SPE special Interest Reservoir Group, Calgary
March 26, 2014

The ever increasing importance of reservoir geomechanics

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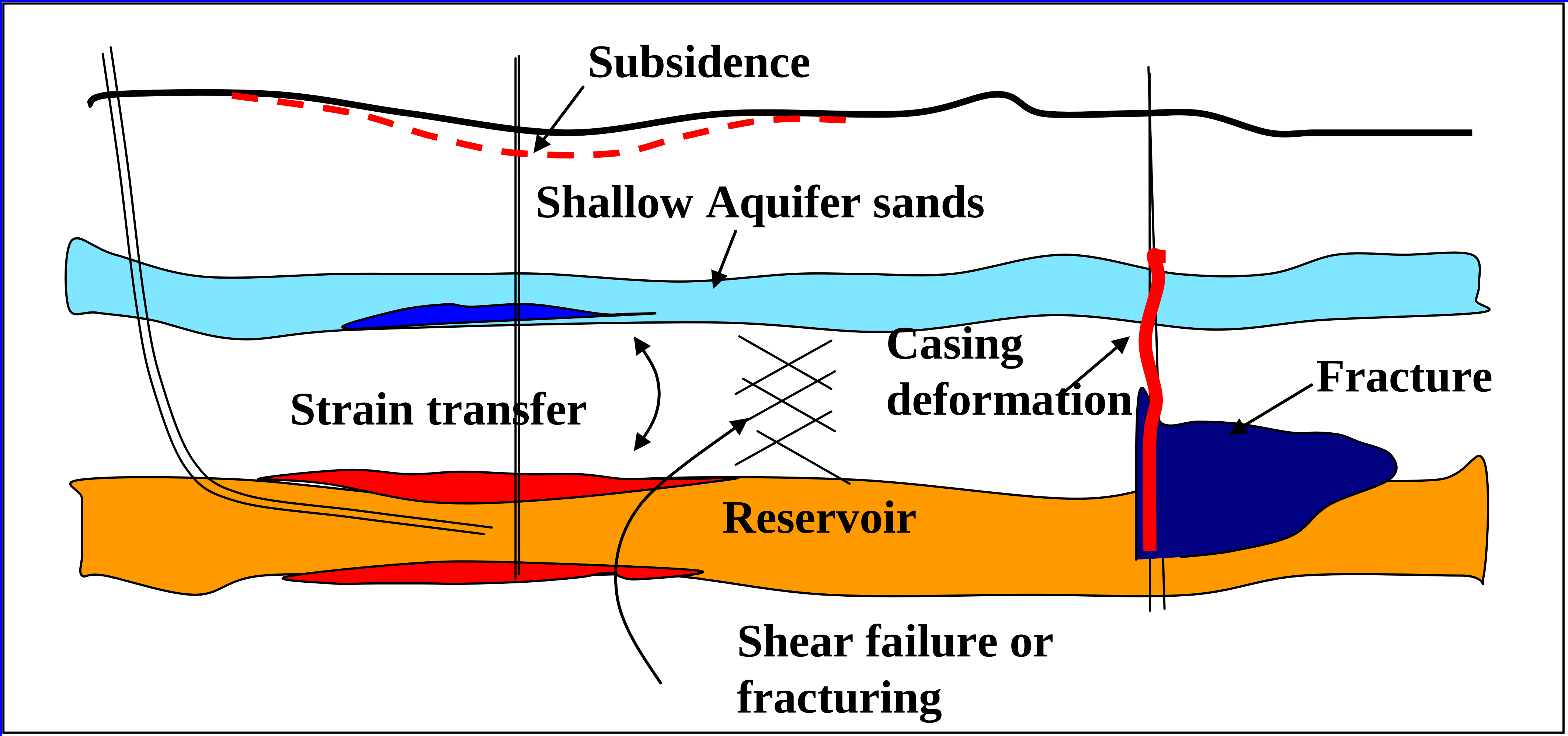
What is reservoir geomechanics?

- Deformations and stresses in the reservoirs and their surroundings (rock/soil/fracture mechanics)



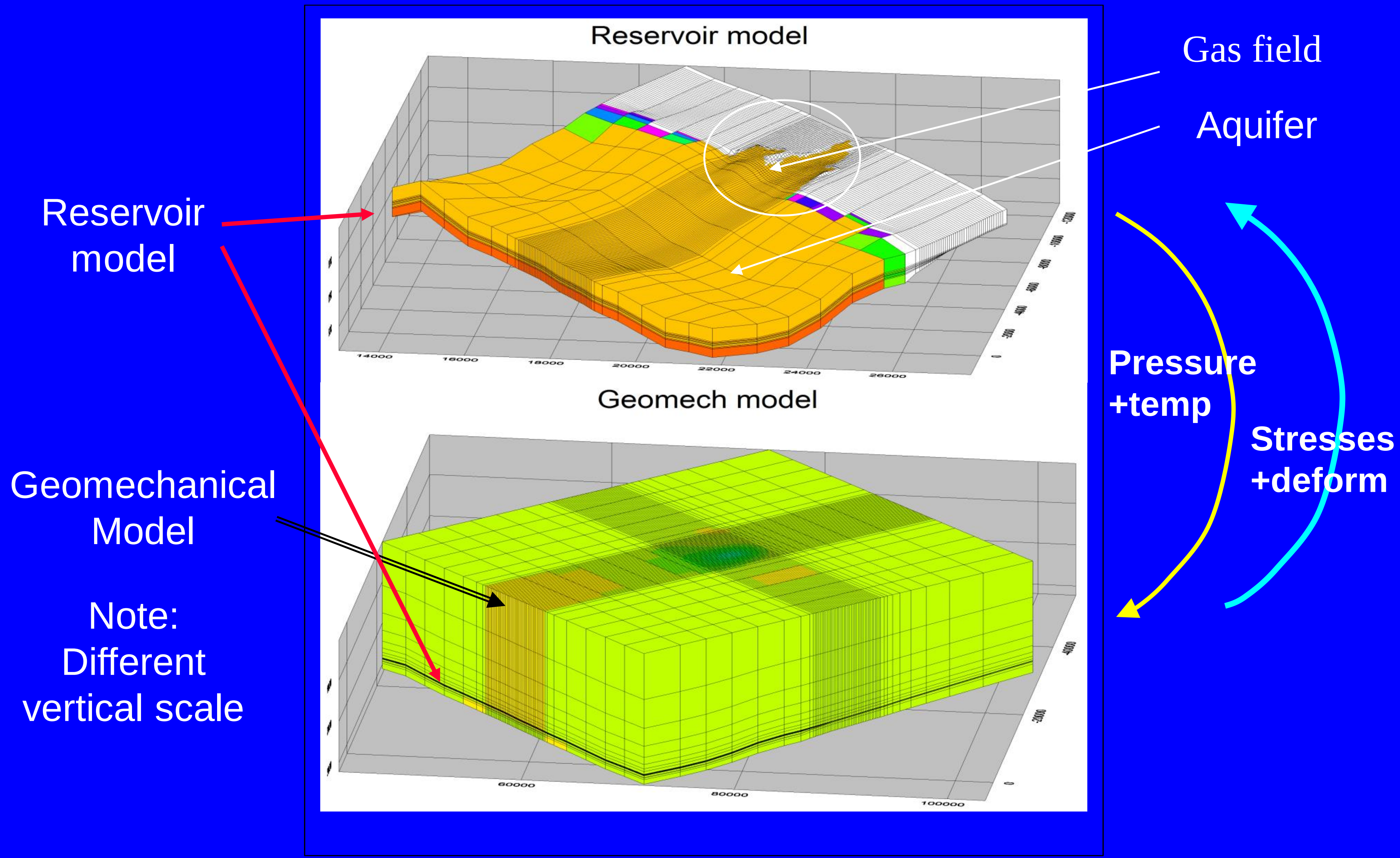
Coupled processes in geomechanics of porous media

- Processes coupling primarily Thermal, Hydrodynamic, and geoMechanical phenomena (THM processes)
- Many diverse applications
  - Hazardous waste storage
  - Petroleum operations
  - Degasification of mines, in situ coal gasification
  - Unconventional energy sources (geothermal, hydrates)
- **The importance for petroleum engineering was only recently fully realized**

Examples of coupled geomechanical processes in petroleum recovery

- Compaction of “soft” reservoirs
  - Surface/sea floor subsidence
  - Reactivation of faults (induced seismicity)
- Thermal recovery in heavy oils and oil sands:
  - Dilation and permeability changes major mechanisms
  - Reach fracturing pressures (by high pressure steam injection)
  - Caprock integrity and MOP (Max Operating Pressure)
- Induced fractures in waterflooding/Produced Water ReInjection and waste disposal
  - Environmental solution during drilling
  - Improved economics of waterflooding
- Stimulation (hydraulic fracturing) in tight gas and shales
  - Necessary for economics

Coupling between flow and stress (geomechanics)



