Balanced Restoration of Geological Volumes with Relaxed Meshing Constraints*

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Abstract

Balanced restoration aims at unfolding and unfaulting complex deformed structures by iteratively removing deformations caused by successive tectonic events, to retrieve the depositional state of the model. Restoration then helps understanding a geodynamic scenario, reduce structural uncertainties by testing the consistency of the structural model, and, given a correct mechanical behavior law, evaluate retro-deformation.

An elastic finite element model can be used to solve restoration problems by setting displacement boundary conditions on the top horizon, supposedly flat at the deposition time step; fixing some pin zones (typically, it can be a pin point, a pin line and/or/ a pin wall), and defining contacts between the fault foot wall and hanging wall. This method is generally applied on a tetrahedral mesh conformable to both faults and horizons, for it provides accurate representations even in complex structural settings. However, conforming to stratigraphic surfaces, including erosive and onlaping surfaces, drastically increases the number of mesh elements, and possibly reduces mesh quality, causing issues during finite element computations. One consequence is that mesh limitations are the main bottleneck to apply finite-element-based restoration to actual settings. To face this problem, we propose to represent horizons as a property of the tetrahedral model, and to transfer the associated boundary conditions onto the neighboring nodes of the mesh, using an "implicit" approach. New boundary conditions are defined to this new type of horizon, and a hyper-elastic rheology is set to emulate the absence of the restored layers. The proposed method provides results comparable to those of the explicit technique, at much less effort. Also, the implicit method provides a convenient way to handle unconformities in restoration, both for eroded surfaces, and on baselap layer geometries.

Balanced restoration of geological volumes using relaxed meshing constraints

AAPG annual meeting 2009

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CRPG
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Structural restoration

- Aim: unfold and unfault the structural model to the deposition state
  - [Chamberlin, 1910]: cross sections
  - Maps
  - Multi-surfaces

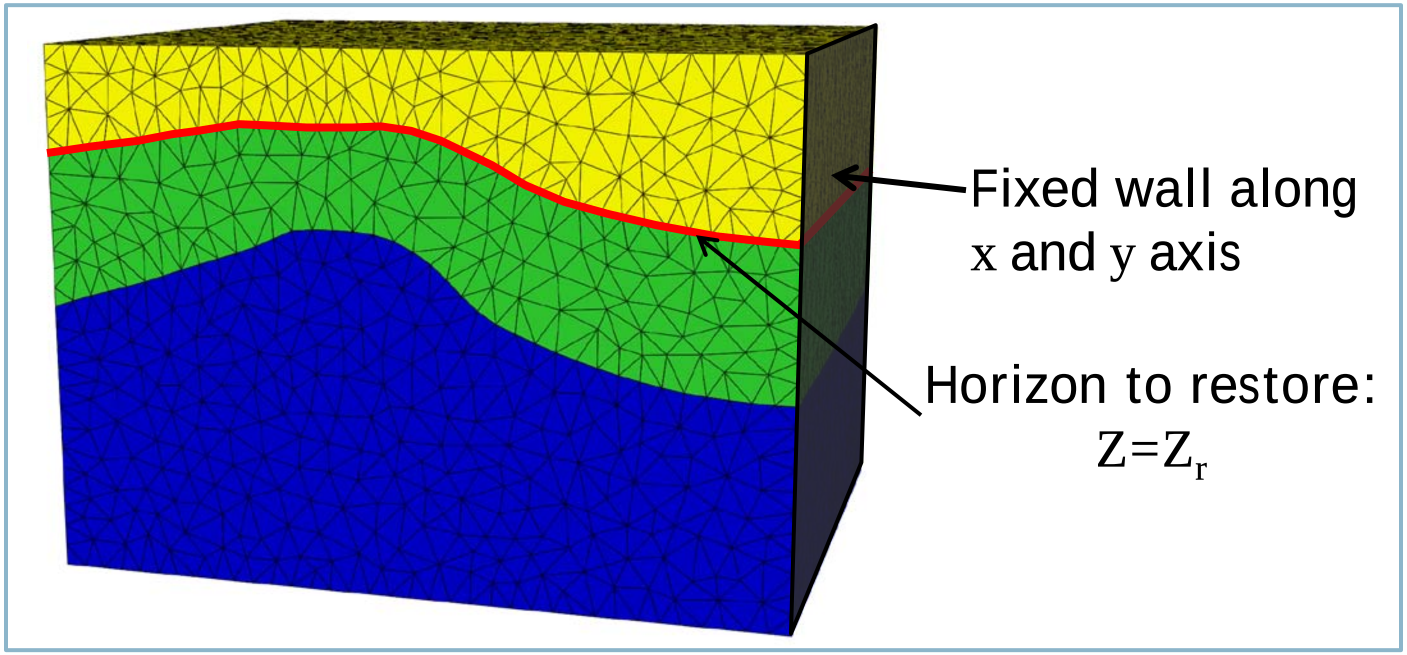
- Uses:
  - Test the consistency of the model
  - Quantify the retrodeformations
  - Predict strong strains zones
  - Process-based simulations

Volume restoration

- Geomechanical approach

[Muron and Mallet, 2003; De Santi et al. 2003; Moretti et al., 2006; Maerten et al., 2006]

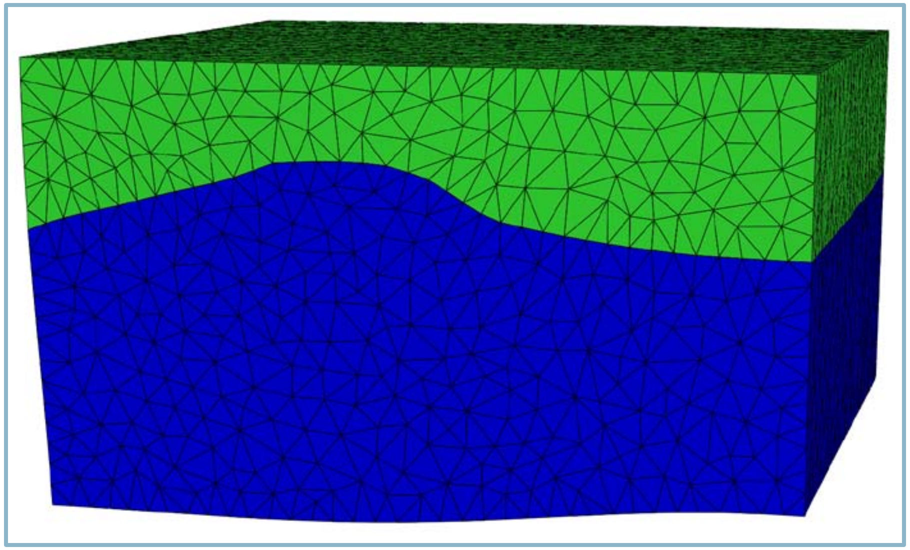
  - Elastic linear model
  - Boundary conditions



Volume restoration

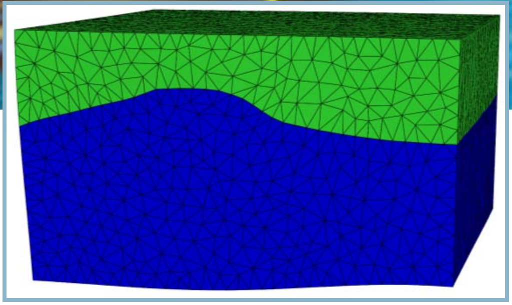
- Finite element based computation

[Muron et Mallet, 2003; Moretti et al., 2006]



RestorationLab,
Muron, 2005

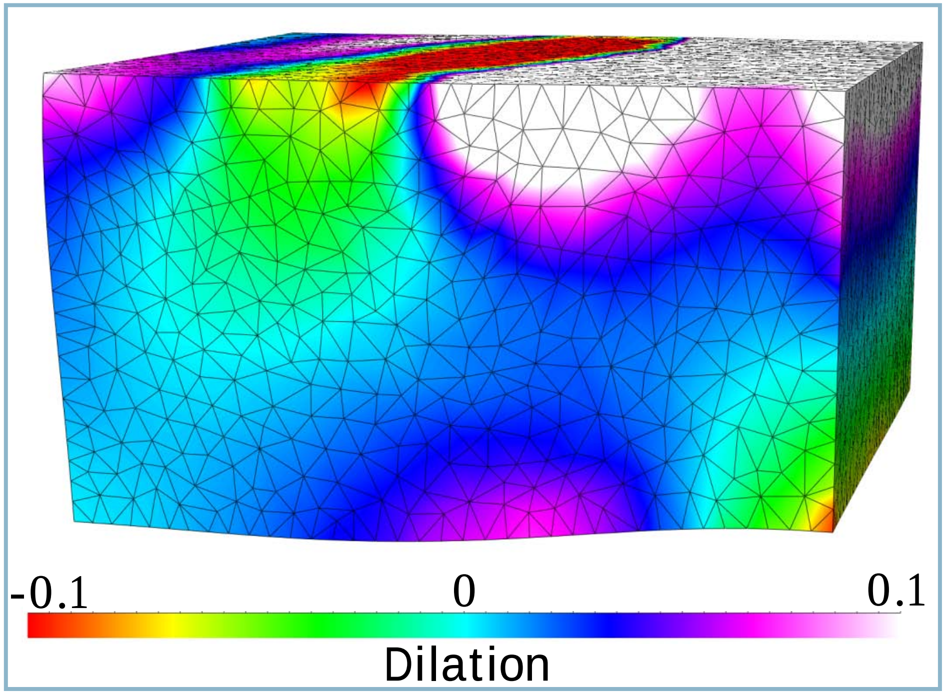
Volume restoration

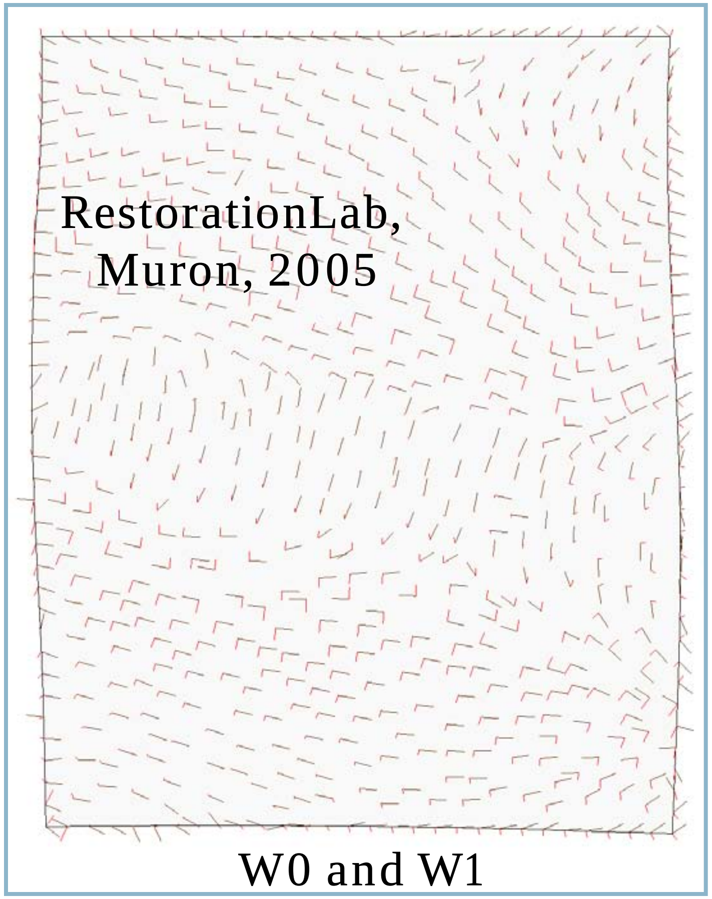


- Finite element based computation

[Muron et Mallet, 2003; Moretti et al., 2006]

