Cellular Automata Applied to Fault and Surface Related Diagenesis in Carbonate Reservoirs*

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Abstract

Early and burial diagenesis are the main processes modifying carbonate rock matrix properties. These processes have been studied extensively and are well-known. Detailed petrographic studies allow geologists to understand the sequence of events that increase or decrease the pore size and connectivity of the reservoir rock types. However, 3D spatial prediction of diagenetic trends or geobodies remains challenging, mainly due to interactions with the pre-existing geology, and because fault and/or fractures, and complex fluids/rock reactions through time produce a very wide range of shapes and sizes.

Traditional variogram-based approaches used to populate rock properties in static reservoir models are not able to capture very complex geometries such as cave networks formed in karsted terrains. It is also very difficult to build 3D training images in order to obtain efficient multipoint statistic predictions for such systems. By contrast, forward modeling approaches are emerging as promising tools to better understand and assess the key parameters for specific fault or surface related diagenetic processes. We present here a new approach based on cellular automata, which uses very simple cell-based rules in order to reproduce trends and geometries.

As examples we present two case studies on fault and surface related processes. The first case will address the ability of cellular automata to predict complex karst sytems in an unconventional oil reservoir. Taking into account the geological architecture, the cellular automata is used to predict the distribution of karst breccias, cave networks or sinkholes. The second case study concerns dolomitisation in a Middle East carbonate reservoir. In this example we will emphasize the ability of the cellular automata approach to be conditioned to well data in order to better predict the spatial distribution of the dolomitised geobodies.

Selected References

Jennings, J.N., 1985, Karst Geomorphology: Blackwell, New York, 293 p.

Lapponi, F., G. Casini, I. Sharp, W. Blendinger, N. Fernandez, I. Romaire, and D. Hunt, 2011, From outcrop to 3D modeling; a case study of a dolomitized carbonate reservoir, Zagros Mountains, Iran, *in* C. Hollis, and I Sharp, (eds.), Albian-Cenomanian-Turonian carbonate-siliciclastic systems of the Arabian Plate; advances in diagnosis, structure and reservoir modeling: Petroleum Geoscience, v. 17/3, p. 283-307.

Saller, A.H., and J.A. Dickson, 2011, Partial dolomitization of a Pennsylvanian limestone buildup by hydrothermal fluids and its effect on reservoir quality and performance: AAPG Bulletin, v. 95/10, p. 1745-1762.

Sharp, I., P. Gillespie, D. Morsalnezhad, C. Taberner, R. Karpuz, J. VergeS, A. Horbury, N.A.H. Pickard, J. Garland, and D. Hunt, 2010, Stratigraphic architecture and fracture-controlled dolomitization of the Cretaceous Khami and Bangestan Groups; an outcrop case study, Zagros Mountains, Iran, *in* F.S.P. van Buchem, K.D. Gerdes, and M. Esteban, (eds.), Mesozoic and Cenozoic carbonate systems of the Mediterranean and the Middle East; stratigraphic and diagenetic reference models: Geological Society of London, Special Publications, v. 329, p. 343-396.

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Focus and Goal of the Talk

Carbonate Diagenesis:
Products, Processes and Prediction

- The talk is focused on
  - Prediction aspect
  - Applicability to reservoir modeling
  - General approach
  - Simple examples

- The main goal of the presentation is
  - Present an alternative method for diagenetic geobodies modeling
  - Be short enough to allow time for discussion

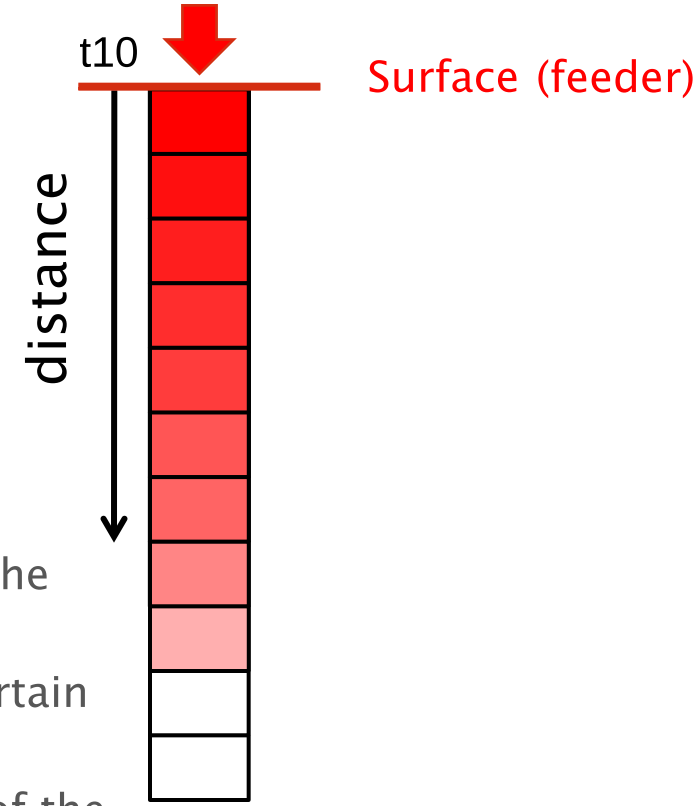
Basics

- In order to build a generic modeling tool for diagenetic geobodies it is important to look at what is common to the majority of the diagenetic processes:
  - Diagenetic processes are almost always related to the interaction between a fluid and the minerals which compose the rock.
  - Fluids tend to follow preferential pathways (faults, emersion surfaces, stratigraphic contacts, fractures network or corridor).
  - In subsurface modeling tools, these pathways are represented by surfaces.
  - Diagenetic processes do not systematically follow the depositional architecture.

- The tool should use surfaces as input and be able to model through the stratigraphic subdivisions of the reservoir.

Modeling Approaches

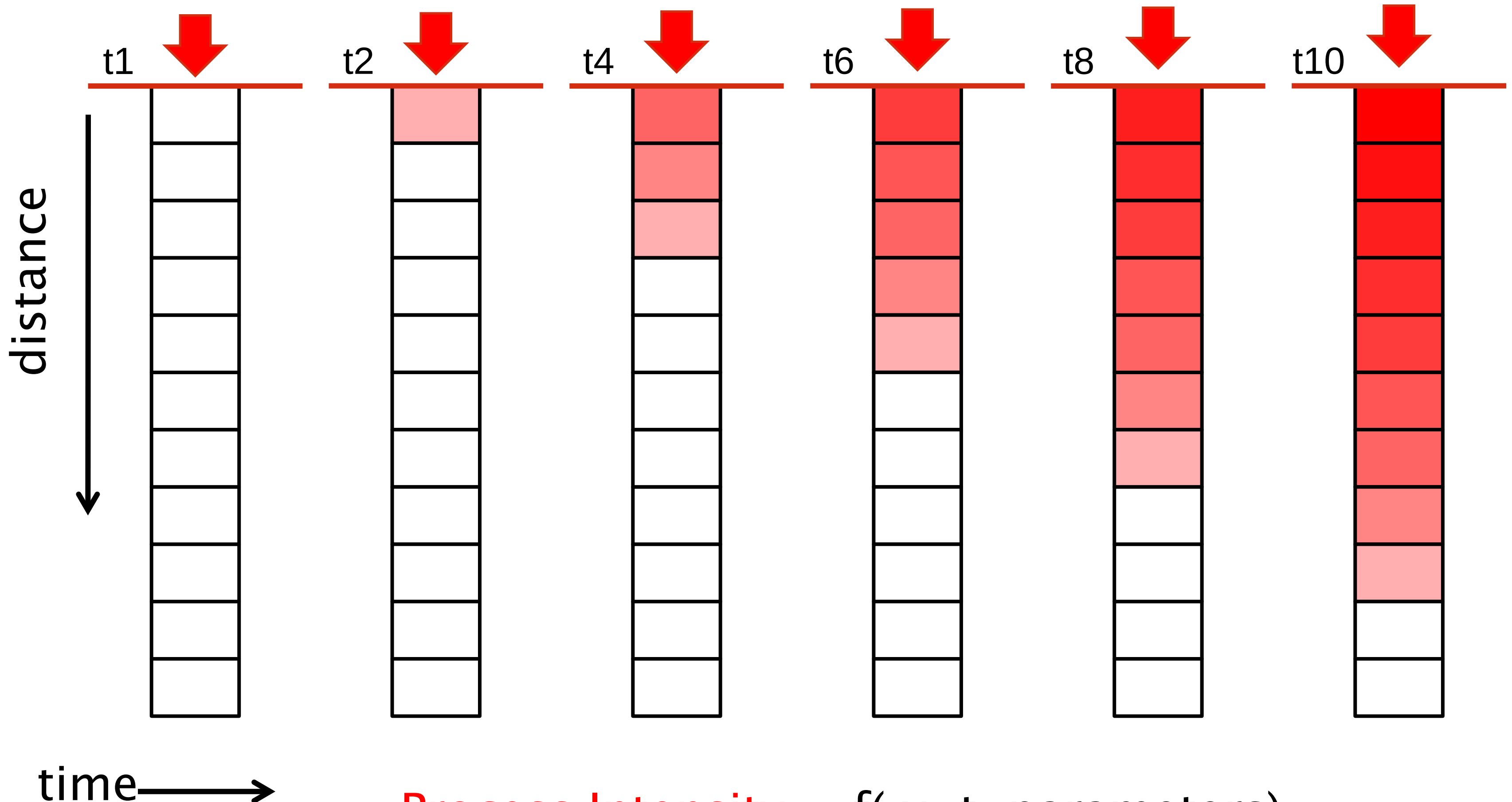
- Simplest (1D) Hypothetical Case
  - The model is made of cells
  - Every cell has the same volume
  - The cells' coordinate is the distance from a given point (surface)
  - The cells are affected by a diagenetic process driven by a fluid coming from the surface (feeder)
  - The fluid starts at t1 to flow away from the surface through the cells
  - The process affects the cells during a certain amount of time (t10)
  - The final Process Intensity is a function of the distance from the feeder, the time and some parameters related to the process type



Process Intensity = f(x, t, parameters)

Modeling Approaches

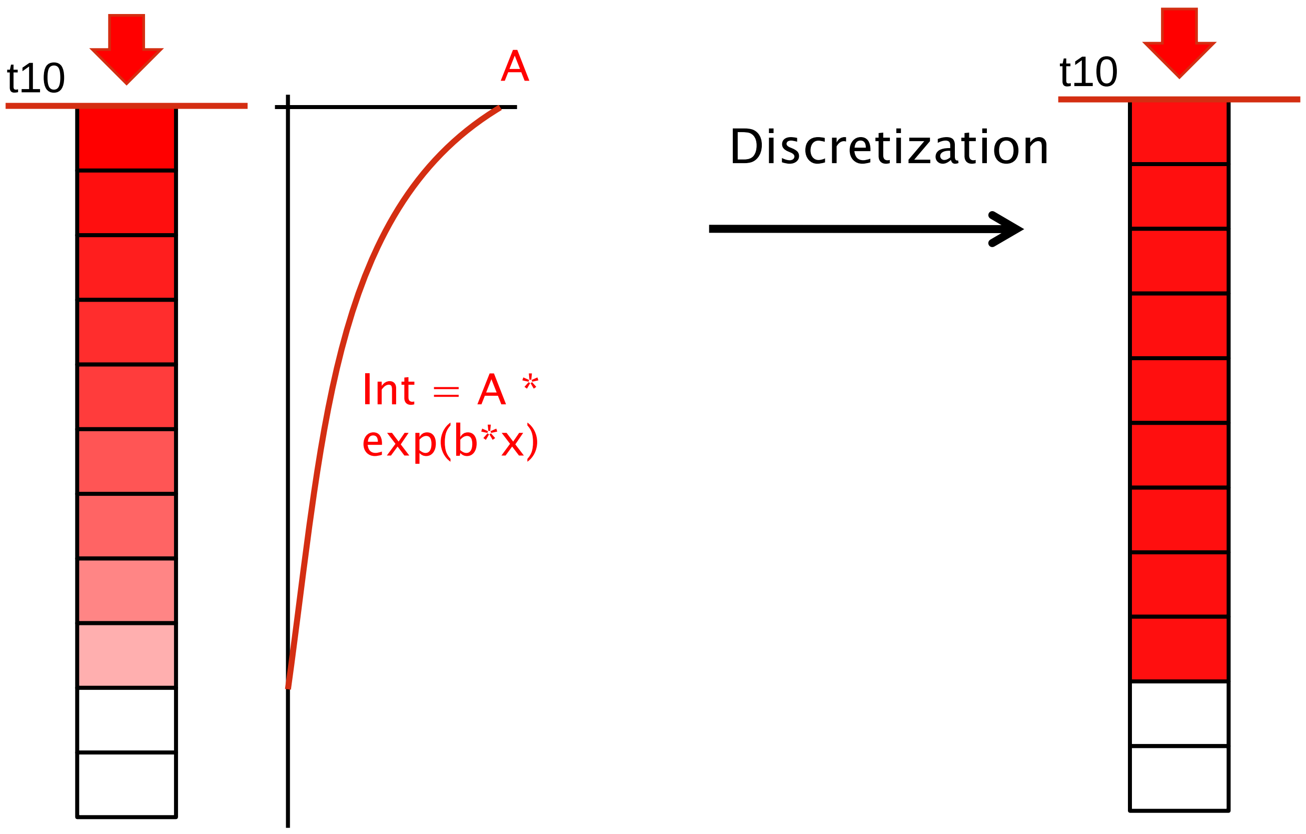
- Forward Approach



Process Intensity = f(x, t, parameters)

