Building Better Integration between Structural Complexity and Basin Modelling*

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Search and Discovery Article #40891 (2012)
Posted February 29, 2012

*Adapted from oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

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Abstract

In a context of growing complexity to explore petroleum basins, significant R&D efforts are multiplied to give answers to these new challenges. In 2006, IFP Energies Nouvelles initiated the development of a new 3D basin simulator which takes into account compaction, heat transfers and maturity, but instead of being limited to vertical deformation as in usual petroleum system simulators, it is now able to handle faulted and moderately to highly deformed geometries.

The classical flow chart to perform a basin study is mainly composed of three steps. The first step is the building of the present day 3D model. The second one is the restoration in order to get a kinematic scenario through geological time. The last step is the forward simulation. This methodology has been equally applied to examples of growing difficulties and various environments.

Hydrocarbon flow across and along the faults is strongly controlled by lithology contrasts, clay content, diagenetic changes during time activity of the faults. With particular attention paid to the fault definition and characterization, where across-fault flow and along-fault flow can be represented and defined, more precise fluid flow is considered during the opening/sealing activities of the faults through time.

Examples following this workflow designed for complex tectonic environments are illustrated in different case studies. These examples demonstrate the impact of the evolution of fault hydraulic properties on pressure and fluid prediction through time and space.

References

Gibergues, N., M. Thibaut, and J.-P. Gratier, 2009, Three-dimensional kinematic modeling of reversible fault and fold development: AAPG Bulletin, v. 93/12, p. 1691-1704.

Pegaz-Fiornet, S., 2011, Development and implementation of percolation models for simulation of sedimentary basins: Ph.D. dissertation Universite Aix-Marseille, France, (unpublished).

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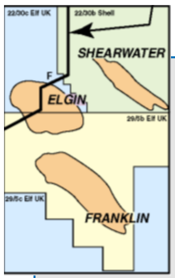
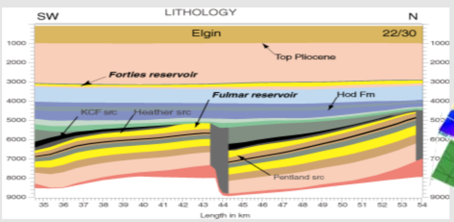
Outline

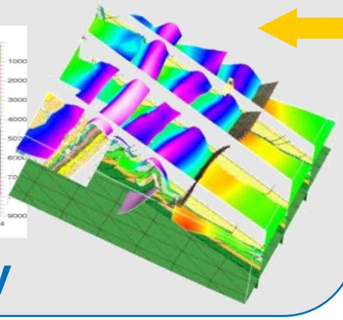
- Current workflow in basin modeling
- Research on the new basin simulator
- Geometric and hydraulic description of the faults
- Applications
- Conclusions

Current Workflow in Basin Modeling



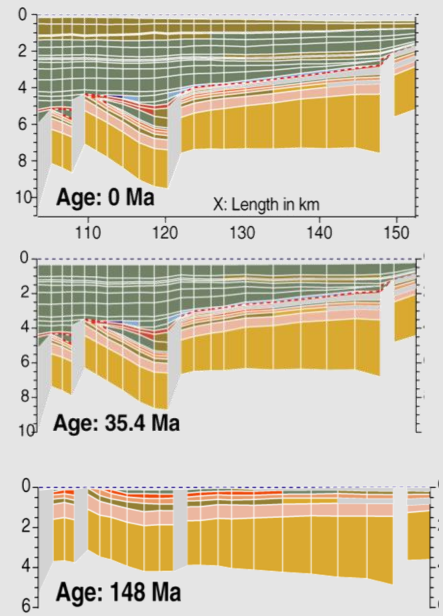
Geological settings
Seismic interpretation





At present day

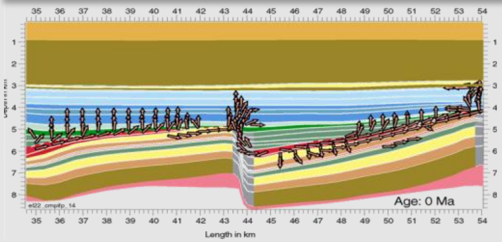
Paleo-geometry by restoration



sandy shale
shale
coaly Brent

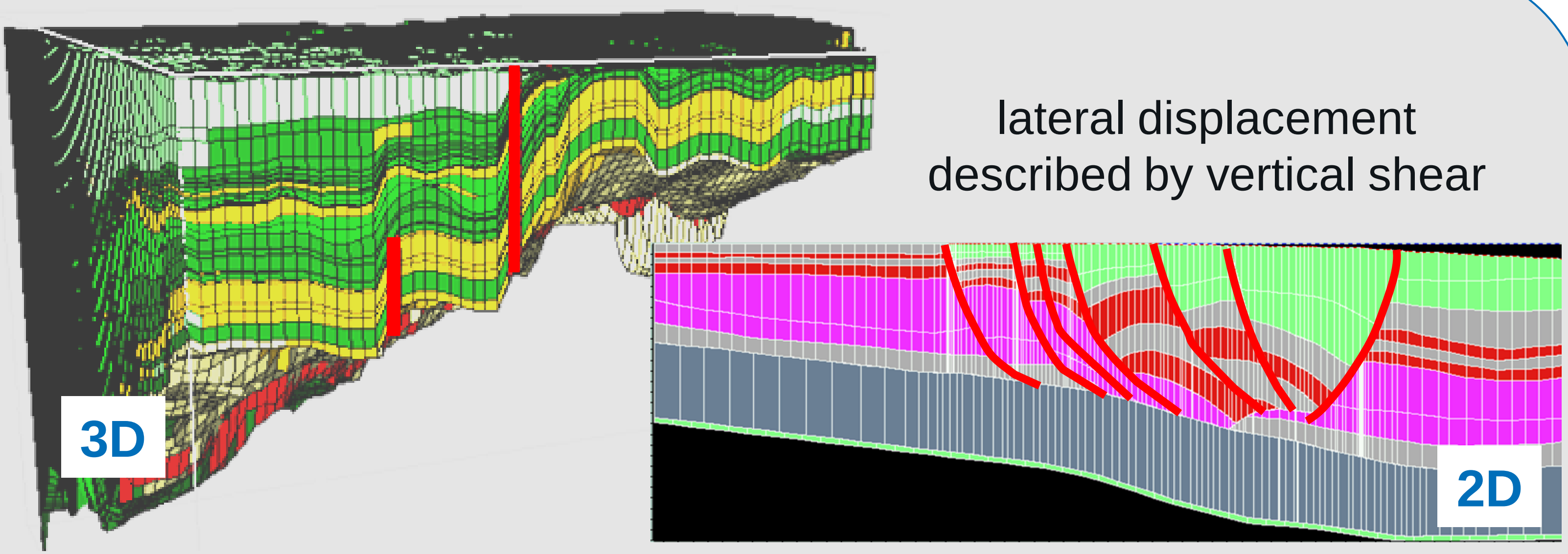
History of the deformation

Forward simulation



Timing of maturity, pressure prediction, fluid pattern through time

State of the art for the structural context

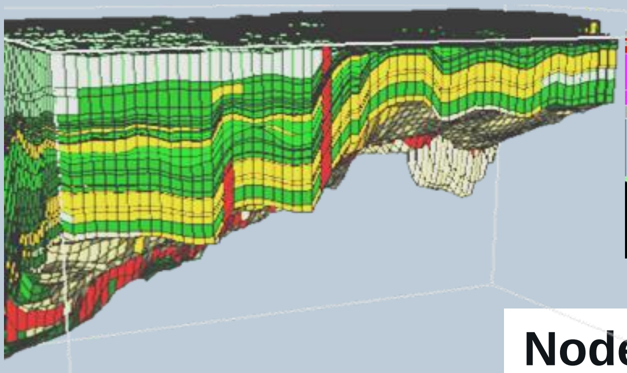


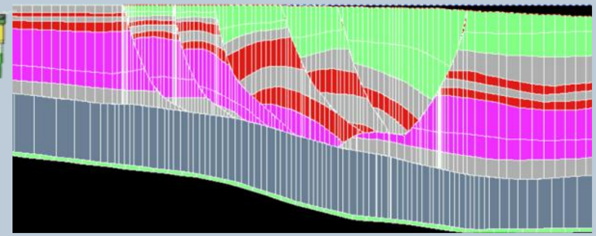
- ✓ in 3D, limited complexity of the structural model
- ✓ in 3D, faults are virtual, only represented by their hydraulic properties
- ✓ in 2D, better kinematic and hydraulic fault description

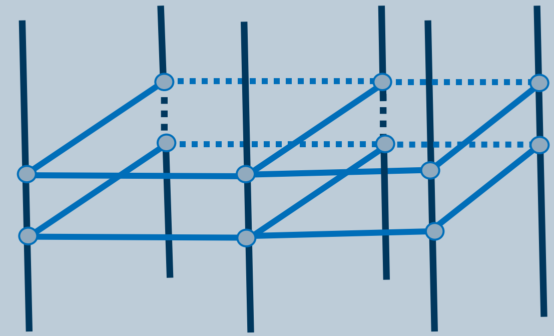
In which direction is research working?

