AN INNOVATIVE METHOD FOR MODELLING THE KARSTOGENESIS IN CARBONATE RESERVOIRS

Gérard J. MASSONNAT

iah • aih 60 years
25-29th September 2016
Montpellier, France
CORUM CONFERENCE CENTER
43rd IAH congress

MODELLING CARBONATE RESERVOIRS

- Because of natural complexity of carbonates :
  - biological aspects of sedimentation
  - usually overprint by diagenetic and fracturing processes

- Which confidence in production forecasts issued from fluids flows simulations in carbonates reservoirs models ?

→ Dedicated methodologies are needed

→ **gOdiag™**, a software for modelling diagenetic products

GODIAG™, A TOTAL IN-HOUSE SOLUTION

- Geological modelling is performed with respect to the successive geological processes that created the reservoir, through a “process-like” modelling

- Dynamic data are used to constrain the geological simulations, through objective functions

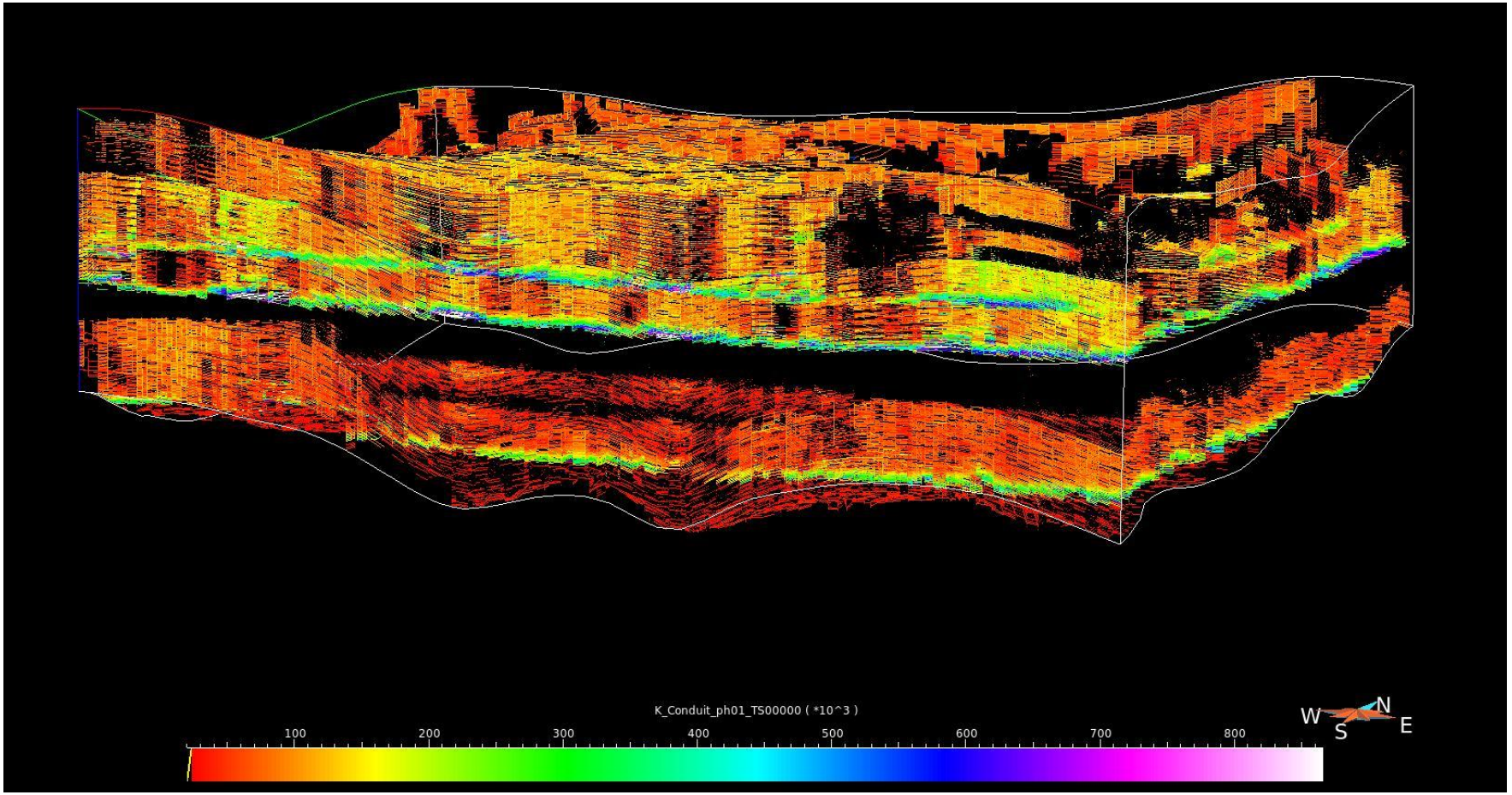
- Connectivity observations, from Seismics or Production history, can be honoured while generating the geological properties

