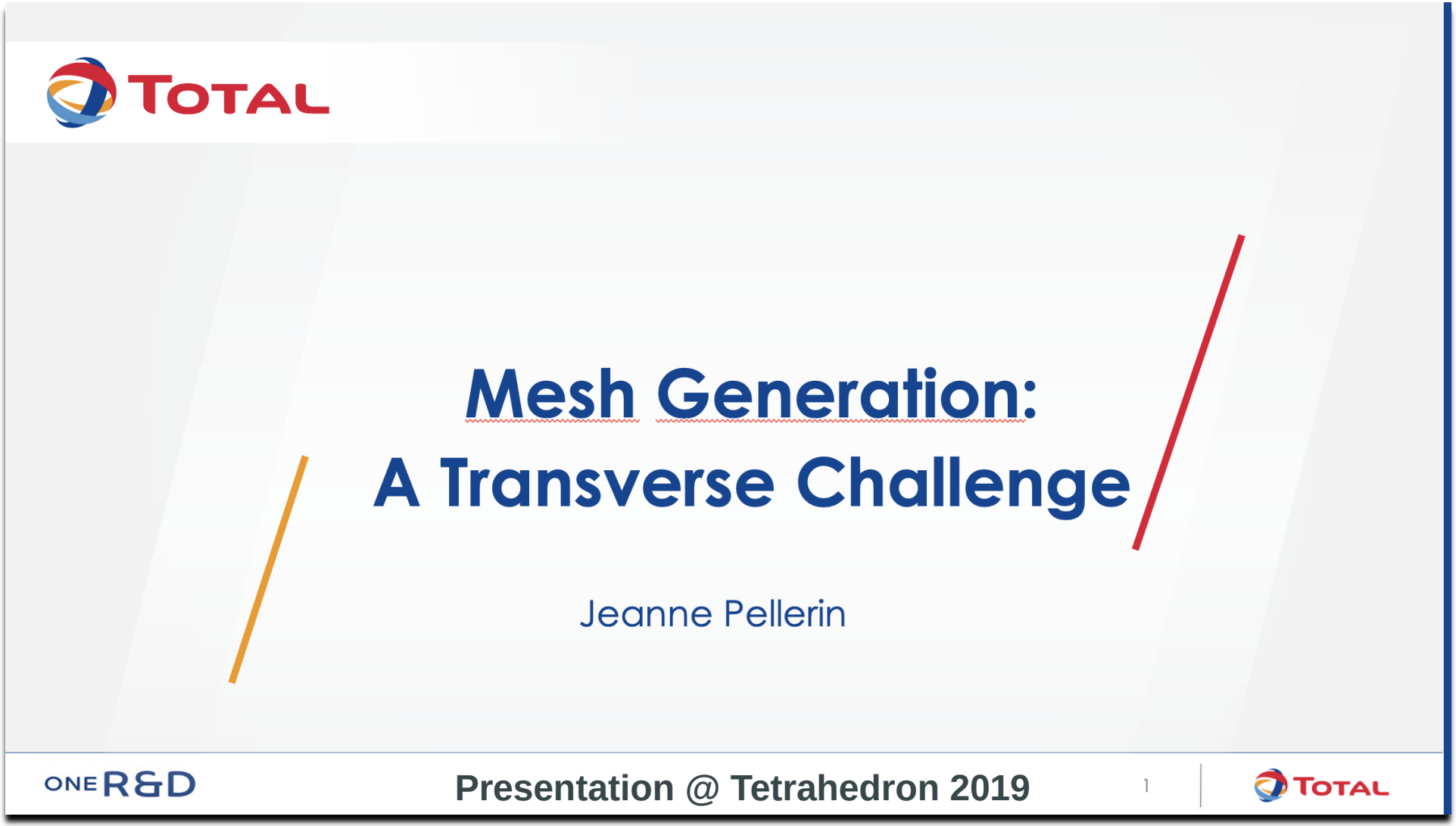
Meshing for geological process simulations: Where are we?

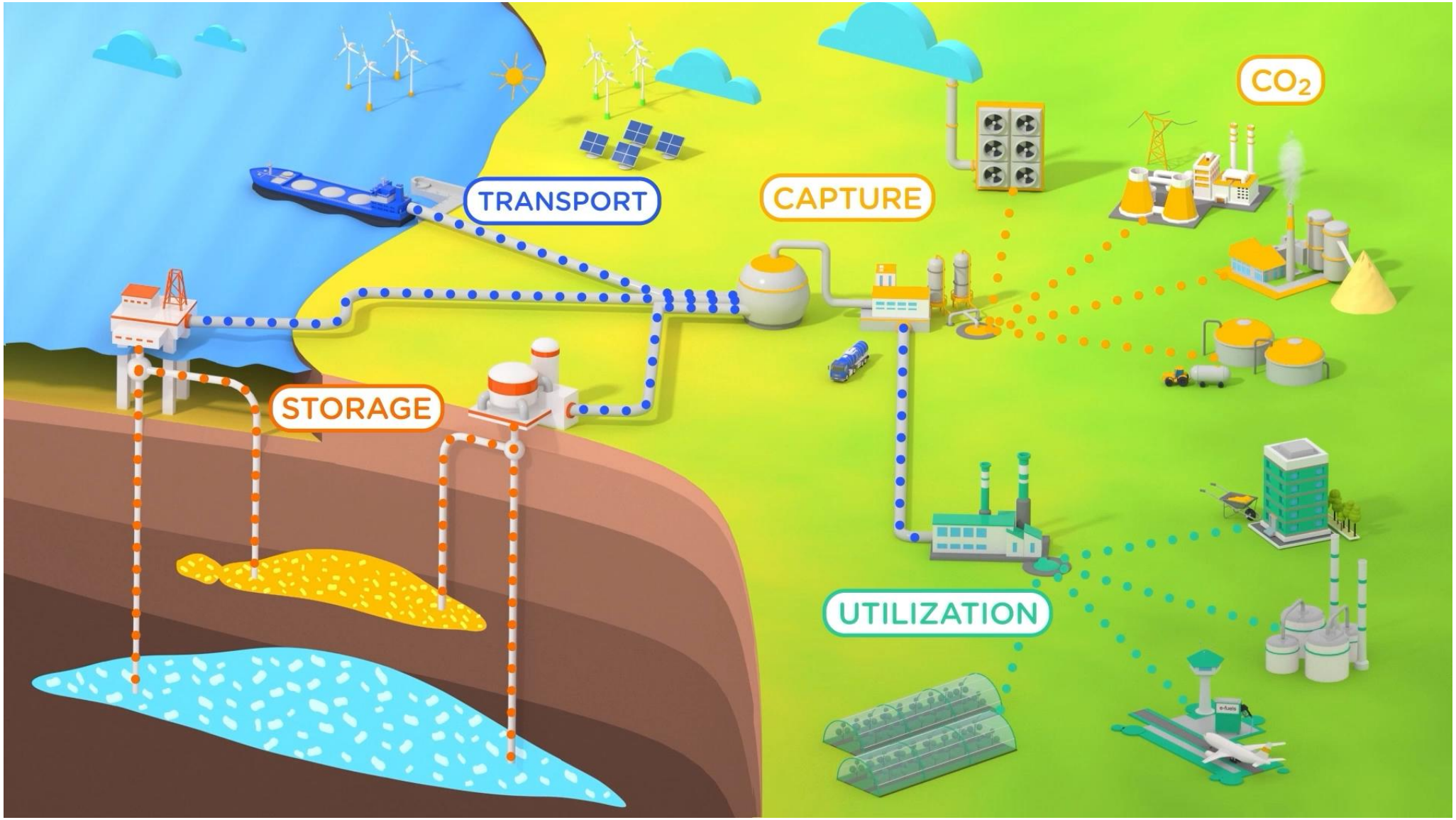
Capucine Legentil – Post Doc TotalEnergies