Examples

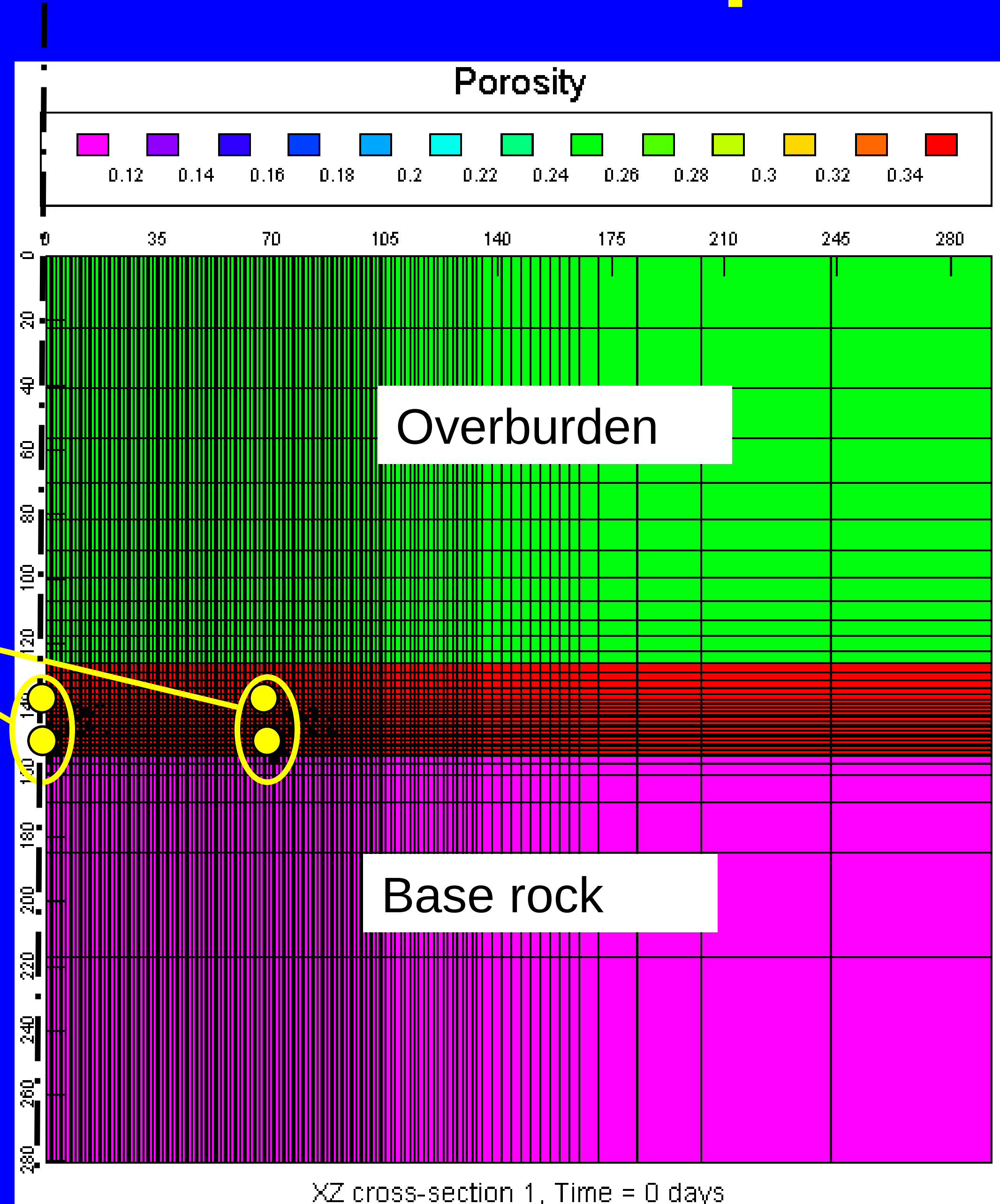
Example: Geomechanics of thermal recovery by Steam Assisted Gravity Drainage (SAGD)

- Simplified example of 3 SAGD well pairs (1/2 model)
- Porous media is unconsolidated
- Heating causes expansion of the media
- Shear stresses develop, causing dilation of the sand
- Both result in increase of porosity and permeability
- Surface deformations result (heave)