GODIAG^{TM} : MODELLING THE KARSTOGENESIS

- 43rd IAH # 2609 : An innovative method for modelling the karstogenesis in carbonate reservoirs (G. Massonnat)

- 43rd IAH # 1604 : Karst genesis modelling of a regional mediterranean aquifer (Lez, France) (V. Leonardi et al.)

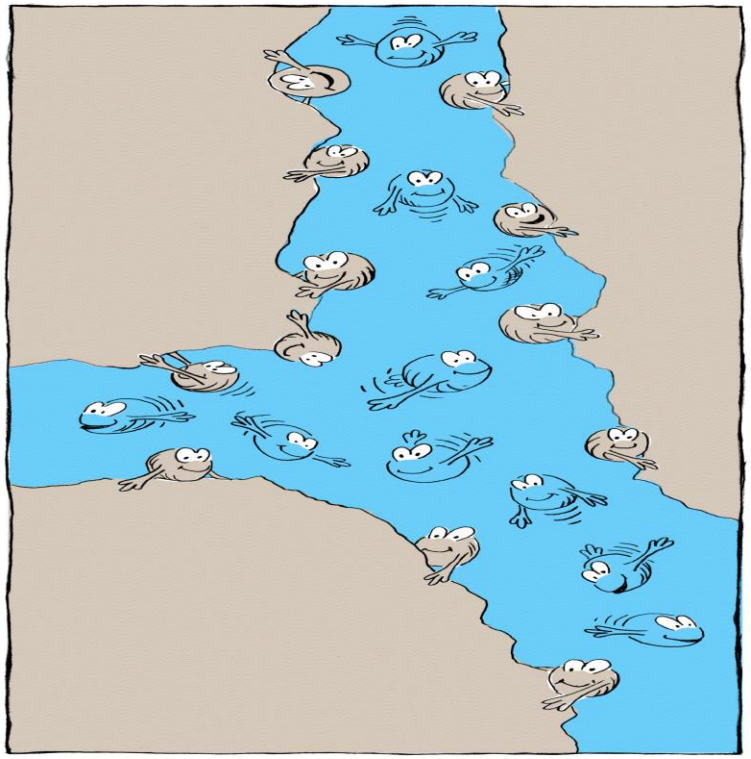
MULTI-STAGES KARST SEQUENCE



GODIAG^{TM} : A CELLULAR AUTOMATON, THE LATTICE GAS

- The fluid flow is simulated through a cellular automaton : the lattice gas

- It enables a triple discretisation :
  - the time by a calculation increment
  - the space through a 3D network of meshes
  - the matter (fluid) represented by particles which can move between the nodes of the network



STOCHASTIC RESOLUTION OF LANGEVIN EQUATION

- The lattice gas numerical methodology enables to transform an original image step by step
- Each new configuration is computed according to deterministic and stochastic rules
- As space, time, and matter (particles) are discretised, the cellular automaton manages the interaction of particles with the displacement of the previous particles
- The simulation reproduces a 3D network in which each particle displacement (a “random walk with memory”) is governed by Langevin equation