Jeanne Pellerin - TotalEnergies

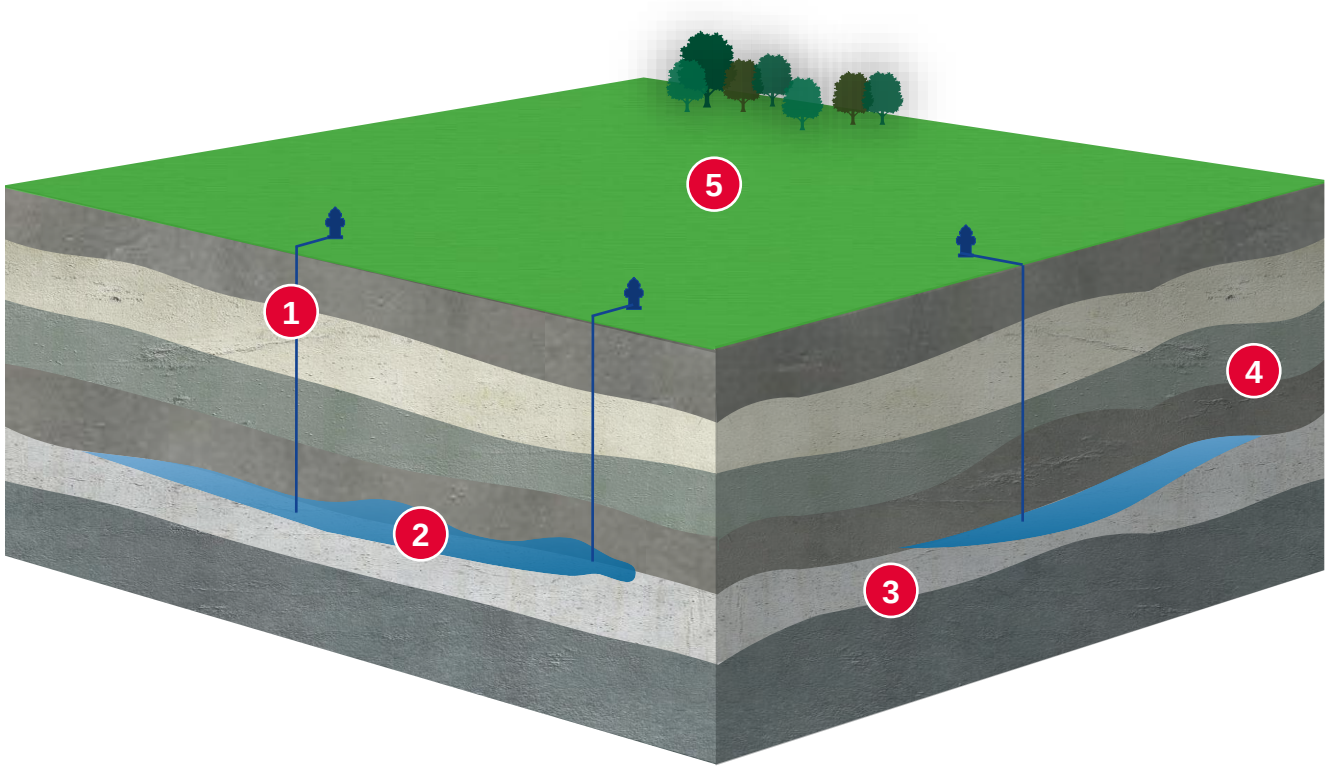
What happened since 2019?



CO2 geological storage



Challenges of CO2 geological storage



1. Well integrity/injectivity
2. Pressure/Stress change
   Fault Activation
3. CO_2 transport & trapping
4. Seal integrity
5. Surface deformation
   Seismicity

Challenges

MULTIPHYSICS	GEOMECHANICS + FLOW
VERY LARGE SCALES	98% STORAGE IN AQUIFERS
LONG SIMULATION TIME	POST-INJECTION MATTERS

Tools

HPC	SCALABILITY – PORTABILITY 2 EXAFLOPS (2023) SCALABILITY
UNSTRUCTURED MESH	CONSISTENT REPRESENTATION OF GEOLOGICAL FEATURES

GEOS

Fully coupled massively parallel simulator for geological formations

Porous media physics

- Poromechanics
- Flow
- Thermal
- Wells

Structured/Unstructured mesh

HPC

C++ LLNL frameworks

Part of Exascale projet

Open-source

LGPL 2.1

GitHub: GEOS-DEV/**GEOS**

VTK I/Os

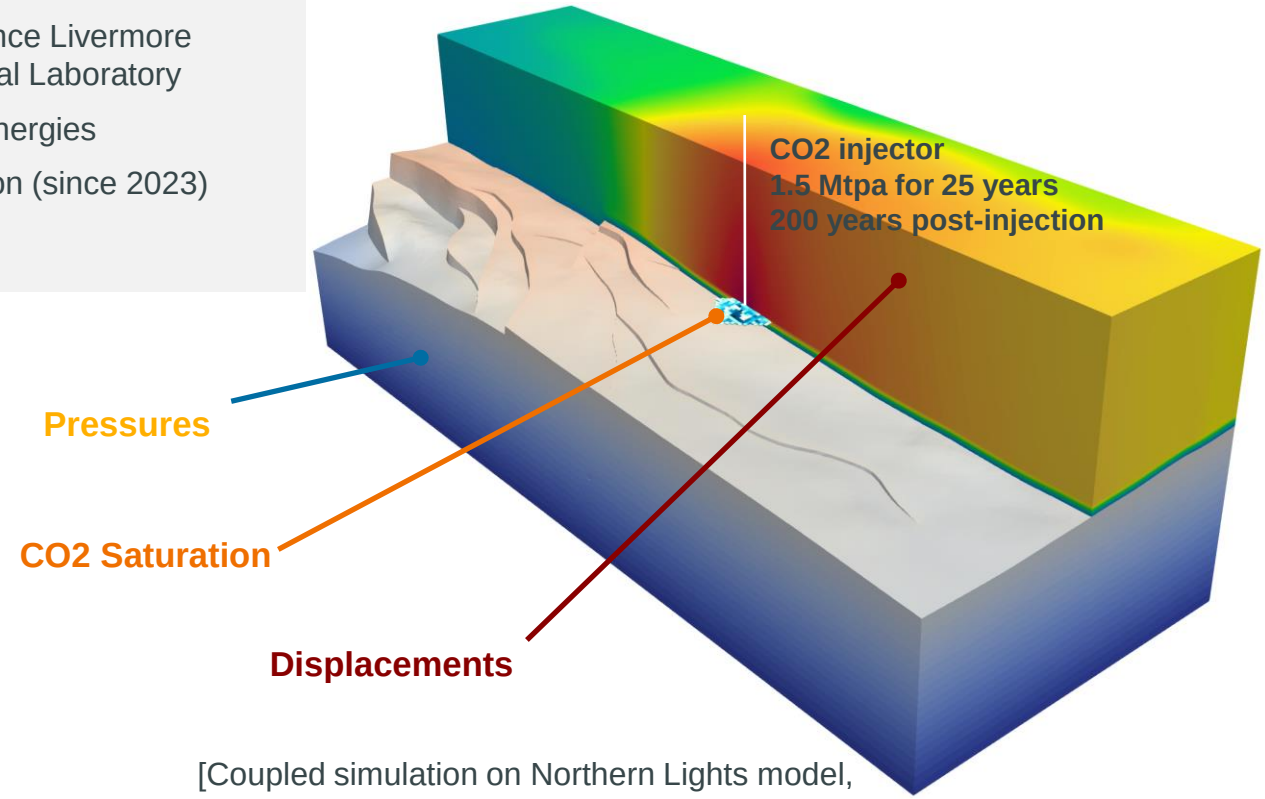
R&D collaboration project

Stanford University

Lawrence Livermore National Laboratory

TotalEnergies

Chevron (since 2023)



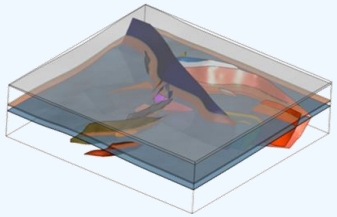
[Coupled simulation on Northern Lights model, Simulations and visuals by TotalEnergies R&D]