Modeling Approaches

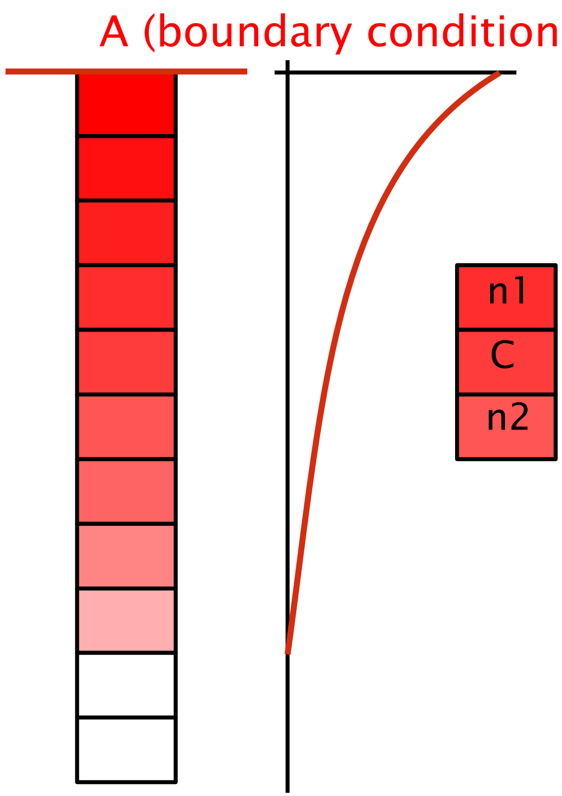
- Trend and Object Based Approach



Process Intensity = f(x, parameters)

Modeling Approaches

- Cellular Automata Approach



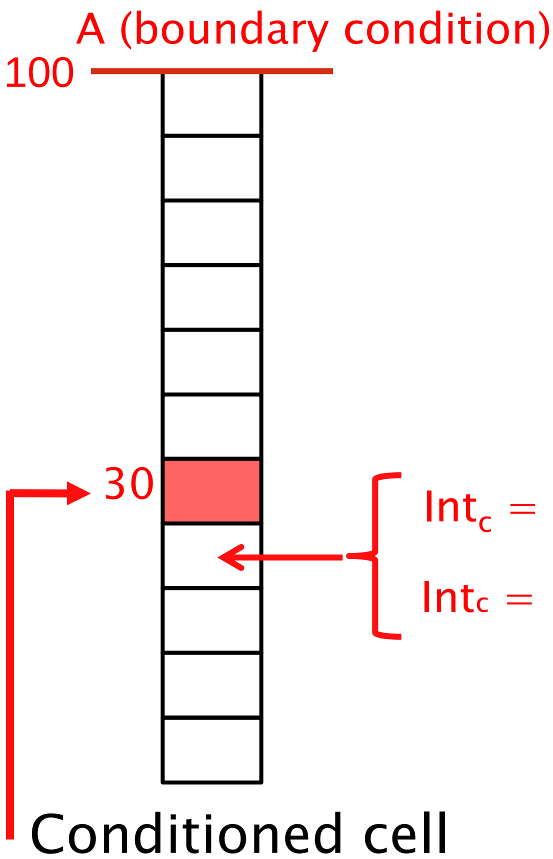
$Int_c = 90\%\ Int_{n1}$

$90\%\ Int_c = Int_{n2} \rightarrow Int_c = 111\%\ Int_{n2}$

Process Intensity = f(Boundaries, Rules)

3. Methods

- Cellular Automata Approach



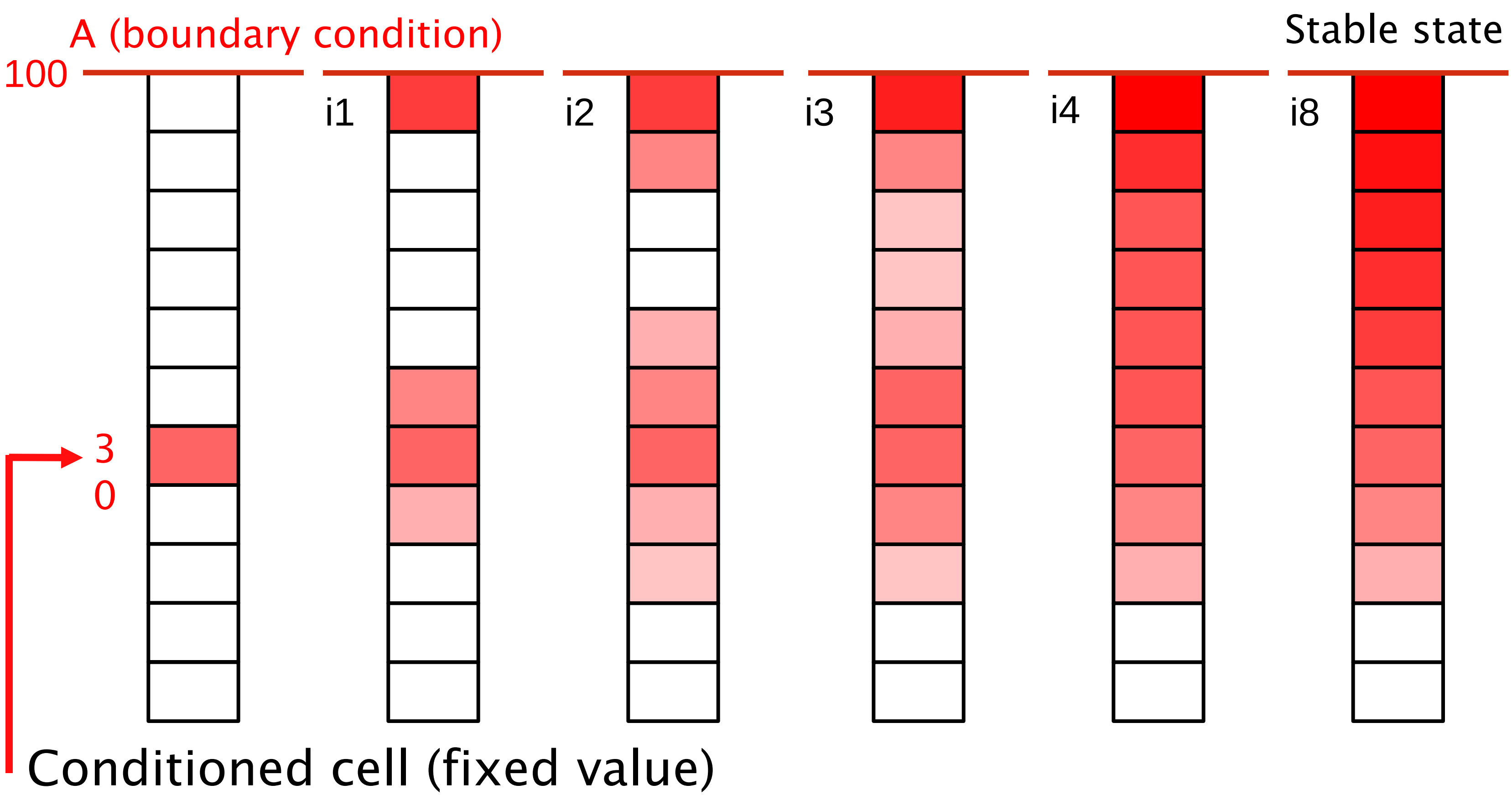
$Int_c = 90\% * 30$

$Int_c = 111\% * 0$

mean → $Int_c = 13.5$

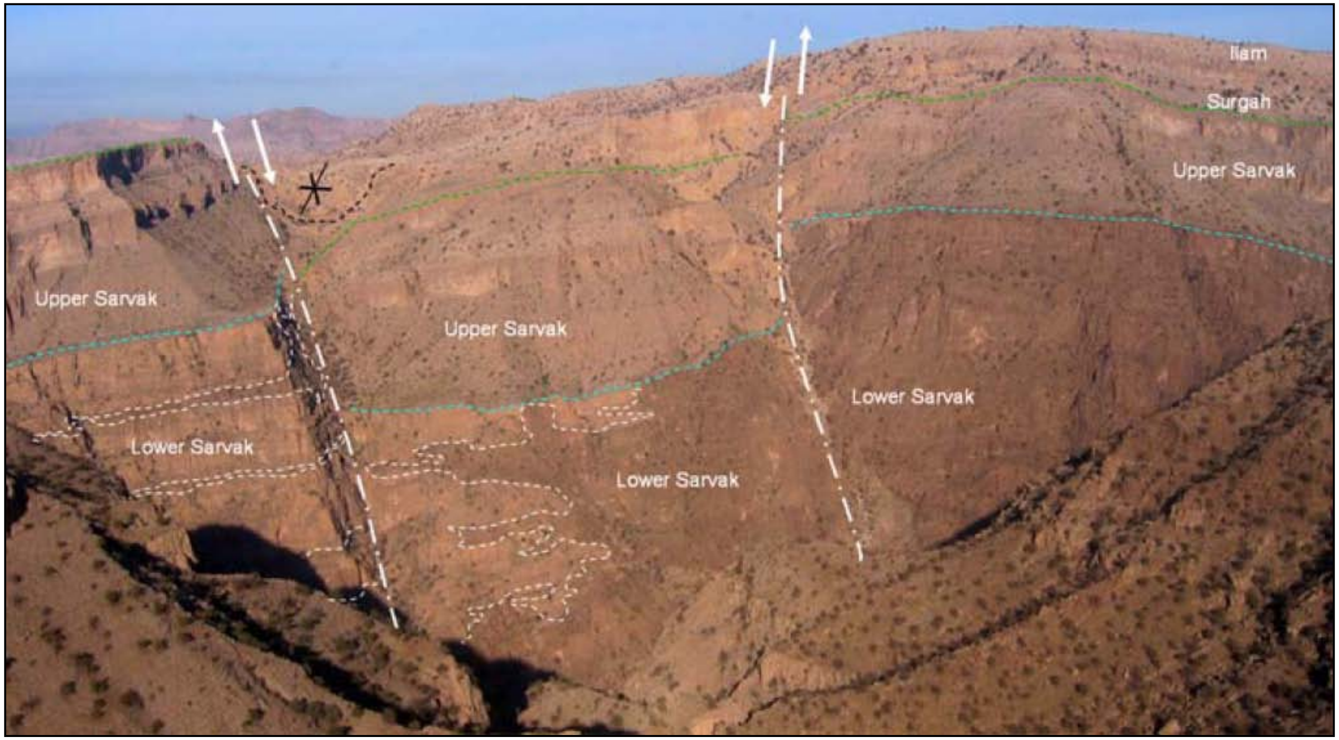
3. Methods

- Cellular Automata Approach



Example 1: Dolomite

Cretaceous Khami and Bangestan groups
Zagros Mountains, Iran (Sharp et al. 2010)



Conjugate normal faults and dolomites bodies, SW flank of Anaran Anticline, NW Dome. Massive dolomites on the right (NE) pass into stratabound dolomites and limestones on the left (SW).

Example 1: Dolomite

Cretaceous Khami and Bangestan groups
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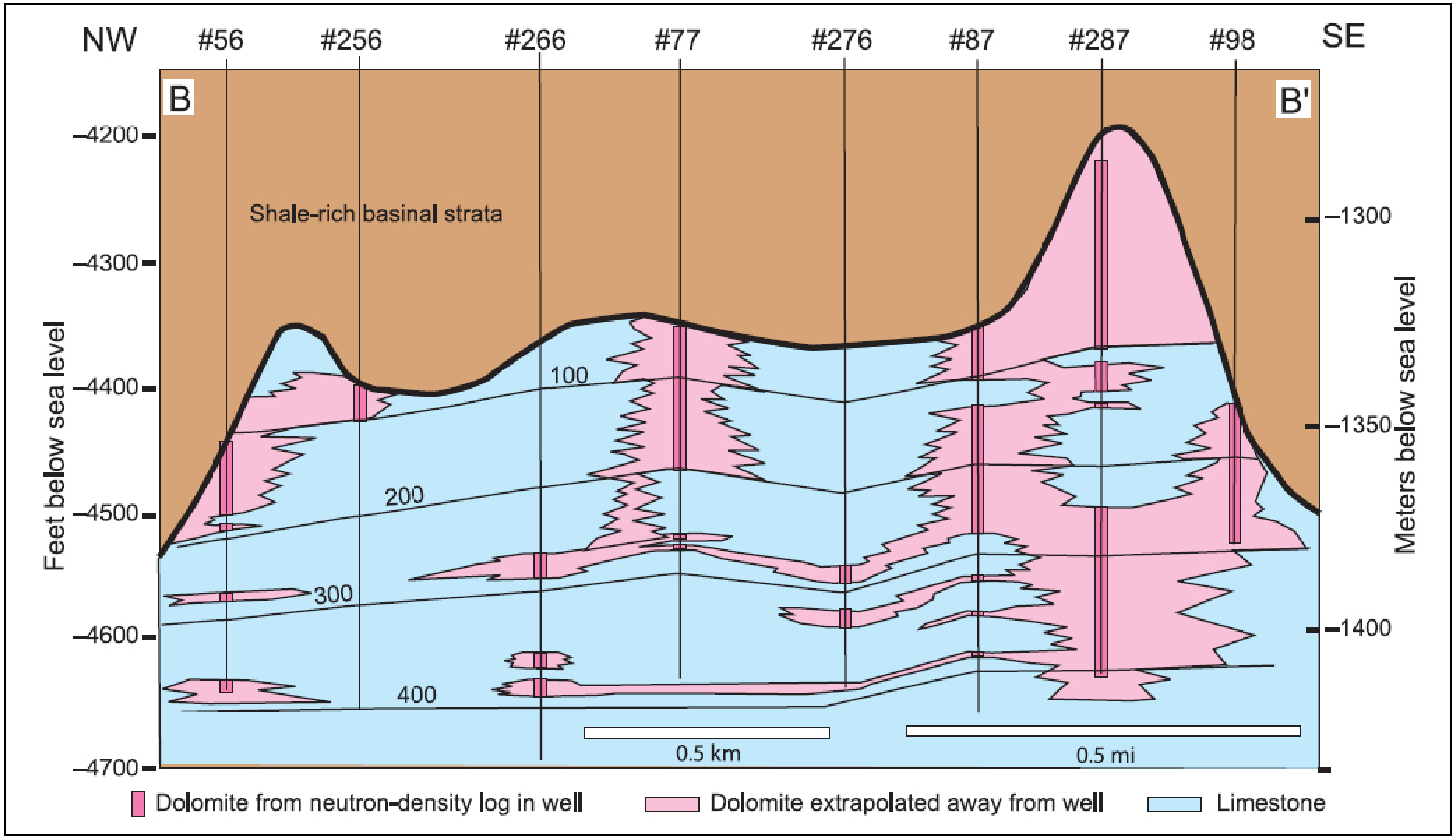
Conjugate normal faults and dolomites bodies, SW flank of Anaran Anticline, NW Dome. Massive dolomites on the right (NE) pass into stratabound dolomites and limestones on the left (SW).c