EQUATION OF TRANSPORT OF MASS IN SOLUTION

- The transportation of dissolved particles in the liquid phase within an heterogeneous medium can be summarized by 3 main physical mechanisms : advection, dispersion, and dissolution

- These physical phenomena can be described through the equation of transport of mass in solution :

$$\omega \frac{\partial C}{\partial t} + \vec{q} \nabla C + div(-D \nabla C) - Q_c = 0$$

dissolution advection dispersion

ω : total porosity

C : concentration

Q : Darcy flow

D : hydrodynamical dispersion

Q_c : source

THE PARTICLES DISPLACEMENT

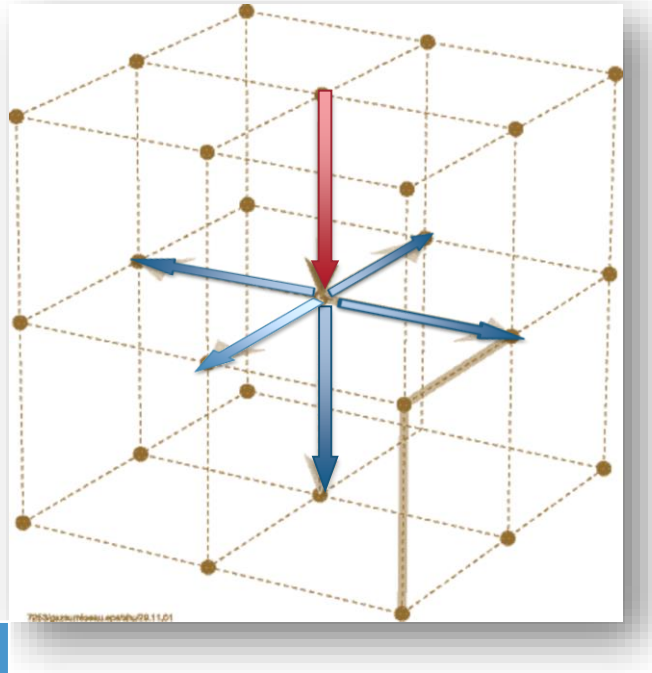
- It is solved by a discrete version of the Navier Stockes equations (numerical solution)

- At each time step, the displacement of particles involves :
  - An advective step
  - A dispersive step

- It is based on a random walk governed by a probabilistic function defined by :
  - The permeability field (matrix + discontinuities)
  - The hydraulic gradient

PARTICLE DISPLACEMENT

At every time-step, each particle moves through two successive steps



Jacquet et Siegel (2004)

	Advective step	Dispersive step
Direction	Deterministic (according to location in space)	Probabilistic (driven by the permeability field)
Occurence	Probabilistic (velocity module driven by permeability)	Deterministic (user choice)
Speed	Normalized (gridblock free)	Normalized (gridblock free)

GODIAG™ OBJECTIVES

- Produce a dual medium with matrix and conduits
- Generate diagenetic products with integration of data and knowledge
- Take into account pre-existing heterogeneity (facies, fractures and beddings)
- Manage multi-stages diagenetic sequences
- Manage several types of reactions (dissolution, cementation, mineral changes,…)
- Upscale reservoir properties for dual-medium fluid flow simulations

KARST MODELLING CHALLENGES AND STRATEGY

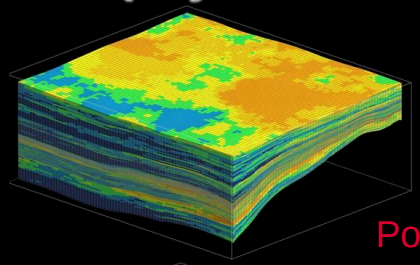
- The final 3D distribution of Petrophysics in a karstic reservoir must be consistent with :
  - the primary distribution of facies and petrophysics before dissolution,
  - the bedding discontinuities,
  - the fractures and other tectonic discontinuities,
  - the evolution of the water table, the hydraulic gradient, the aquifer zonation,
  - and all water flow rules within the groundwater reservoir,
  - the karst origin, history, and level of maturity.