- Strain computation

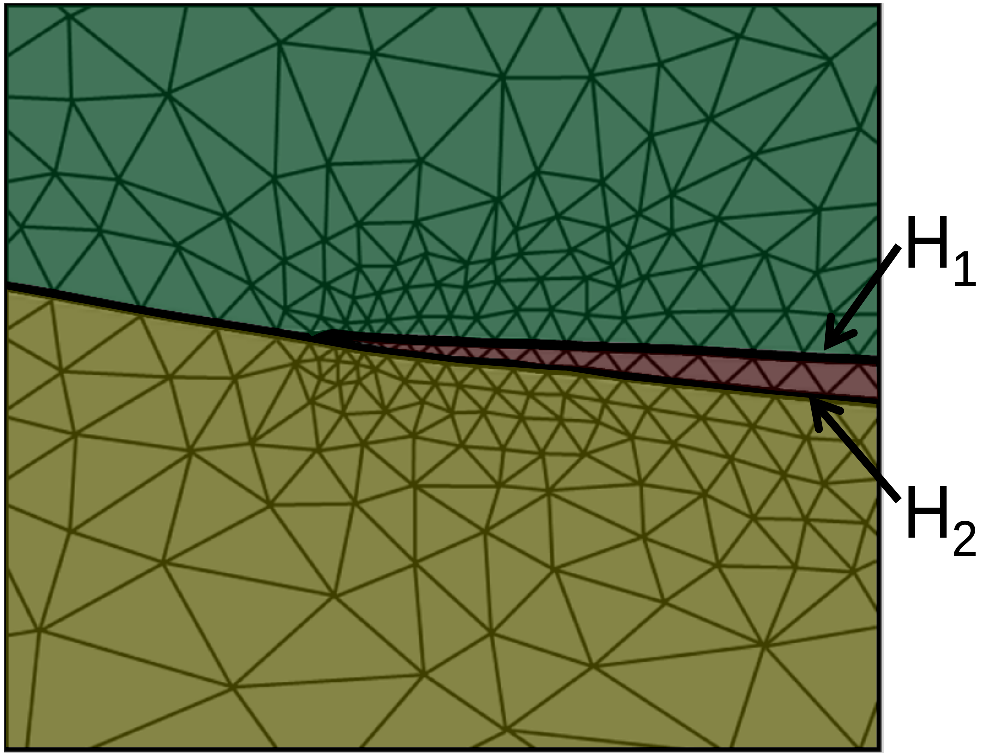




Applicability limits

- Mesh conformable to both faults and horizons
  - Time consuming generation
  - Hardly applicable in case of unconformities or pinch-out

→Limited applicability



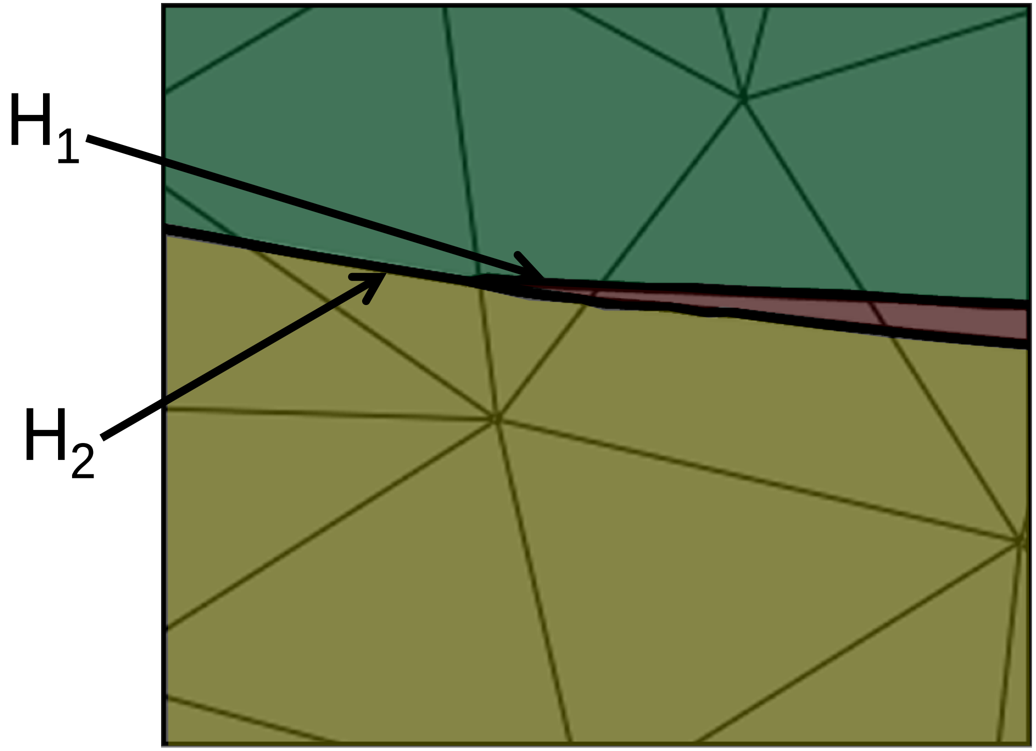
Implicit approach

- Horizons as iso-surfaces of a scalar field

[Moyen et al., 2004, Frank et al., 2007, Caumon et al., 2007,2008,2009]

- Easy structural model building

→Easy mesh generation



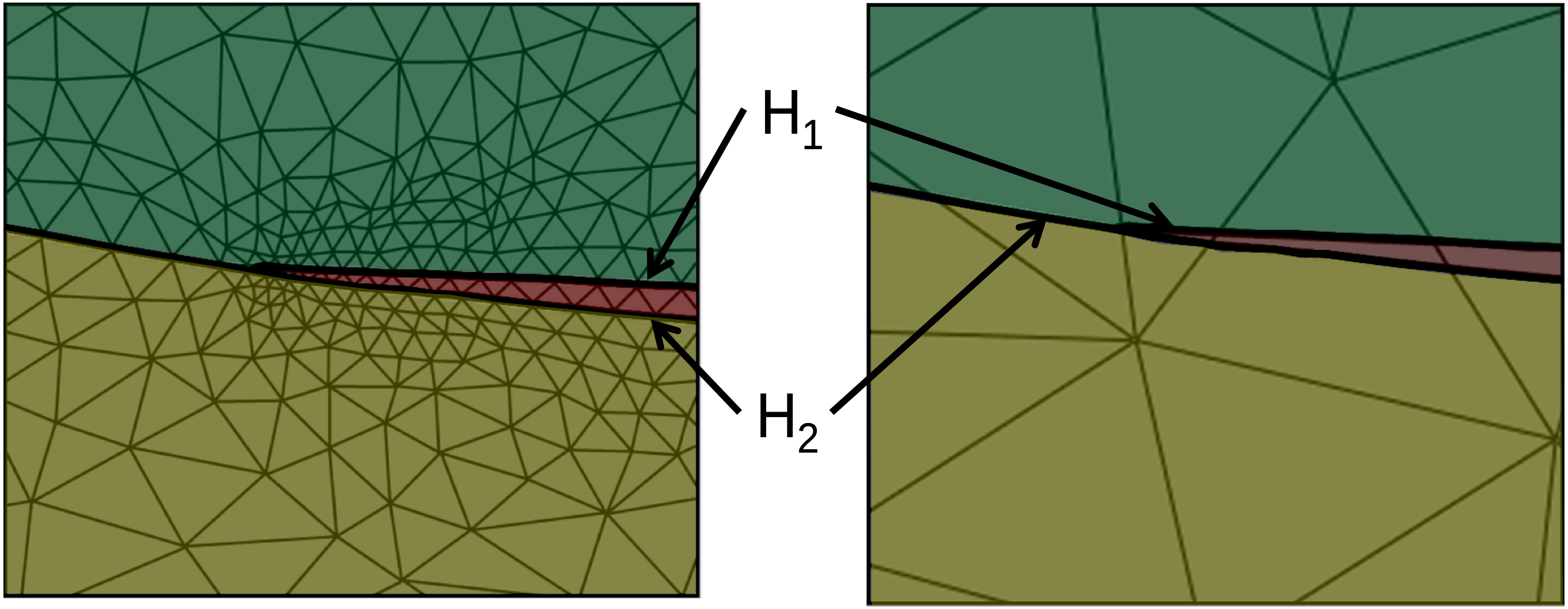
Implicit approach

- Horizons as iso-surfaces of a scalar field

[Moyen et al., 2004, Frank et al., 2007, Caumon et al., 2007,2008,2009]

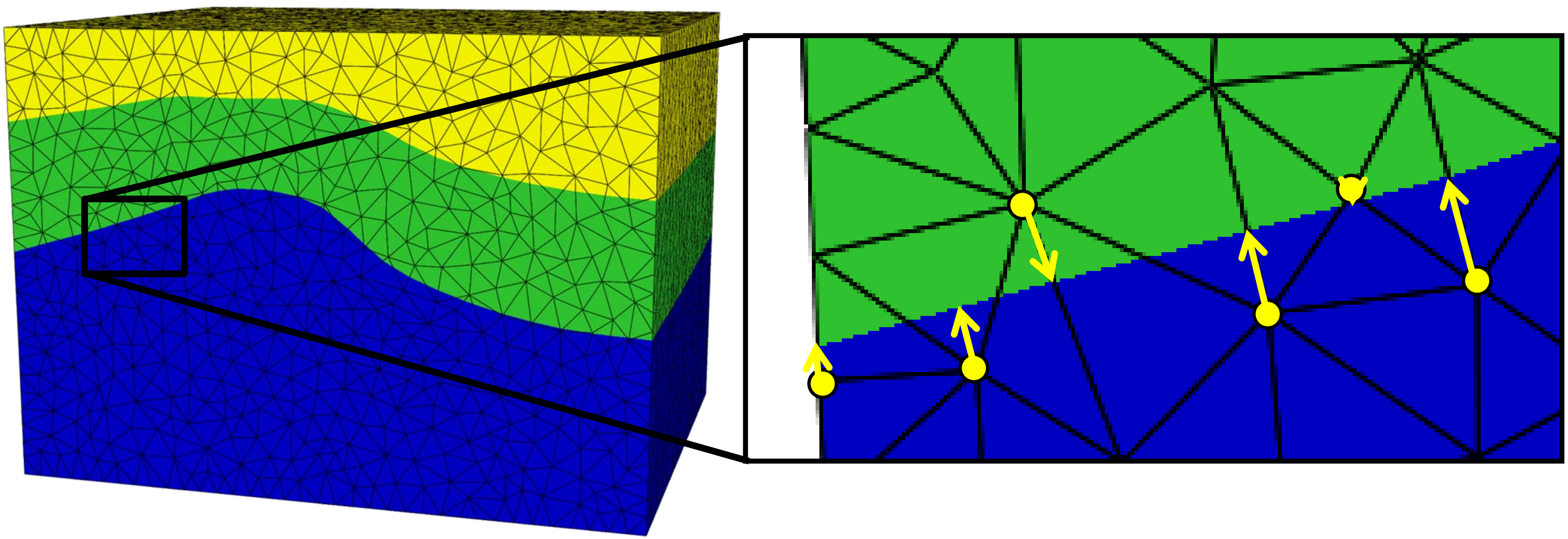
- Easy structural model building

→Good quality even with coarse elements



New Boundary Conditions

- Transfer the BC to the neighboring nodes
  - Find the closest nodes n
  - Compute the signed shortest distance $d(n)$