Example 1: Dolomite

Reinecke field in west Texas (Saller & Dickson, 2011)



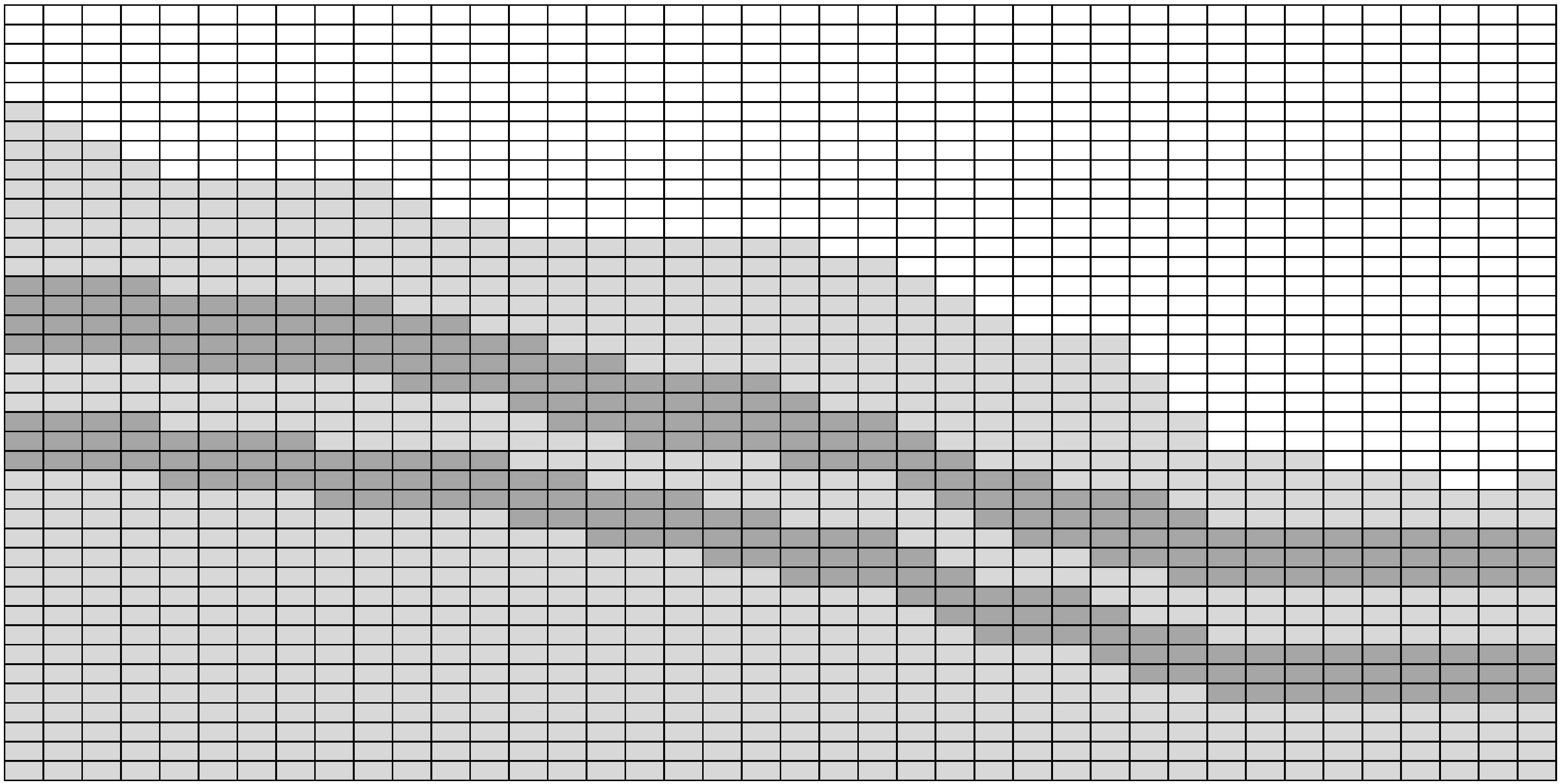
Cross section through the Reinecke south dome, showing the distribution of limestone and dolomite identified from neutrondensity logs in wells.

Example 1: Dolomite

Permo-Trias, Jabal al Akhdar, Oman

Example 1: Dolomite

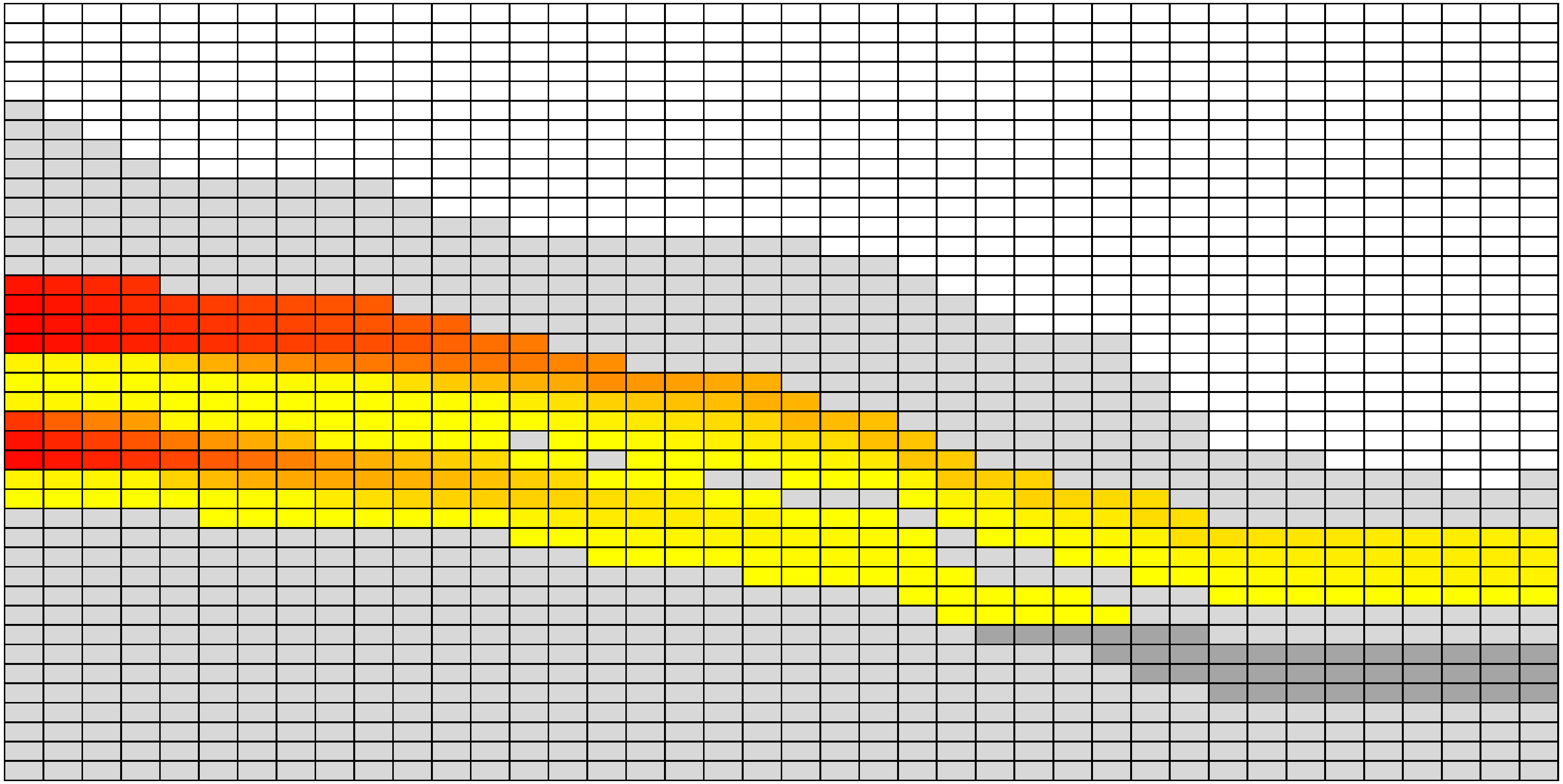
Simple algorithm: 2D models can be run directly in excel



Iterations: 45

Example 1: Dolomite

Simple algorithm: 2D models can be run directly in excel



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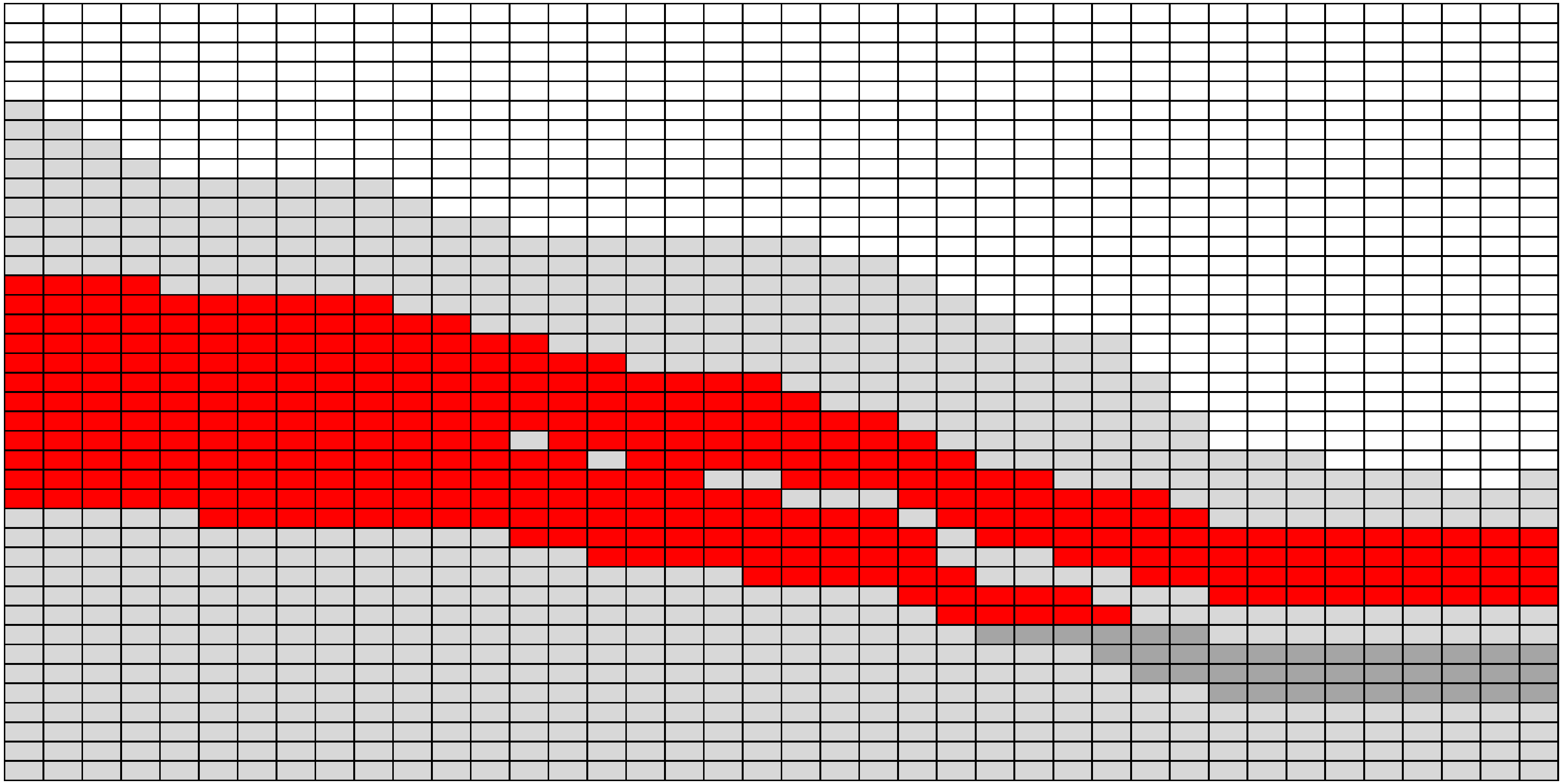