- Since 2006, a new forward basin simulator : Arctem
  - to help industry needs now focused on more 3D structurally complex targets
- For that, we need to consider
  - 3D geometry based on an unstructured mesh
    - much more difficult
  - fluid flow coupled with compaction and heat transfer
    - made as in the previous basin simulator
  - faults are meshed individually, allowing fluid flow along and across the faults
    - for a precise description of the kinematic and hydraulic behavior

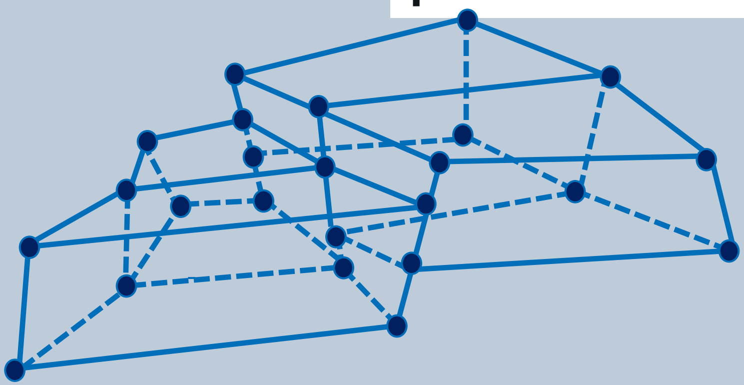
An unstructured mesh

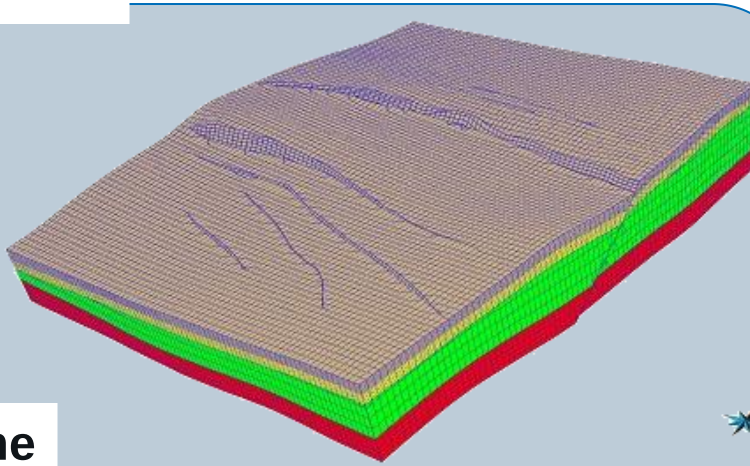






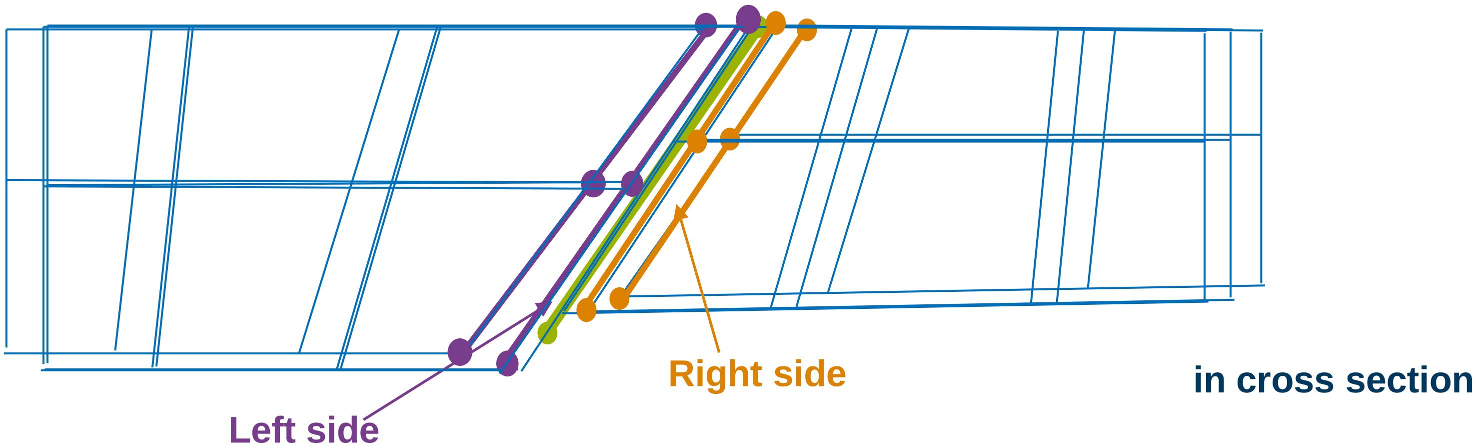
Nodes aligned along pillars





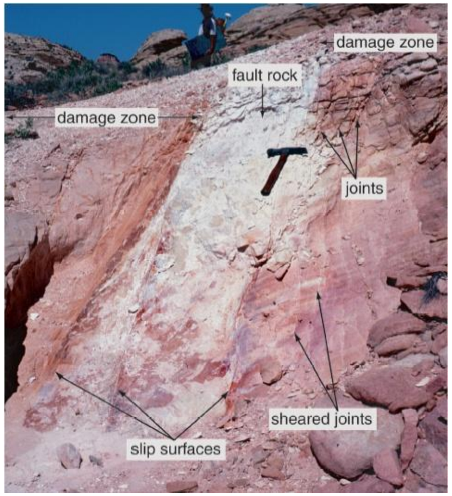
A more realistic deformation through time

Geometrical description of the fault

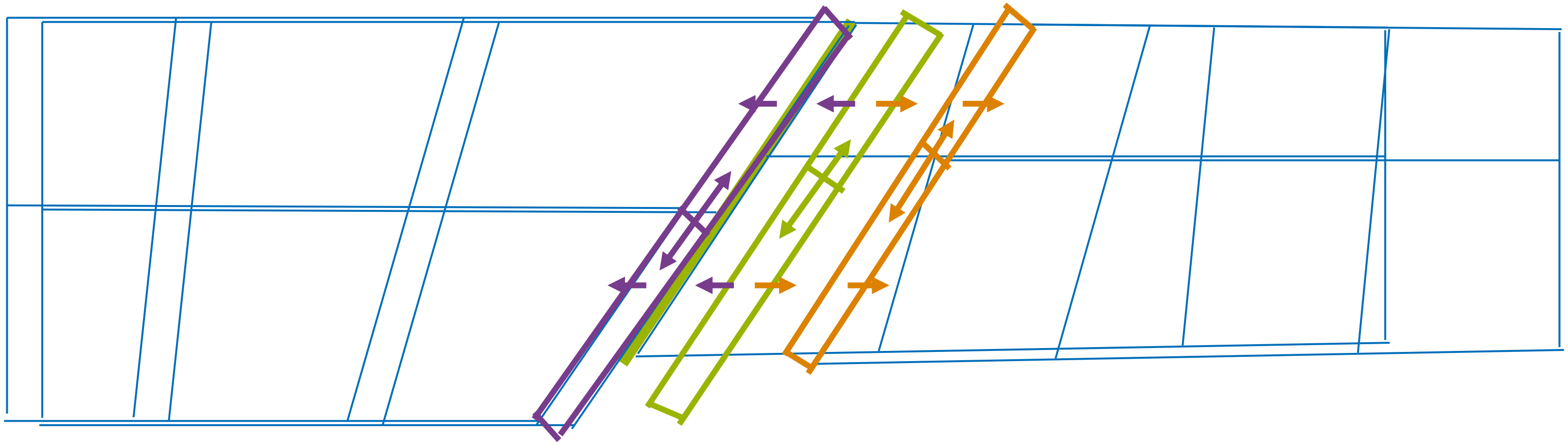


- **Fault is a boundary surface**
  - with a left and right side
  - assign properties to simulate different behavior through time and space
  - overburden, temperature, heat flux are continuous across the fault