New Boundary Conditions

- Transfer the BC to the neighboring nodes
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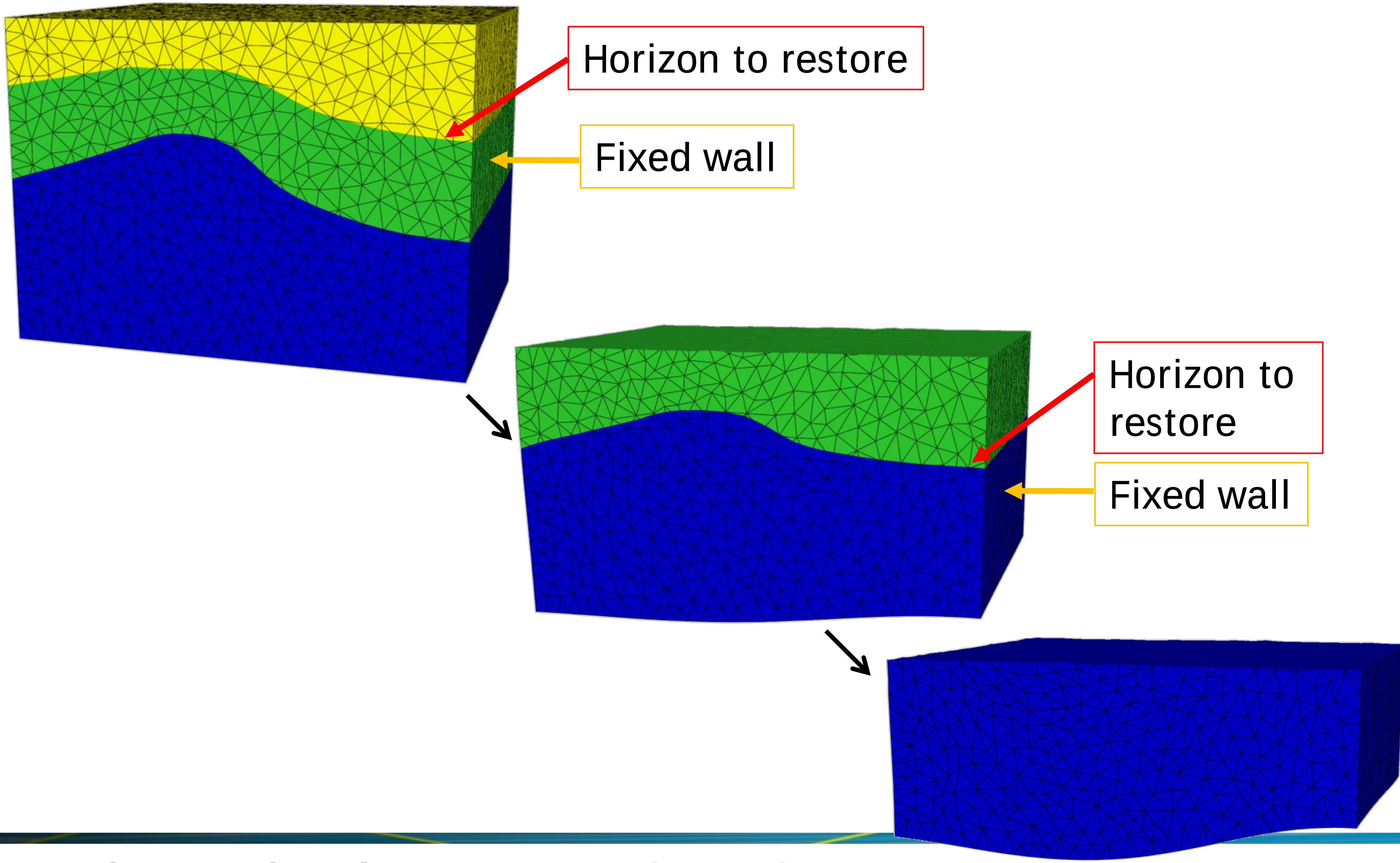
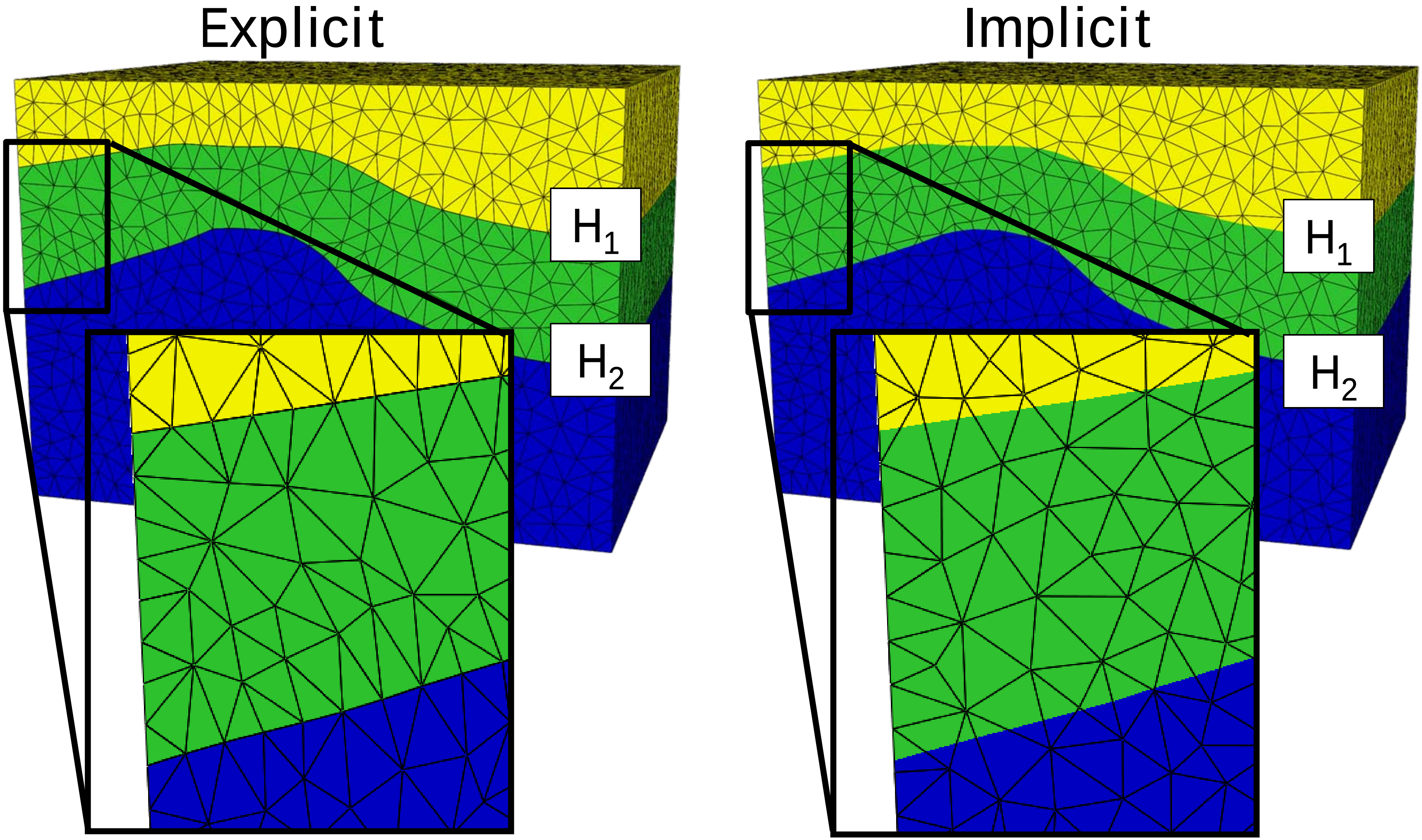
→Target condition: $Z(n)=z(n)+d(n)$

→Fixed components: $X_i(n)=x_i(n)+d(n)$

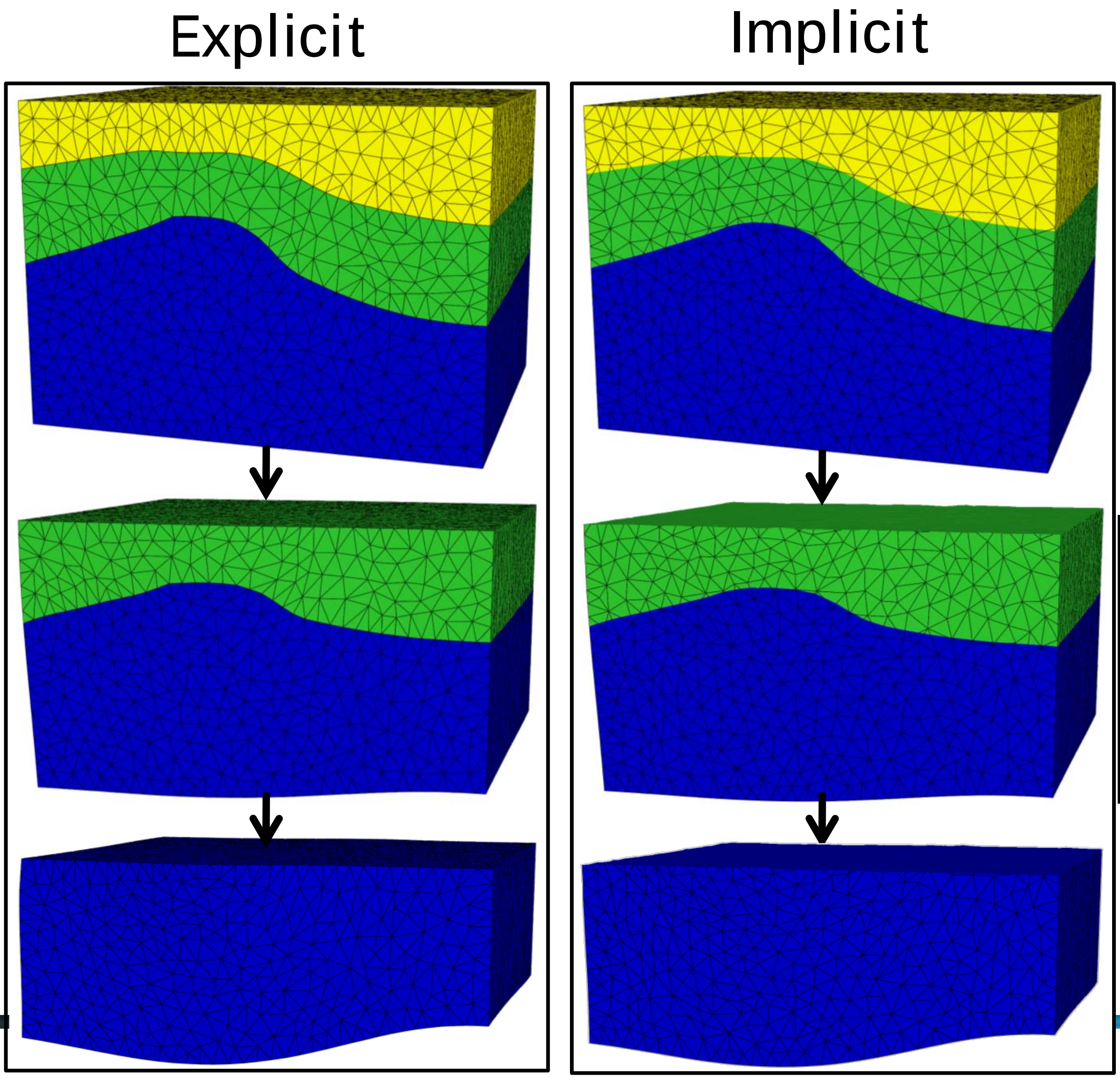
Results of the implicit restoration



Results and comparison



Results and comparison



Error function:

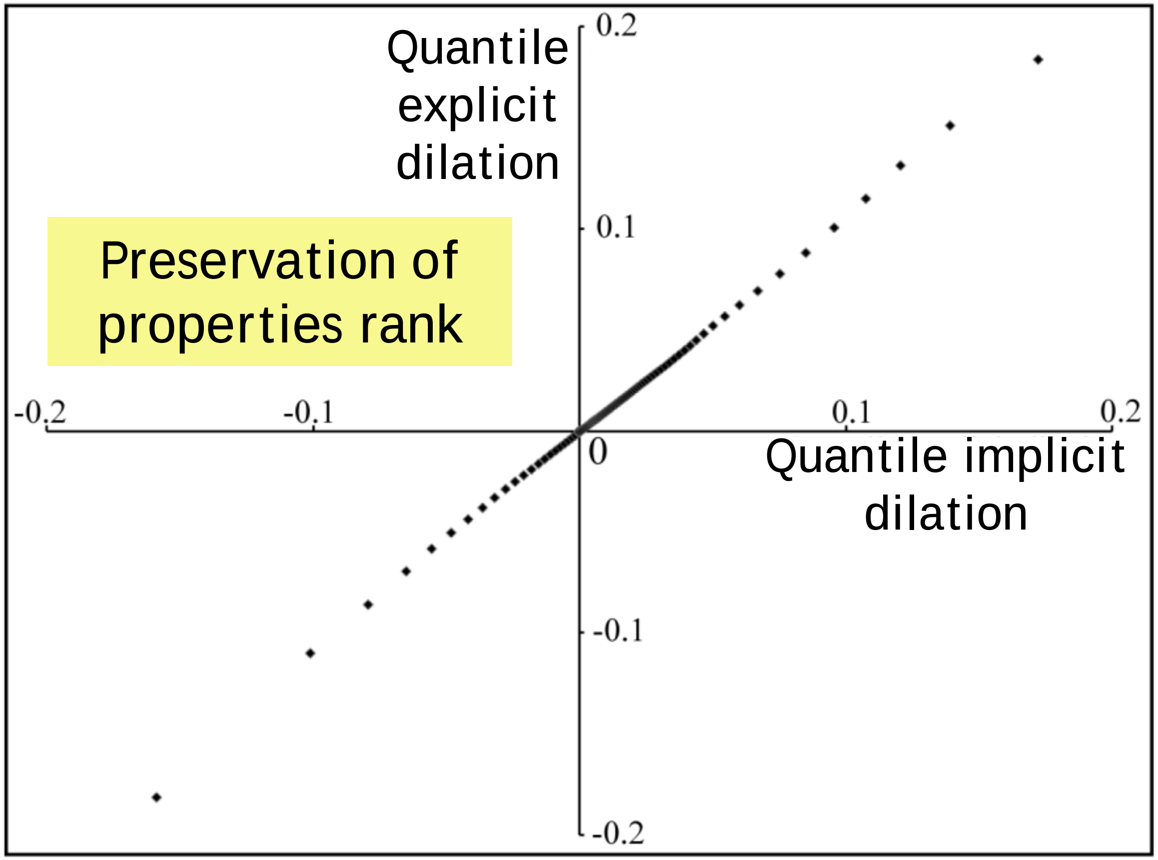
$$\Delta f^{(j)} = \frac{f_i^{(j)} - f_e^{(j)}}{f_i^{(j)}}$$

f \ j	0	1	2
V(%)	0	0.02	-1.31
D (%)	0	0.01	0.12

Results and comparison

Explicit

Implicit



Error function:

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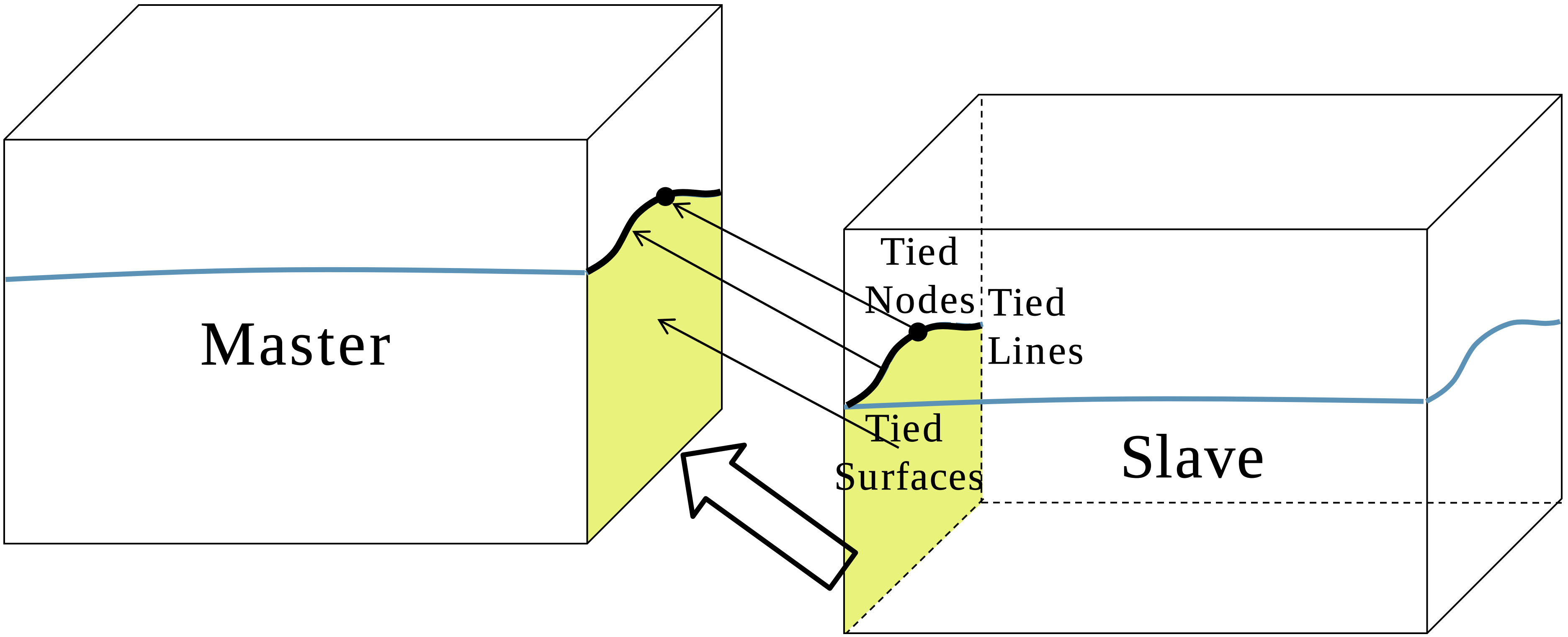
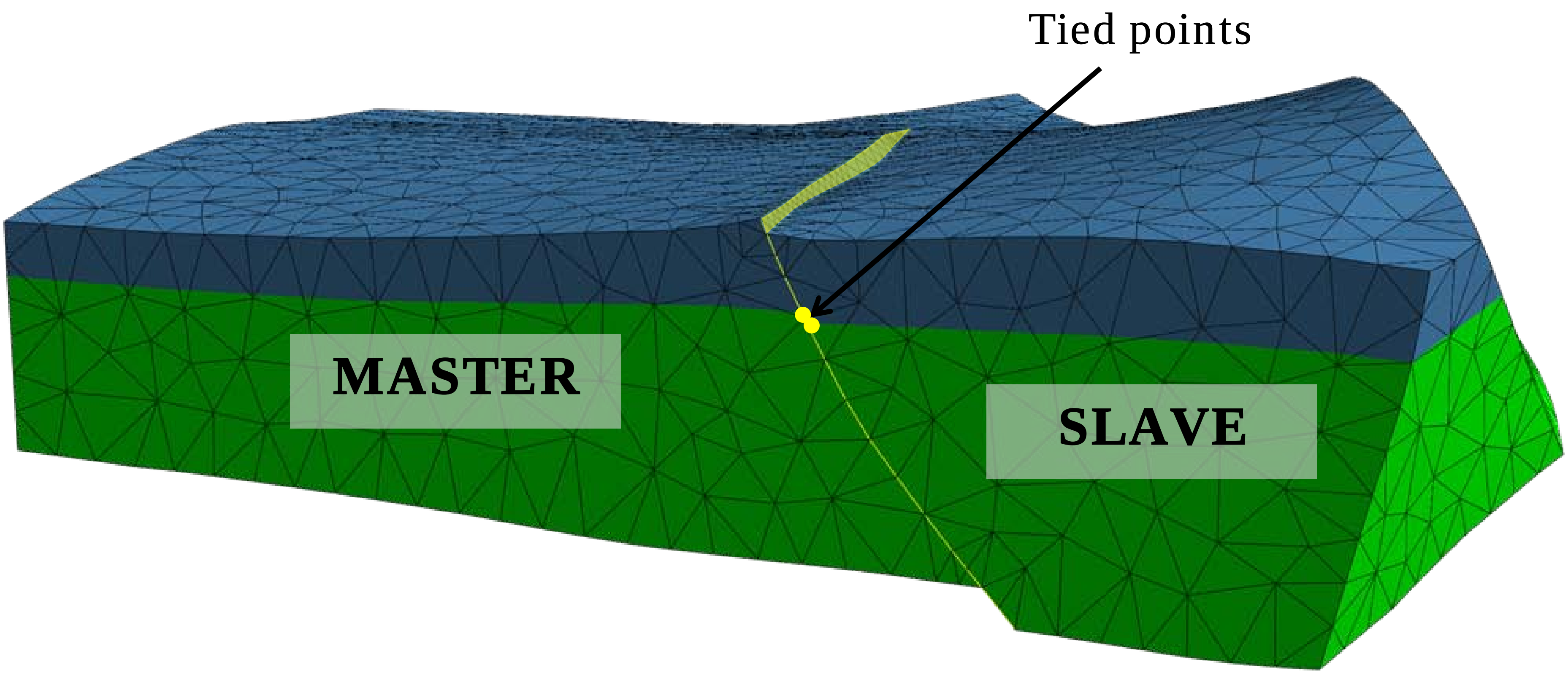
Handling faults

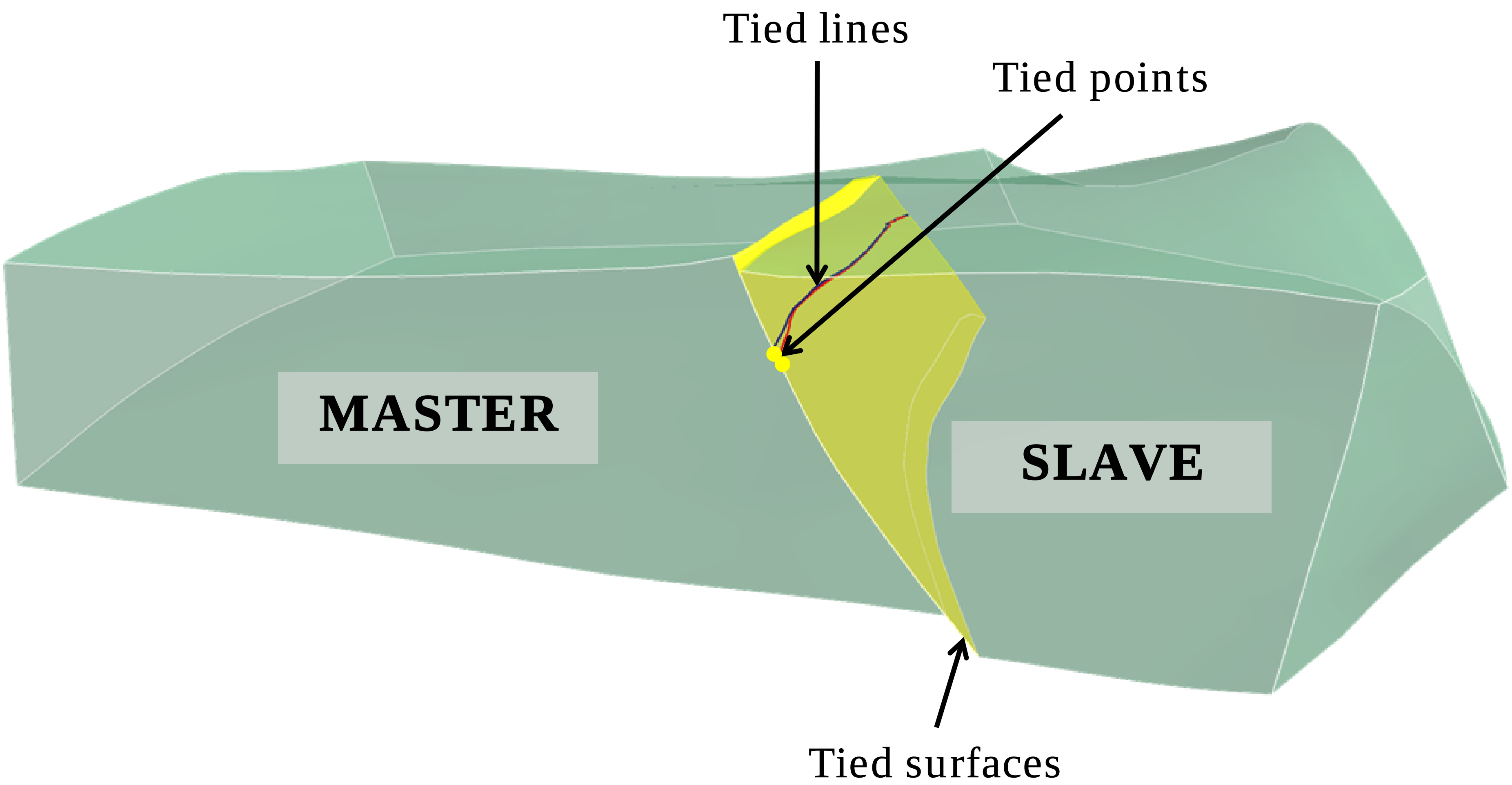
- 3 contact conditions:



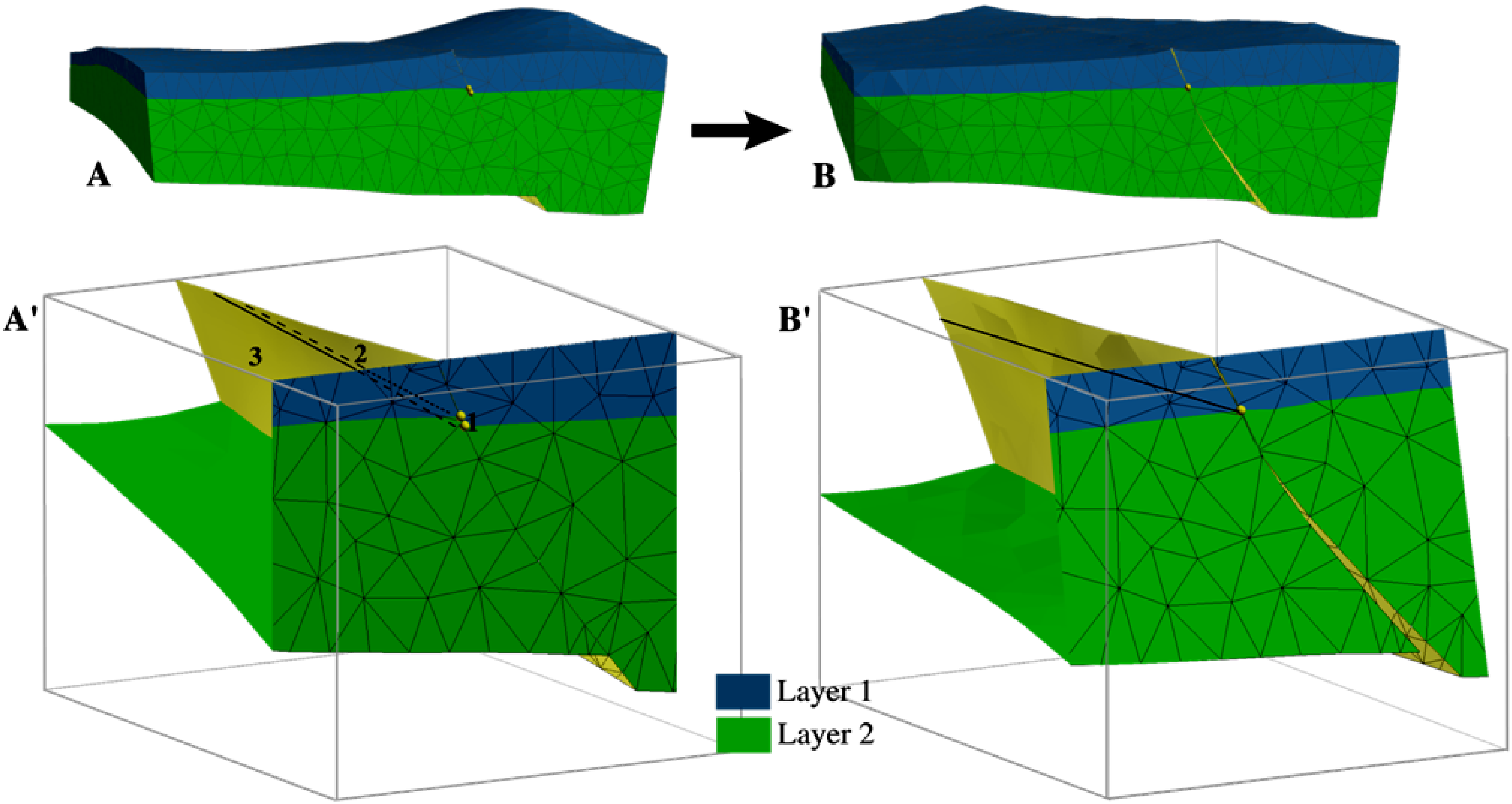
Results on a synthetic case



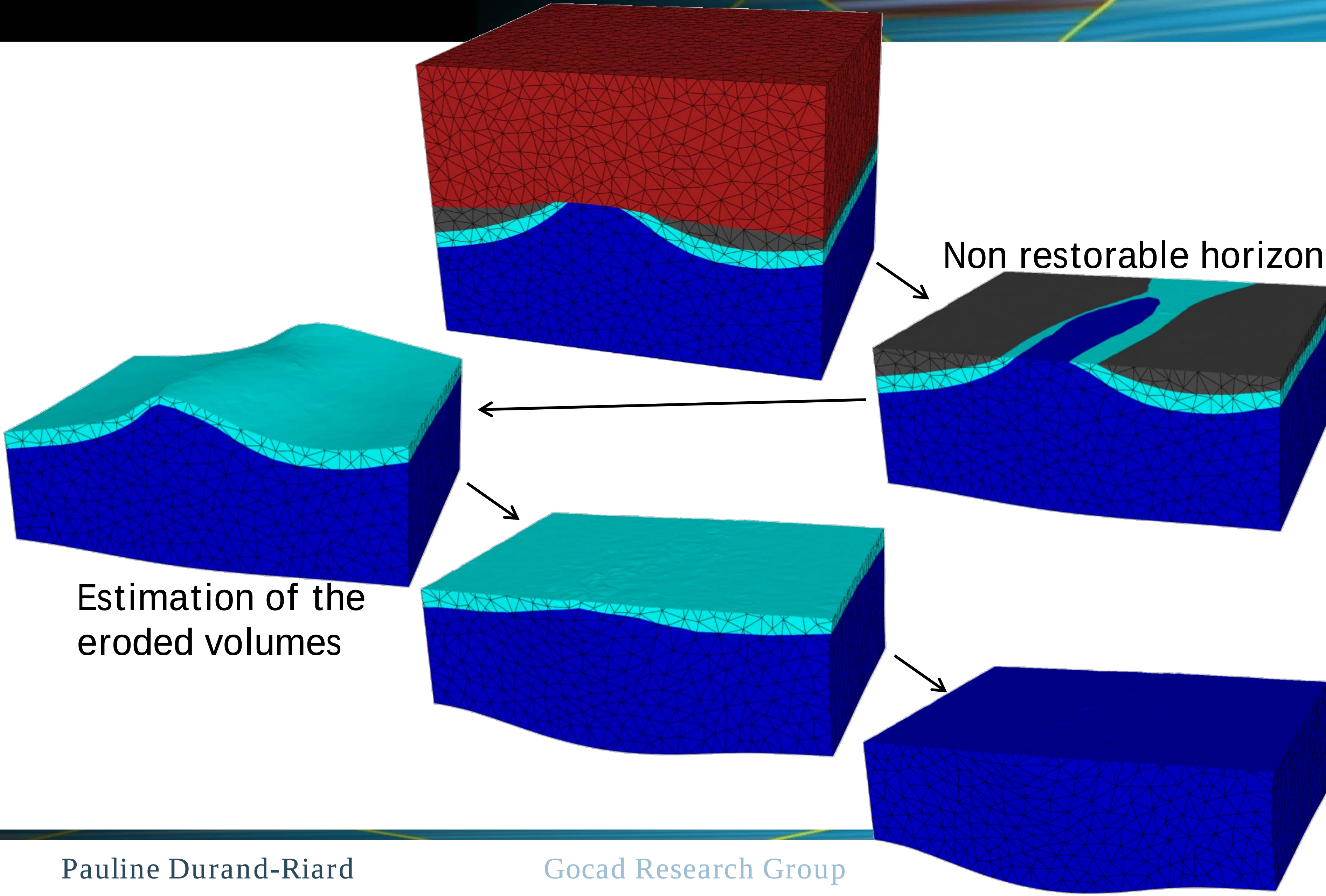
Results on a synthetic case



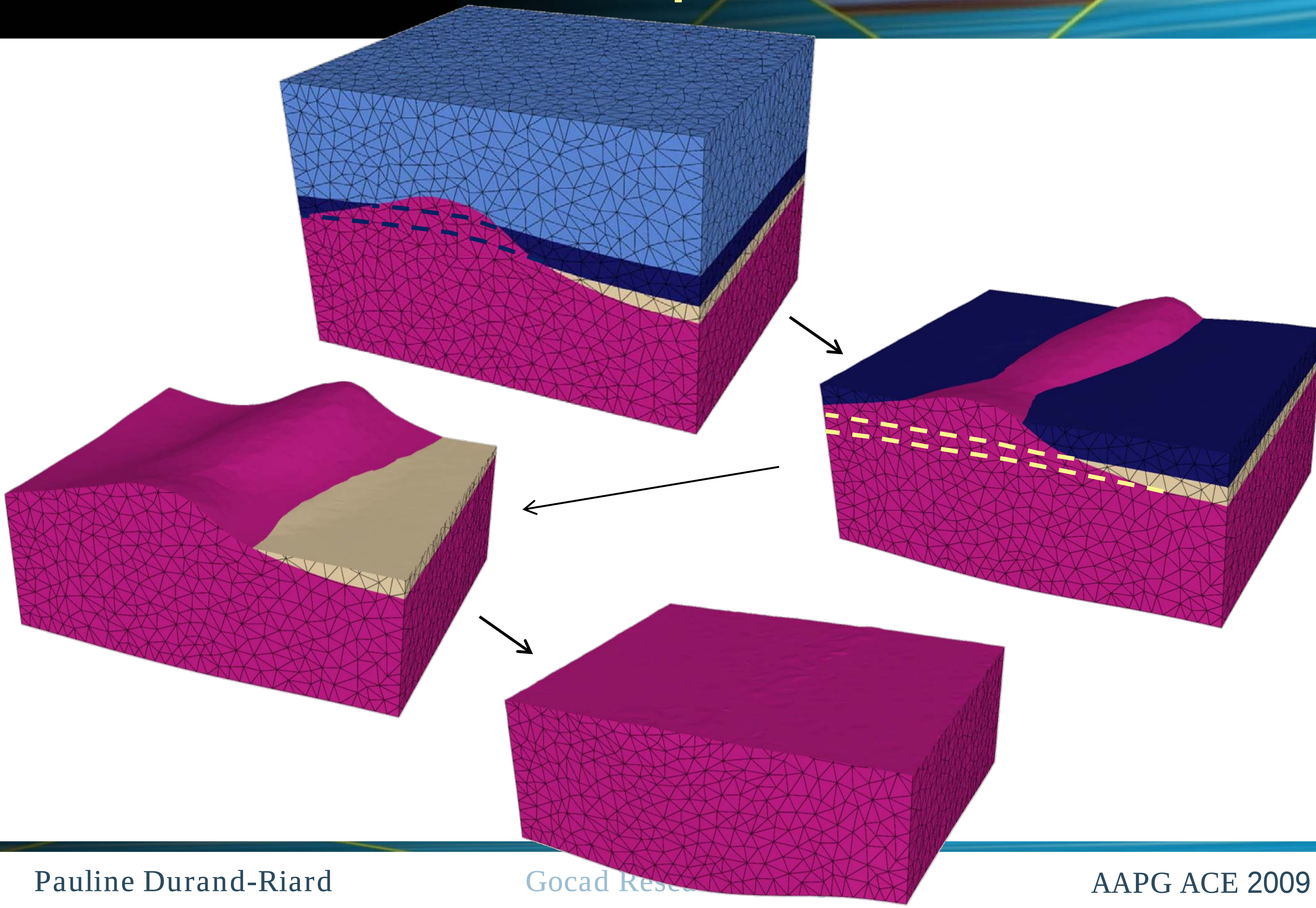
Results



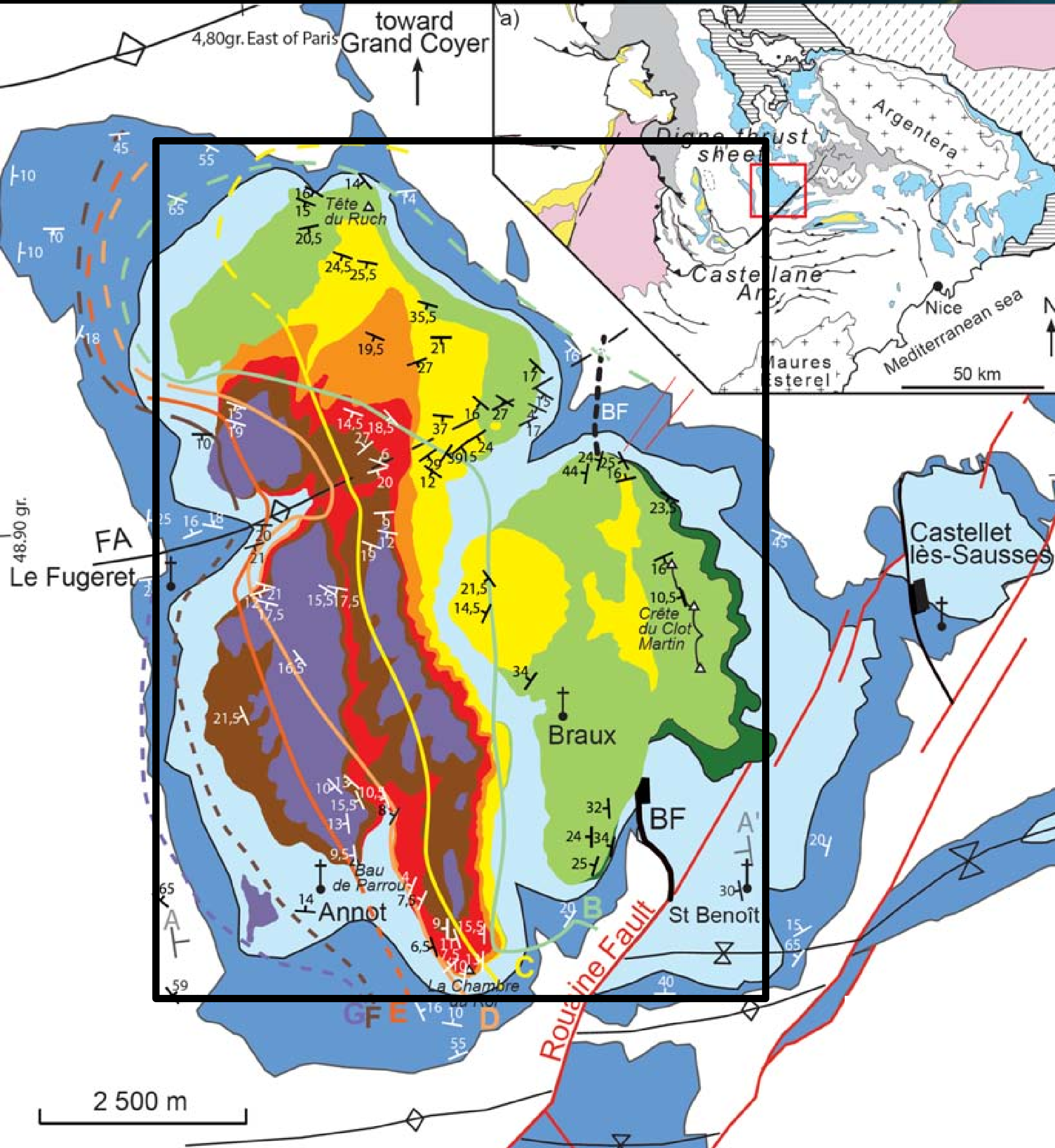
Restoration of erosion

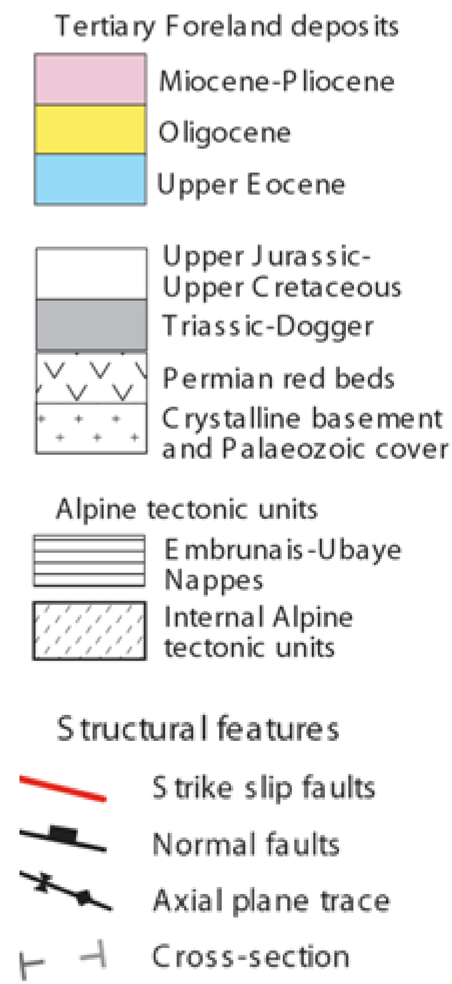


Restoration of onlaps



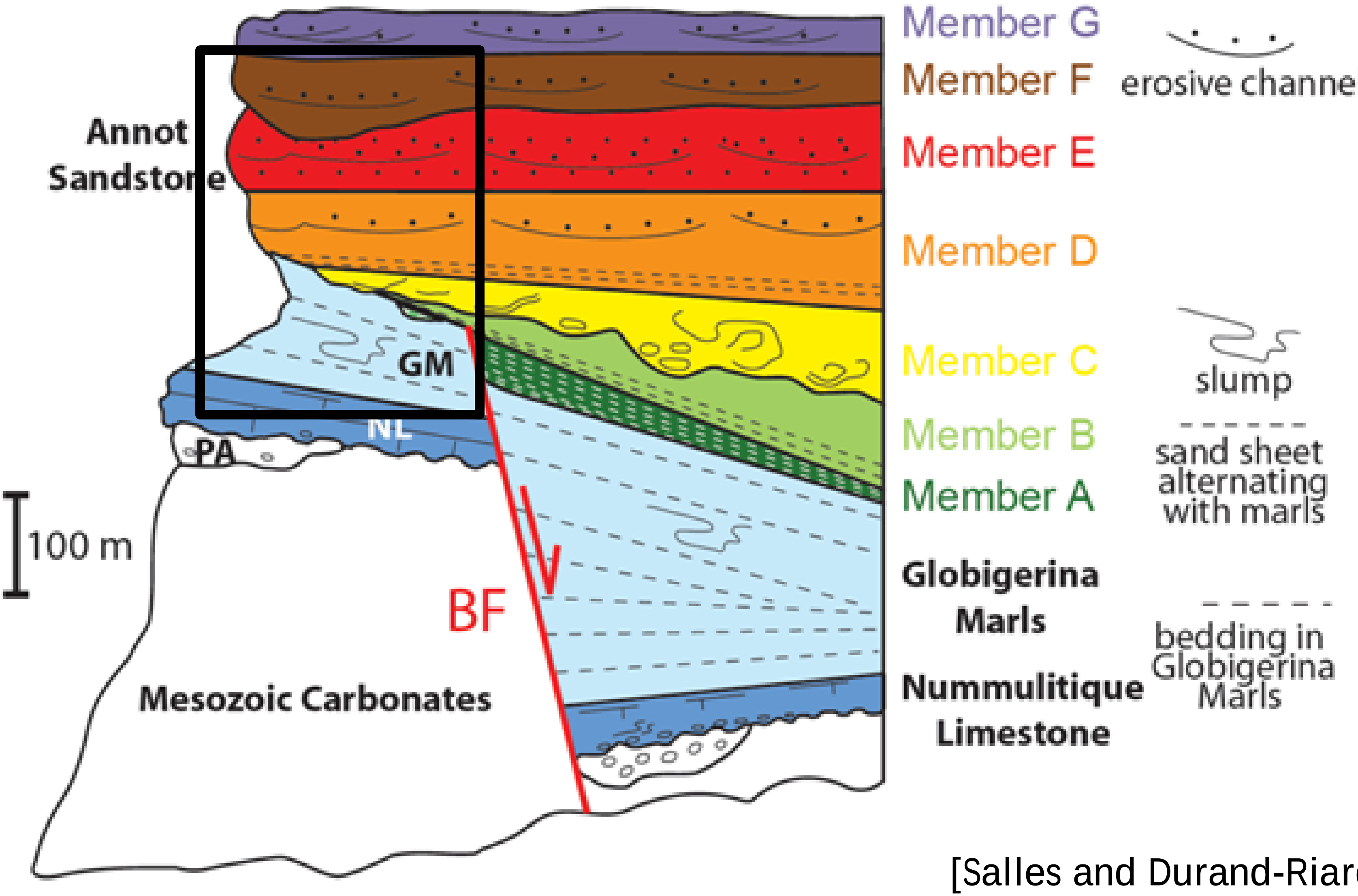