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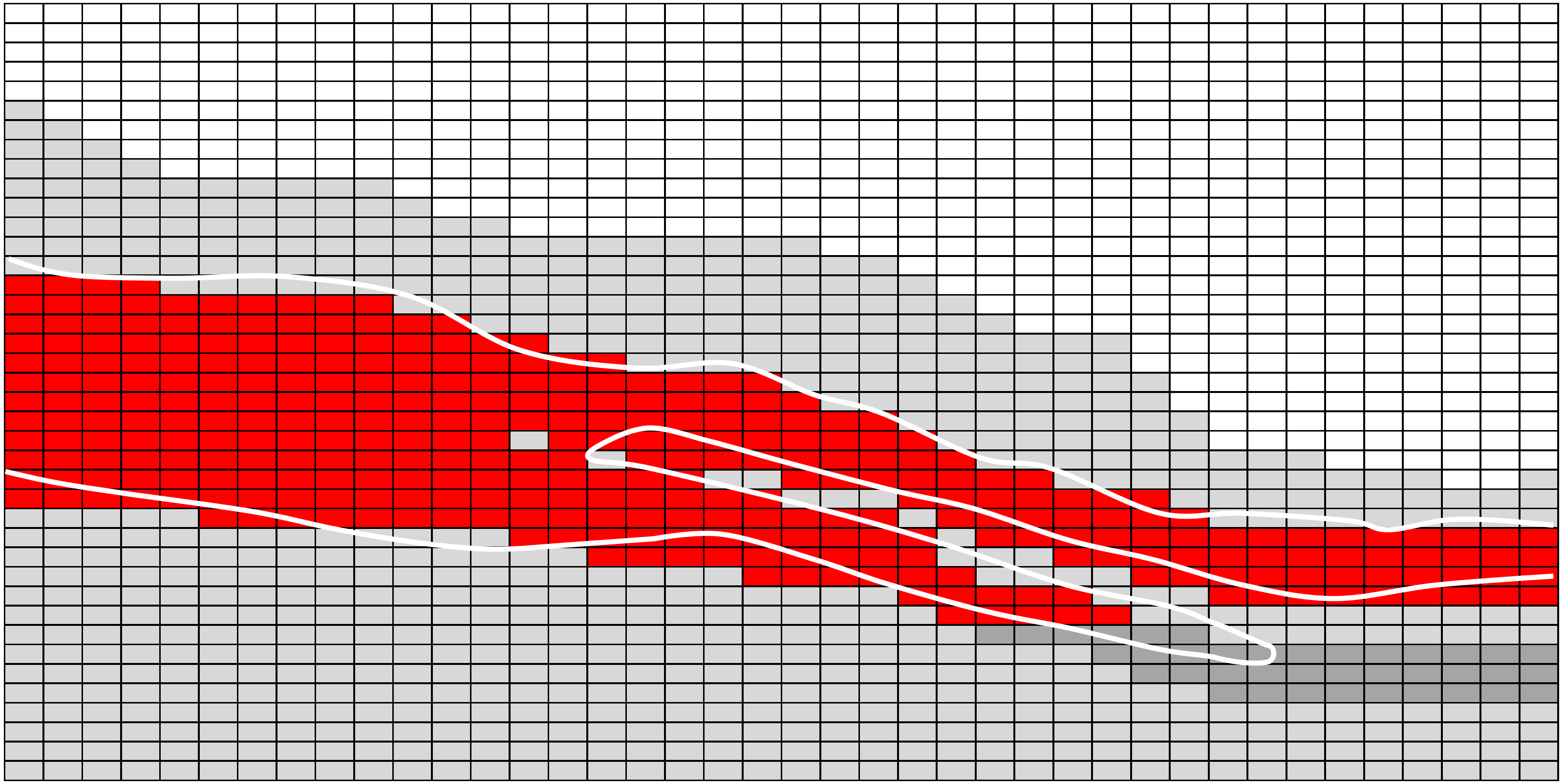

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Example 1: Dolomite

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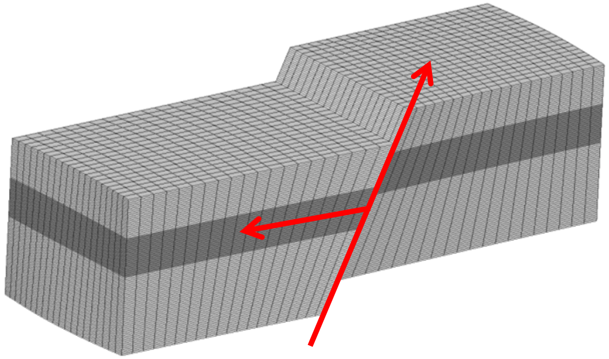
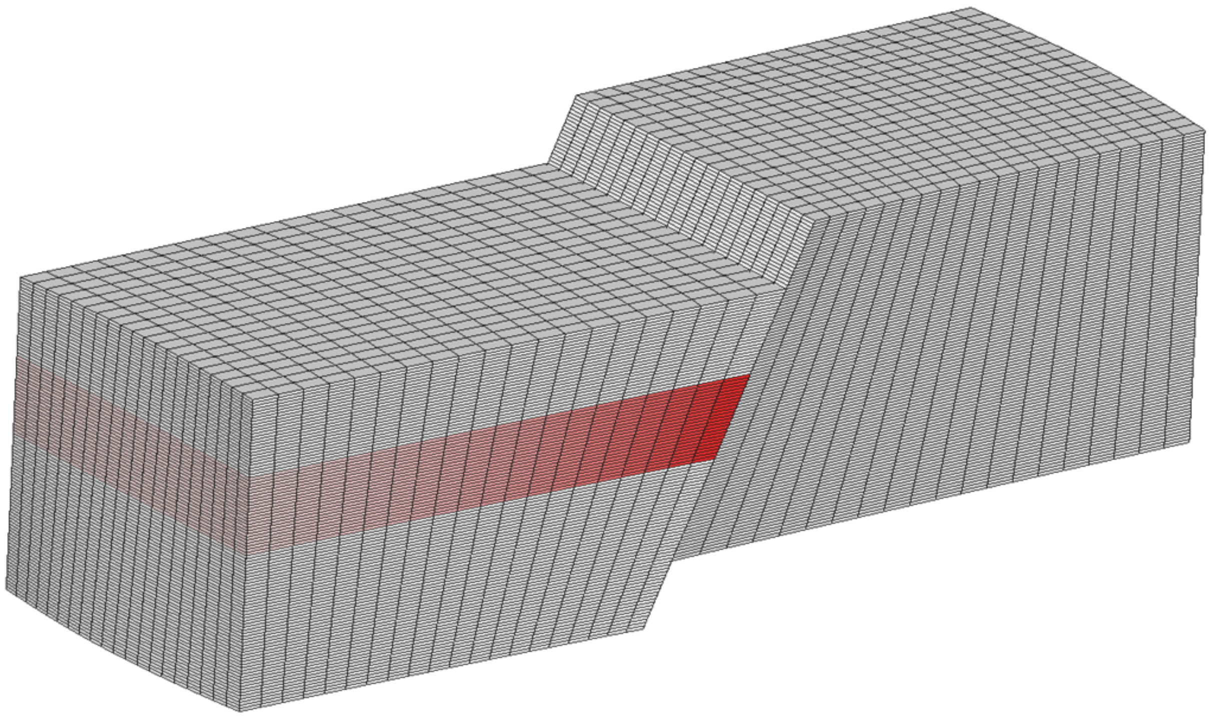
Iterations: 45

Simple 3D models

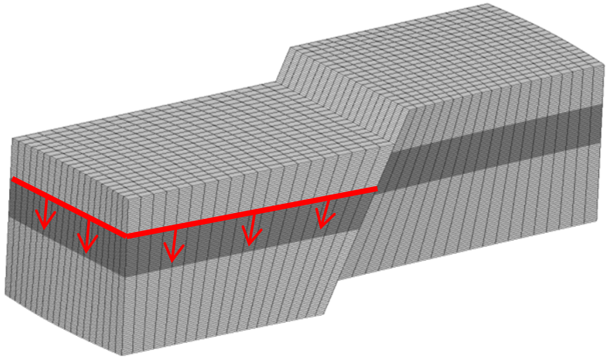
- Fault feeder
- Exponential horizontal trend (1 neighbor)

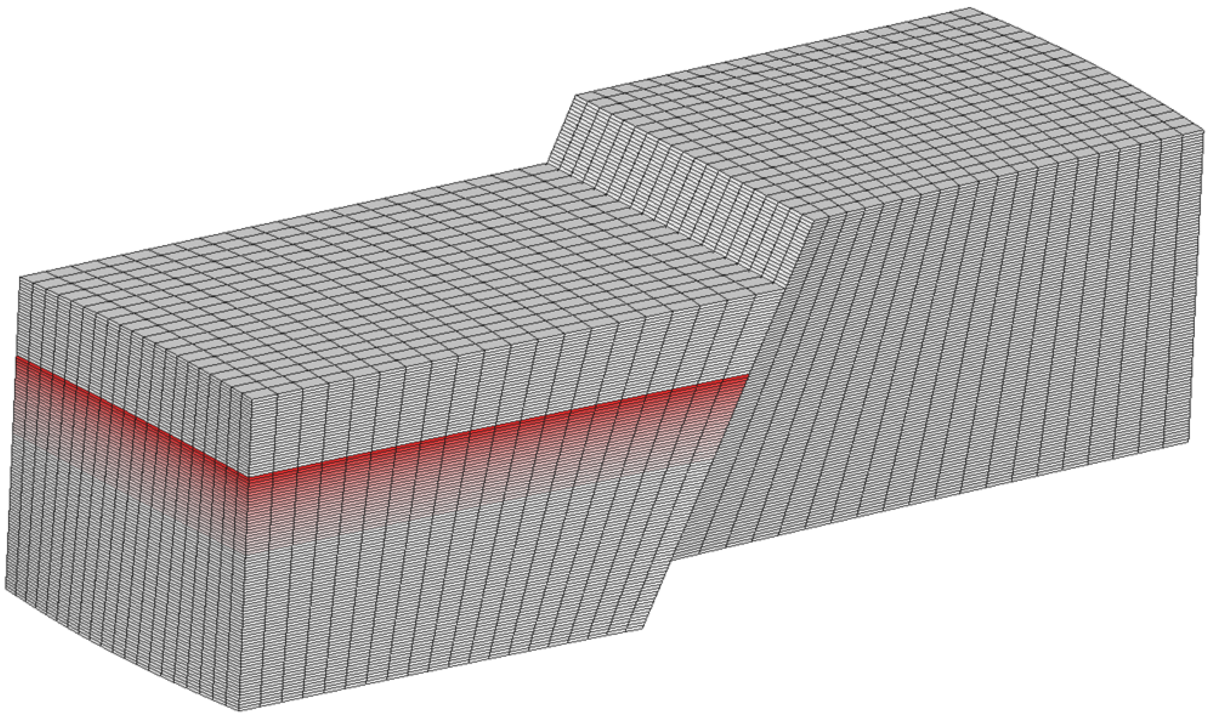




Simple 3D models

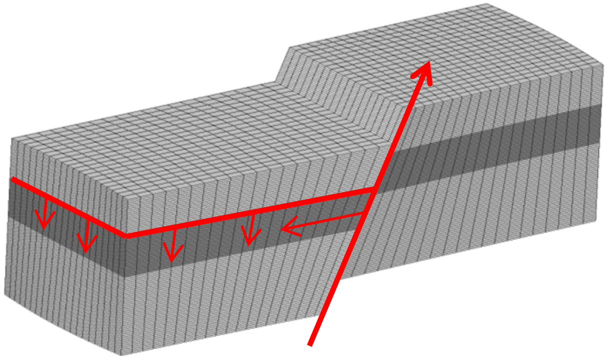
- Horizon feeder
- Exponential vertical trend (1 neighbor)