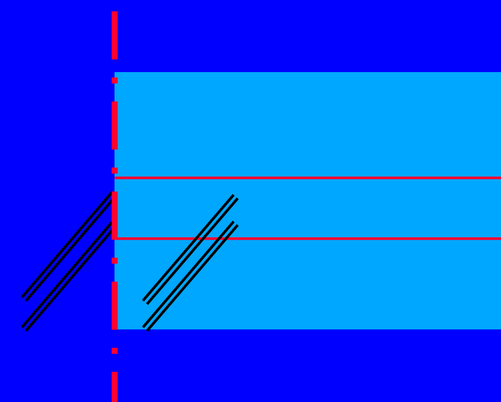
Physical model/computational grid

Plane of symmetry

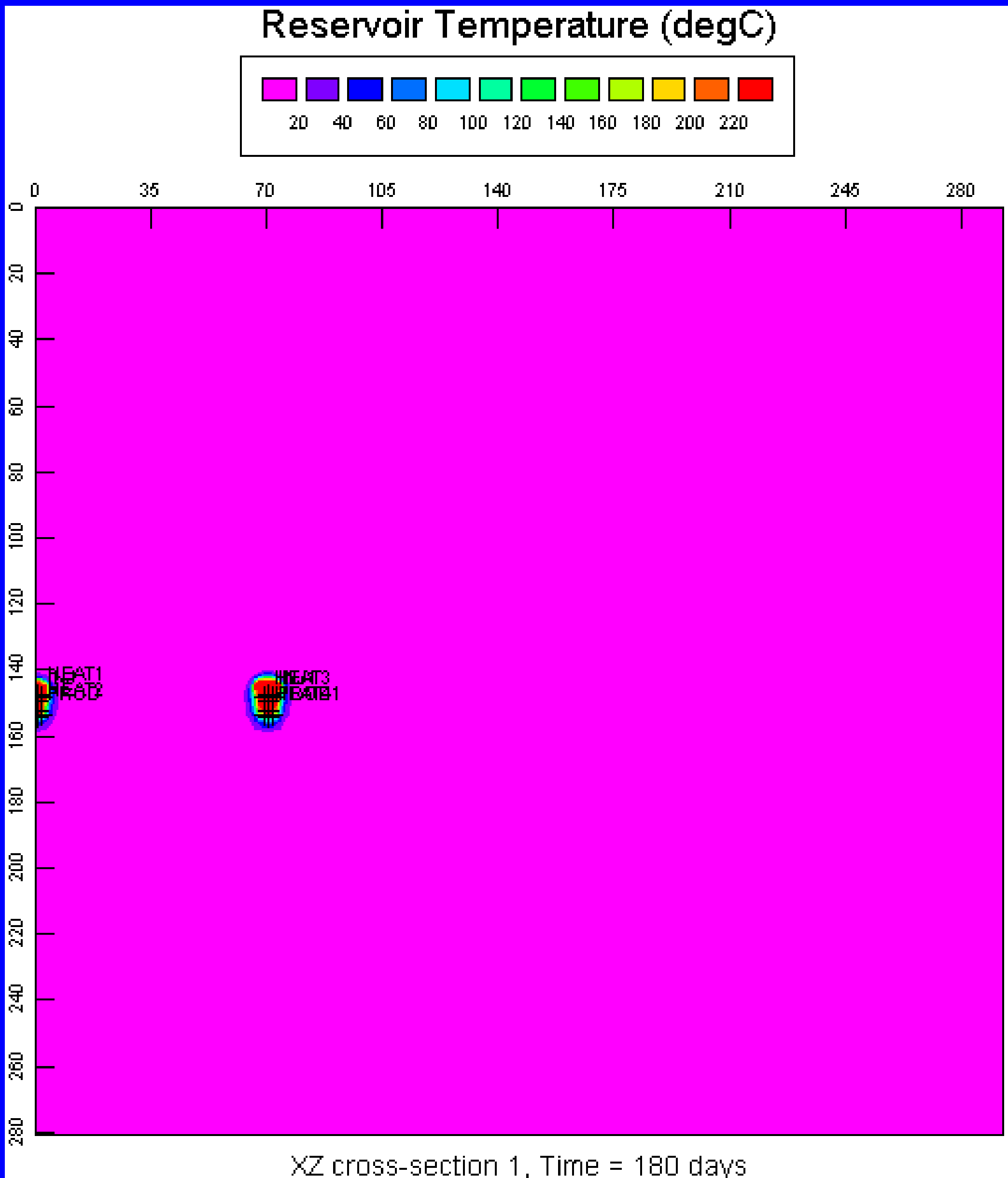
Well pairs

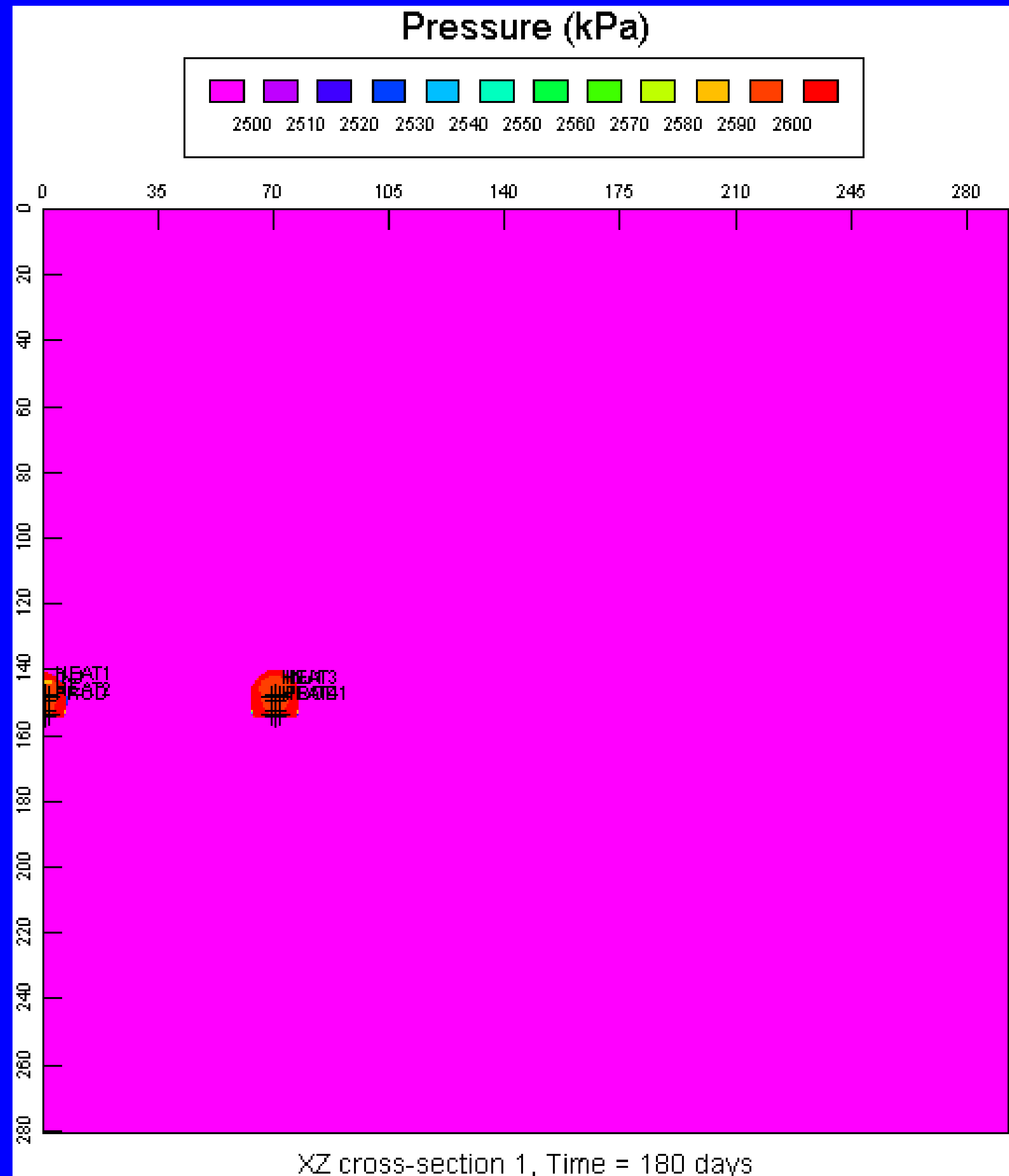


Crossection perpendicular to the well trajectories

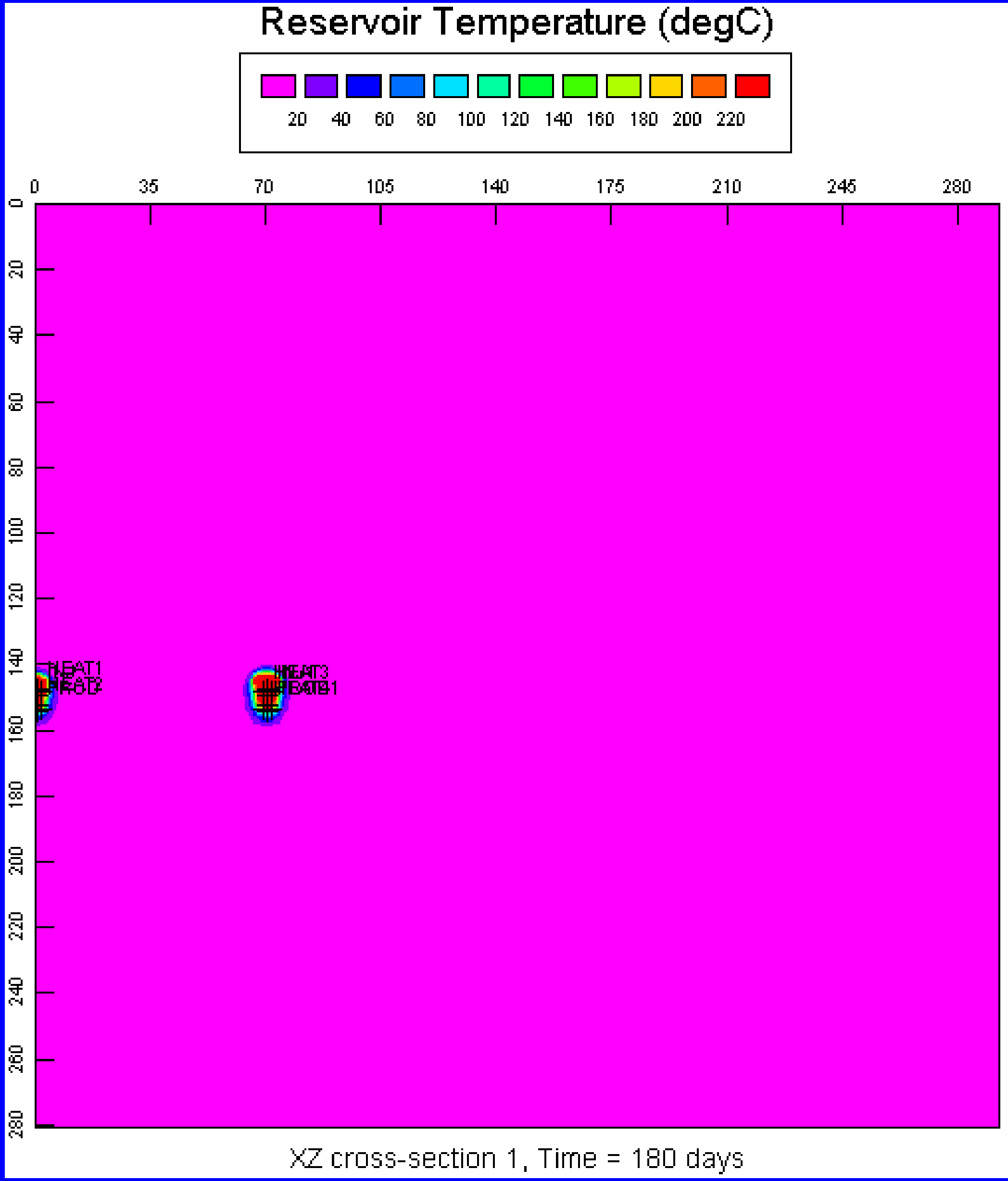


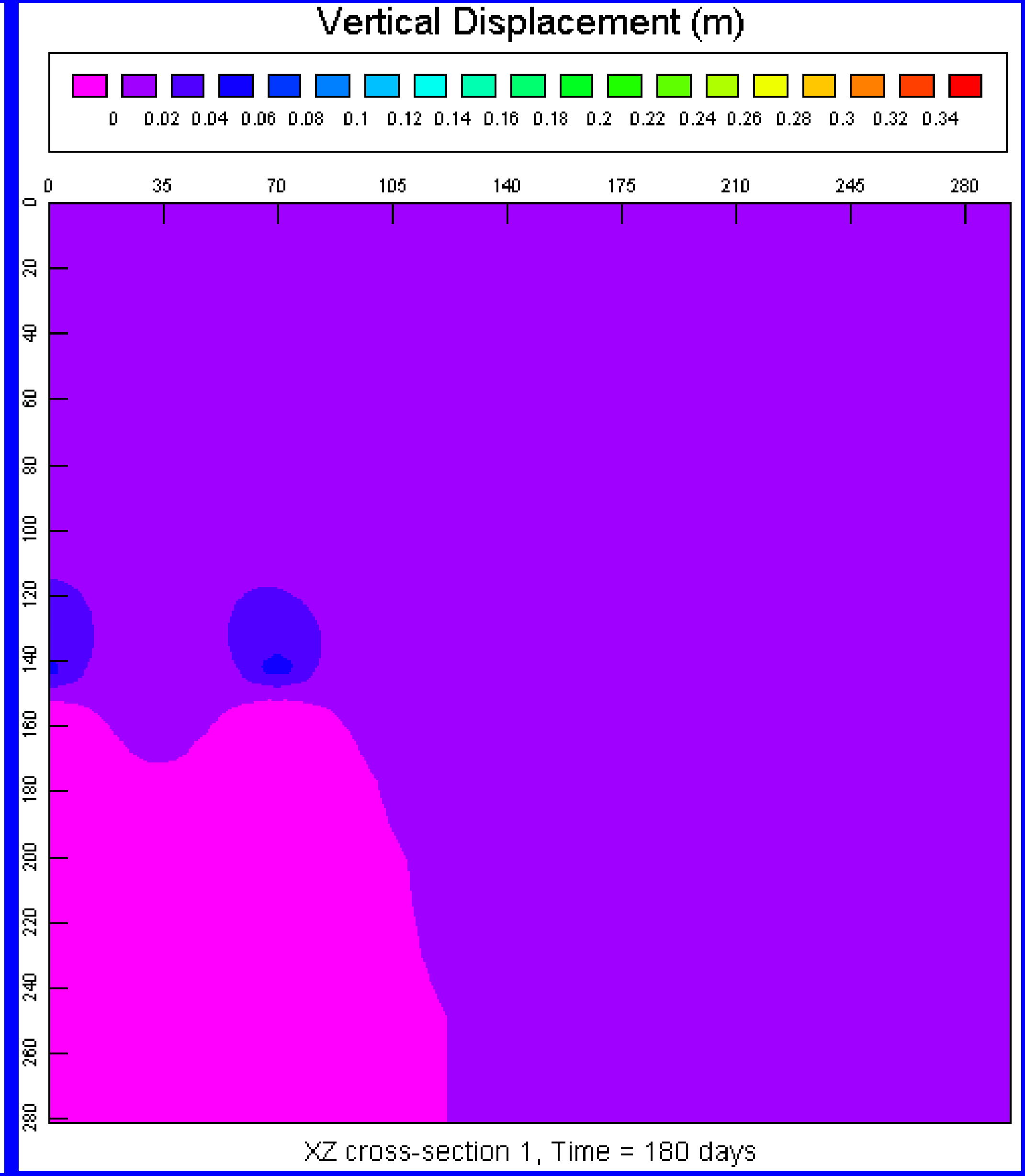
Temperature/Pressure



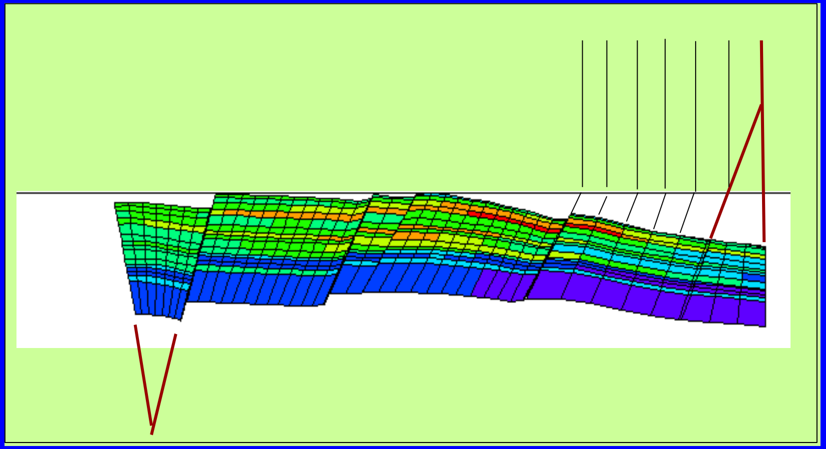


Temperature/Vertical Displacement



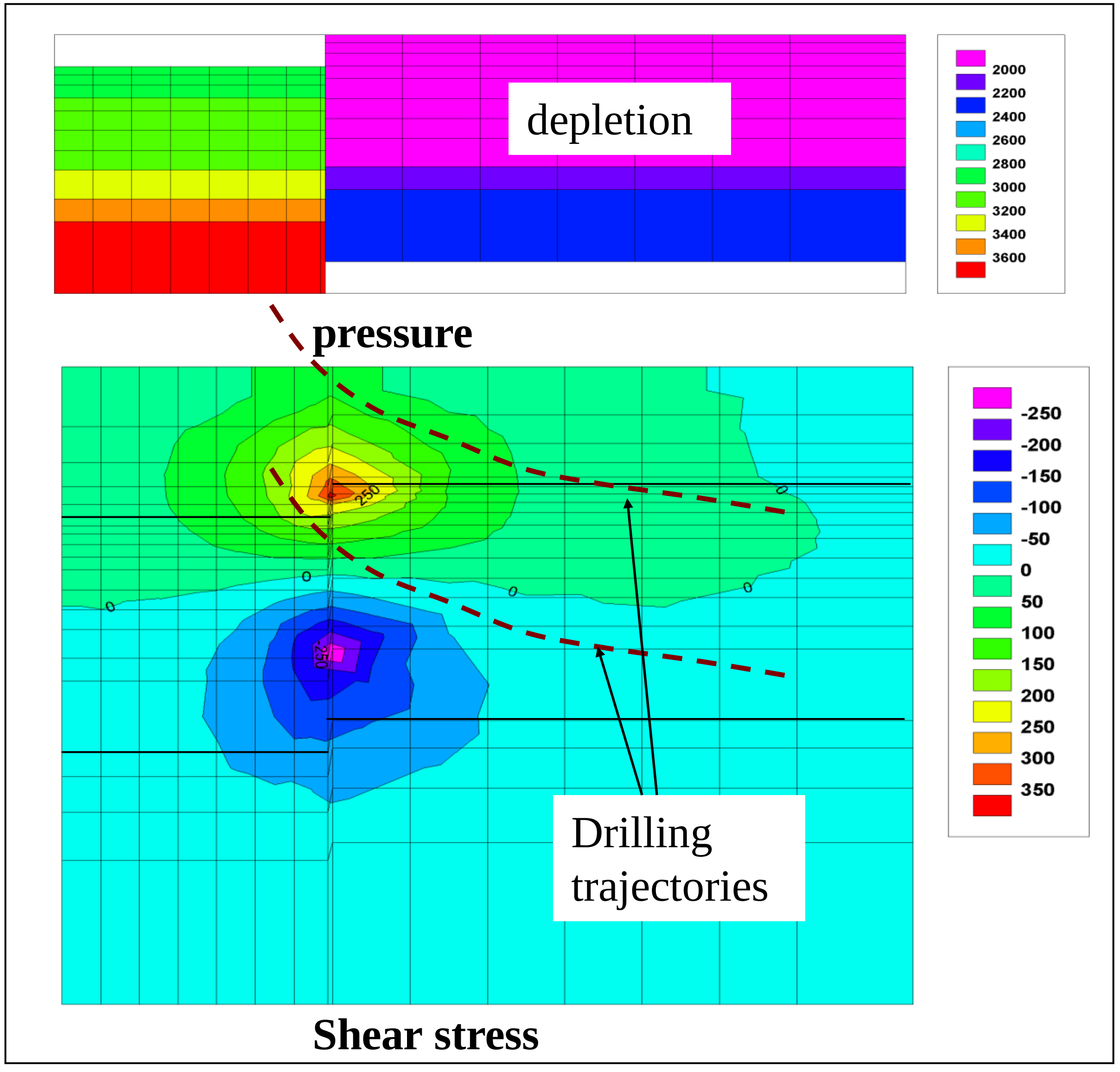


Example : Pressure depletion induced seismicity



- Petroleum reservoirs are often compartmentalized by faults