Simulation workflow for CO2 injection

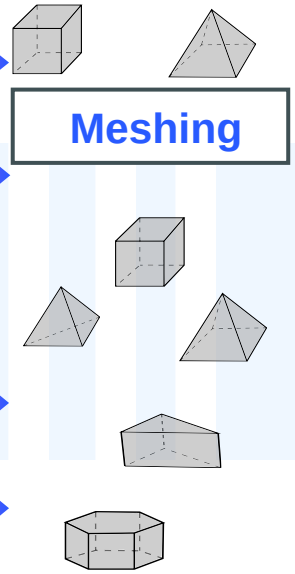
TotalEnergies

Coupled poromechanics - flow
Open-source

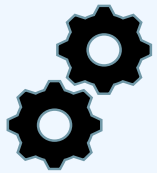
3D model



Meshing



Property modeling



GEOS

Preprocessing

Simulation

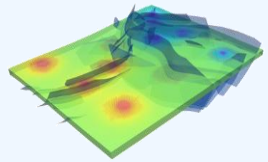
IX

Preprocessing

Intersect

Flow only
Commercial software SLB

Visualization



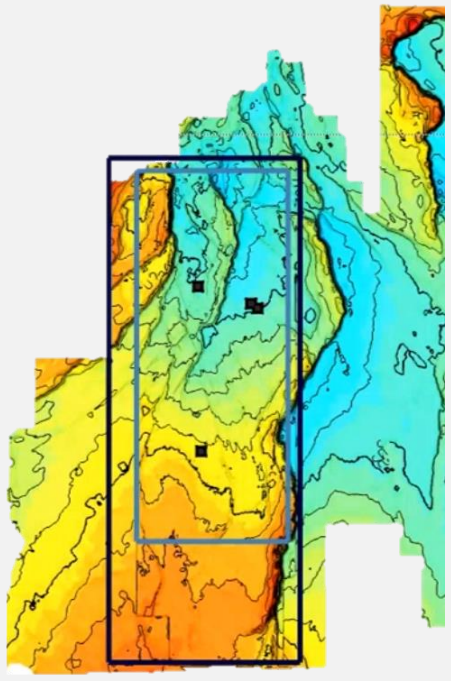
ParaView

Geological surface model building

- Built by geologist from available data using dedicated software
  - Petrel (SLB) - Skua-Gocad (Emerson) - Sismage-CIG (internal – TotalEnergies)

3D model

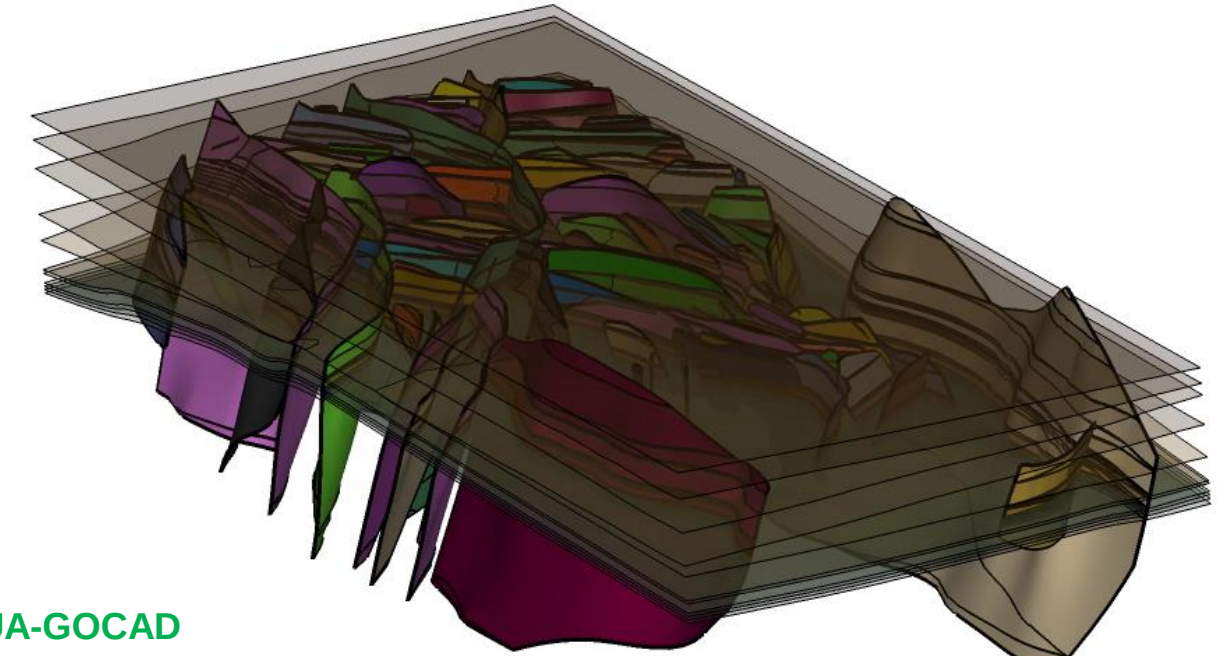
- **Output:** BRep watertight model



Input data

108 faults

12 horizons



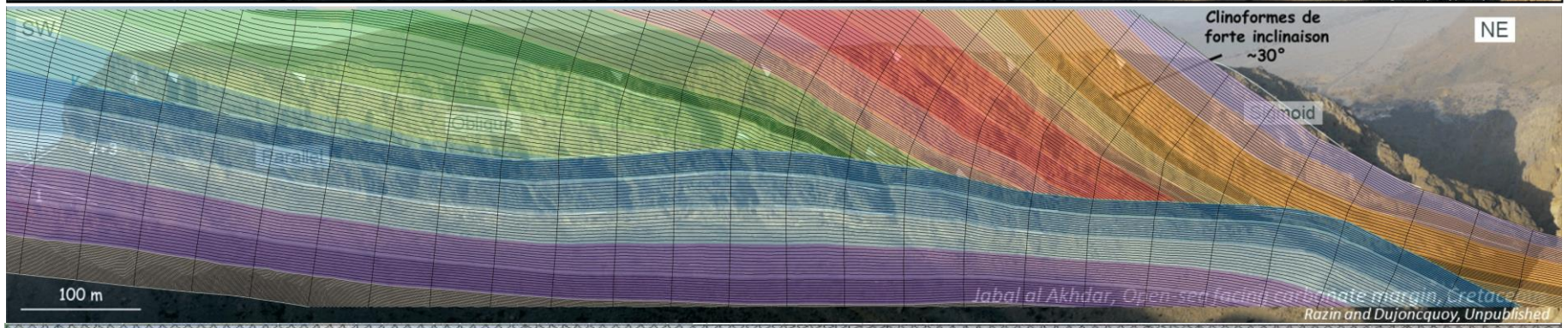
SKUA-GOCAD

[Northern Lights model
Model built by TotalEnergies OneTech]

Meshing geological models for multiphysics simulation
Which mesh?