"The heterogeneity of the karstic medium leads to a needs : the construction of models using geological rules and geostatistics in 3 dimensions, in order to deliver realistic answers to questions initiated by water flows in karst systems."

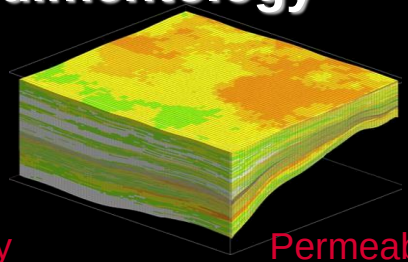
(A. Mangin, 1973)

GODIAG™ INPUT DATA

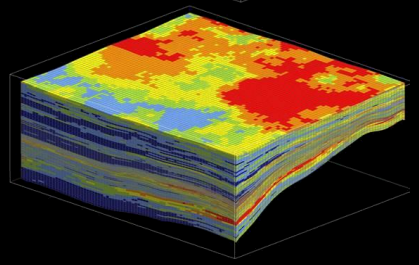
Petrophysics and sedimentology



Porosity



Permeability



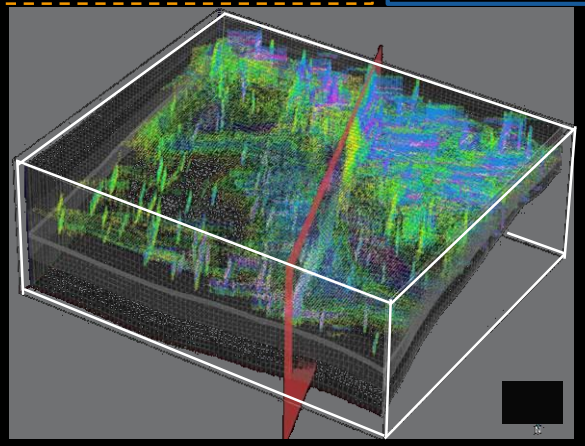
Facies

Diagenesis history

Dissolution

Cementation

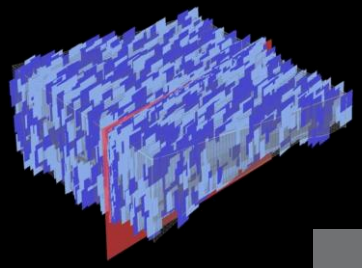
Mineralogy modification



Velocity module (matrix + conduit)