- Differential depletion changes stress on the faults and can induce seismicity (well documented)
- Magnified by large throw of faults and compaction
- Similar consideration in injection operations close to faults
- **Risk to the environment and to the oilfield operations, bad publicity**

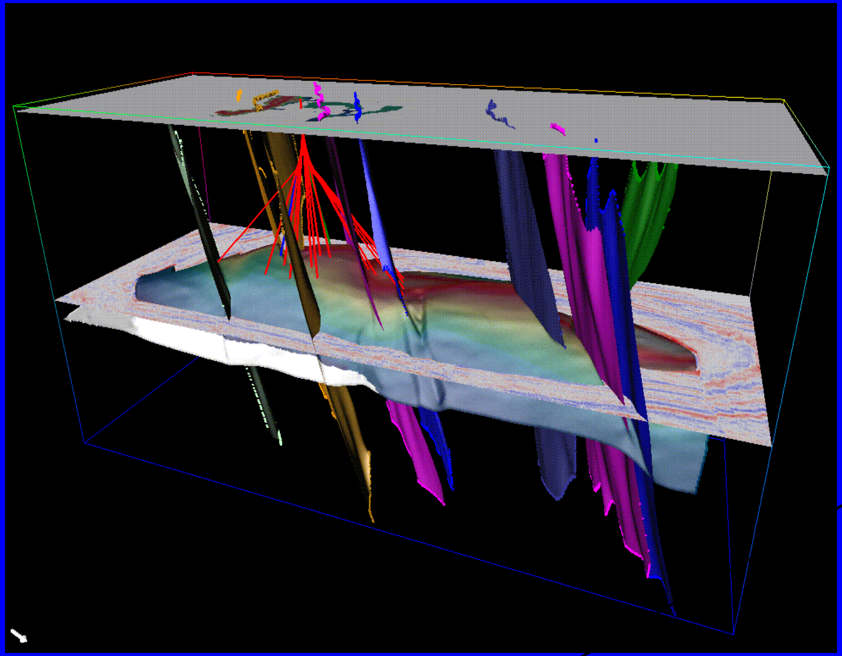
Differential depletion generates shear stress on faults

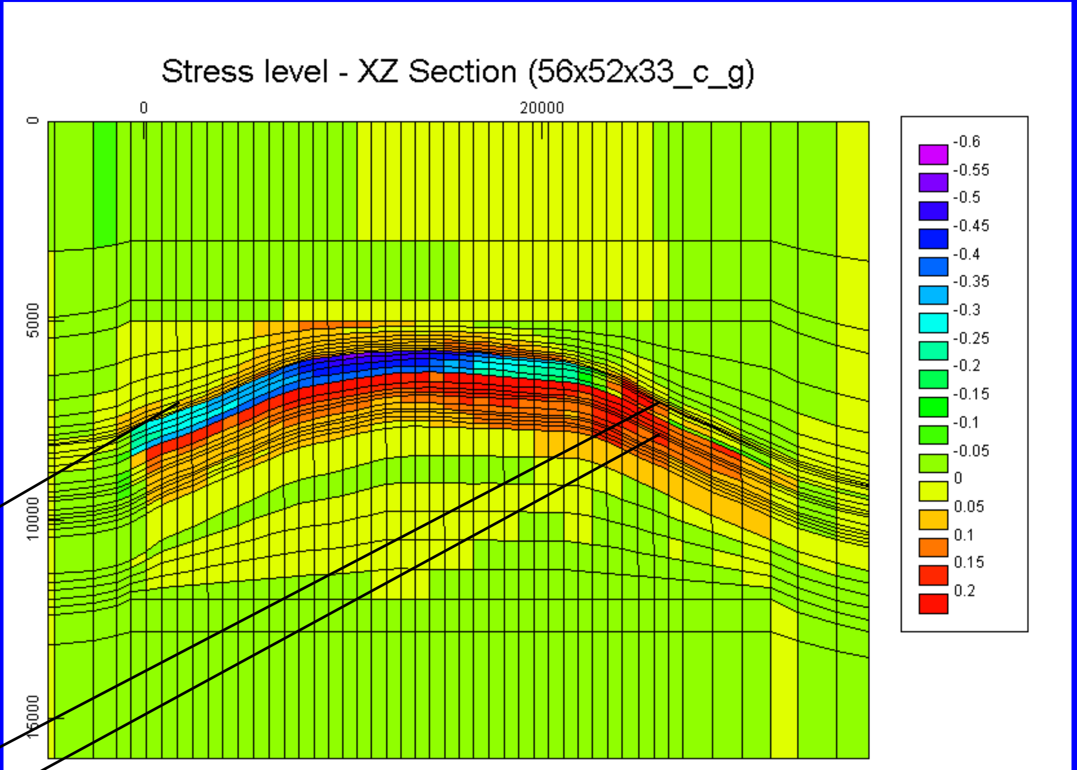


Flow model - **pressure**

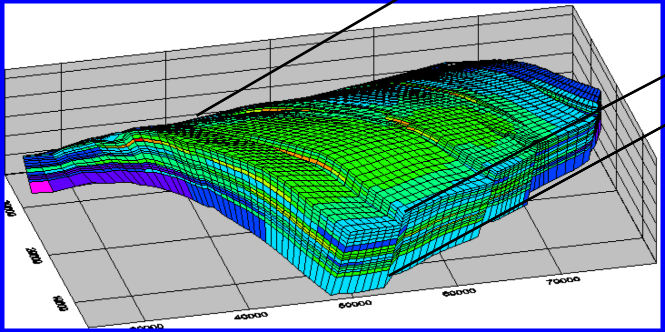
Stress-strain model – **shear stress**

Example – Lunskoye field, offshore Sakhalin Island
(ARMA/USRMS Paper 05-732, 2005)