TotalEnergies

Meshing



Fluid
Flow driven by small scale vertical heterogeneities

➔ **Flat structured cells**

Poromechanics
Larger scale heterogeneities
Model main interface and faults

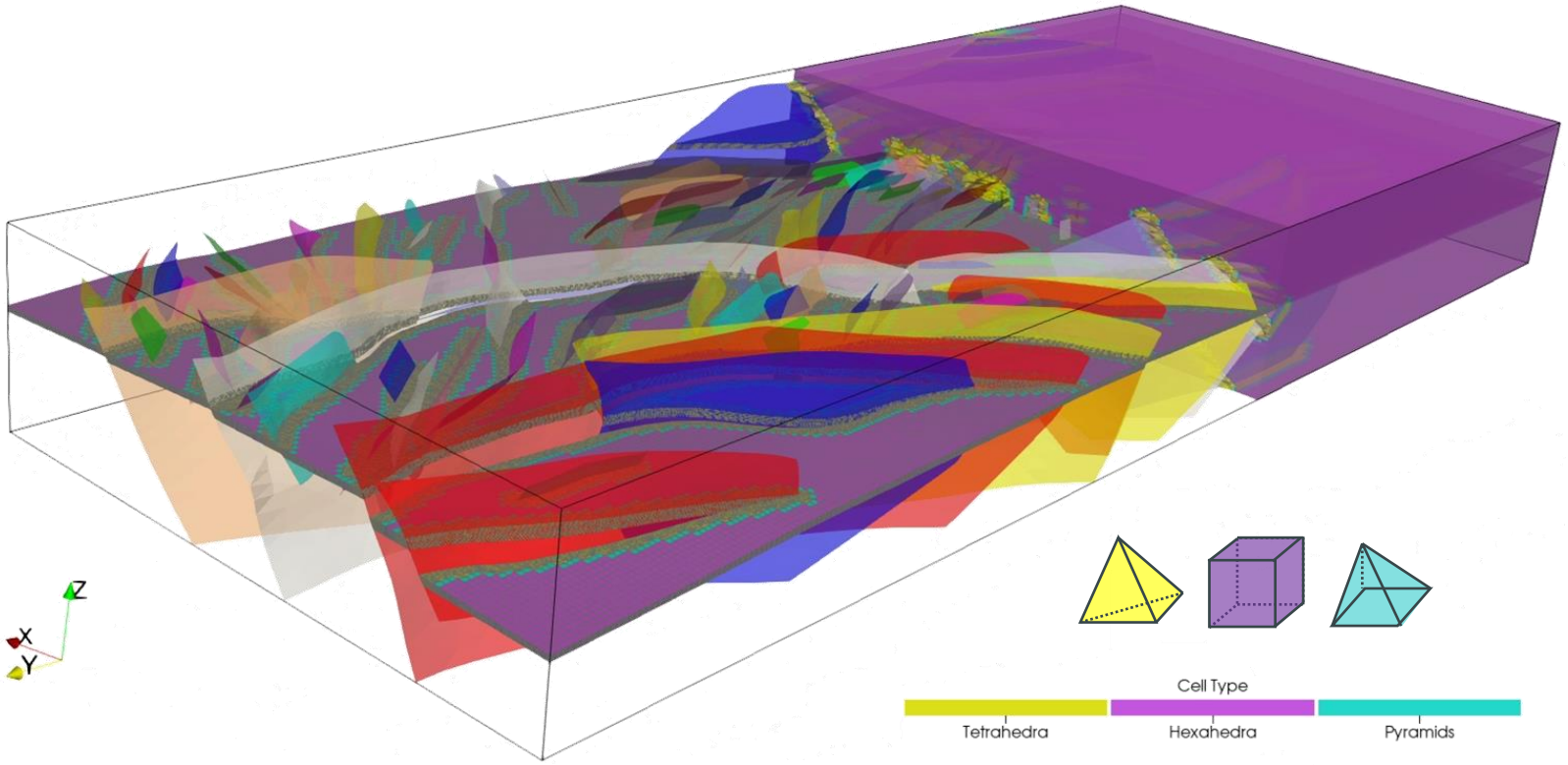
➔ **Tetrahedra**

Hybrid mesh for conformity

TotalEnergies

Meshing

- Extruded quad mesh
- Tetrahedra near subvertical discontinuities (faults)
- Pyramids to ensure conformity
- Constant rock properties (porosity / permeability)
- Real case: geostatistical filling



Hybrid mesh of Northern Lights model generated by TotalEnergies OneTech
Collaboration with Tessael

8.9 million cells: 6.1M tets - 1.8M hex – 1million pyramids

[Visuals by Margaux Raguenel]

Property modeling on unstructured grids

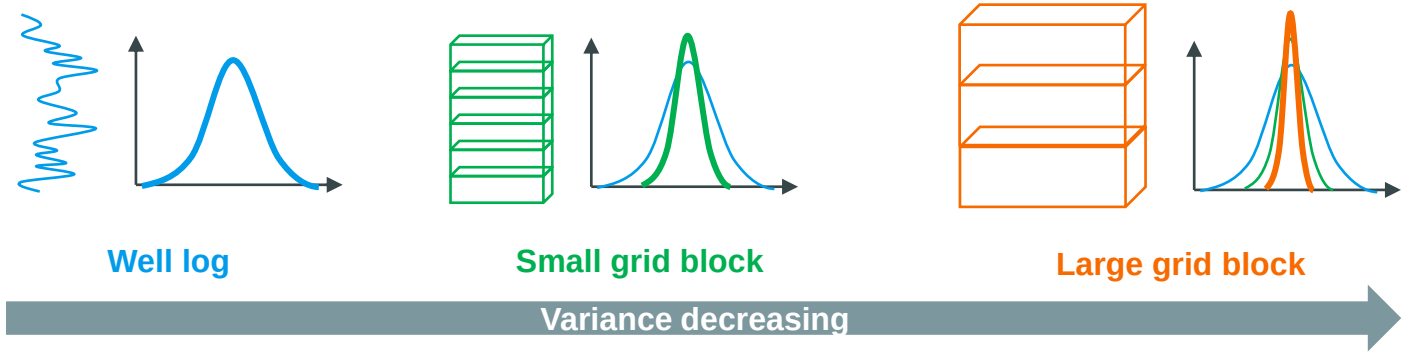
TotalEnergies

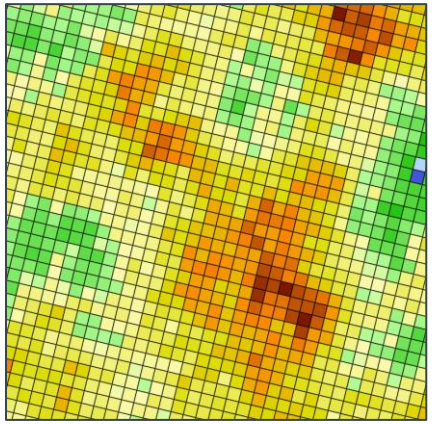
Property modeling

- Rock properties vary (porosity, permeability, other) in each layer

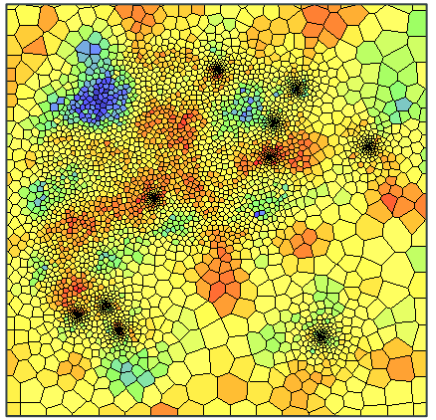
- Objectives:
  - Represent geological features not captured by material interfaces
  - Match available data at wells
  - Consistent with geological implicit rules

- Geostatistics: spatial statistics
  - Point based geostatistics solving SPDE – Average point value in cell