Structural framework of Annot





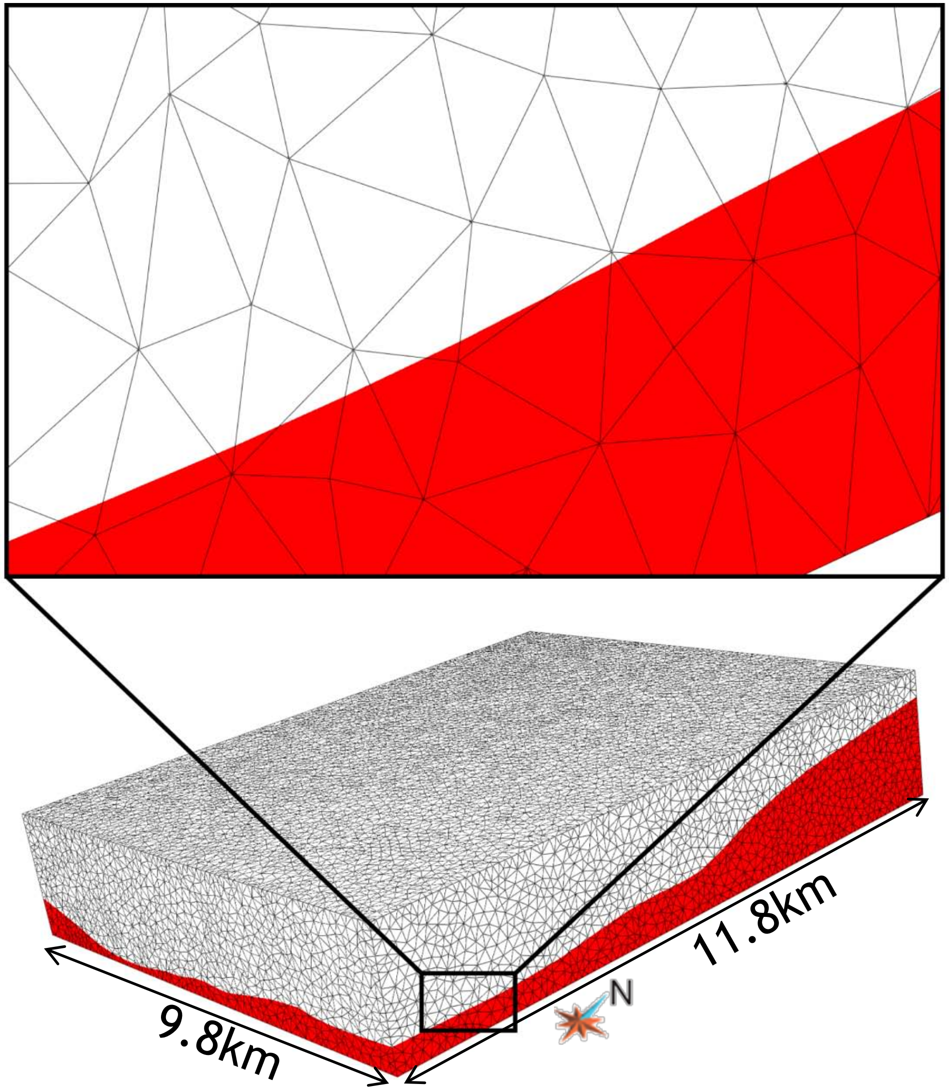
[Salles and Durand-Riard, 2009]

The Annot sandstone

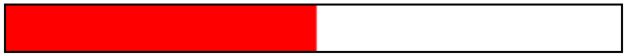


[Salles and Durand-Riard, 2009]

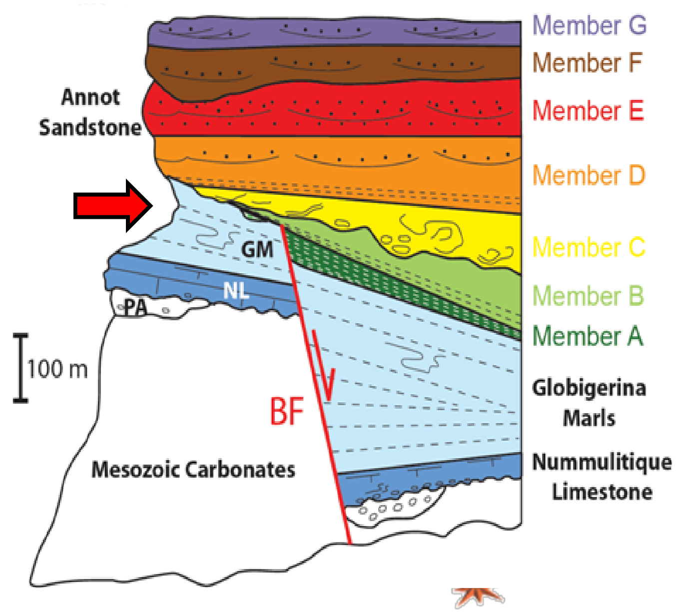
Gocad model of Annot



Base of discordance

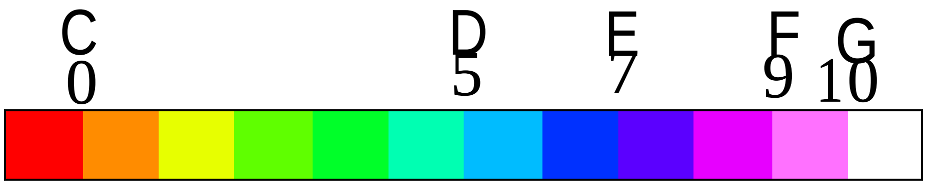


Property “unconformity”