Large Model: Fault between 3 & 4 –Incremental Stress Level between 2006 to 2051

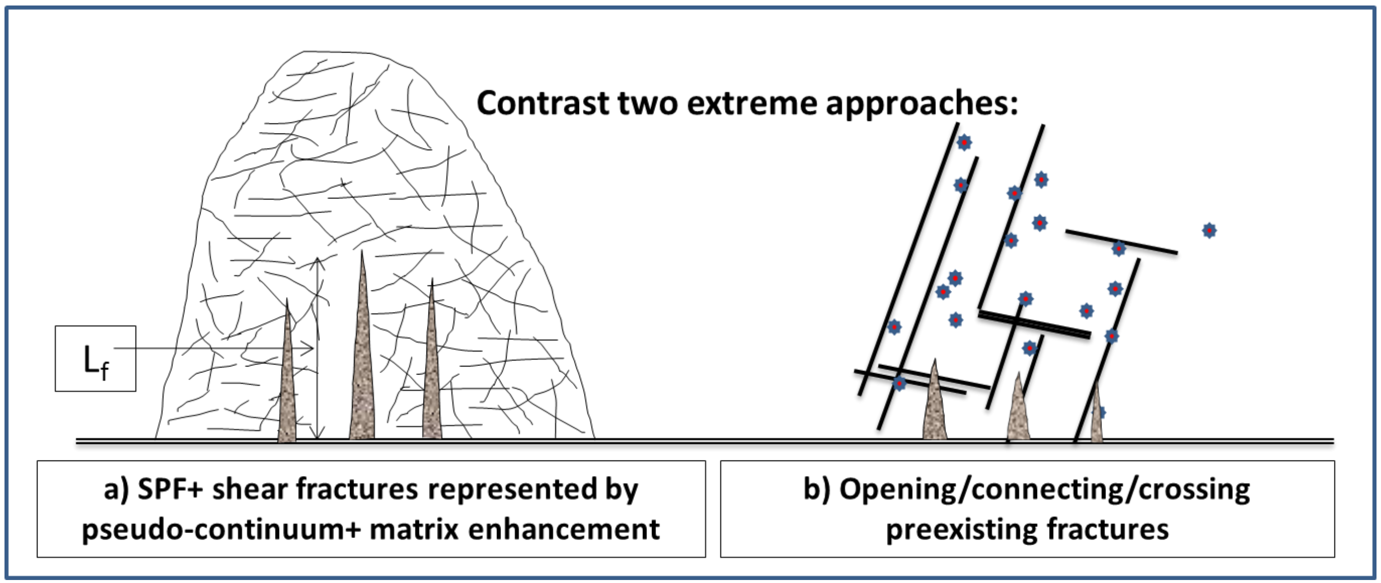


-Depletion strengthens the faults in the reservoir

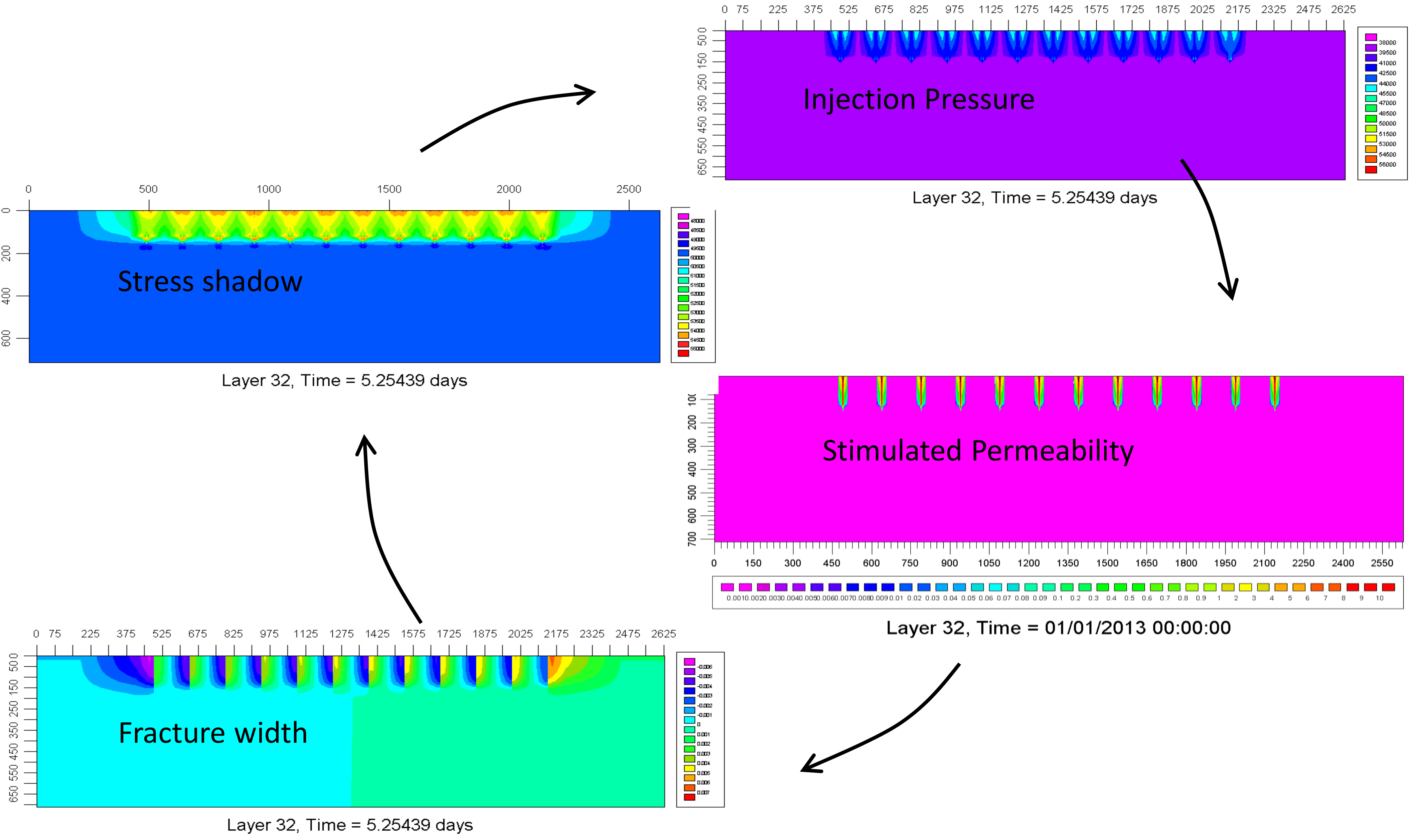
- Direction of max shear rotates

Example – coupled modeling of shale gas completions

- Look at stress shadowing and its effect on casing deformations
- Coupled fracturing, reservoir and geomechanics (perm development in SRV)
- Model entire sequence of pumping
- Pseudo-continuum modeling of SRV
- Explicitly coupled with lower frequency of solving stress vs flow
- Fracture propagation solved on the same time steps as flow



Example of modeling the entire stimulation sequence using the pseudo-continuum approach – can be run in 1 day on a single workstation in coupled mode



Example : Modeling Geomechanics of shale fracturing and Microseismic (MS)

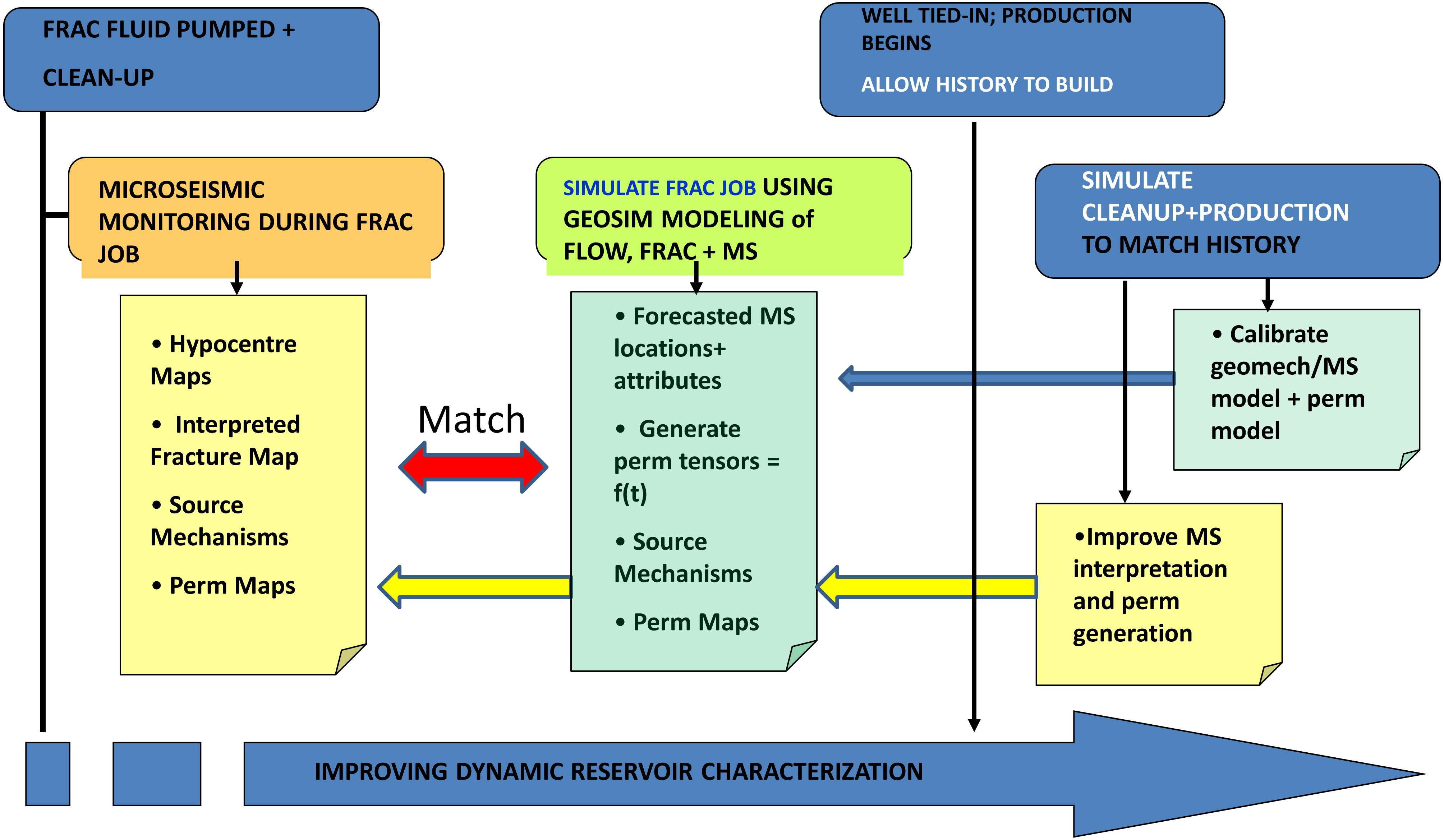
Why coupled modeling of MS?