Structured mesh: constant size



Unstructured with size changes

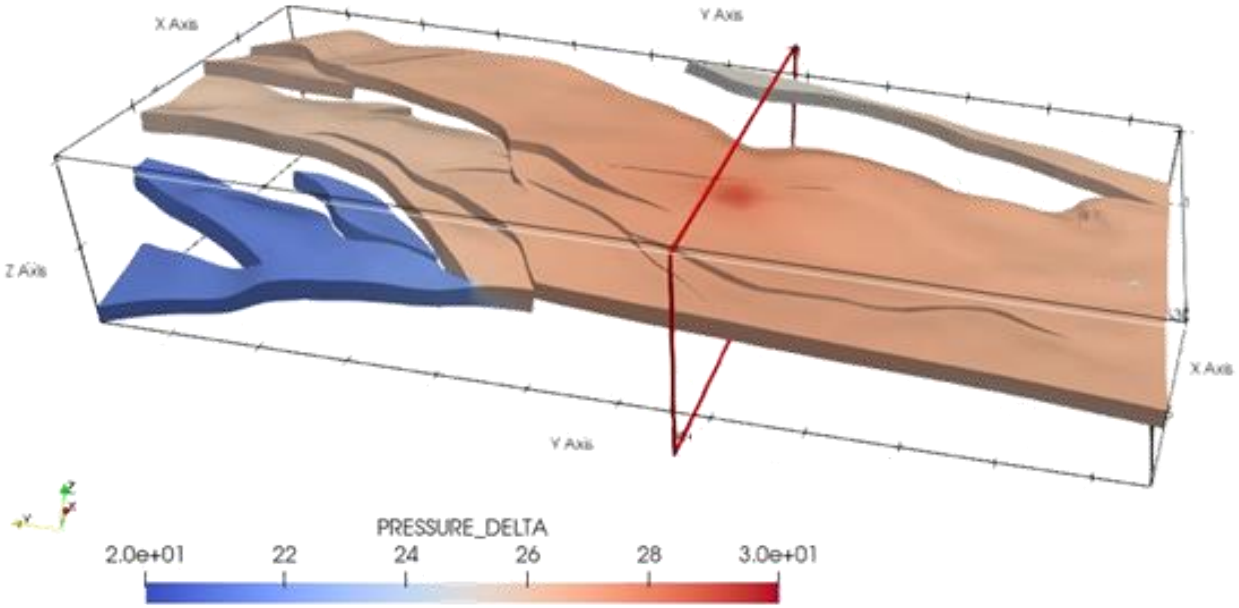
GEOS flow simulation results

Simulation of CO2 injection with GEOS in 1 well for 26 years

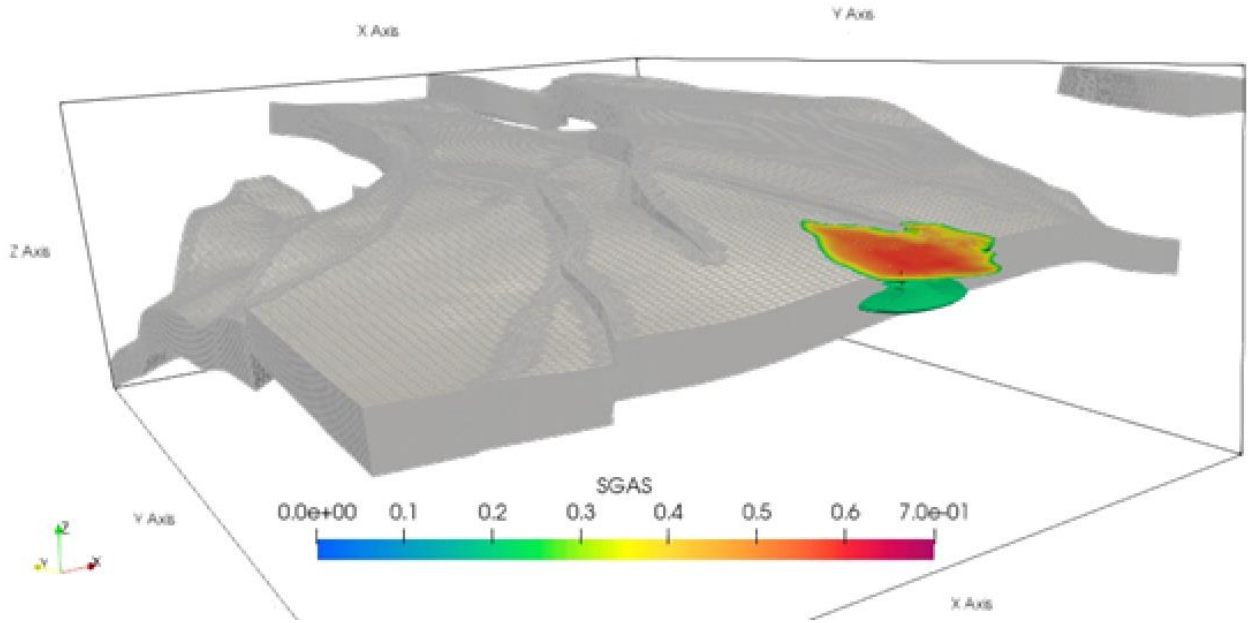
3D results vizualisation with Paraview

Simulation

Visualization



Pressure difference with t = 0

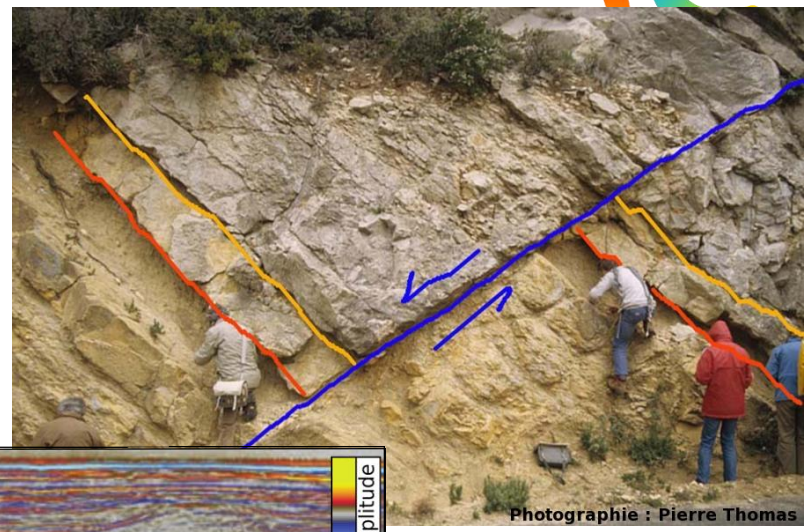


Cross section CO2 plume

[Simulation and visuals by Margaux Raguenel]

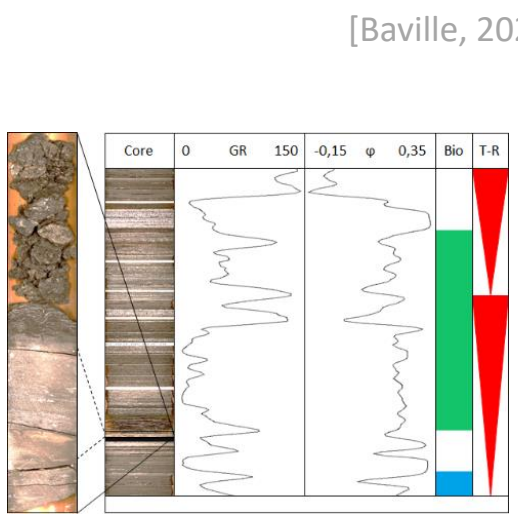
What about geological uncertainties?

[Personal picture]

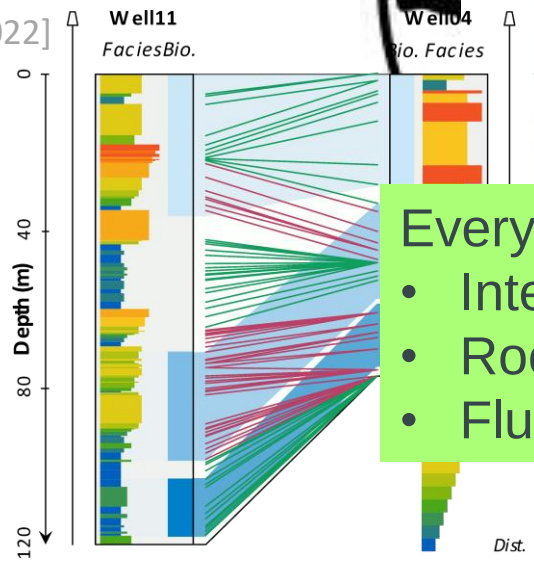


[Planet-terre]

[Baville, 2022]

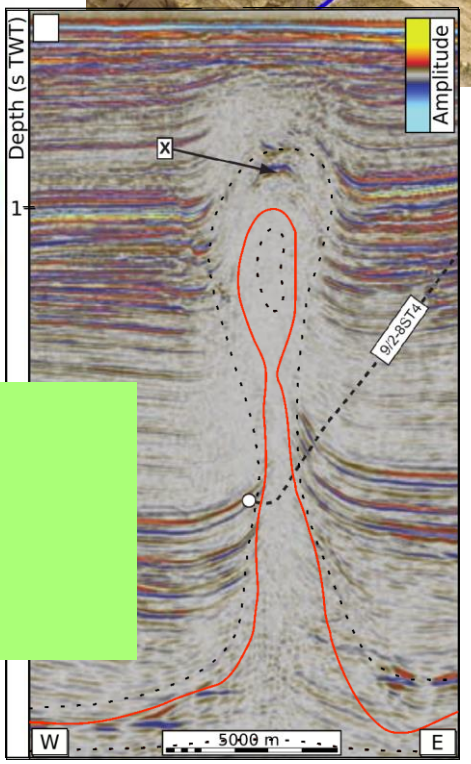


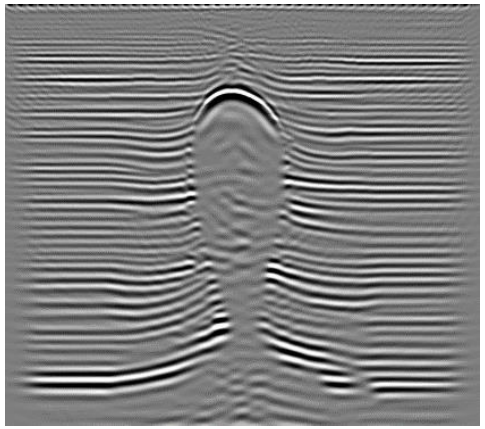
[Data courtesy of Equinor]