Hydraulic behavior of the fault

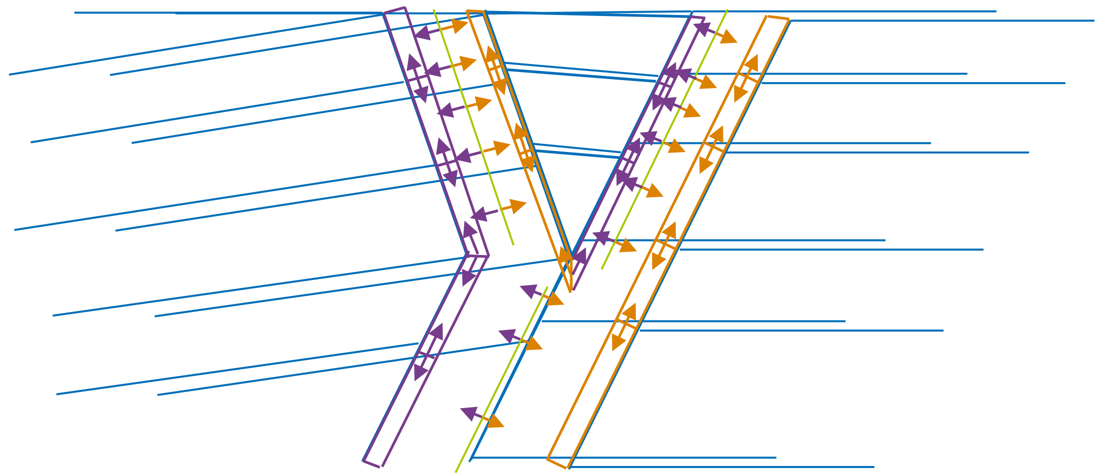


- Visually, the fault is geometrically represented as a surface
- Internally, it is a zone
  - with a thickness
  - a spatial permeability with an history
  - fluid flow across and along the fault



Fault network definition

- No specificity between junctions
- Connection is done by the connectivity of the surface meshes

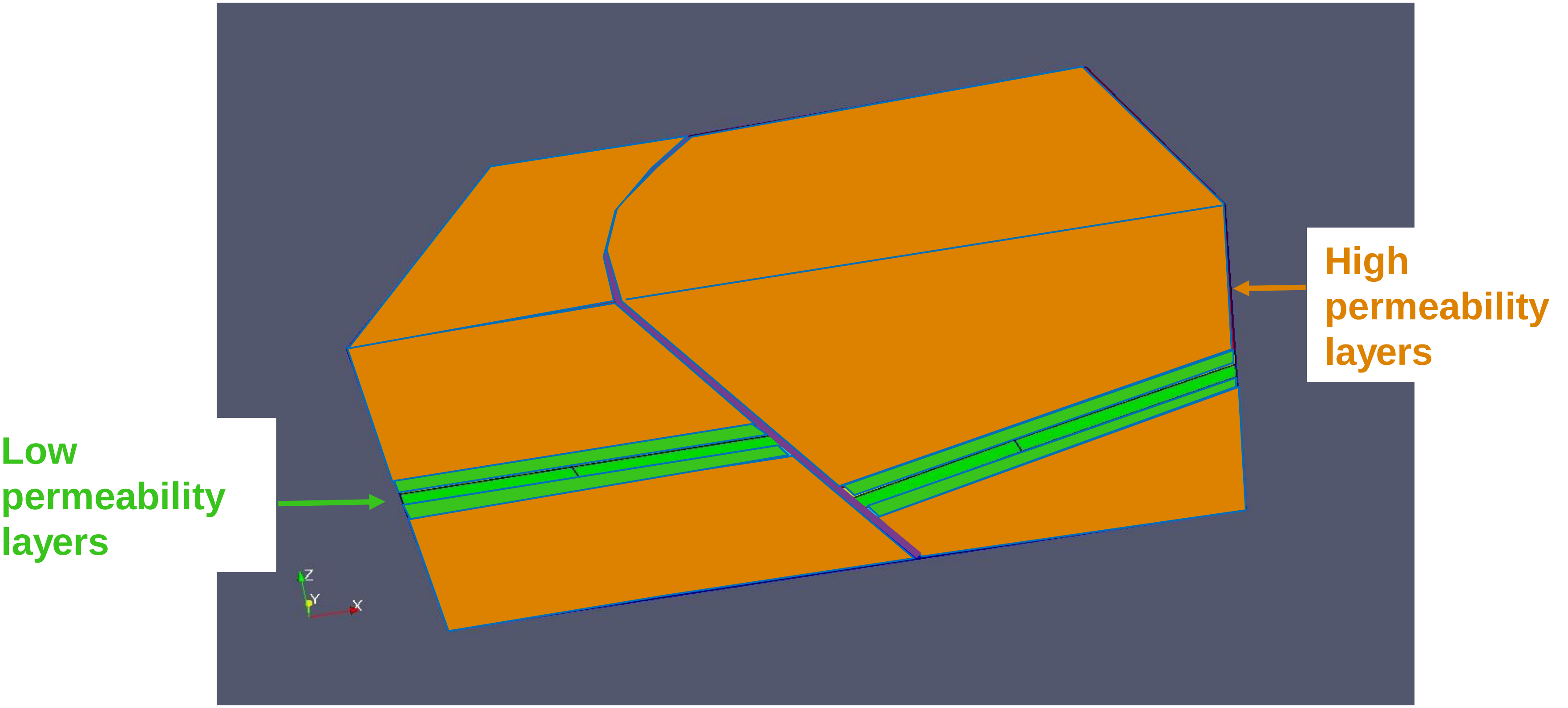


How complex could the description of the faults be?