- The relation between the main fracture, SRV and MS cloud is not yet understood
- Interpretation of the MS via moment tensor analysis is difficult
- Only the production modeling after stimulation can establish the link of MS to permeability
- **Therefore we need a model of MS coupled with a flow (reservoir) model in order to utilize all available data**

Integration with MS monitoring and interpretation

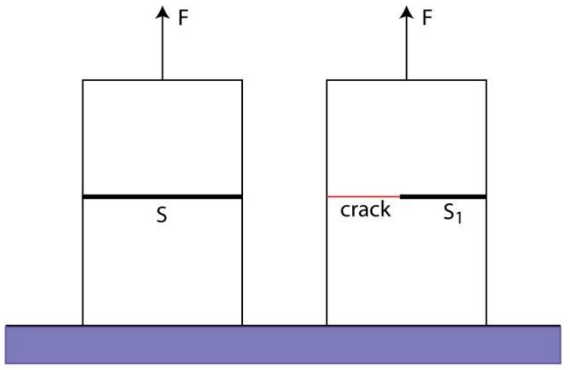
- Compare forward simulation of MS with MS data during frac job:
  - **Locations and timing of interpreted events**
  - **Generated modes of failure, permeability field evolution in time**
- Calibration during and immediately after stimulation:
  - **Main (tensile) fracture propagation depends on SRV permeability**
  - **Pressure fall-off and clean-up data immediately after the treatment**
- Long term calibration: model 1-2 years of production history
  - **Extend the permeability model to production stress path – challenge!**
  - **Match ALL data: production rates (all 3 phases), pressure transient (PBU), PLT's, well interference, ….**
- Potential:
  - **Improve the interpretation provided by MS companies in terms of permeability tensor**
  - **Use the integrated tool to interpret reservoir heterogeneity!**

Integration of geomechanical modeling with MS monitoring and interpretation



Forward modeling of MS (SPE 159711)

- A coupled flow, fracturing and MS model
  - **MS modeling via damage theory**
  - Main coupling through permeability changes derived from modeled MS events
  - Can model the primary tensile fracture as a coalescence of failures
  - Uses B.B. joint theory to evaluate perm increase
  - Based on the GEOSIM coupled system of TAURUS
- Model matches well the Bossier Burger C-17 data
- Potential to use it as a reservoir characterization tool, because it is dominated by heterogeneity



***E* = original modulus**

***E*$_d$ = damaged modulus**

$E_d = E\, S_1/S$

$D = 1 - E_d / E$

Scales of fractures contributing to permeability changes

Main Fracture:

- propagation independently through another modulus, deformation through damage mechanics modulus

Mesofractures:

- size of the representative volume; form process zone around the main fracture; we assume that they correspond to MS events

Microfractures:

- their effect averaged in the Representative Volume Element (REV); their coalescence is represented through Mohr-Coulomb limit; the variability is described using heterogeneity

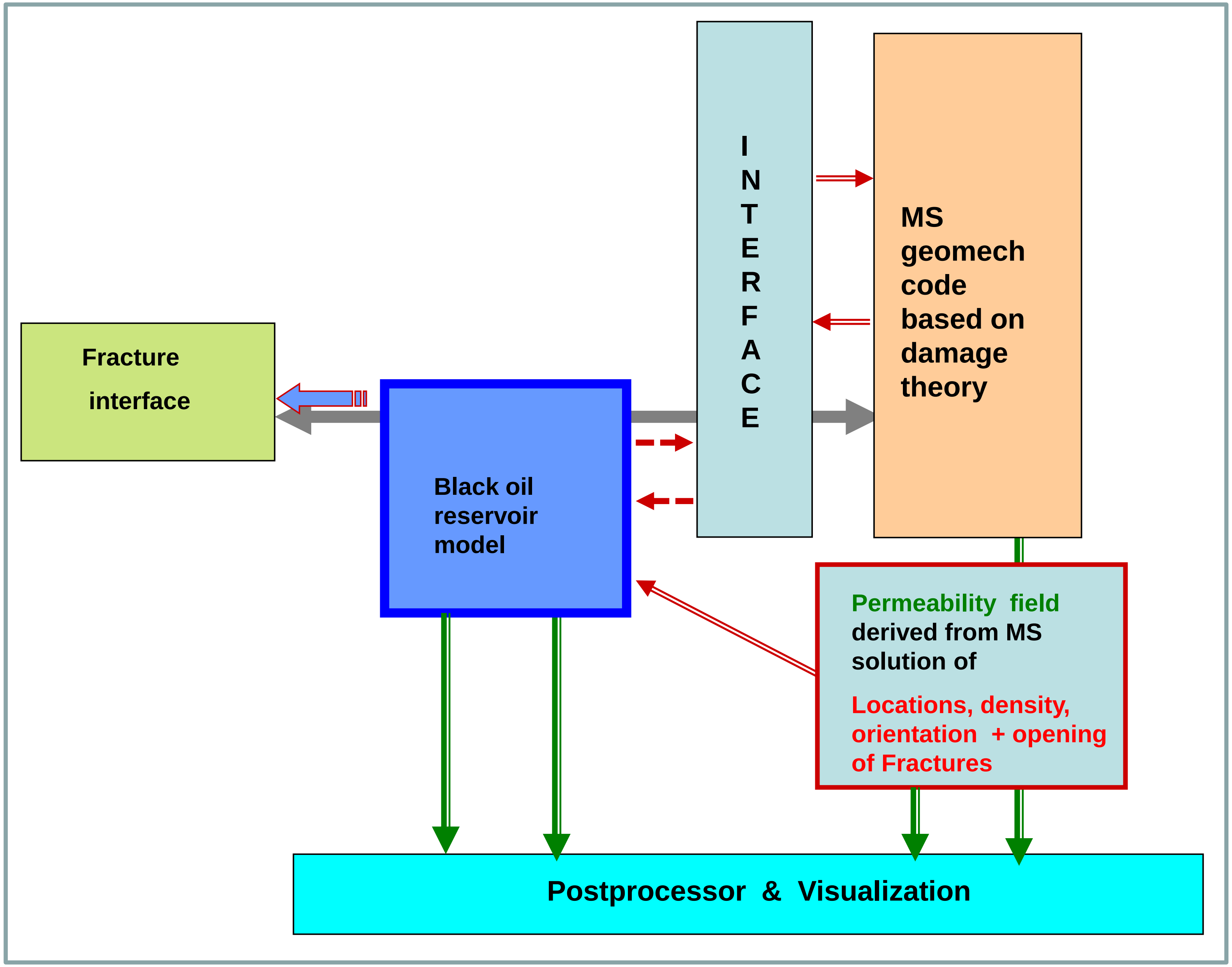
Permeability Coupling with Reservoir Flow:

- **Main fracture**: Open fracture (pumping) or Propped fracture (production) conductivity
- **Mesofractures**: Tensor representation of the permeability of joint sets

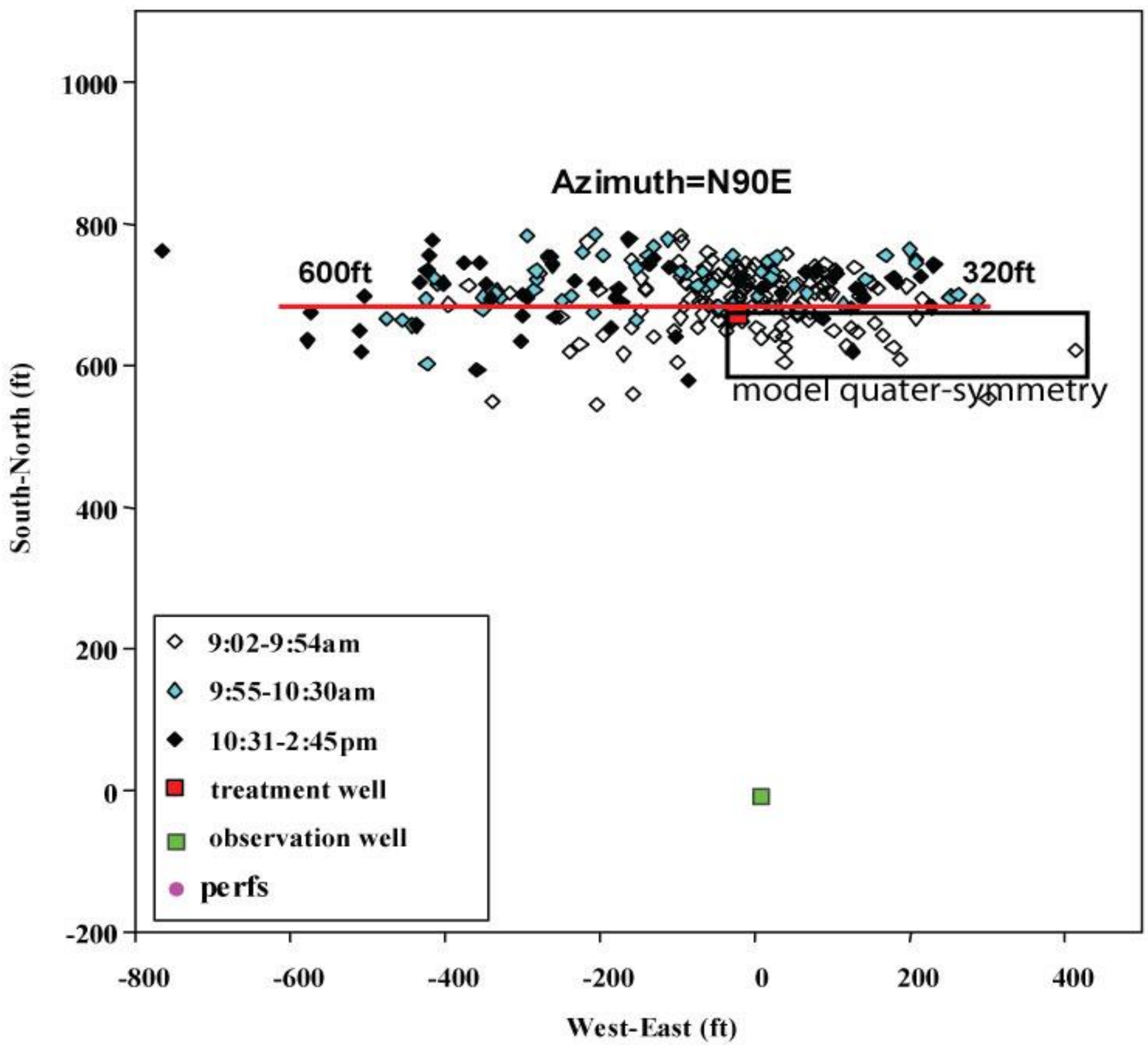
$$K_{ij}^{F} = \eta \frac{w_{fe}^{3}}{12S}(\delta_{ij} - n_i n_j)$$