Everything is uncertain

- Interface positions
- Rock properties
- Fluid properties



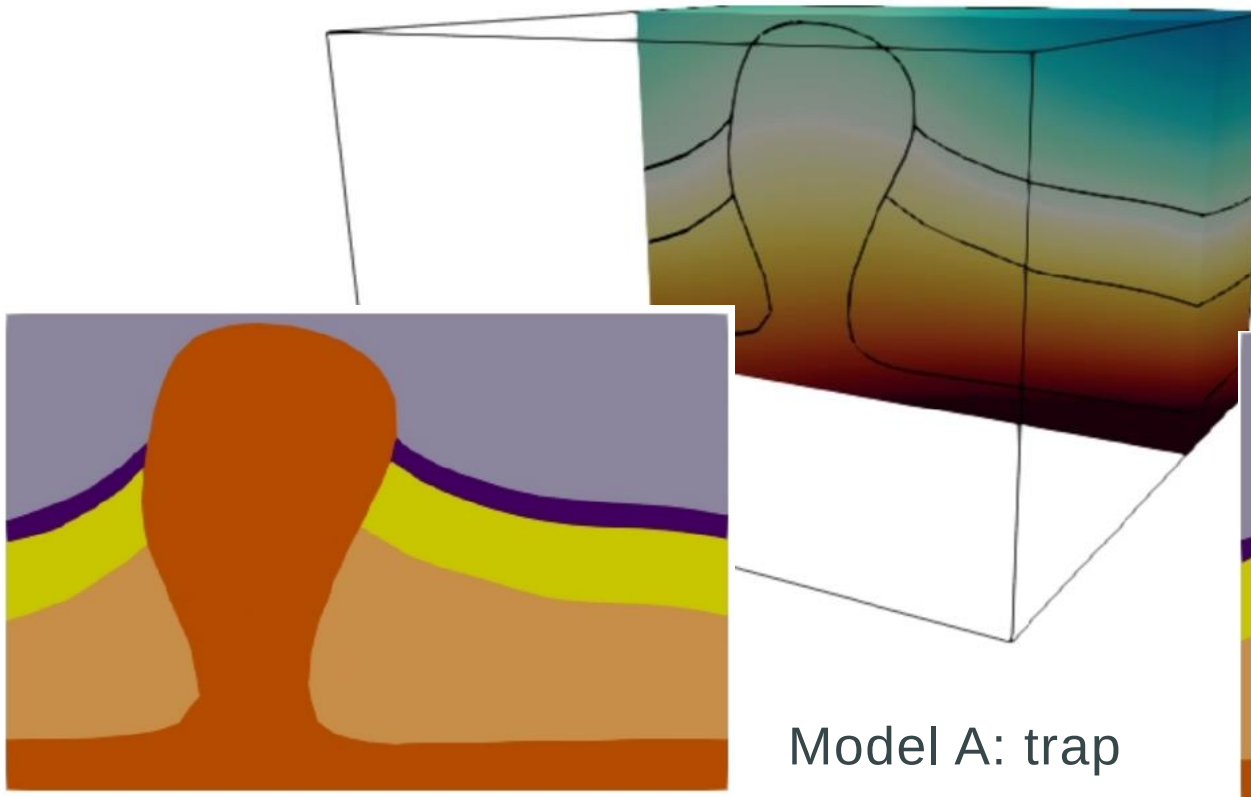


[Clausolles, 2020]

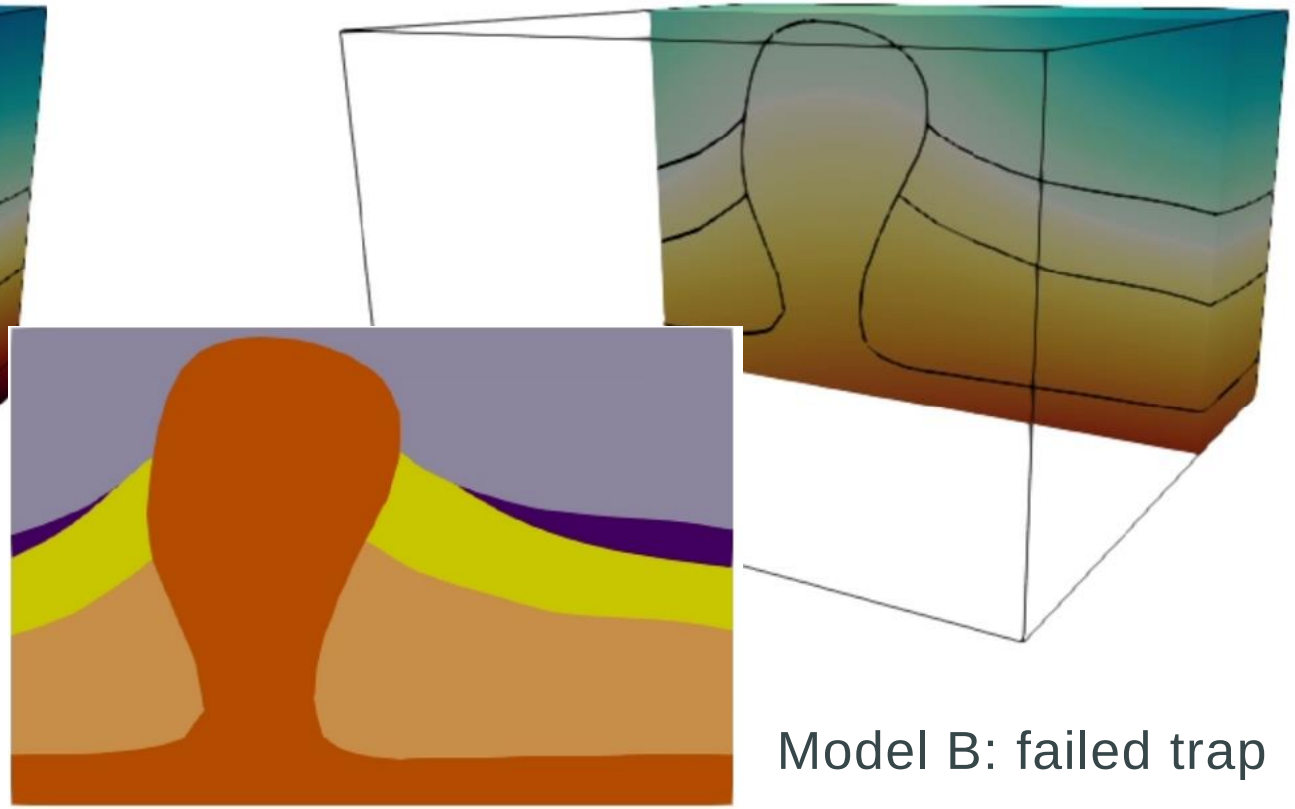
Taking into account uncertainties on interfaces

- Represent interface by scalar field isovalue
- Two equiprobable models
  - Geometry of the purple layer (low permeability caprock) changes

Color	Geological Formation	Lithology	Porosity	Permeability (m^2)
	Overburden	Limestone	0.2	1e-14 (10 mD)
	Reservoir	Sandstone	0.2	1e-11 (10 D)
	Underburden	Limestone	0.2	1e-14 (10 mD)
	Salt geobody	Halite	0.1	1e-18 (10 μD)
	Inserted layer			
	Cap rock	Shale	0.1	1e-16 (0.1 mD)