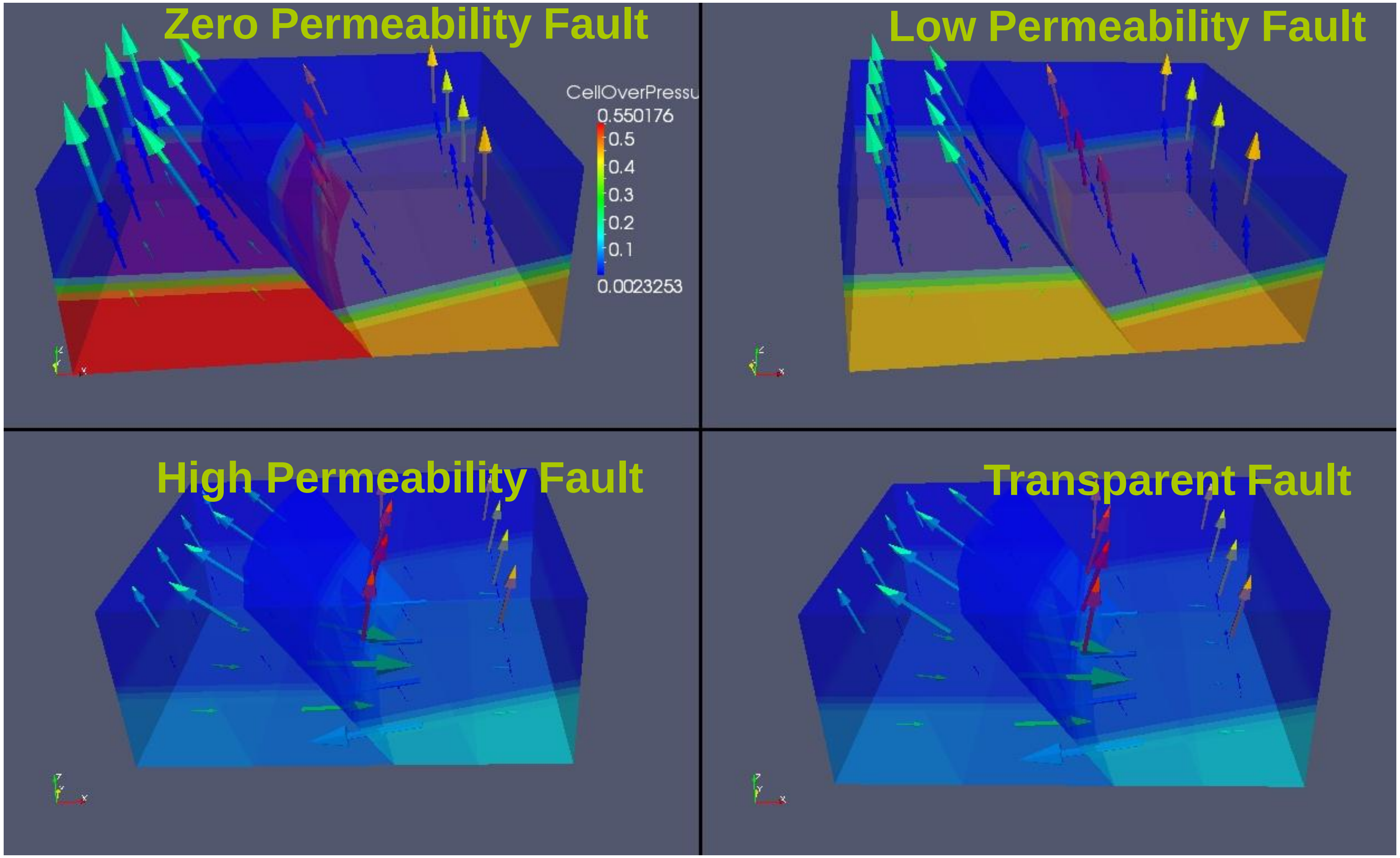
- Geometry
  - complex network of faults
  - bending or branched, secondary faults
- Hydraulic
  - fluid flow across and along the faults
  - evolution of spatial permeability through time
  - thickness of the gouge and damaged zone

Illustrations on an academic example

- Normal case with a fault as a boundary surface
- Impact of the fault permeability

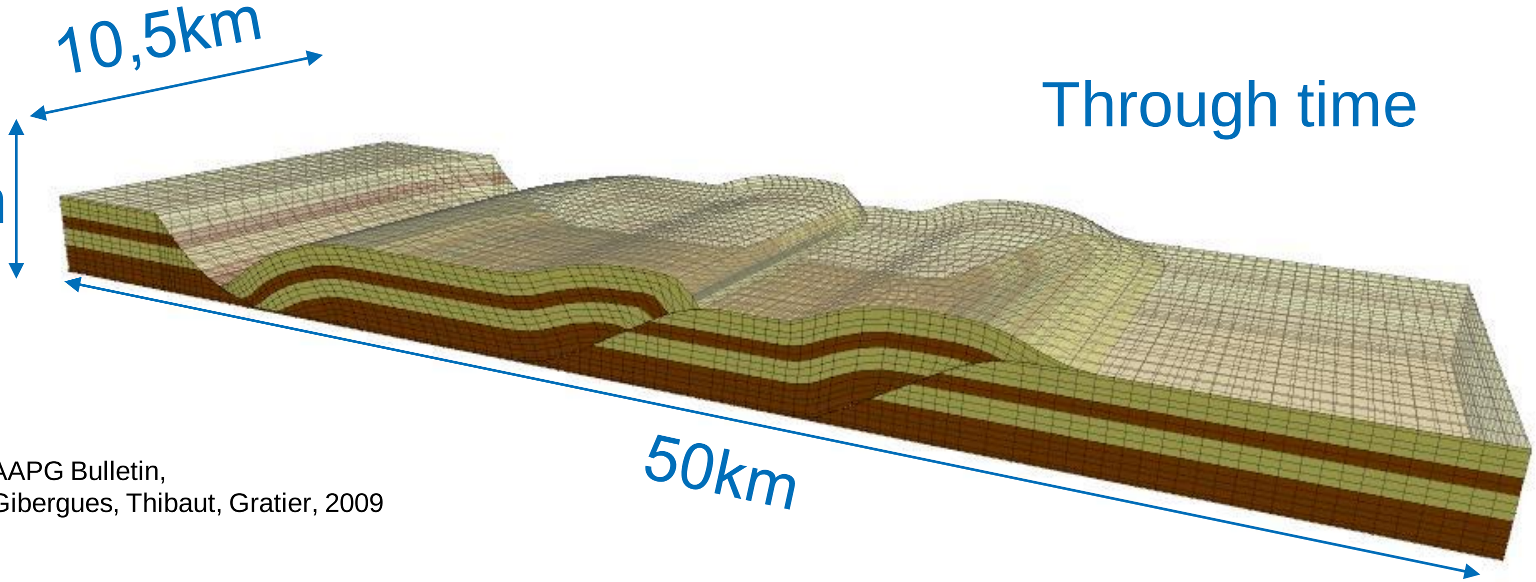


Overpressure evolution and fluid velocities



Illustrations of a simplified case

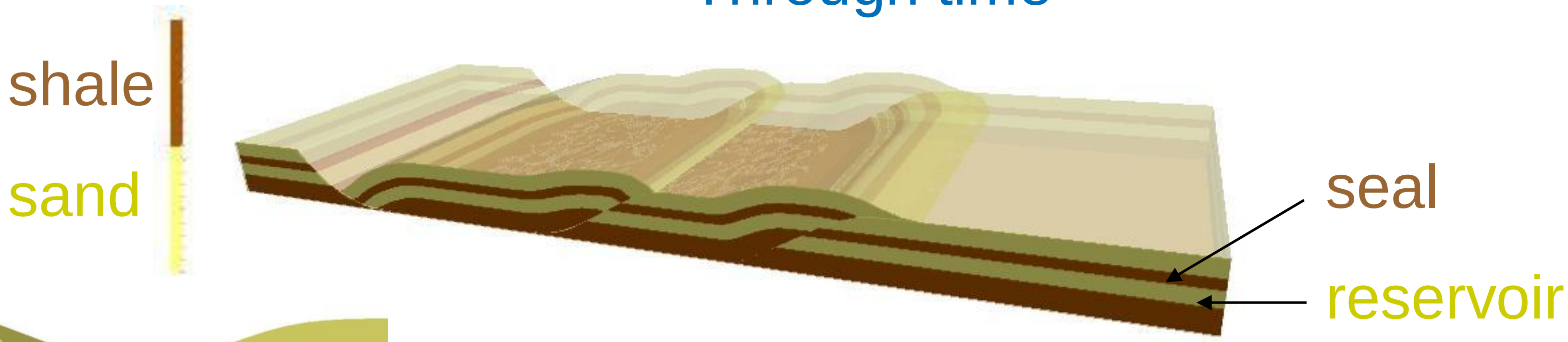
- Compressive case with a lateral displacement after sedimentation
- Impact of lithologic contrasts and capacity of fault (drain/seal)