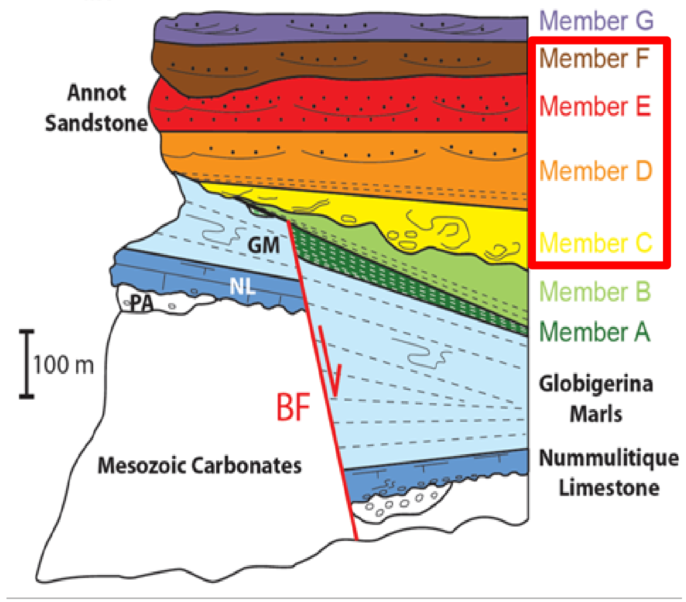


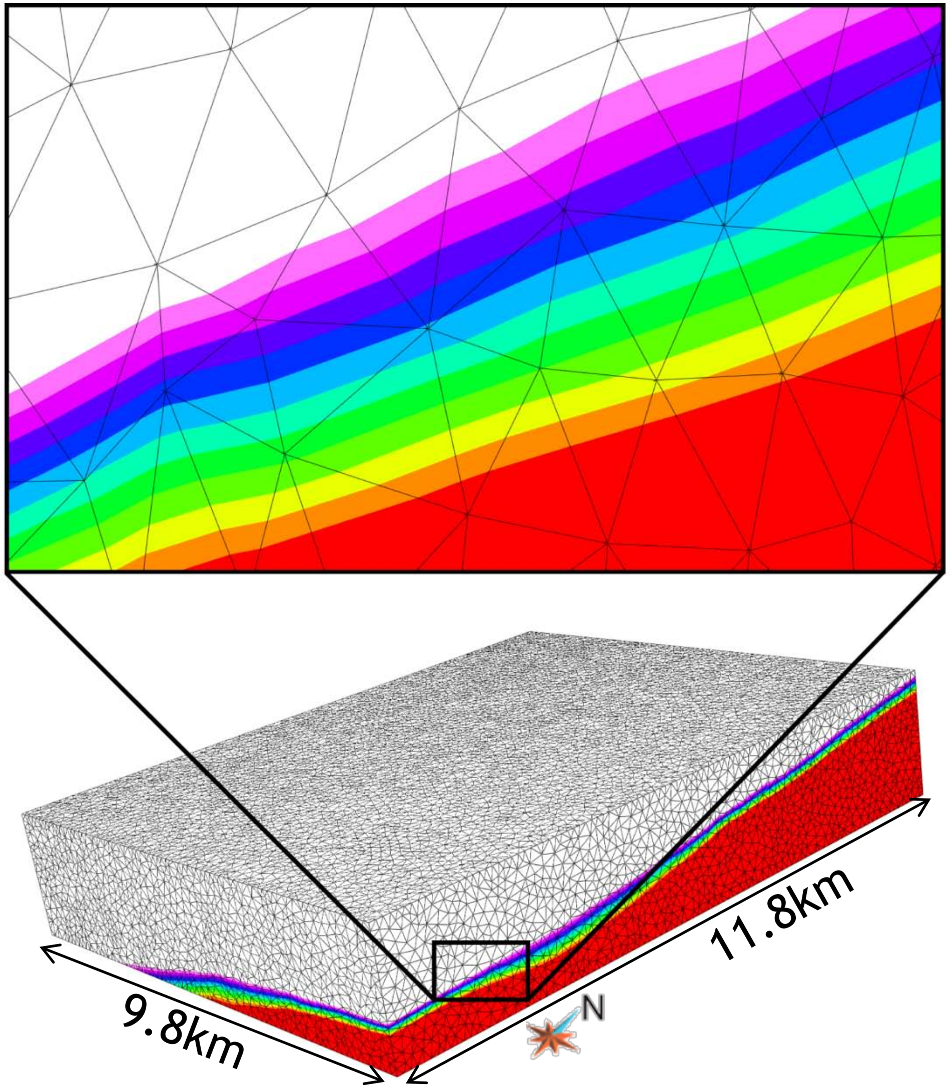
Gocad model of Annot

Bases of members:

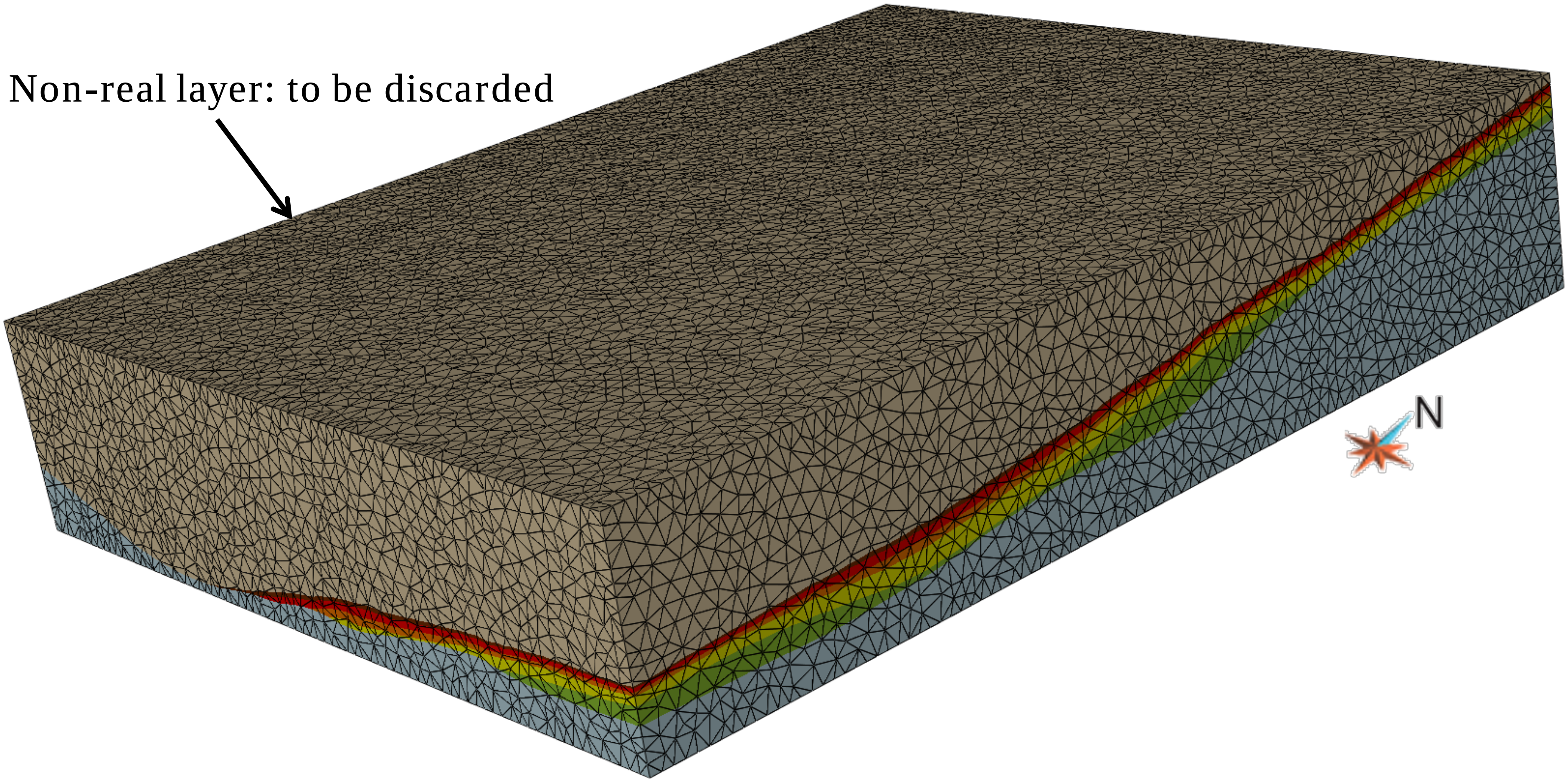


Property "in Annot sandstone"