Model A: trap

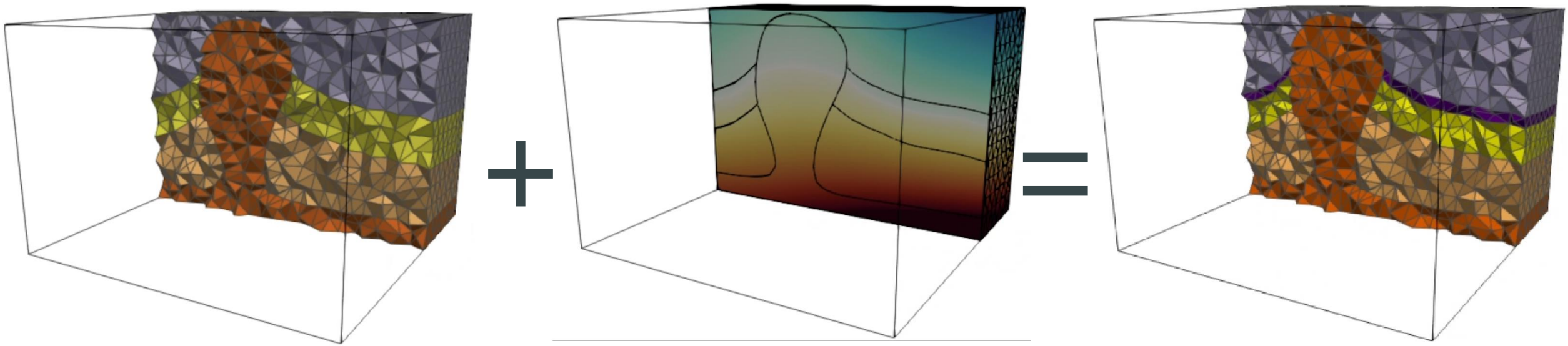


Model B: failed trap

3D Meshing

- Tetrahedral mesh to capture complex geometries

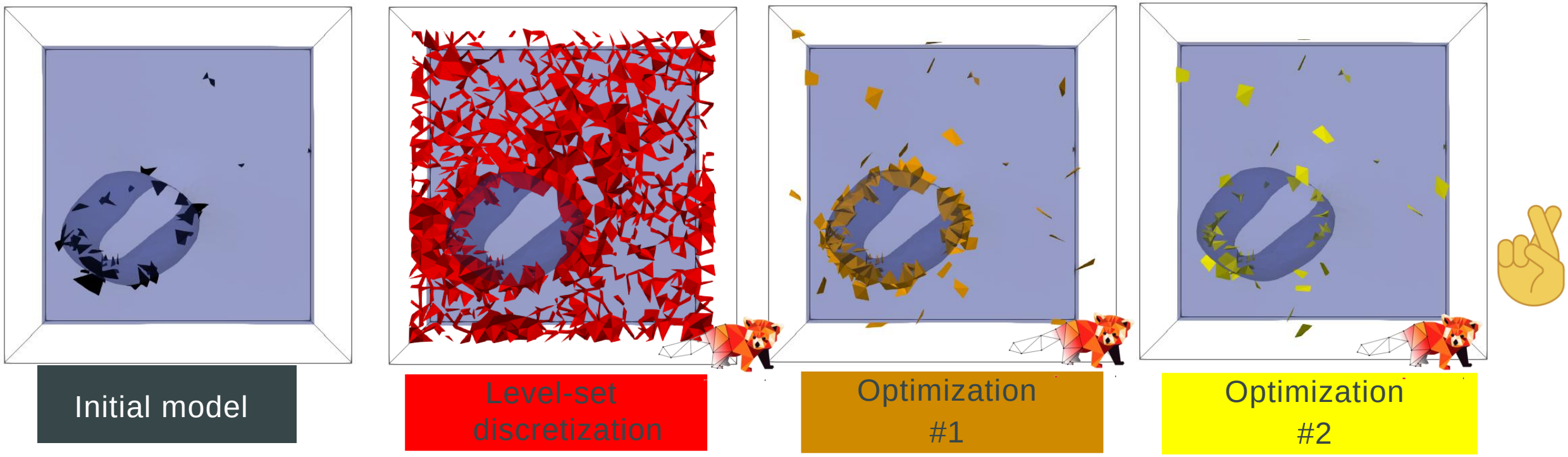
- Use Mmg to insert level-set in tetrahedral mesh
  - Restrict mesh modification to a subpart of the model



Meshing to run simulations with GEOS

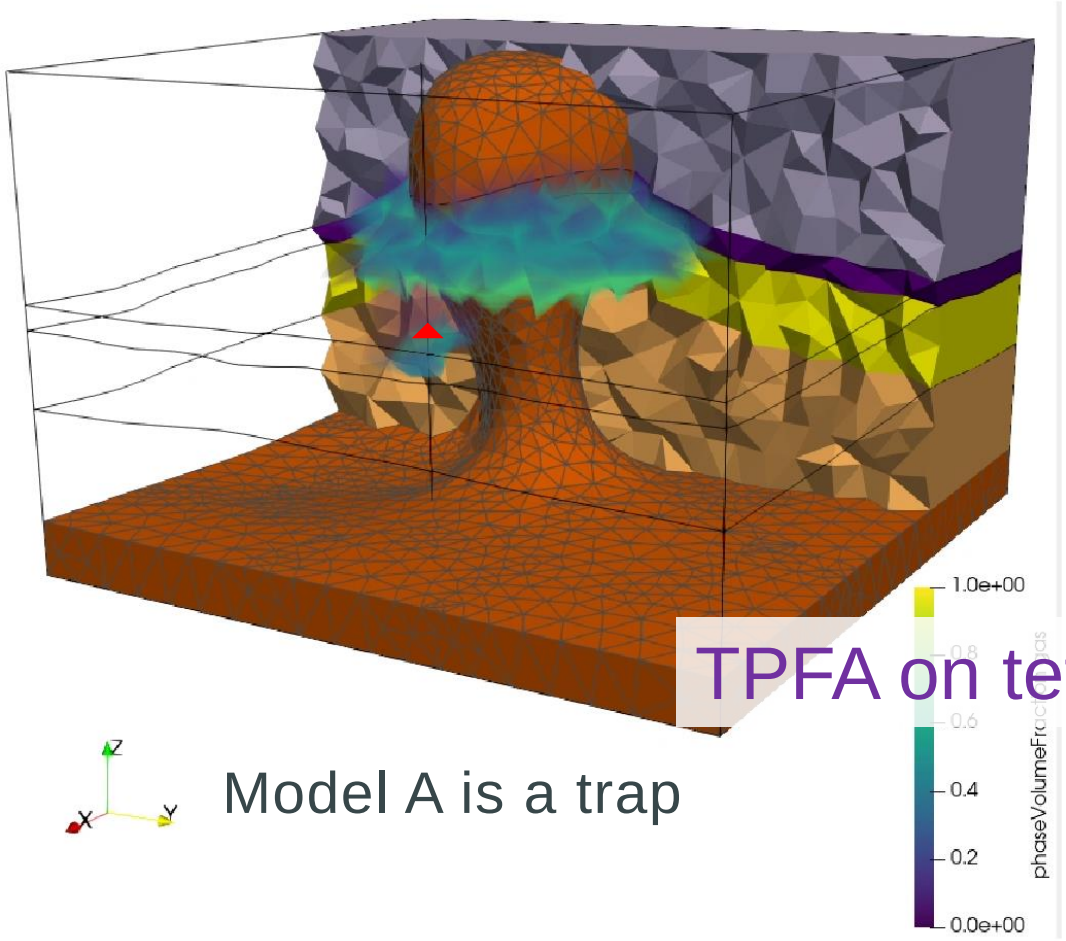
- Objective: CO2 injection with GEOS – 1 well – 3 years

- No information available yet for mesh quality in GEOS
- A priori mesh quality: inscribed sphere radius