AAPG Bulletin,
Gibergues, Thibaut, Gratier, 2009

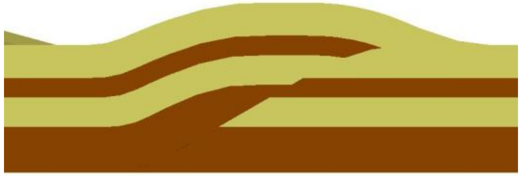
Lithologic contrasts and fault contacts

Through time



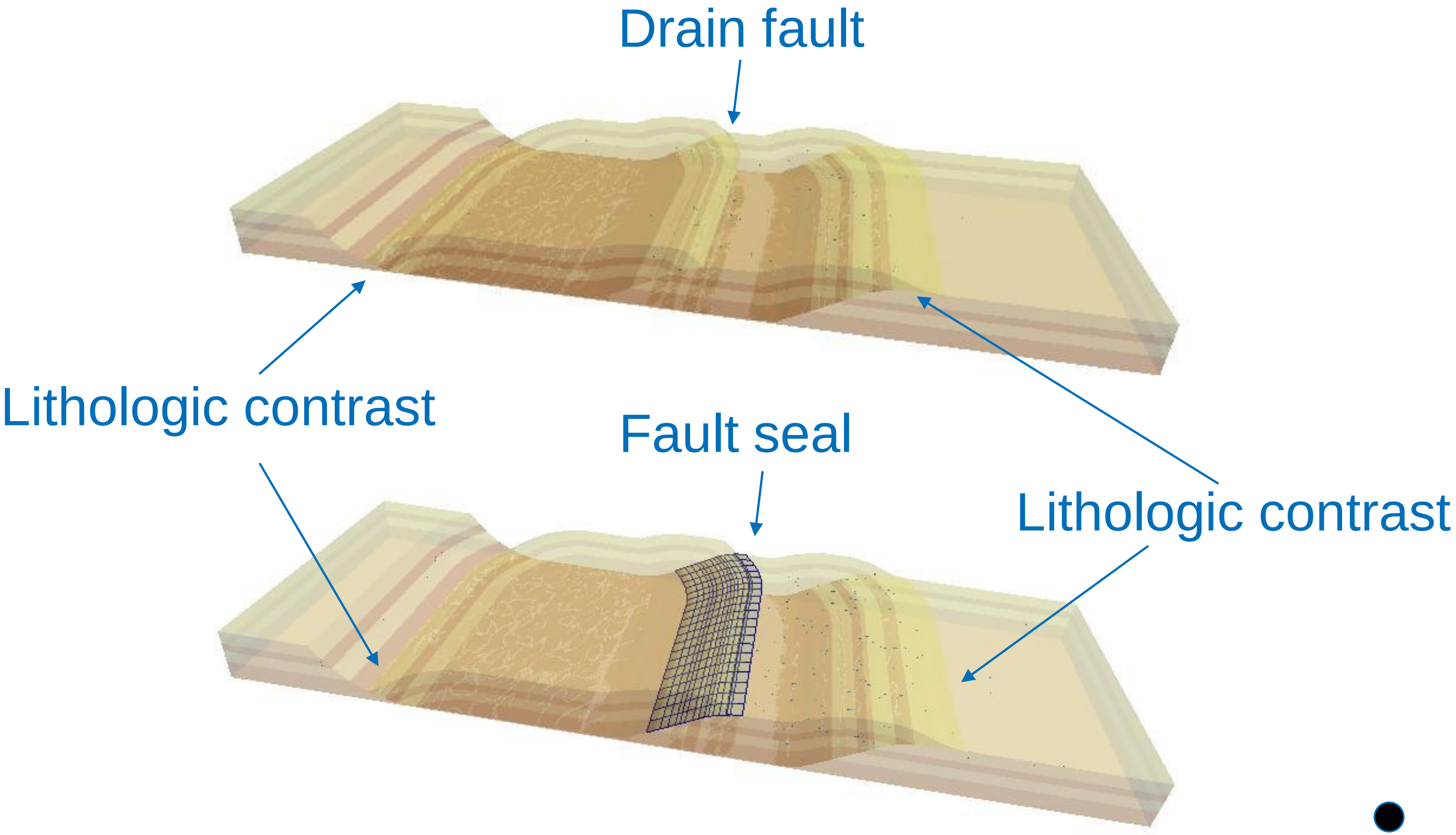
Lithological contact

Fault surface

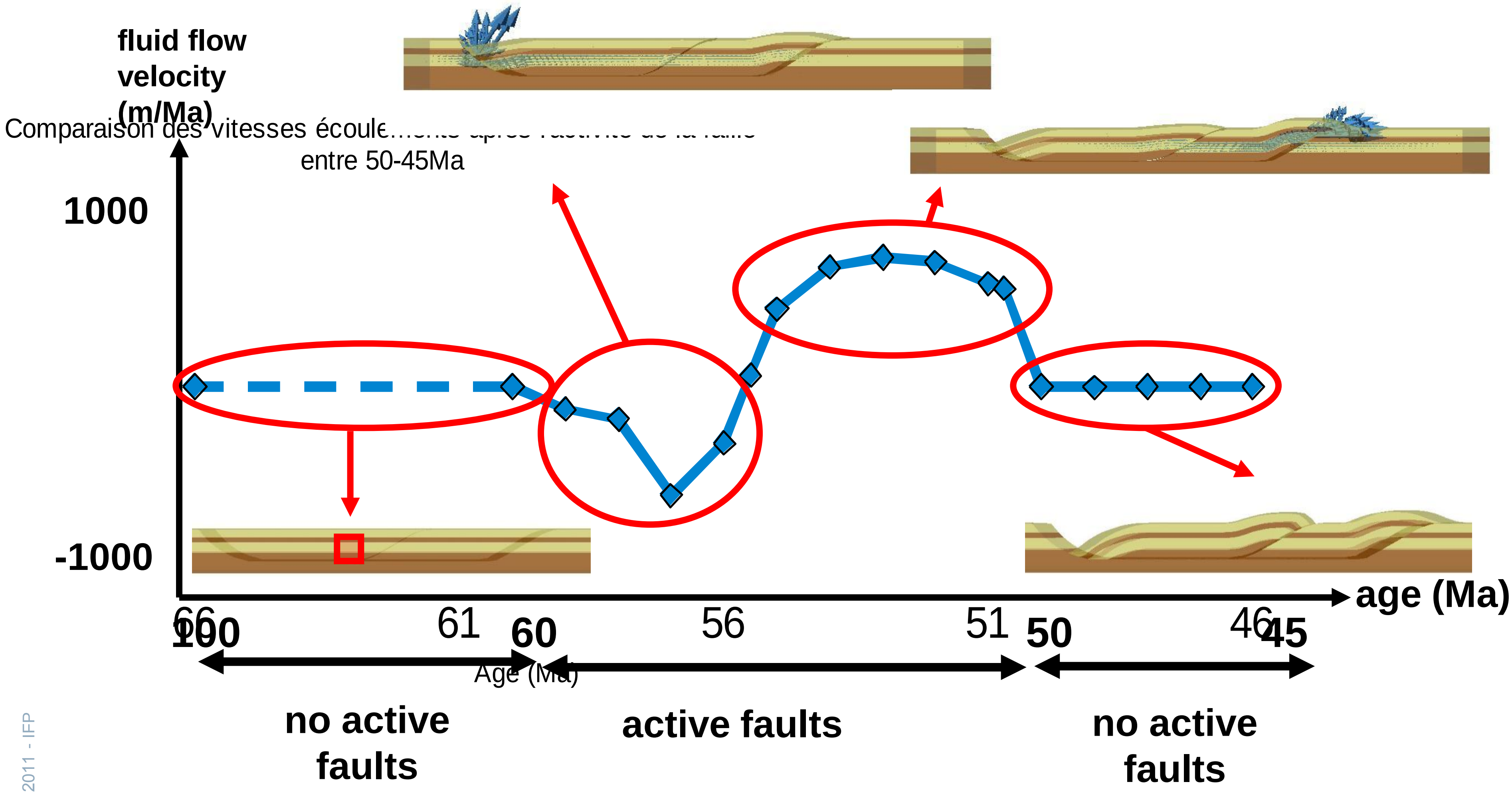


Lithological contact

Capacity of the fault surface

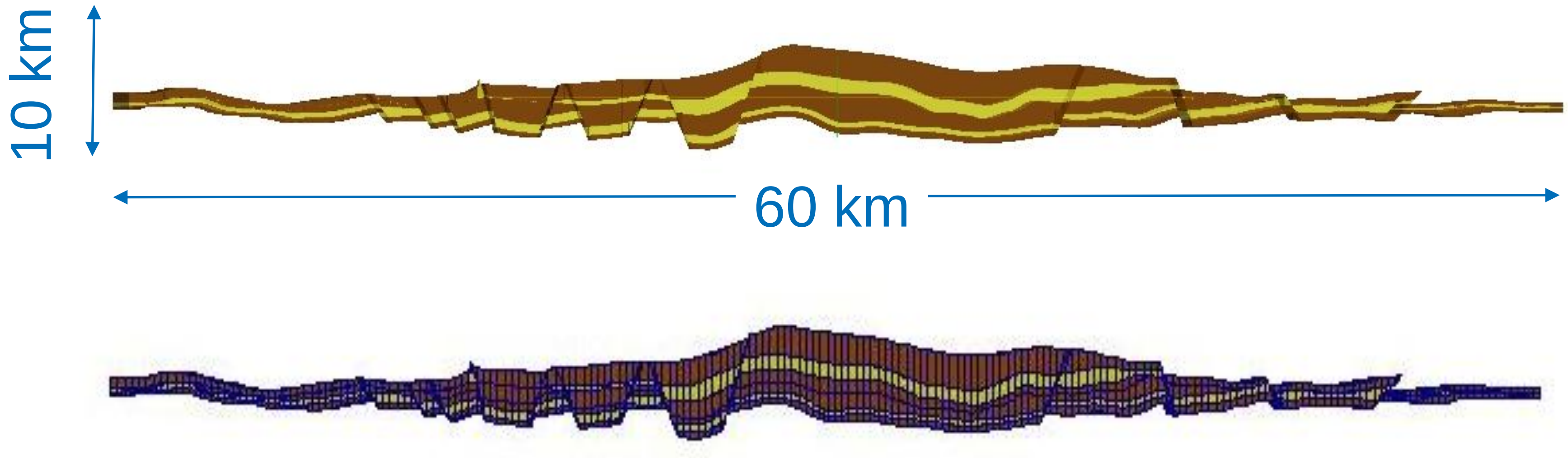


Variable permeability through time

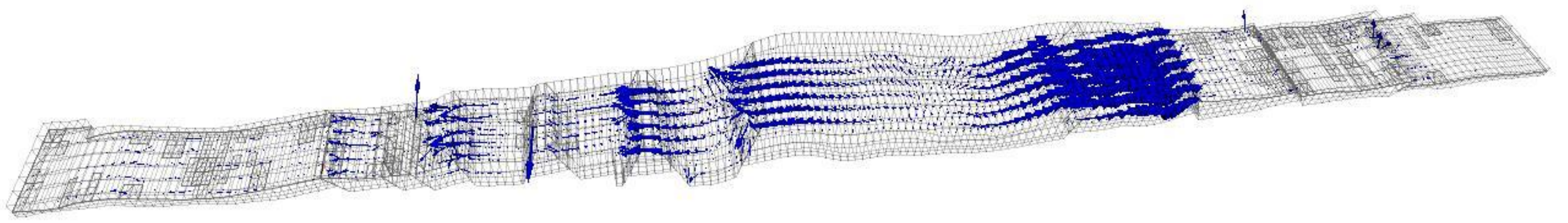


Illustrations of a more realistic case

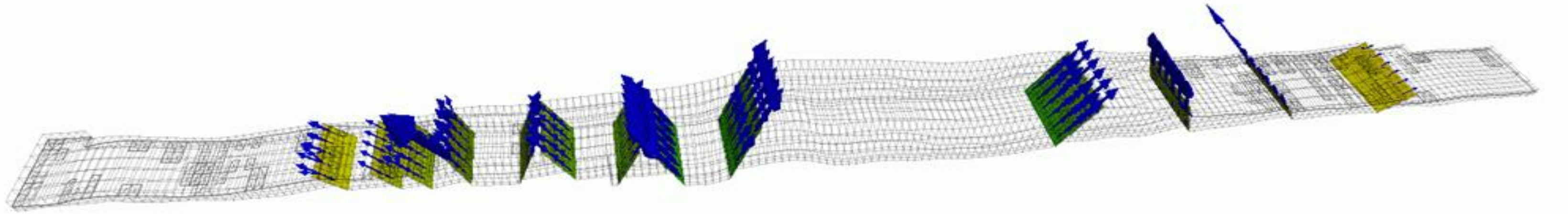
- Based on real data, a lateral extension due to a rift
- Impact of the fluid flow along the faults with variable thickness for the damaged zone
- Alternation of sand and shale