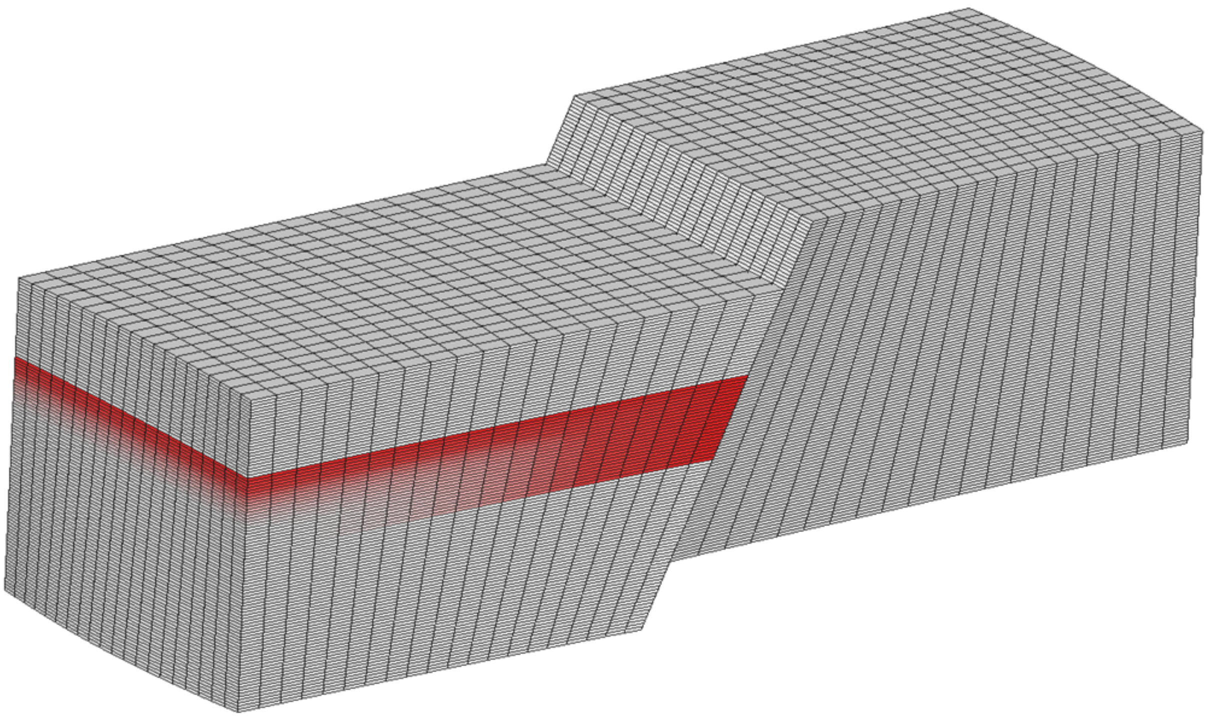




Simple 3D models

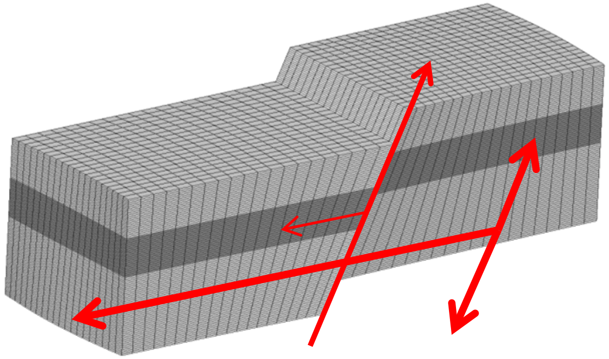
- Combined feeders: Fault + Horizon
- Exponential horizontal and vertical trend (2 neighbors)

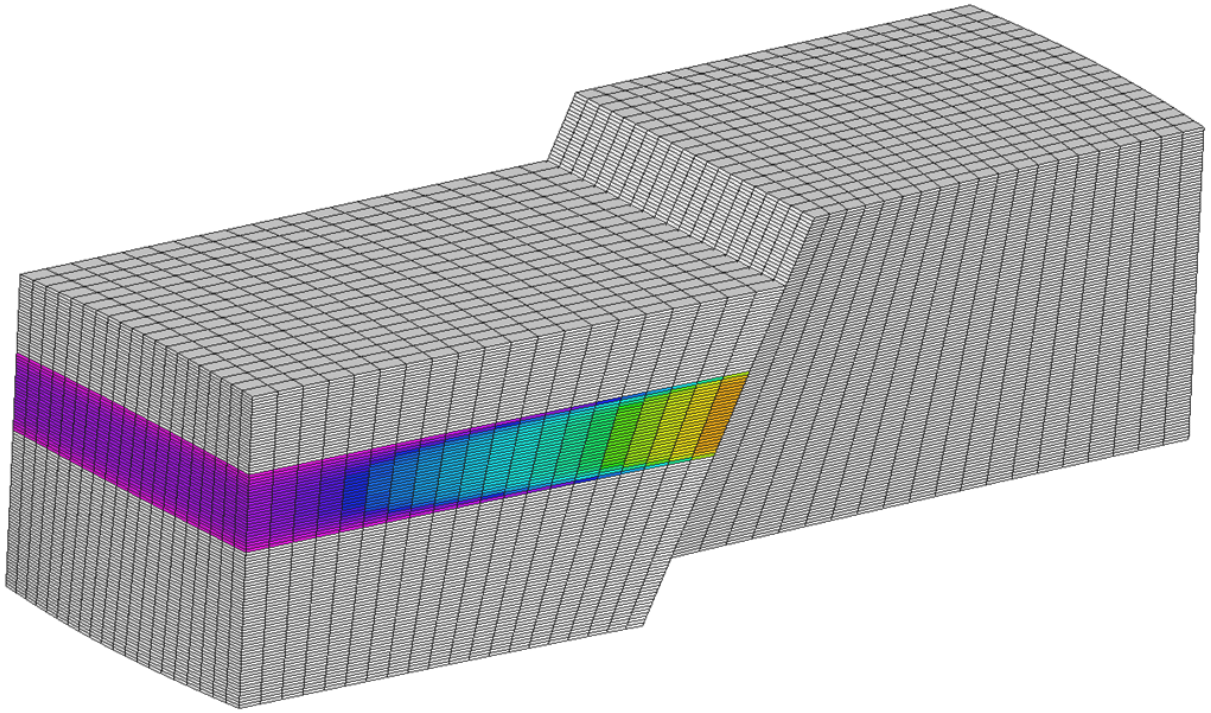




Simple 3D models

- Fault feeder
- Exponential 3D trend (3 neighbors)





Simple 3D models

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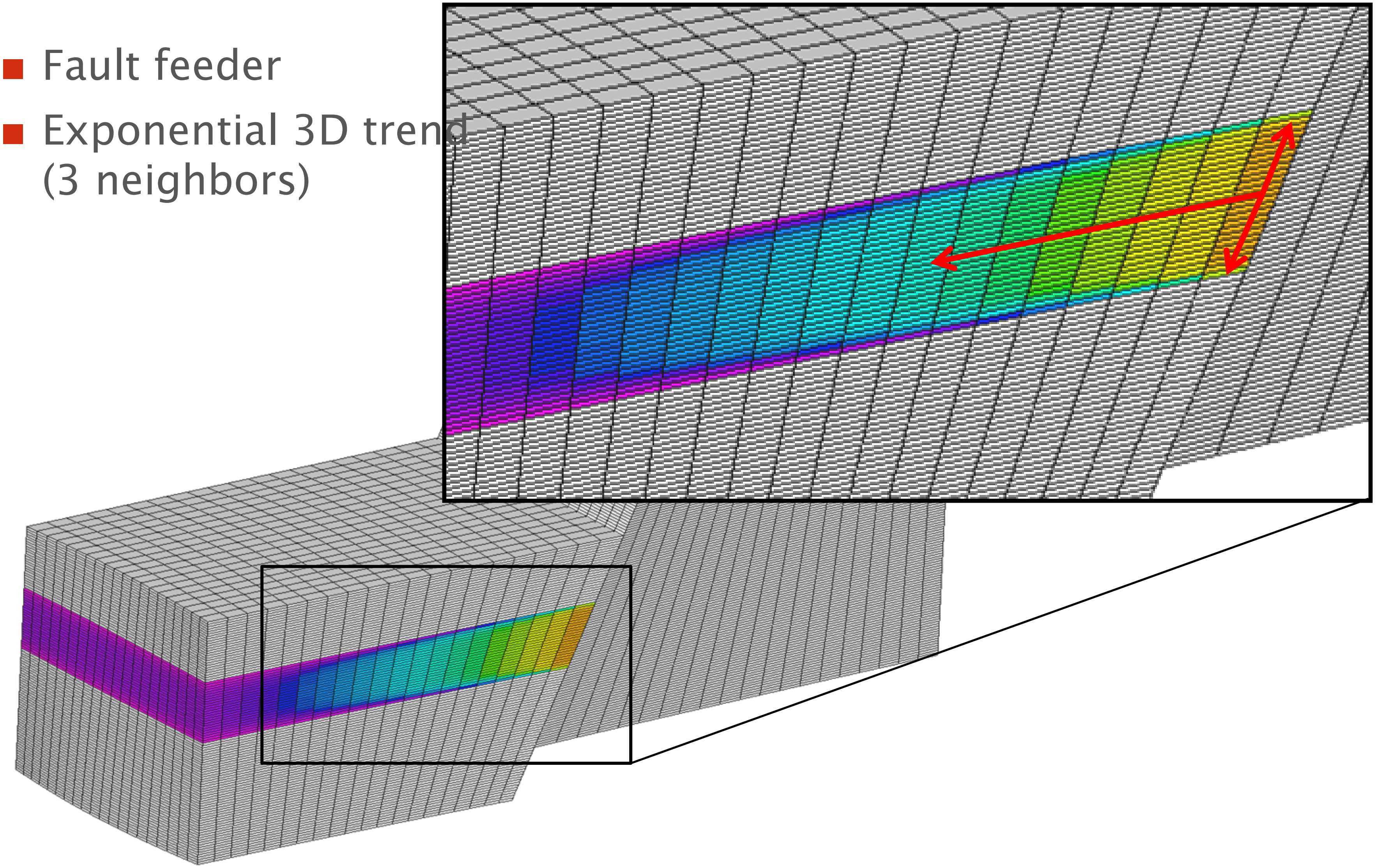
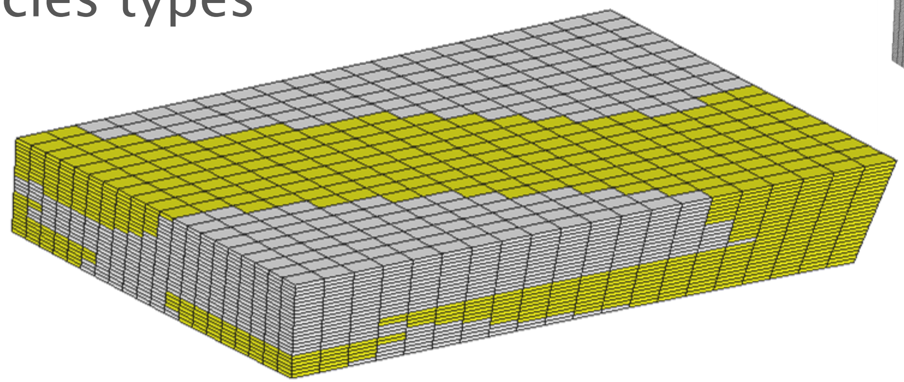
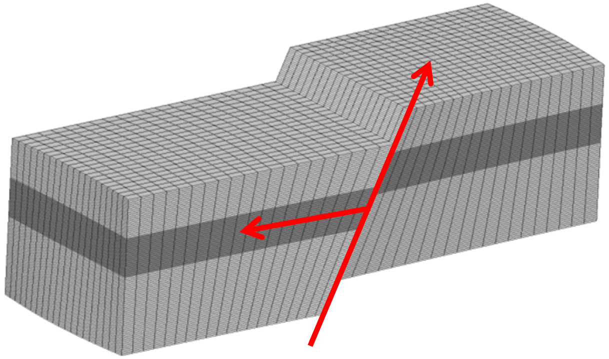


Simple 3D models

- Fault feeder
- Exponential 3D trend
- Two Facies types





Simple 3D models

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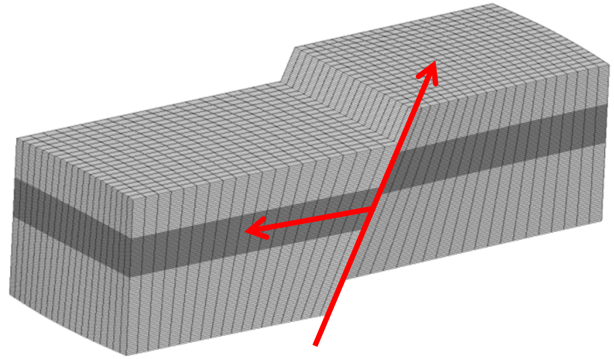
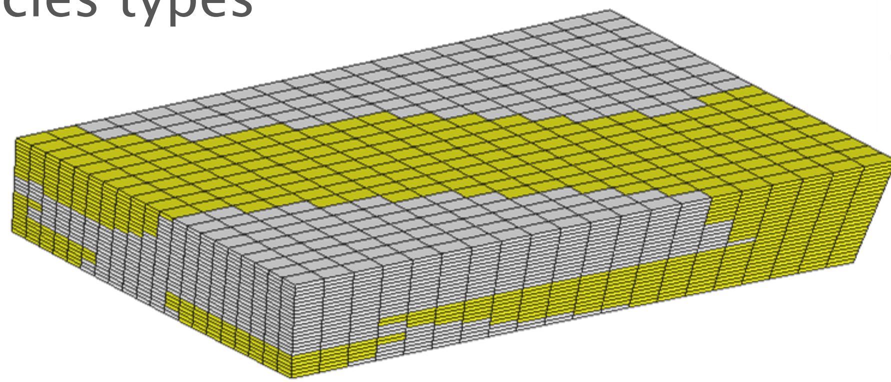
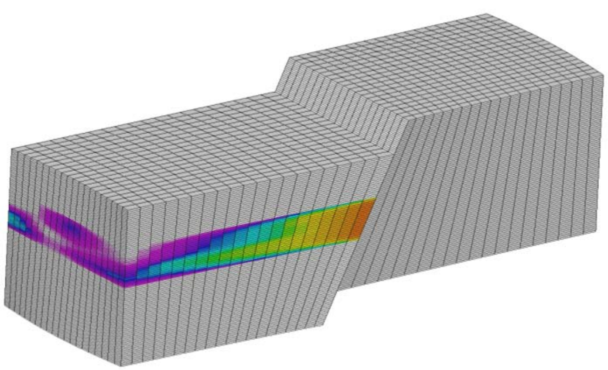
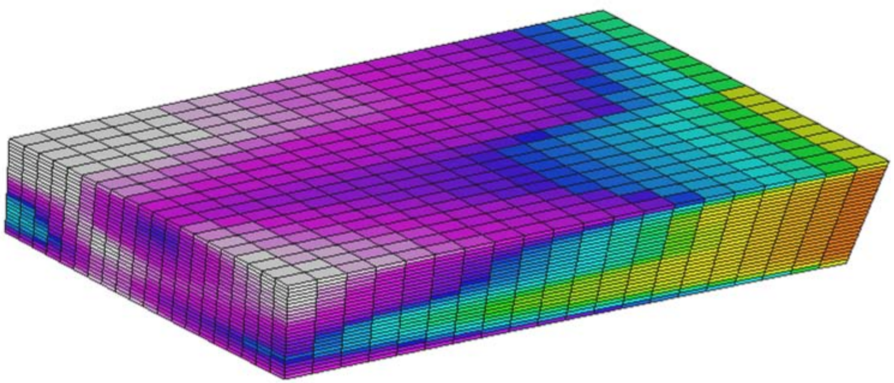