- **Microfractures**: Pressure or stress dependent matrix permeability

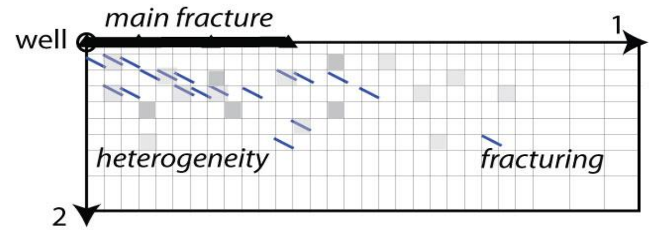
Coupled software architecture



Example of coupling - Flow model of Bossier

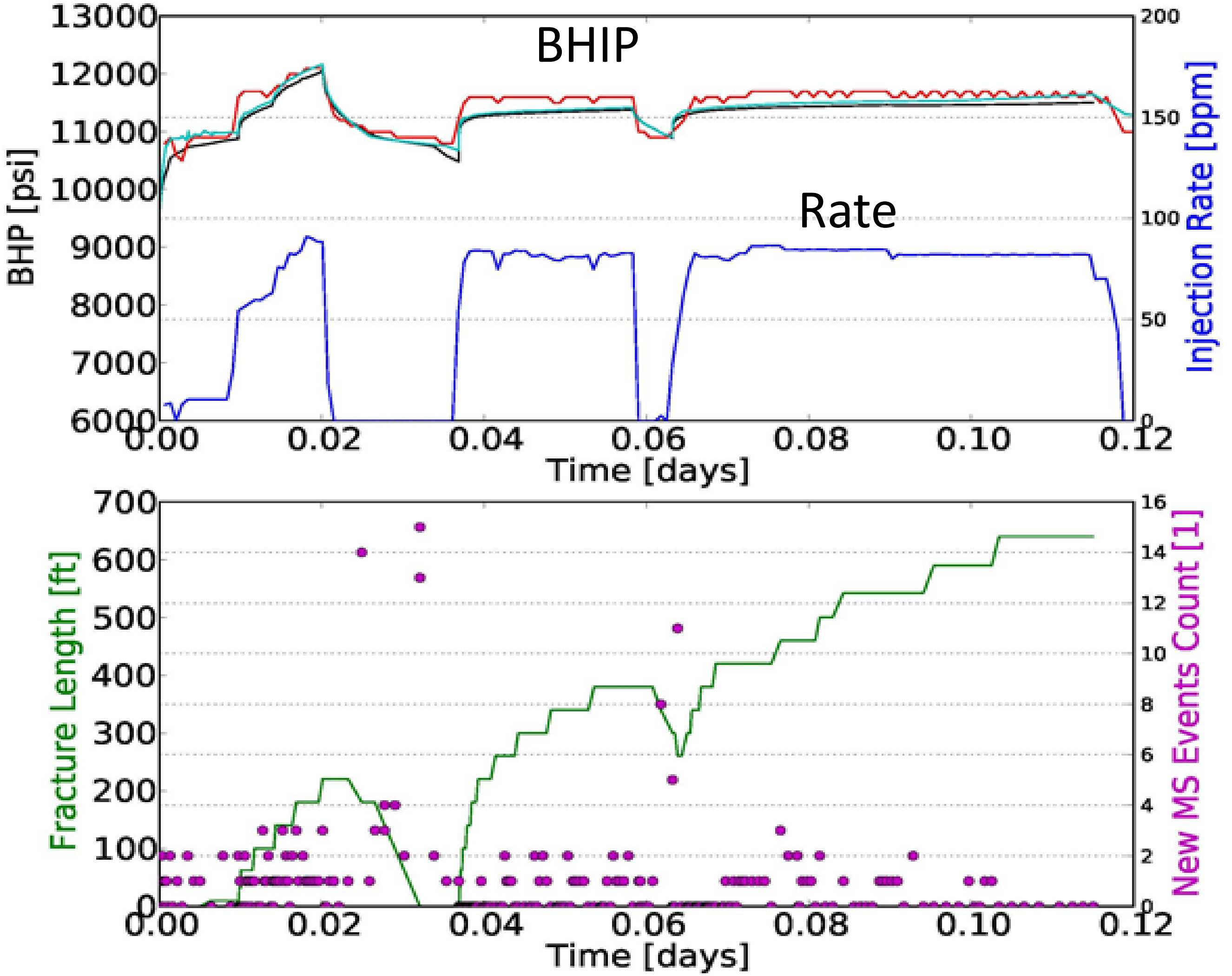


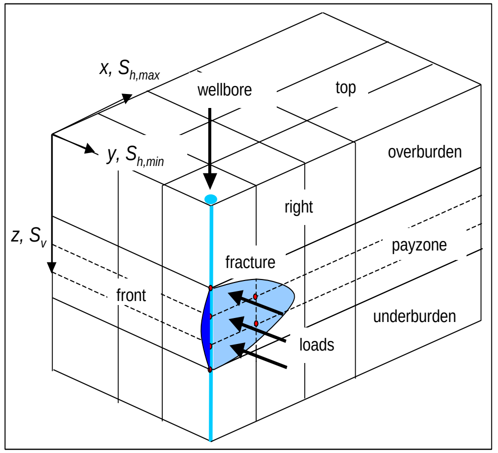
- Fracturing in a tight sandstone, 0.01 md, Texas
- Vertical fracture, ~2 hour injection

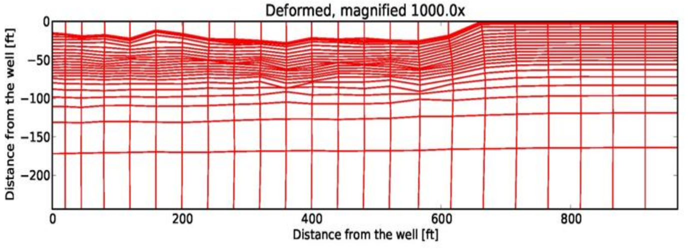


Previous modeling with coupled flow and geomechanics, using MS as a “upper bound” for main fracture length – SPE J. Sept. 2009

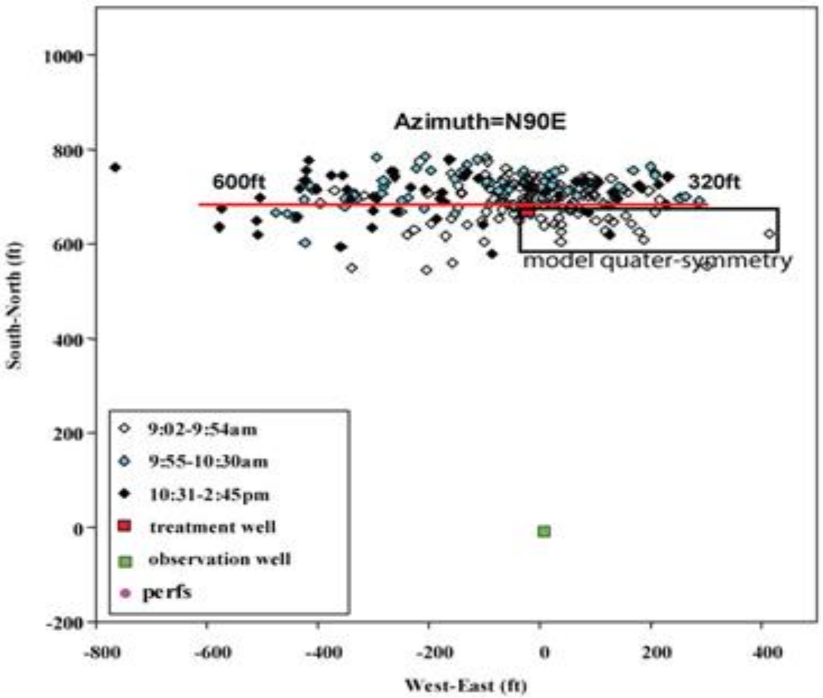
Burgher C-17 – Flow model comparison:
Fully coupled Frac model (L. Ji, 2008) vs the MS