Fluid flow along and across the faults



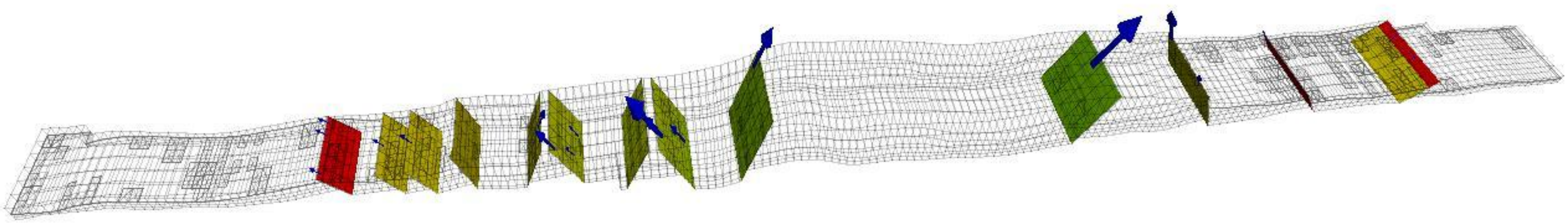
Fluid flow across the faults



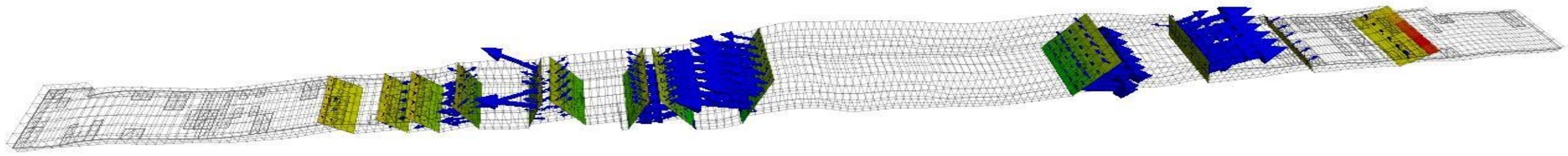
Fluid flow along the faults

Impact of bed thickness of the gouge and the damaged zone on fluid flow

Gouge = 0.5 m, damaged zone = 10 m

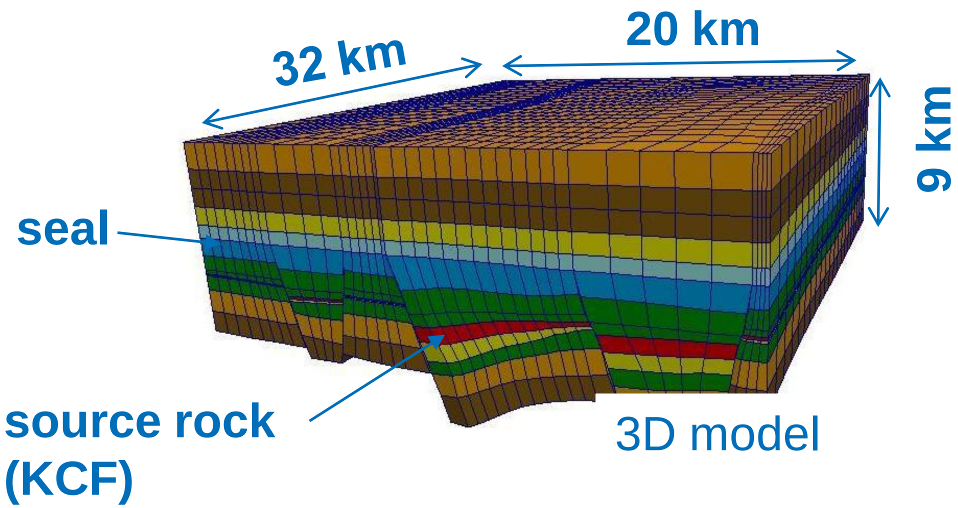


Gouge = 1 m, damaged zone = 30 m

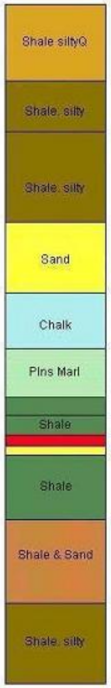


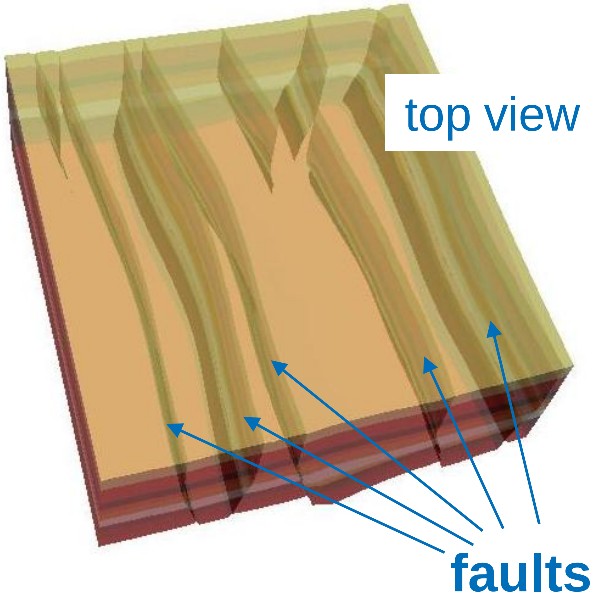
Illustrations of a mimic of a real case

- **Extensive case based on a HPHT project in North Sea**
- **Basin workflow: timing of maturity, pressure prediction, fluid pattern through time**