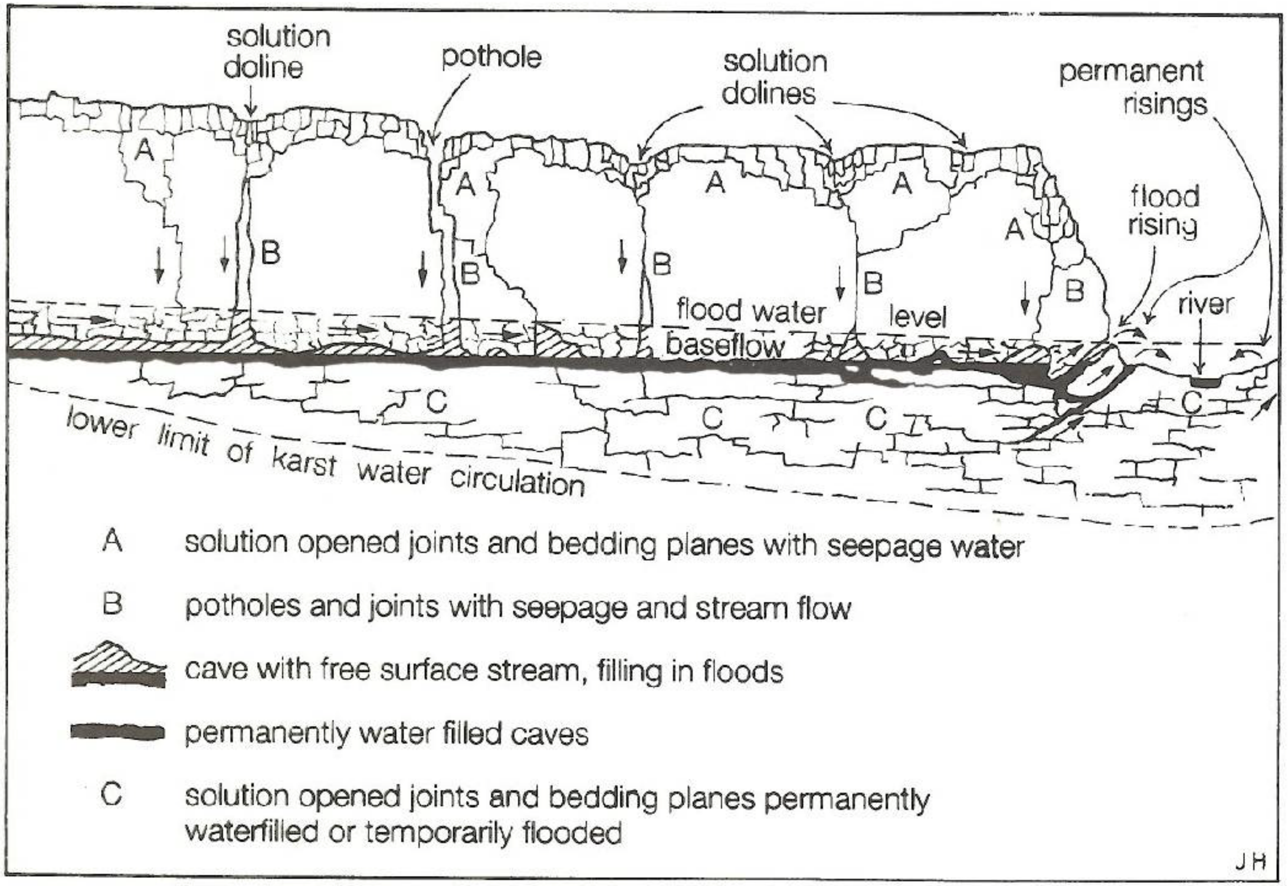






Example 2: Karst (sinkholes)

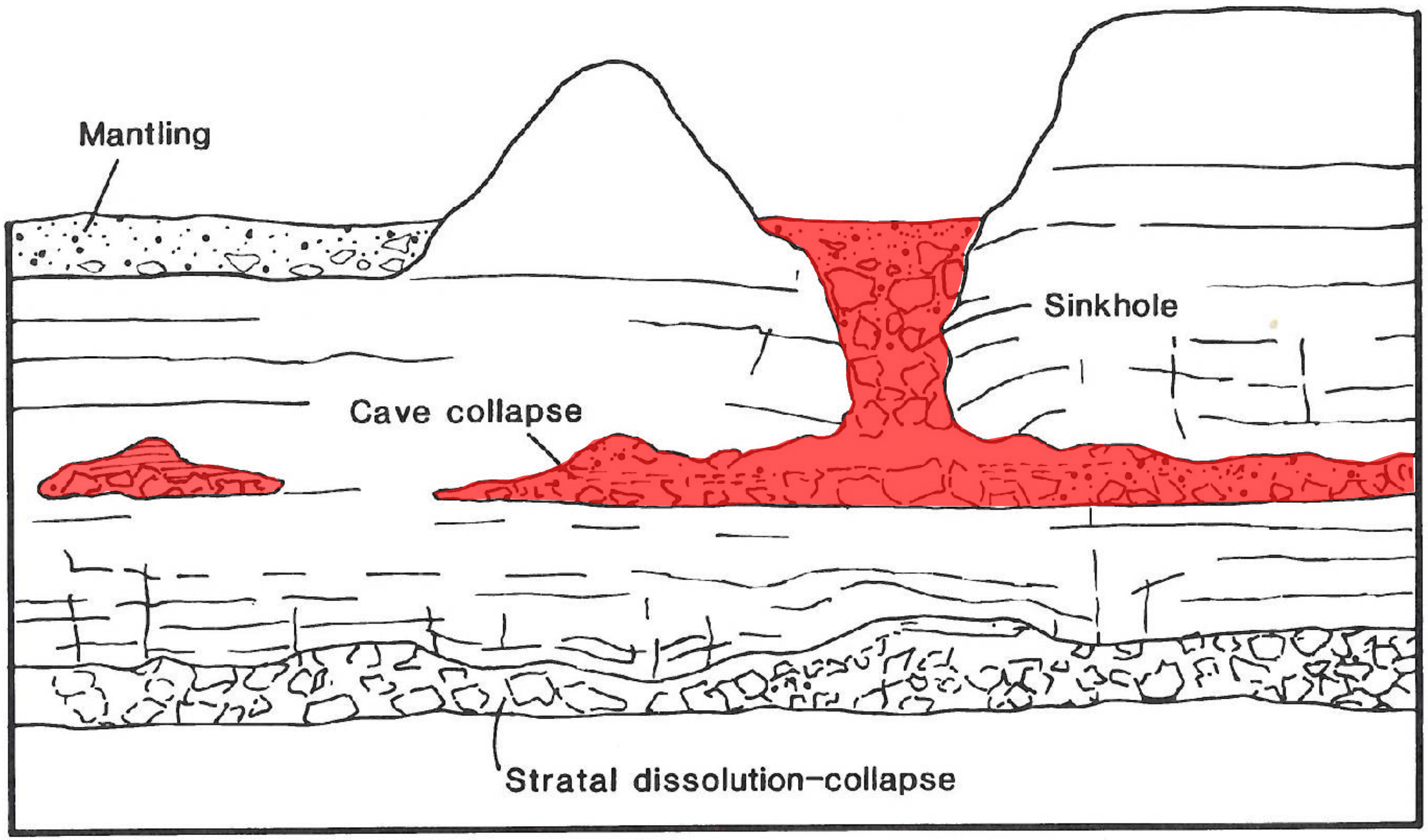
Jennings (1985)



Karst hydrologic system based on the concept of independent conduits, after Cavaillé (1962)

Example 2: Karst (sinkholes)

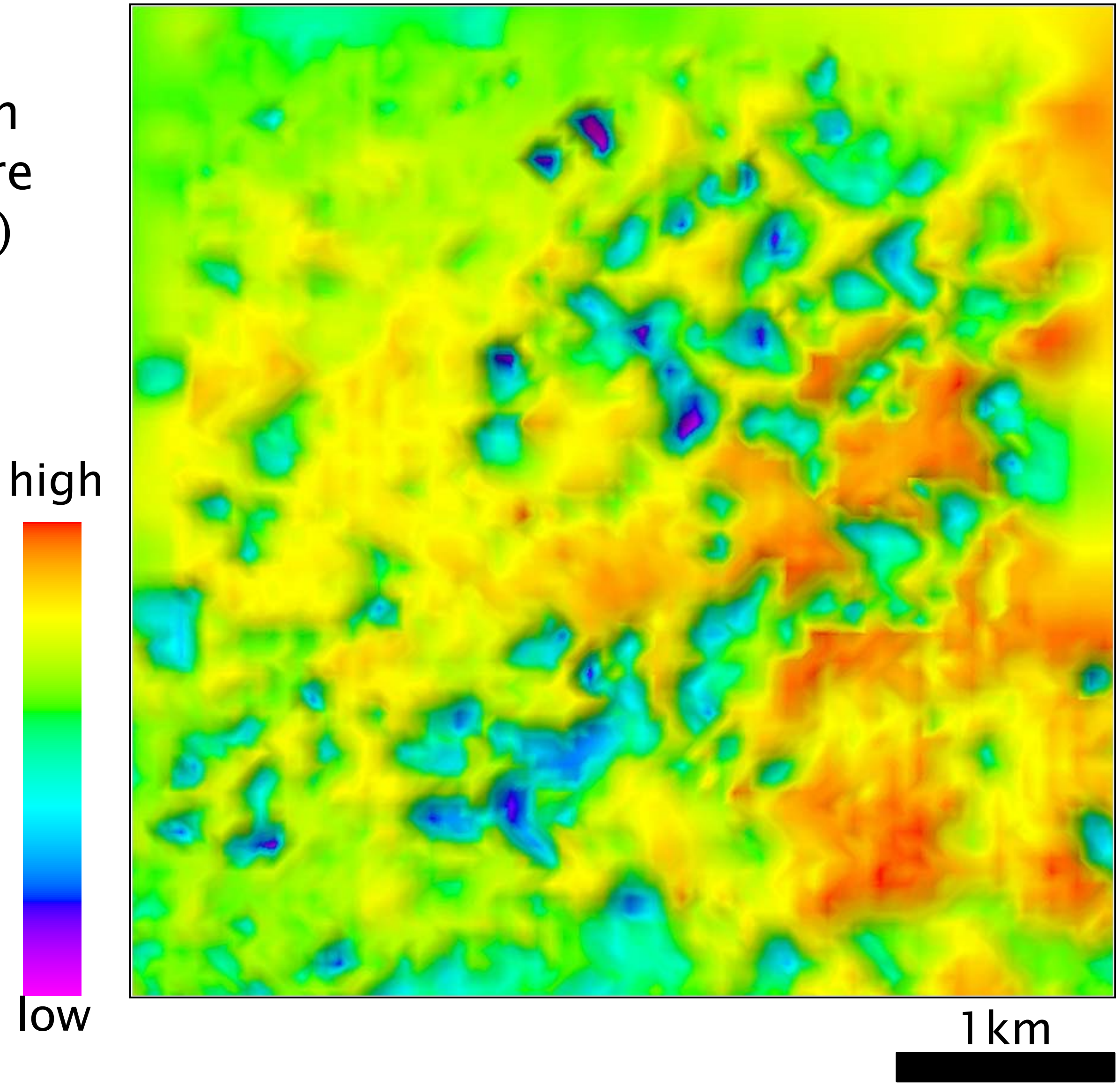
Choquette & James (1985)



Sketch outlining common types of sirface and subsurface breccia in Karst terranes

Example 2: Karst (sinkholes)

Example of karst terrain expressed in 3D seismic structure map (unconformity)



