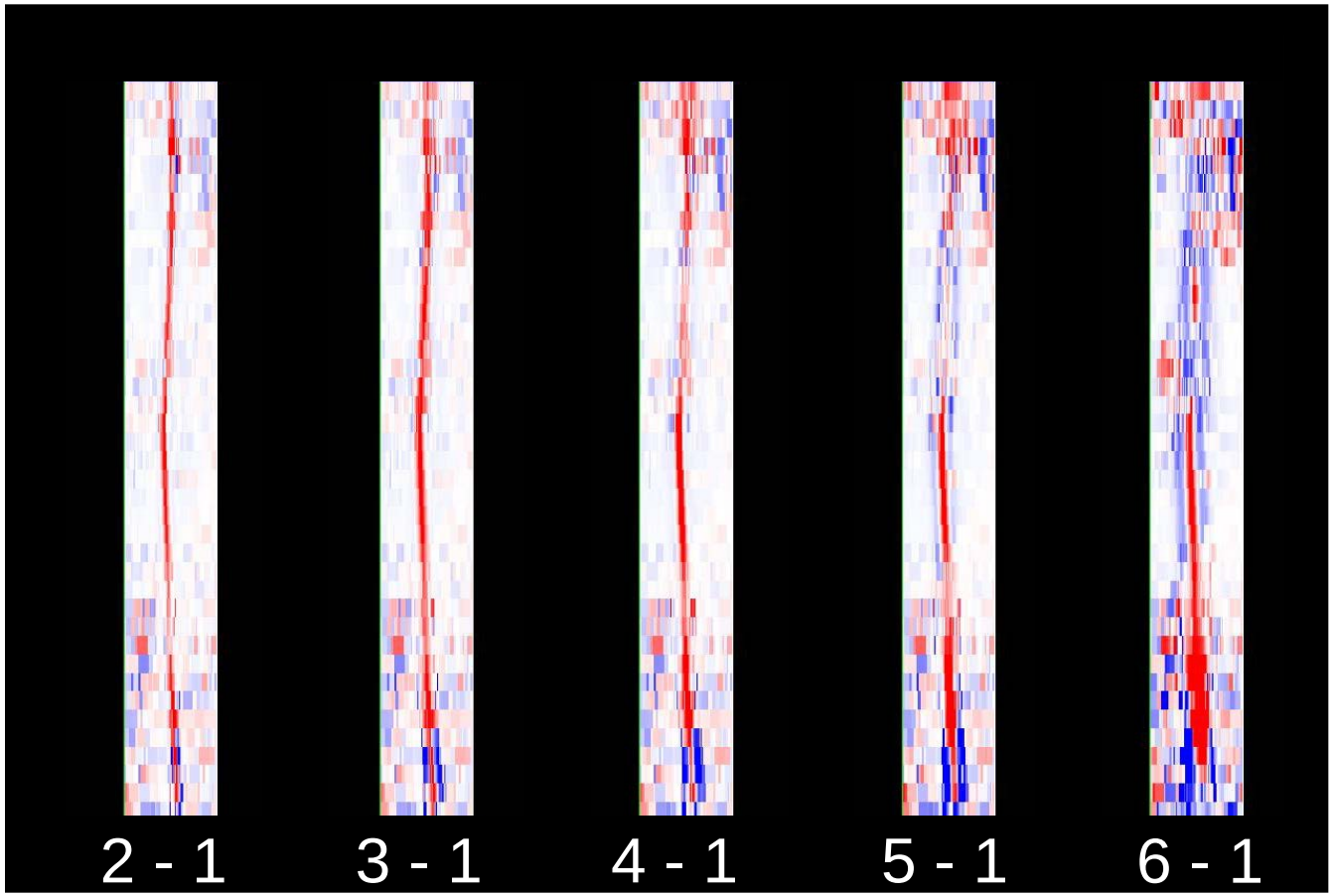
P-wave
80Hz

6 Months



# Depth Slices

P-wave Seismogram Difference @Z =-314.5m




6 Months

# Summary

- Fully integrated study from static to dynamic modeling
  - Facies, petrophysics, geomechanics, petroacoustics
- Simulations of full production history
  - Steam rate matched in the injector
  - Oil and water rate matched in the producer
  - Proportion of oil and water respected
  - Lateral steam connection between sections is taken into account
- Impact of heterogeneities on steam chamber development
  - Influence of shale beds is clear on 3D visualizations
  - Mechanical behavior of shales needs to be further characterized

# Summary (continued)

- Seismic modeling
  - Petroelastic modeling shows realistic images
  - Model updates according to dynamic properties evolution
- Monitoring
  - Improved understanding expected through SeisMovie interpretation

# Thank you!
# Questions?

Passion for Geoscience
cgg.com