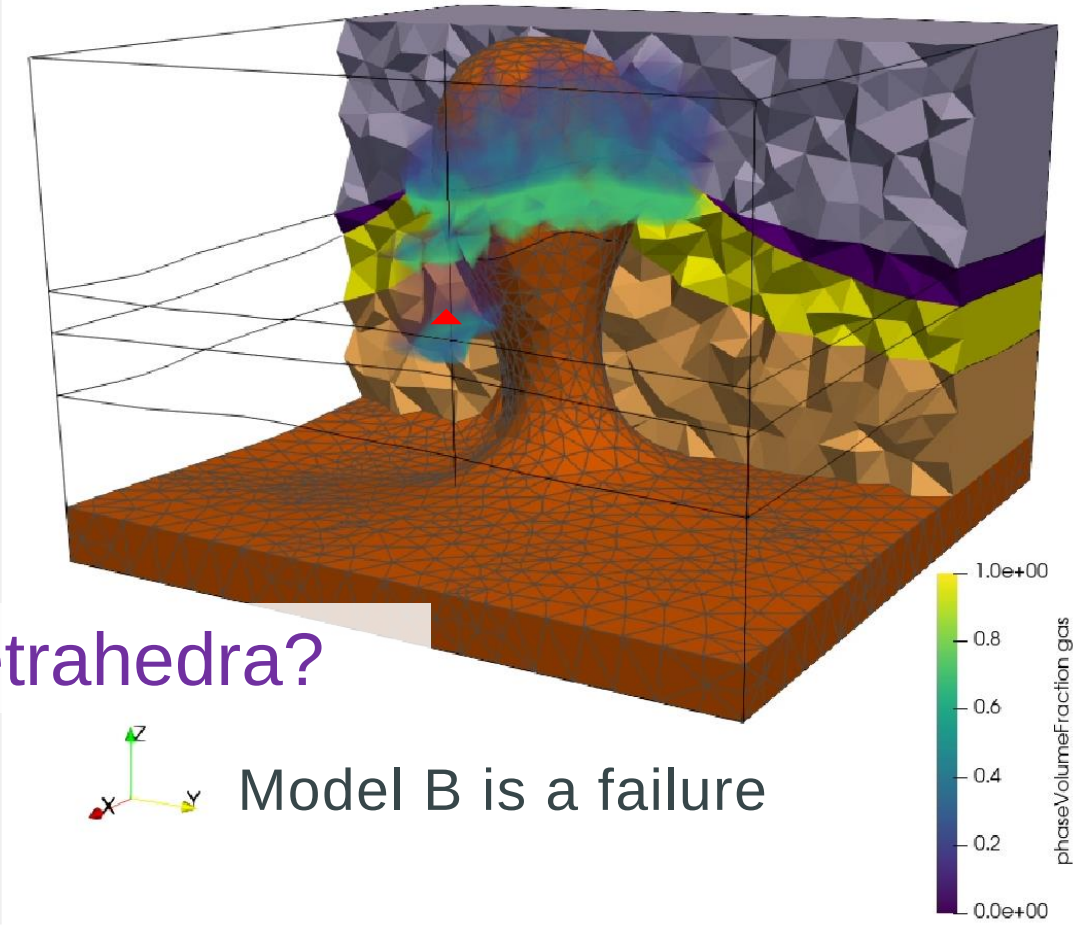
Top view of bad tetrahera through steps

Meshing for simulation
CO_2 Injection with GEOS – 3 years



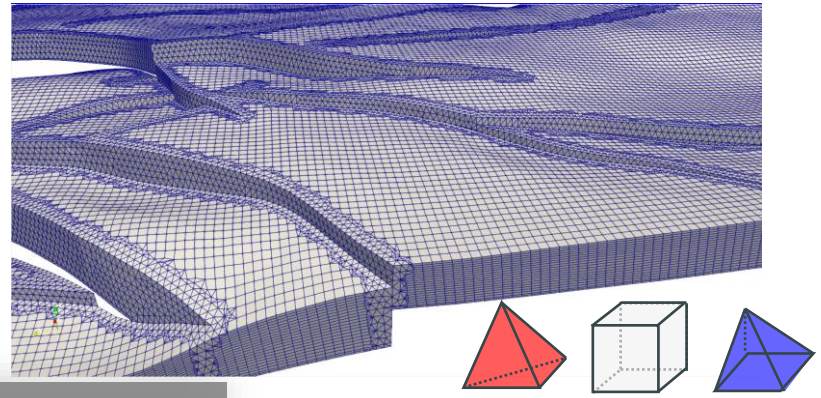
Model A is a trap

TPFA on tetrahedra?



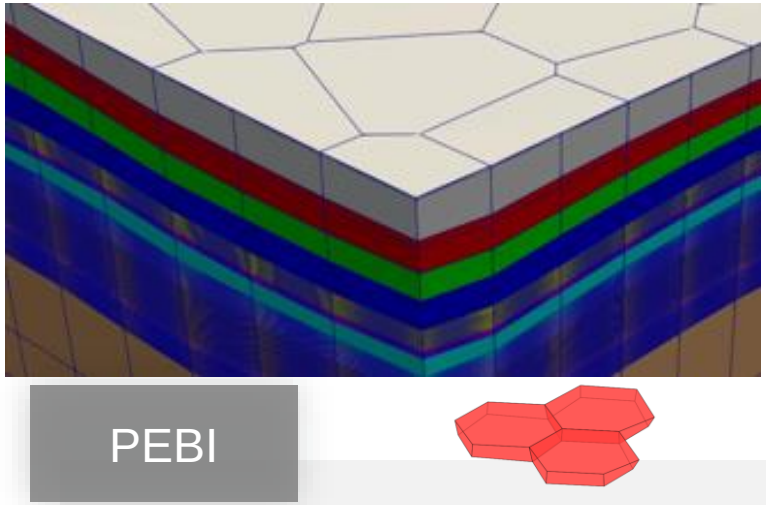
Model B is a failure

Does GEOS ideal mesh exist?



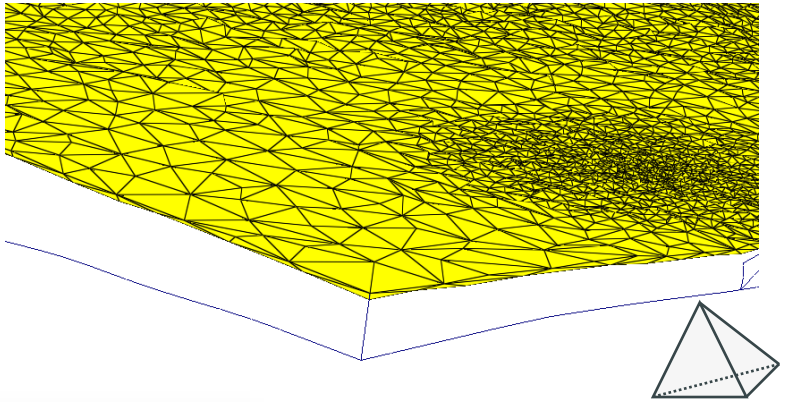
Hybrid

- Good properties of extruded hexahedra
- Bad properties of tetrahedra for capturing thin layers and for TPFA simulations
- Conformity thanks to tetrahedra



PEBI

- Extruded 2D Voronoi diagram
- Refinement flexibiltiy
- Very good properties for flow simulations (TPFA)
- Not conformal on faults
- No mechanics



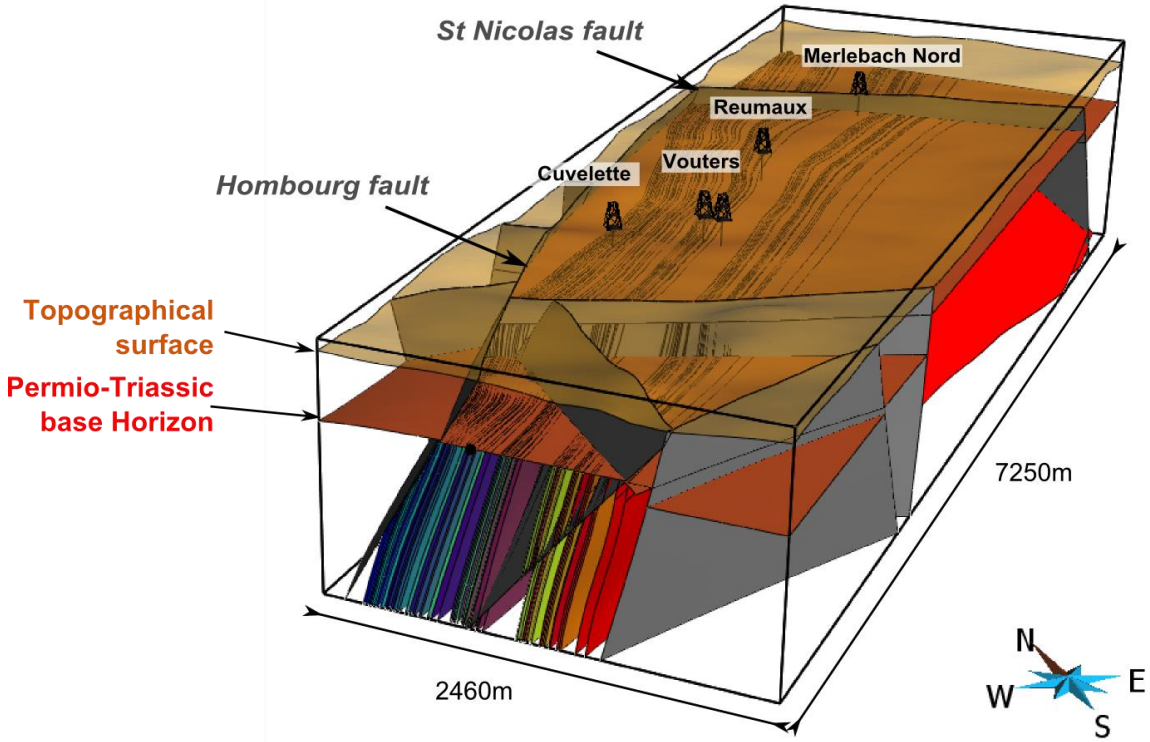
Tetrahedra

- Easiest to generate
- Cell resolution, orientation and shape can be adapted
- Bad representation of geological layers and wells
- Bad properties for flow simulation in porous media (TPFA and other schemes)

Does GEOS ideal mesh exist?

Meshing dream

- Good quality
- Good quality for FEM, FVM, VEM
- 100% conformal
- Aligned on all geological boundaries



Can one mesh rule them all (numerical schemes)?

Can this mesh be generated for geological models?

Can this mesh be modified when model is modified?

Can this mesh be optimized for a dedicated quality metric?

[From Tetrahedron 2019 presentation
Non-watertight model to be meshed
Collon et al., 2015]

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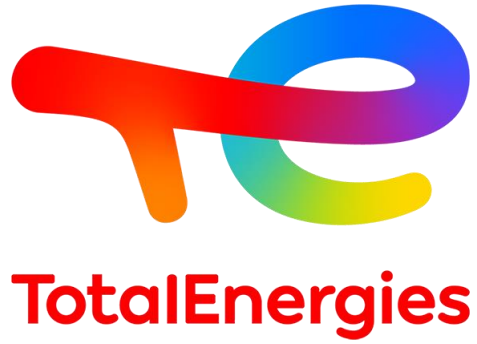

Merci.