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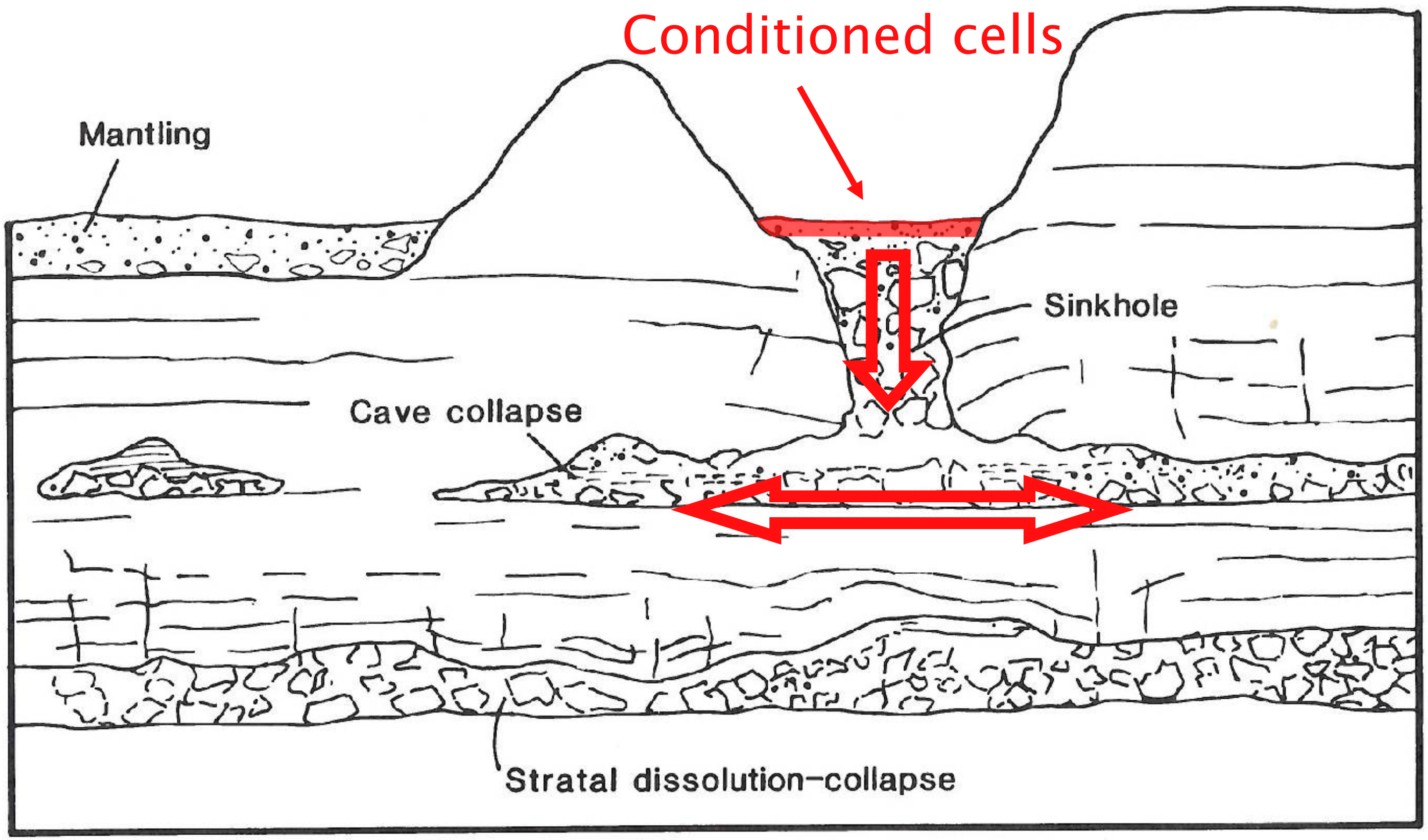

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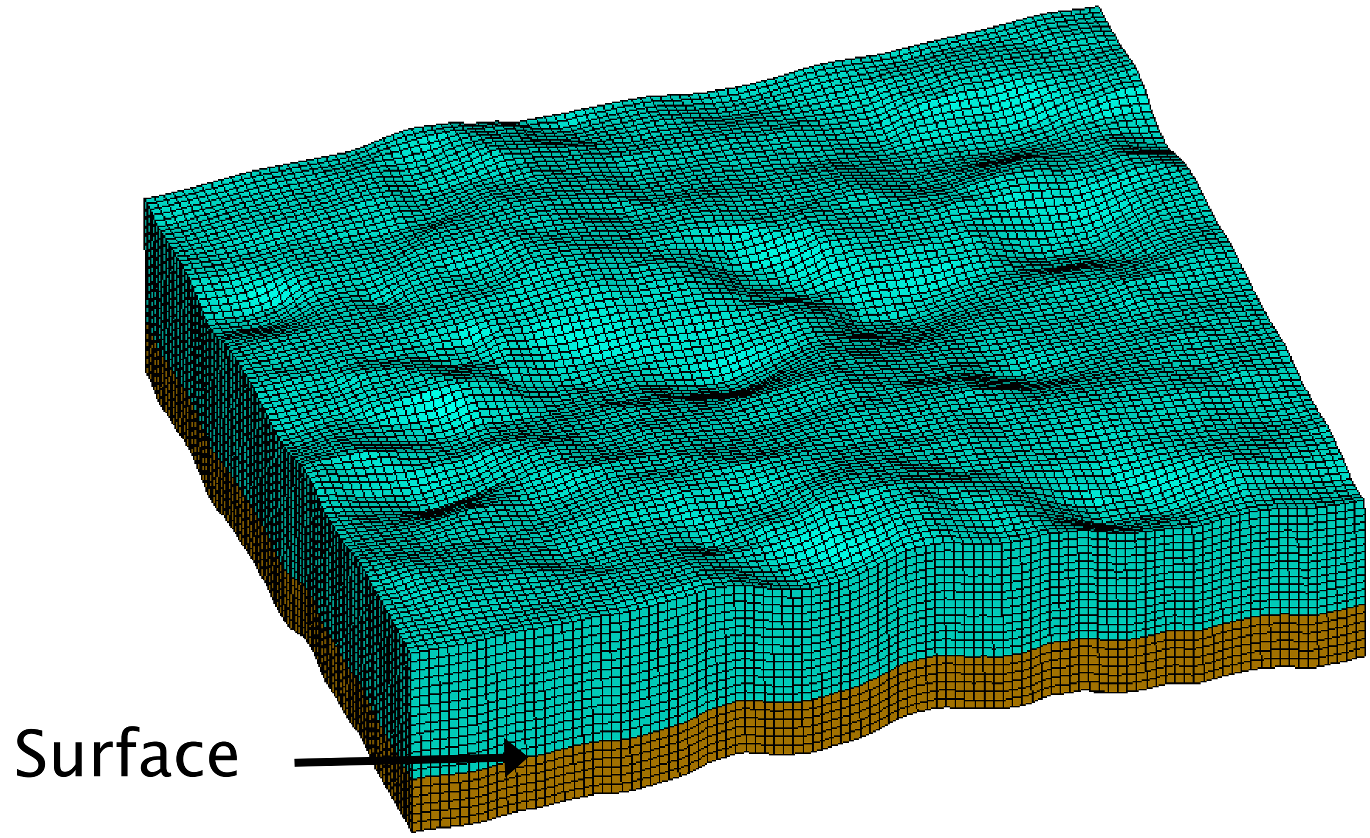
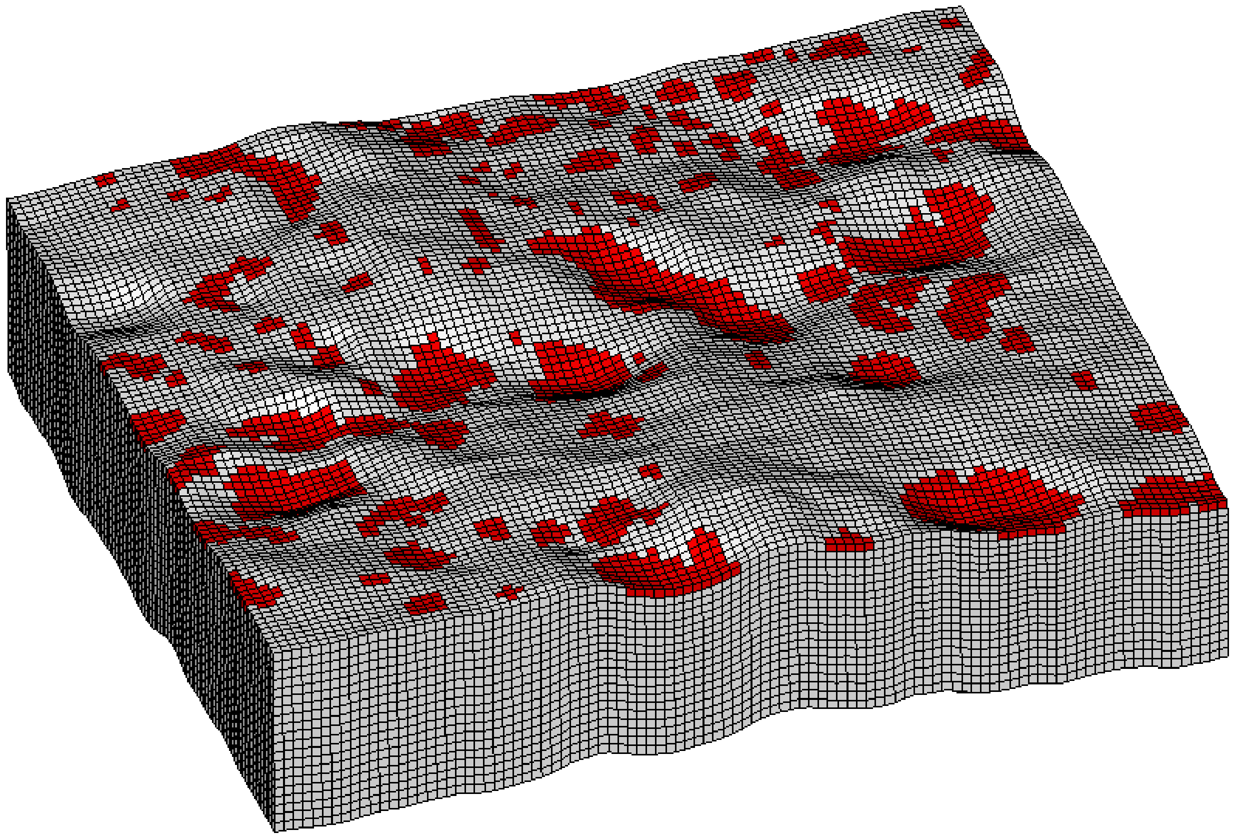


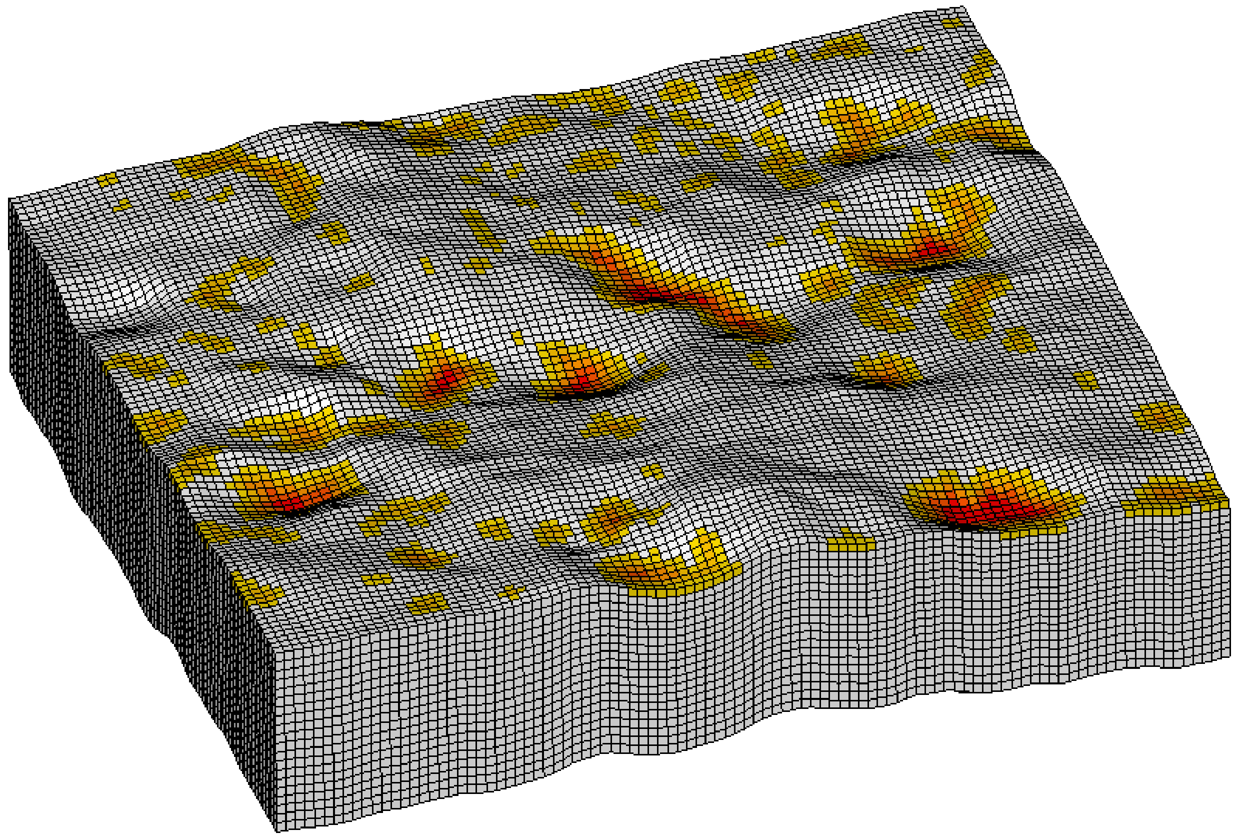
Simple model with two lithologies

Example 2: Karst (sinkholes)