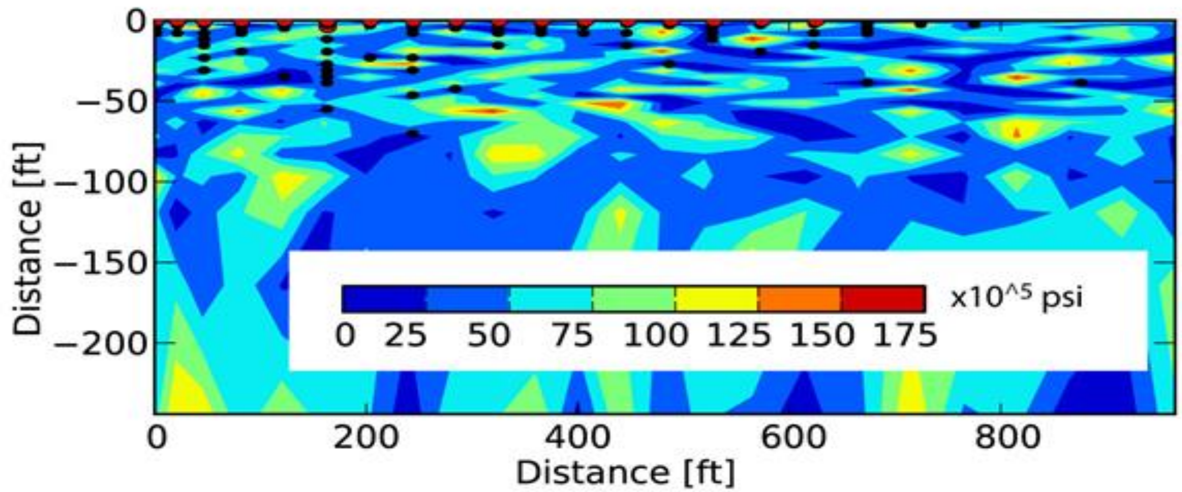




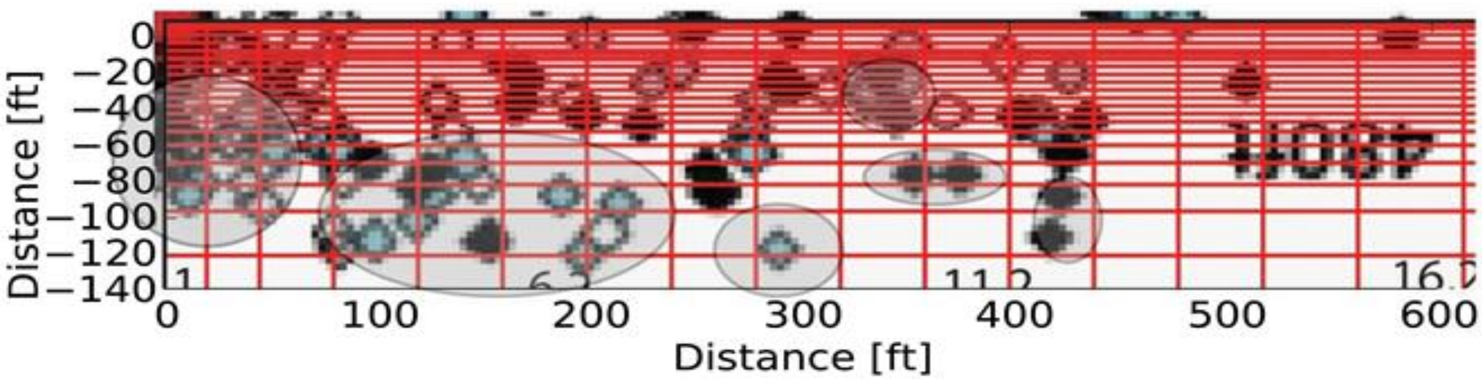
Validation results



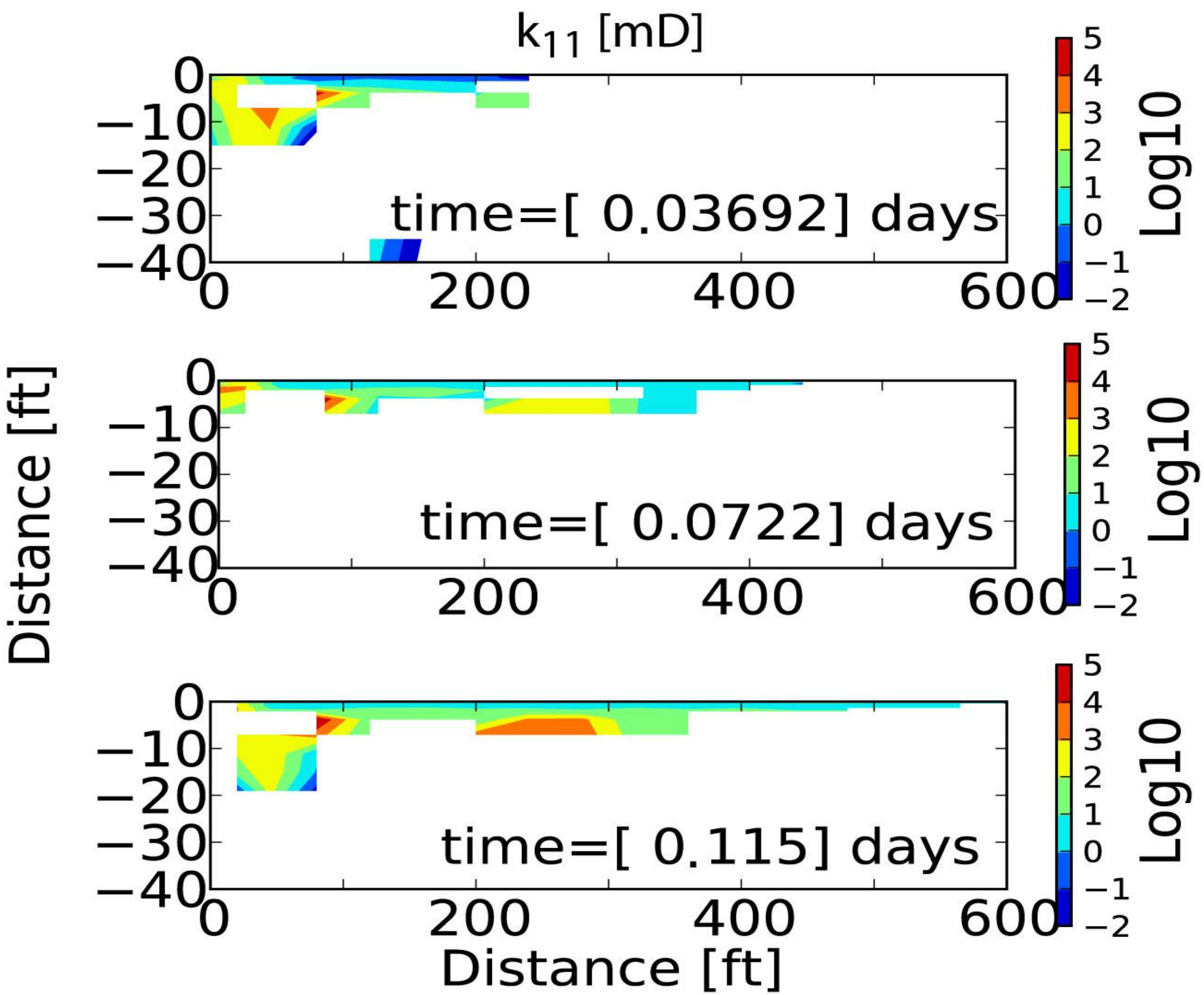
MS events generated with random heterogeneity of E and c



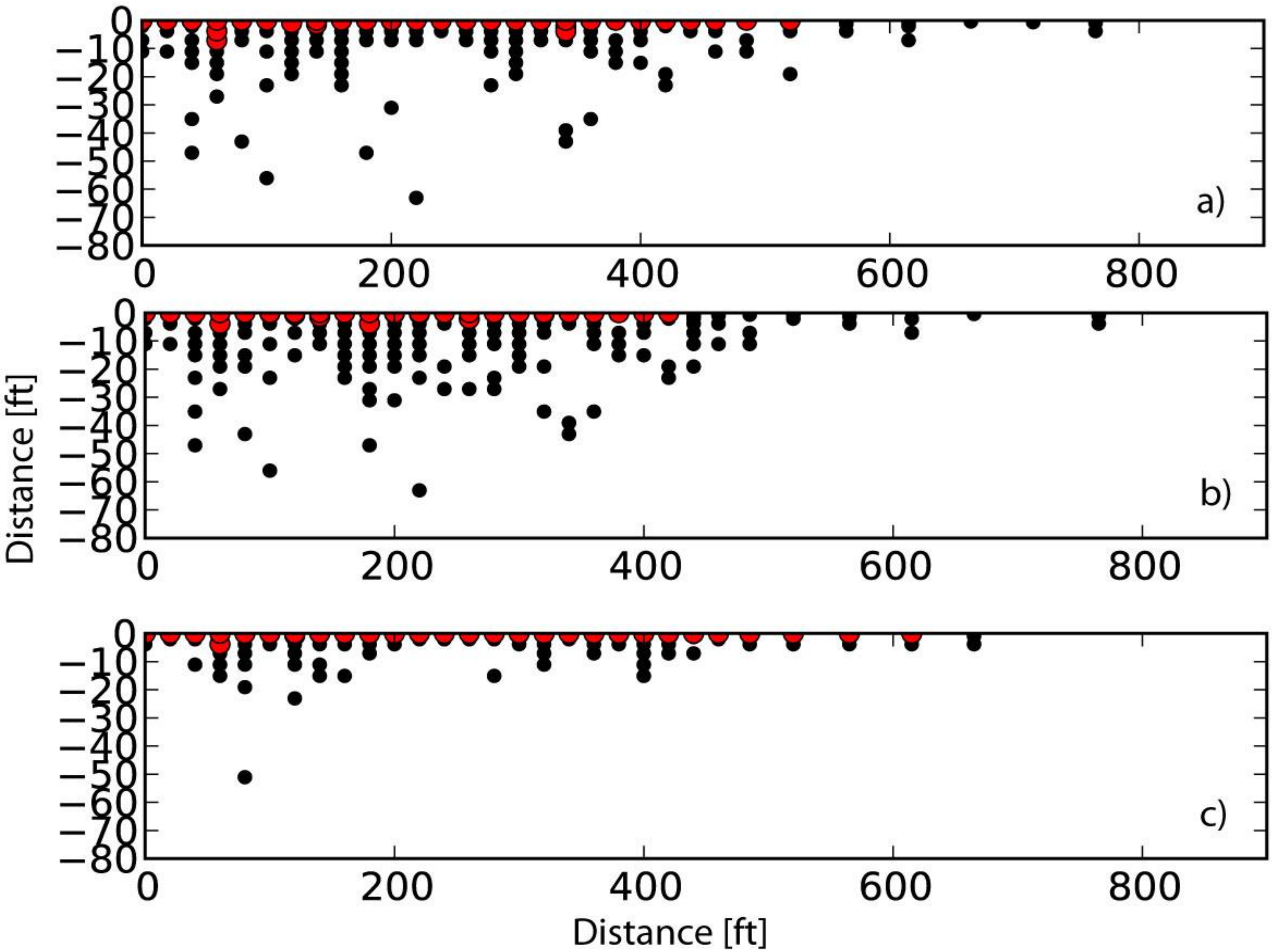
Test: Define the heterogeneity by measured MS, then reproduce the locations



Permeability changes with time



Parametric Study – permeability and heterogeneity



Base case

Overestimated permeability

Less heterogeneous reservoir

Outlook

- Geomechanics is here to stay
- Modeling techniques are developing and “workflows” getting easier
- It allows us to integrate more disciplines and utilize more data in an integrated fashion
- The number of application areas is still increasing ….

Thank You!

Questions?