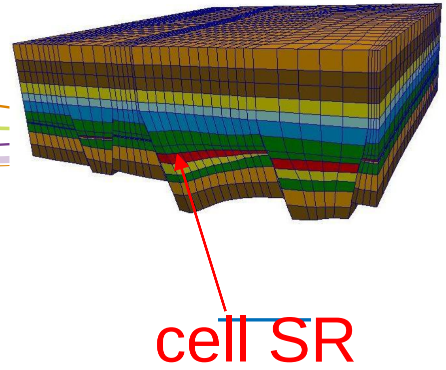


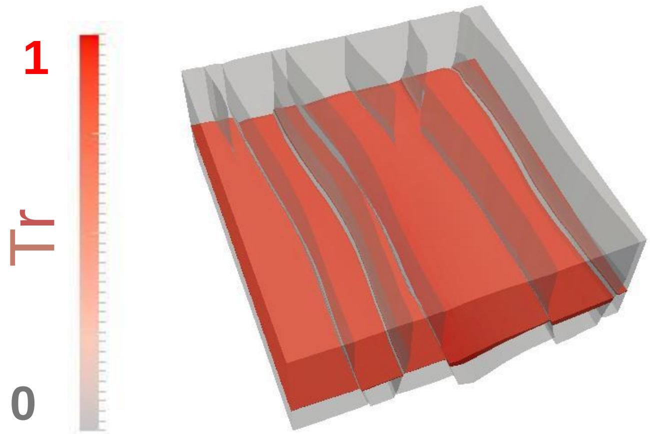
13 layers over 245Ma



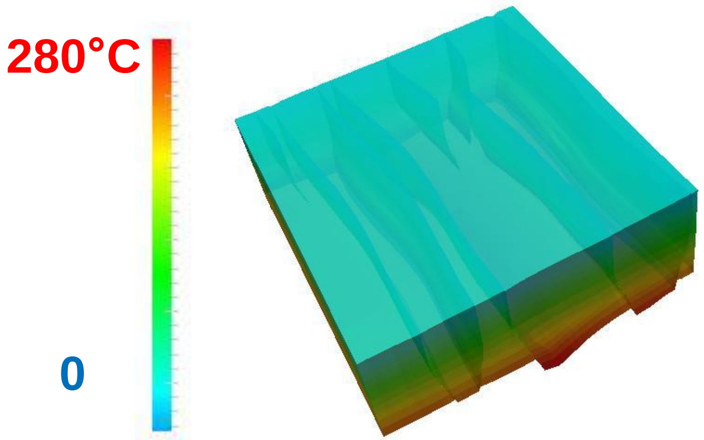


Timing of maturity

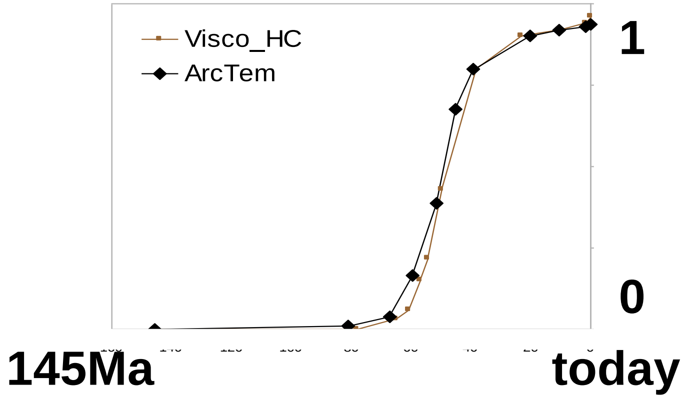


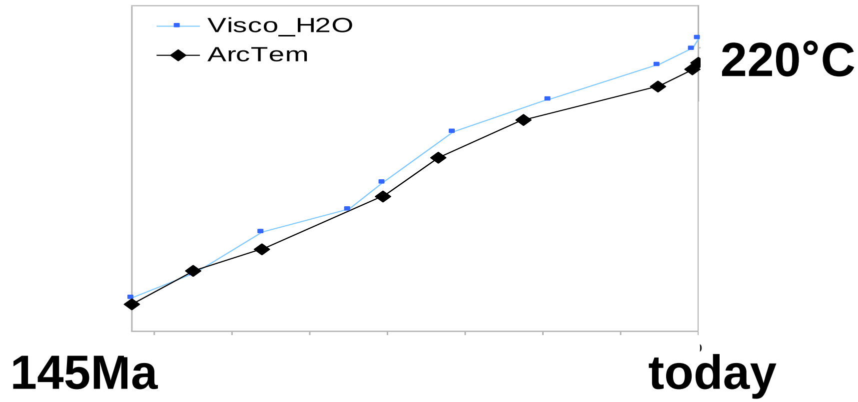


Transformation ratio



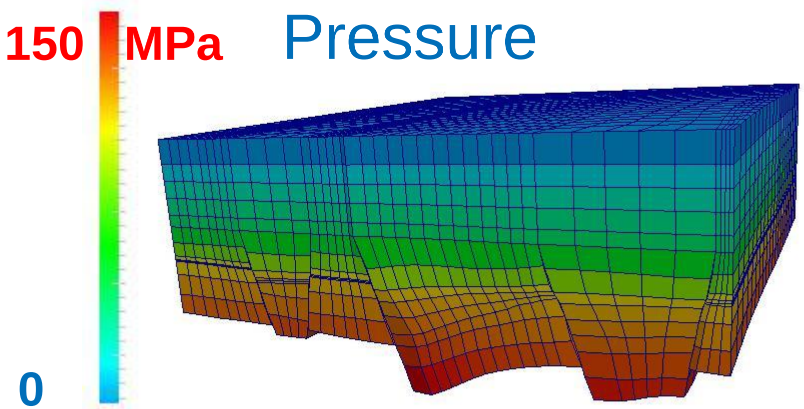
Temperature

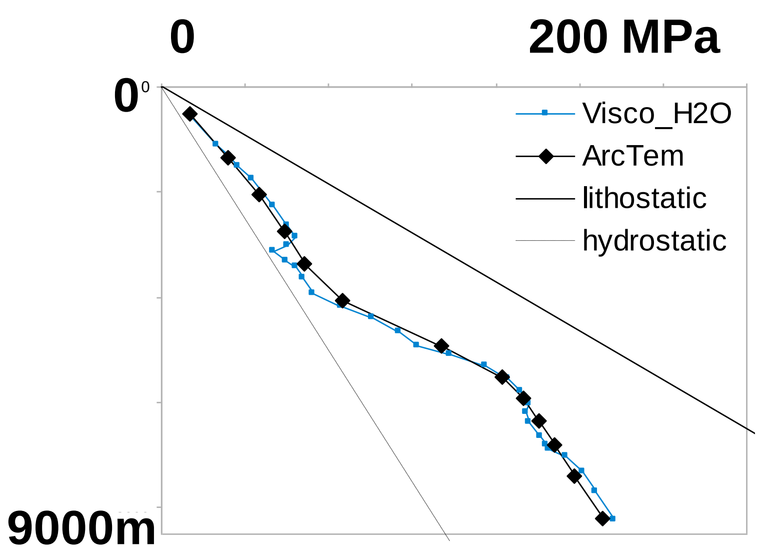




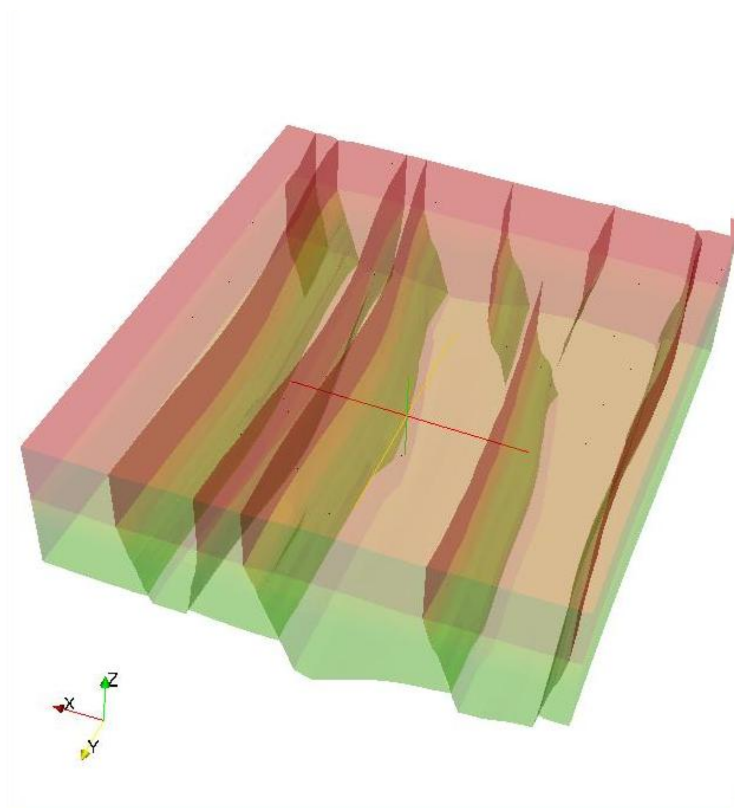
Pressure prediction, fluid flow in the fault blocks

Pressure



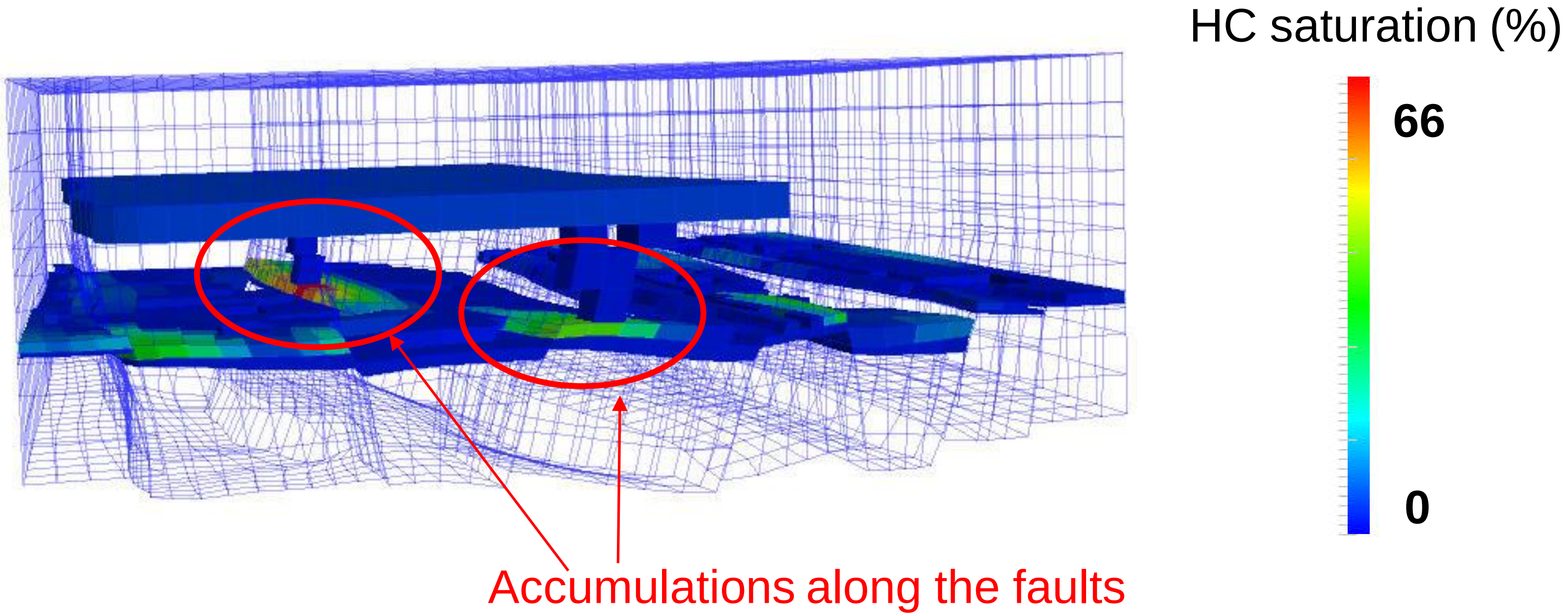


Fluid flow velocity



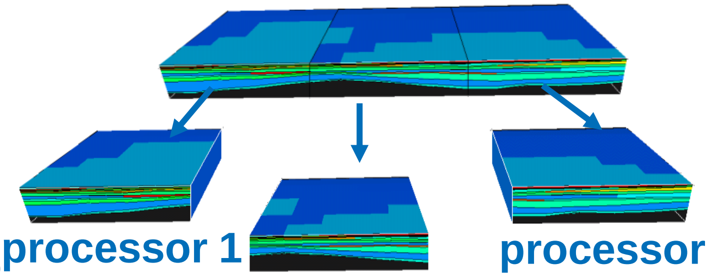
What about migration ?

- Research prototype
  - PhD Thesis of S. Pegaz-Fiornet – 07/2011
  - Tests on the invasion percolation algorithm for unstructured mesh

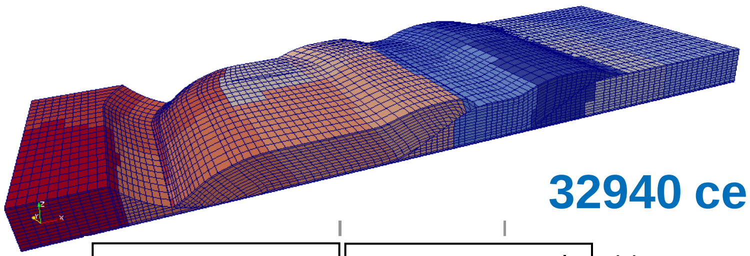


What about CPU performance ?

- Dynamic domain decomposition adapted for non-conformities
- Taking into account topologic modifications of the volumetric mesh through time



classical parallelization



32940 cells

Processors	Time(s)	solver (s)	evt (s)	speed-up
1	115,7	17,7	10,8	1,0
2	92,6	13,3	24,6	1,3
4	48,4	5,6	14,2	2,4
8	31,8	2,3	11,7	3,6
12	26,8	1,8	11,0	4,3
16	27,1	1,7	11,9	4,3
24	21,3	1,3	10,3	5,4
32	21,2	1,3	11,2	5,5
48	19,3	1,1	11,2	6,0
64	19,4	1,1	12,2	6,0

Conclusions

- Next generation of basin modeling is on its way
  - a more realistic description of fault network
  - increased possibilities for the hydraulic behavior of faults
  - fluid flow coupled with compaction and heat transfers already operational
  - with CPU performance concern

Thank you for your attention