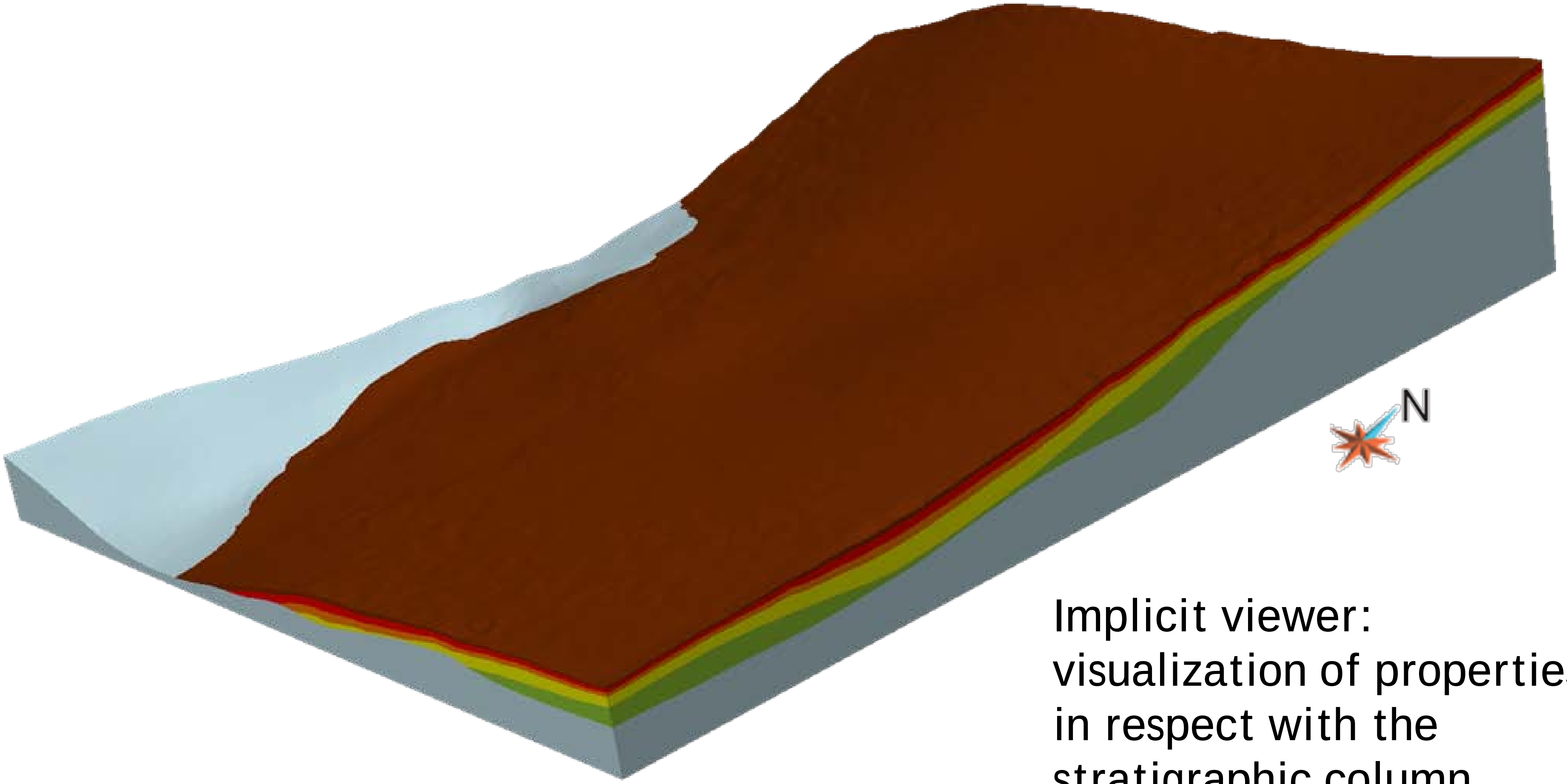




Gocad model of Annot

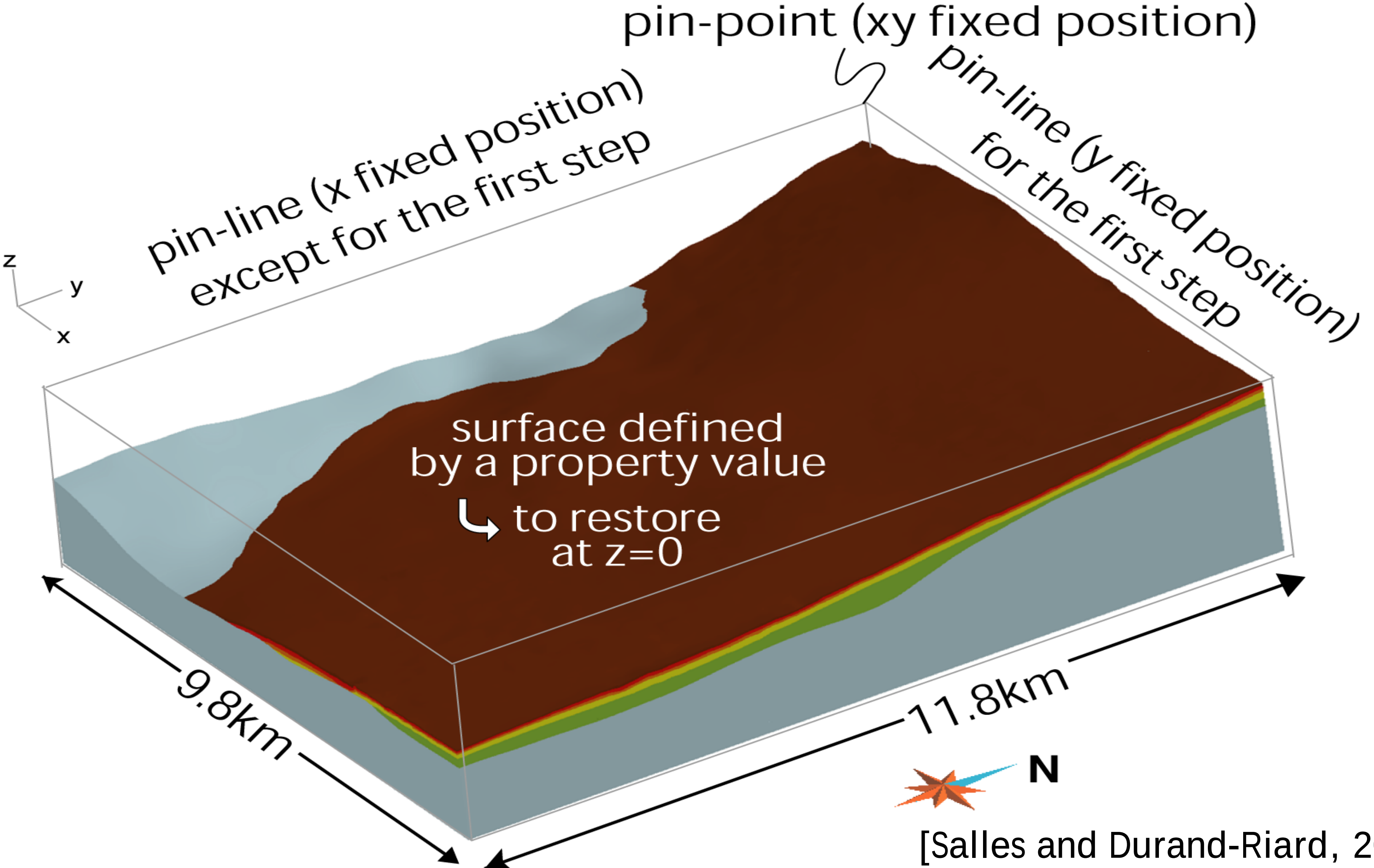


Gocad model of Annot



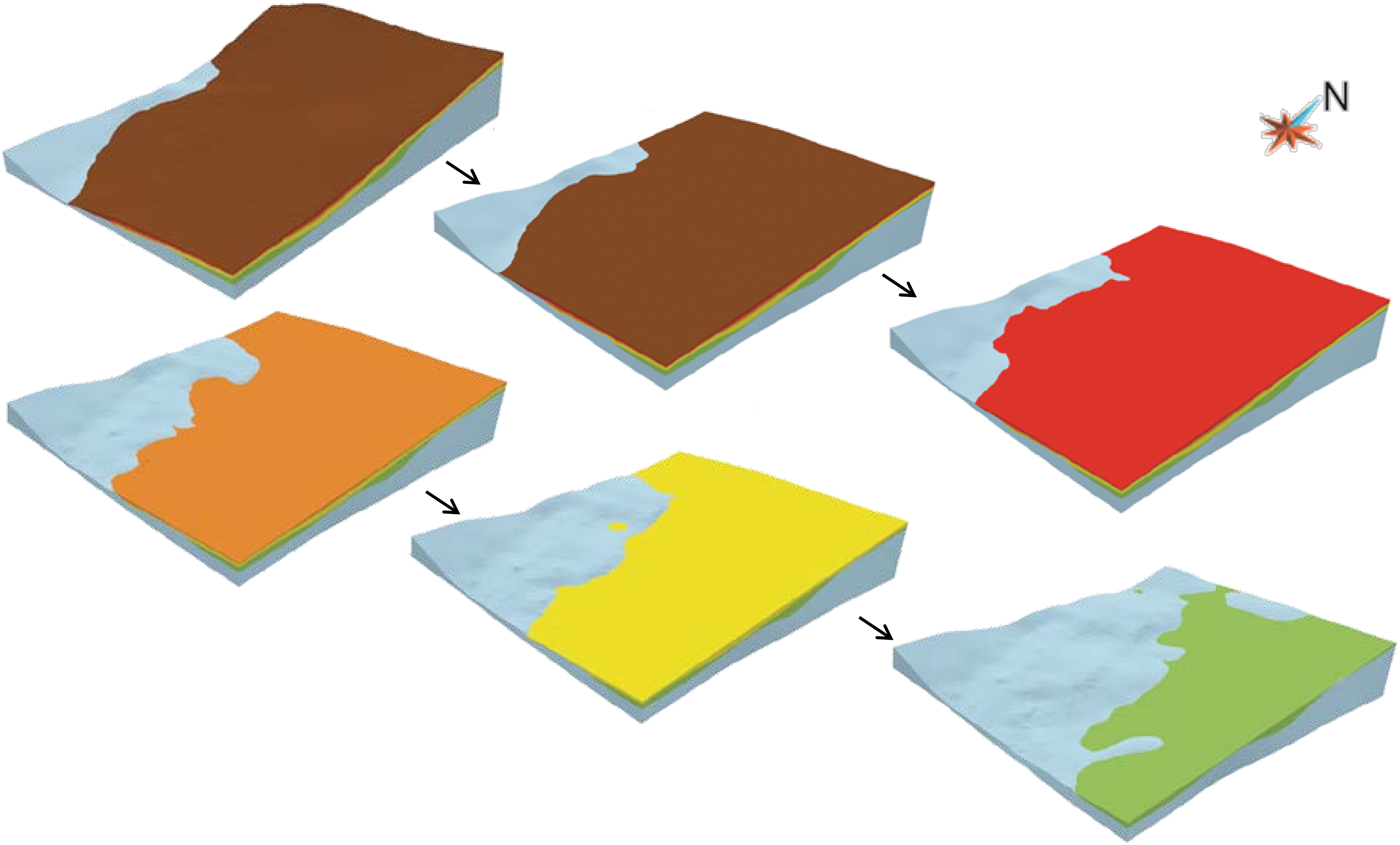
Implicit viewer: visualization of properties in respect with the stratigraphic column [Viard et al., 2009]

Boundary conditions



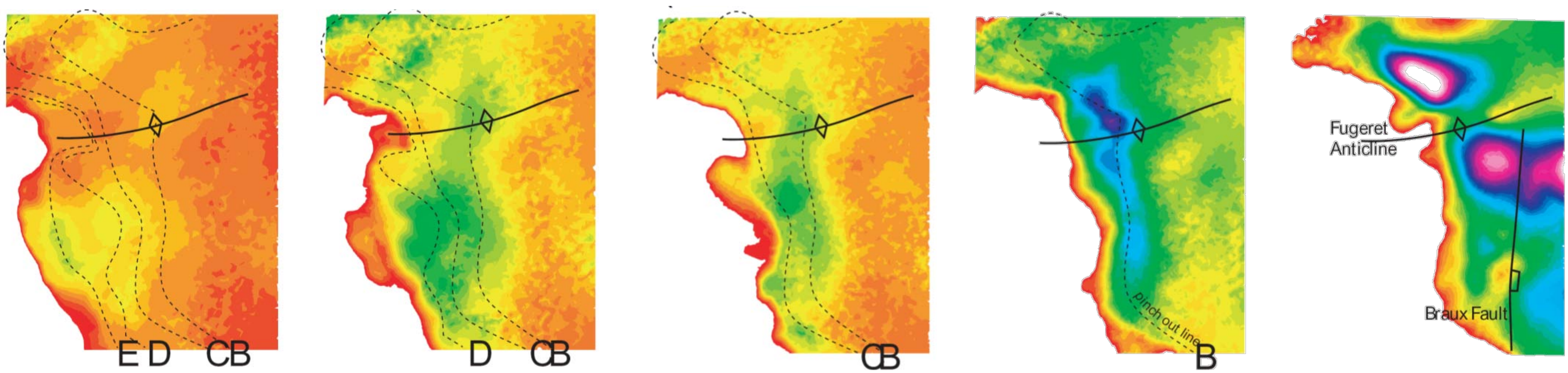
[Salles and Durand-Riard, 2009]

Restoration of the Annot sandstone



Interests of the Annot restoration

- Illustrate the onlap and depocentre migration during the turbidite sedimentation
- Get the initial topography of each turbidite member – initial locations of rich sandstones
- Constrain the evolution of the substratum
- Improve results of the process-based simulation (poster: Teles et al.)



Conclusions and perspectives

- Full 3D restoration method
  - Flatten implicit horizons
  - Handle faults (to be applied to a real-case study)
- Restoration of unconformities

- Restore to paleotopographic surfaces
- Use of small increments of properties
- Deal with more complex geological models (thrust belts, …)
- Model true flexural slip process

Acknowledgements

- Chevron and Gocad consortium
- Paradigm

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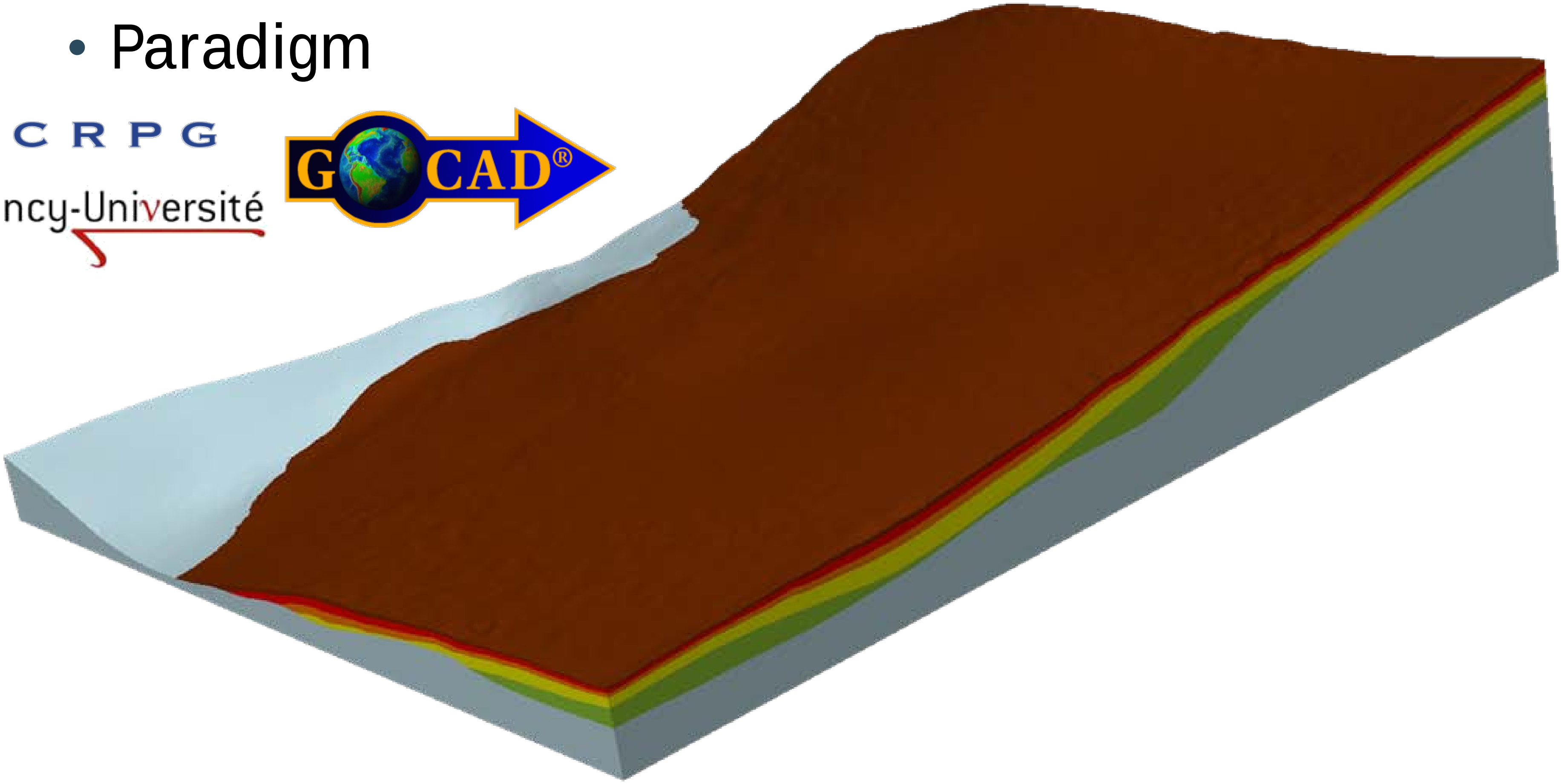

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