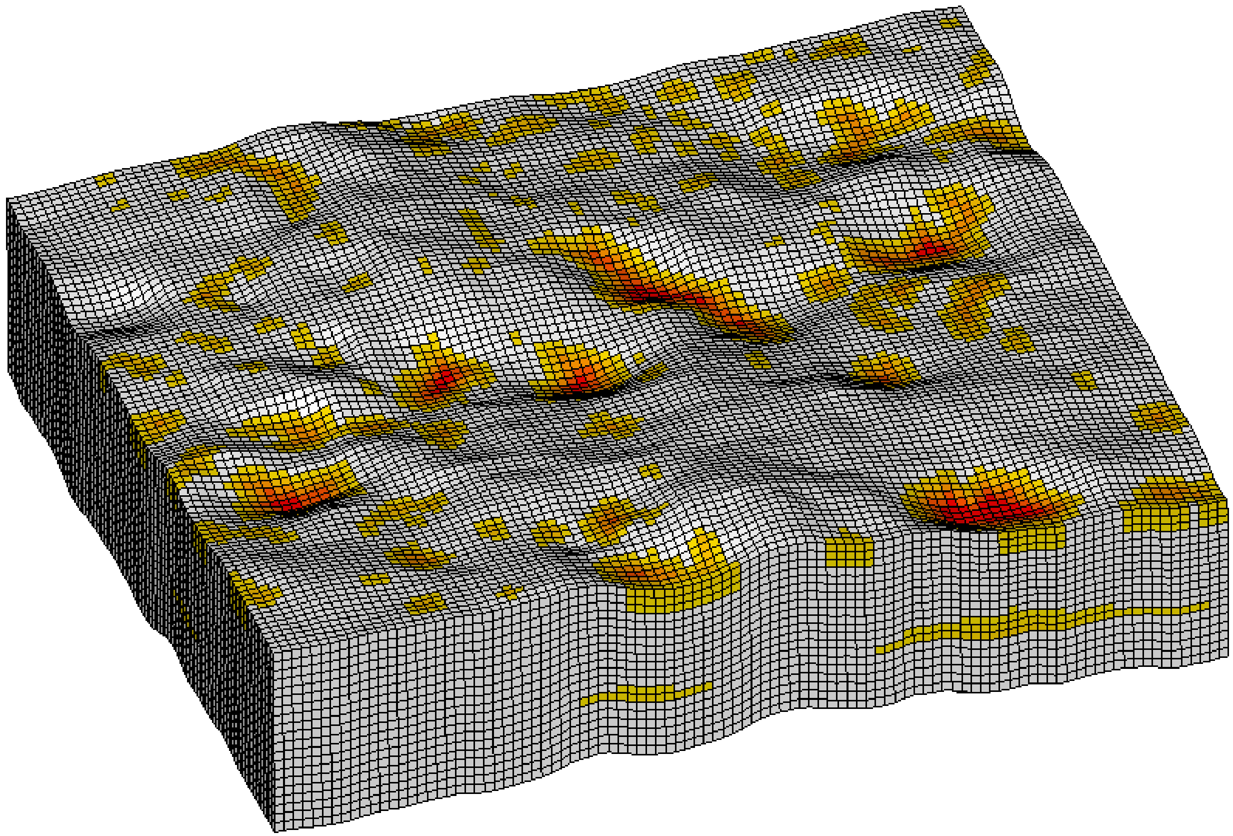
Sinkholes are mapped on the top surface using 3D seismic

Example 2: Karst (sinkholes)



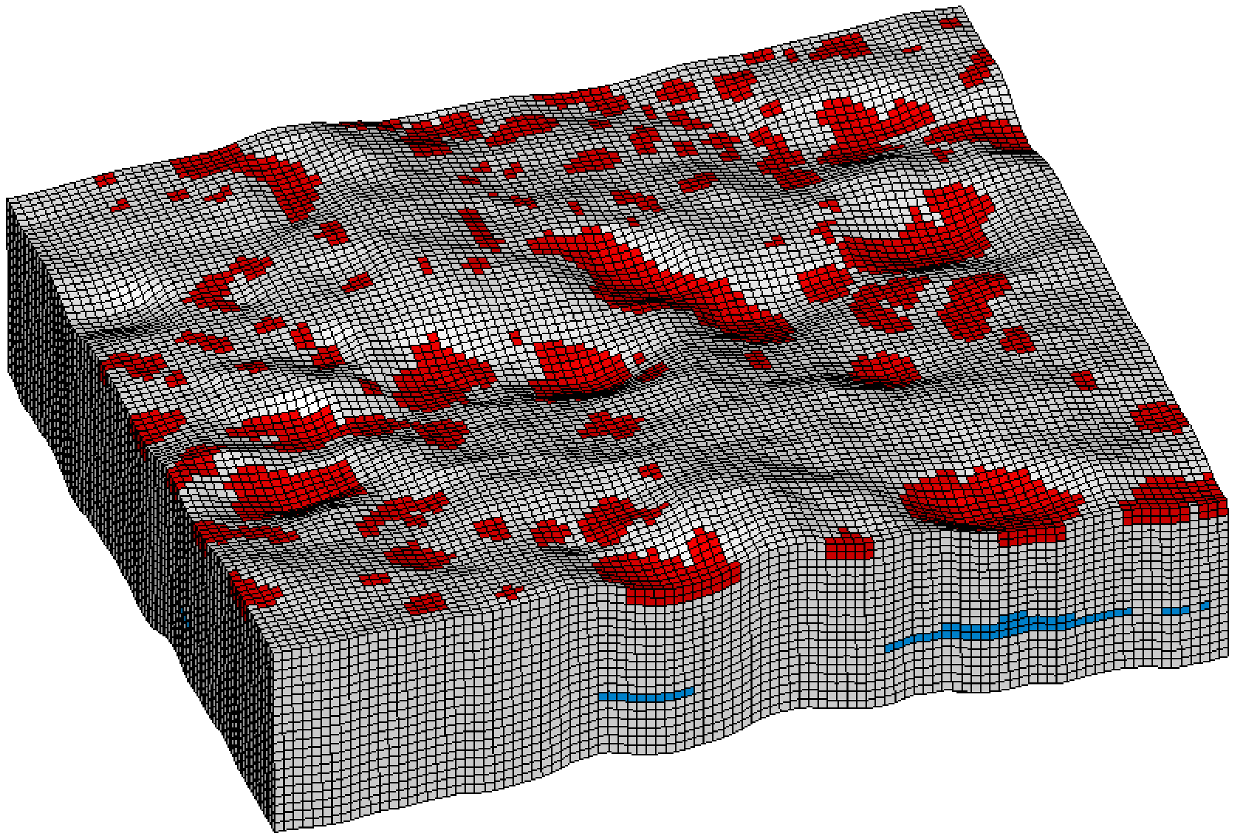
An artificial karst intensity is derived from sinkholes' surface area conditioned cells)

Example 2: Karst (sinkholes)



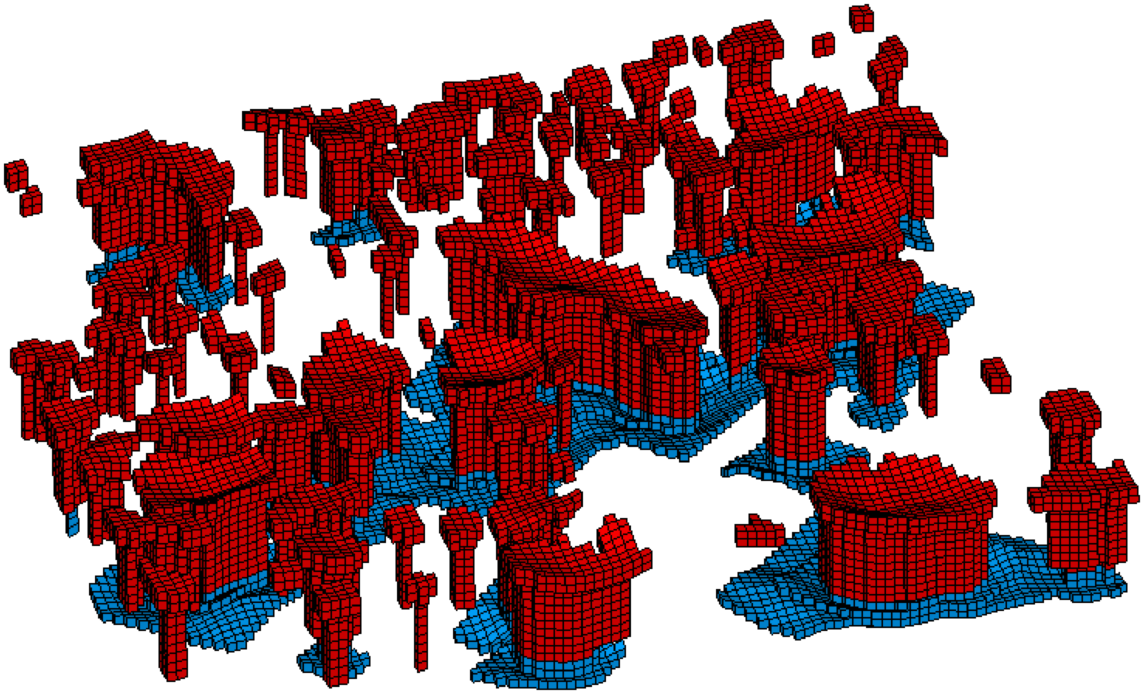
The cellular automata propagate down the pseudo karst intensity in the upper lithology. The stratigraphic contact between the two lithologies acts as a drain (feeder)

Example 2: Karst (sinkholes)



3D karst model

Example 2: Karst (sinkholes)



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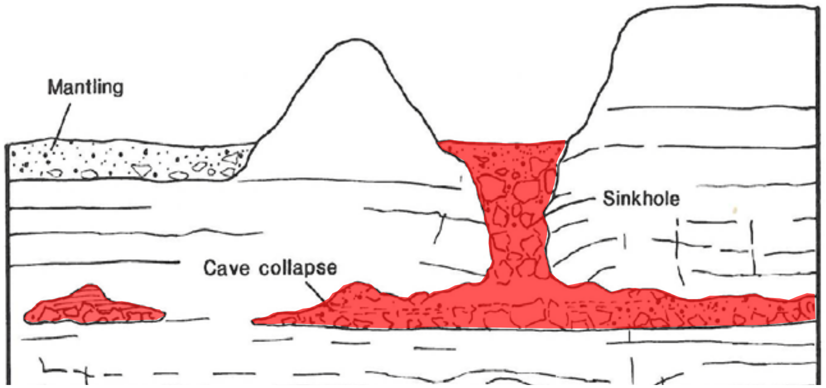

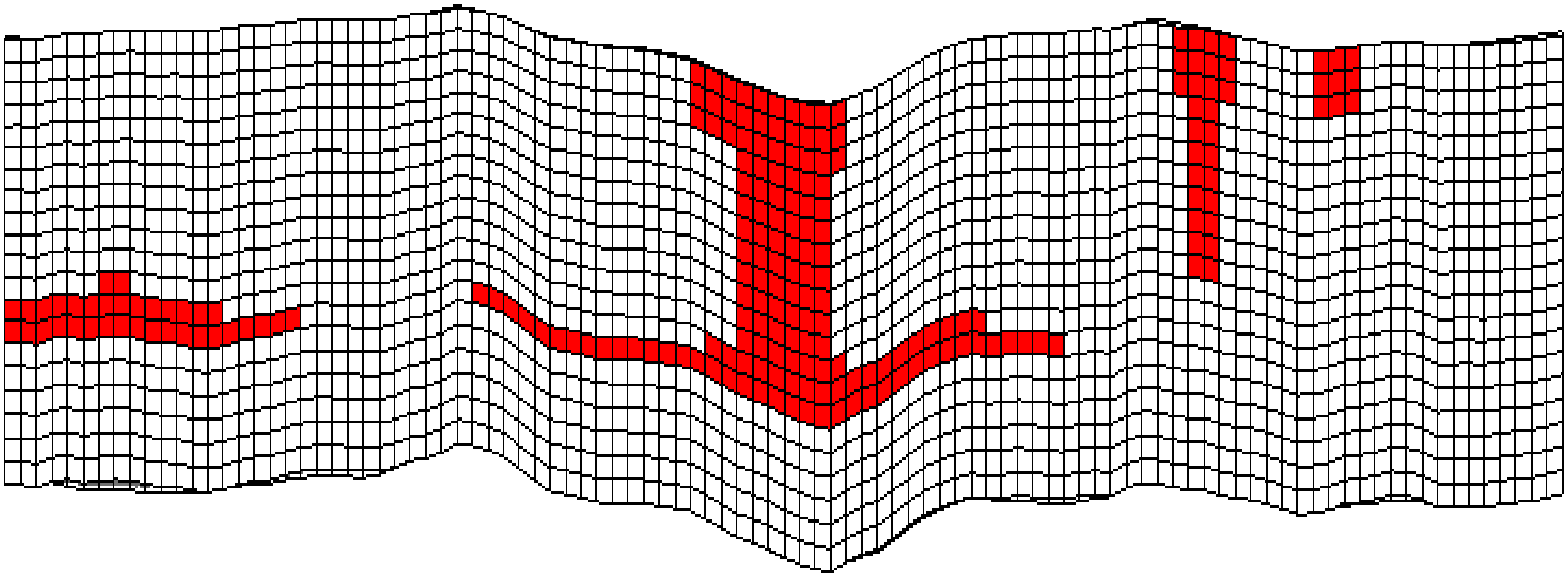

Conclusions

- Cellular automata present important advantages as static modeling tool:
  - The structure of the cellular automata is based on a regular grid of cells (lattice). → Easy to implement in subsurface modeling packages.
  - The cellular automata are scale independent. → Work at the scale of the relevant heterogeneities within a subsurface reservoir.
  - The rules applied to every cell are fixed and are functions of its neighbors. → Conditioning to hard data is straightforward by directly fixing the value for specific cells.
  - Cellular automata are efficient in simplifying processes by postulating cell-based rules. → Make easier the deployment of new technology.
  - Every process which can be discretized in space could theoretically be modeled by a cellular automaton. → Not restricted to specific processes.
- Cellular automata is proposed as an alternative approach for the prediction of fault and surface related diagenetic geobodies.

Conclusions

Number of papers on cellular automata published in geosciences