Discontinuities

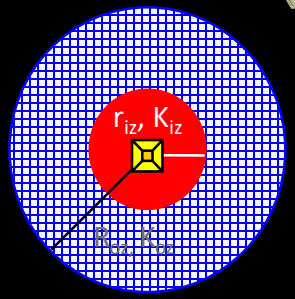
Fractures Network



Bedding and/or barrier

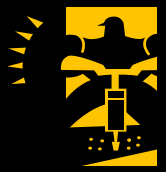
Simulation parameters

Time

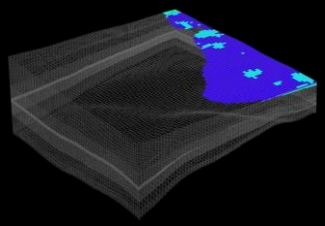


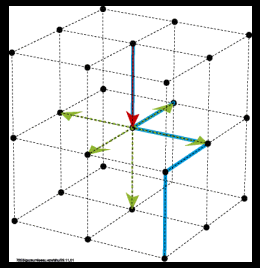
Dynamic data

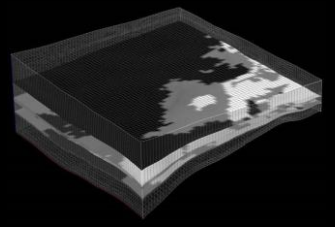
Fluid effects



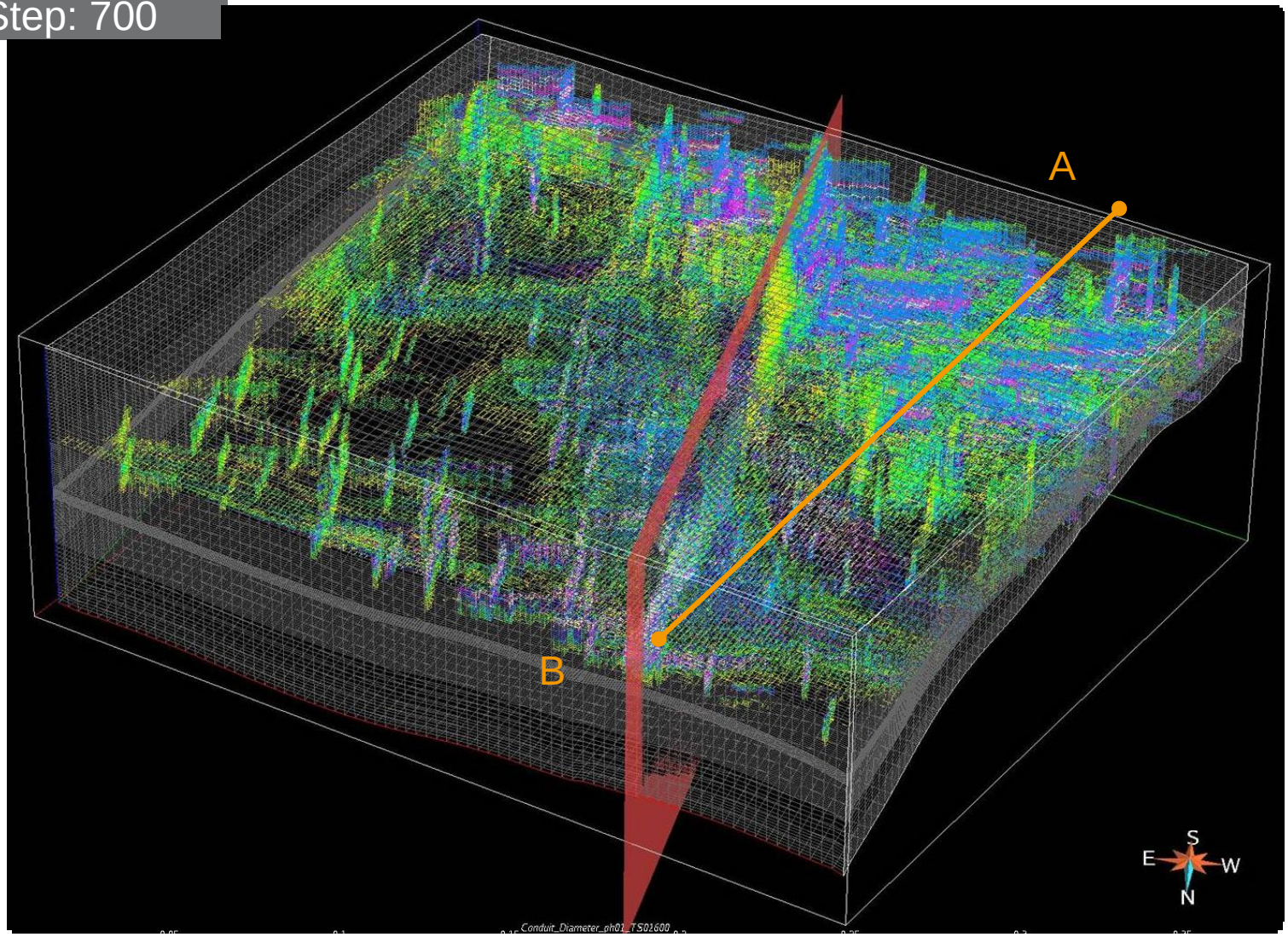
Infiltration







EPIGENIC (METEORIC) KARST : 3D CONDUITS NETWORK



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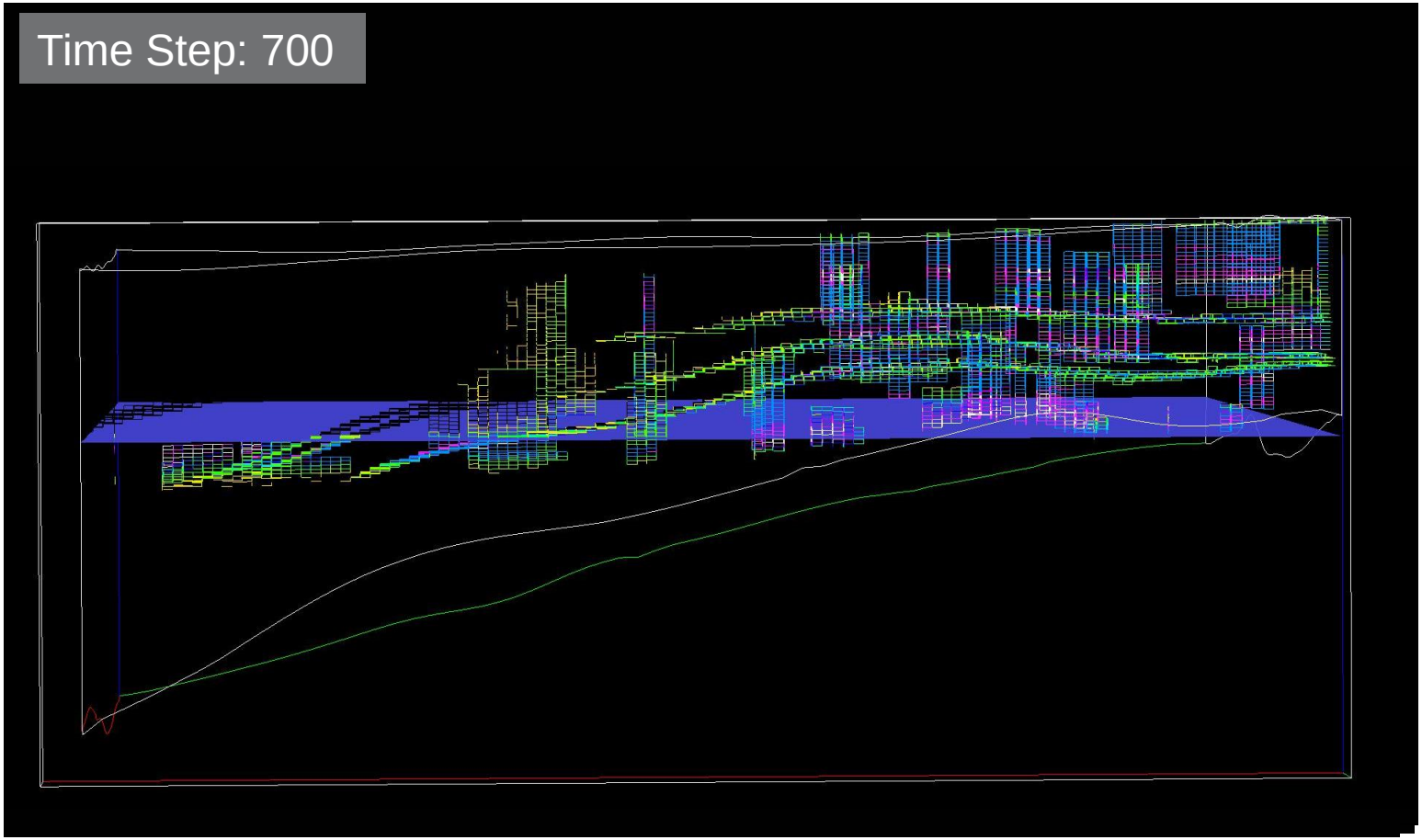
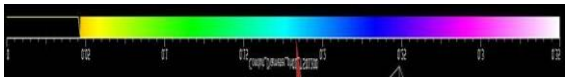
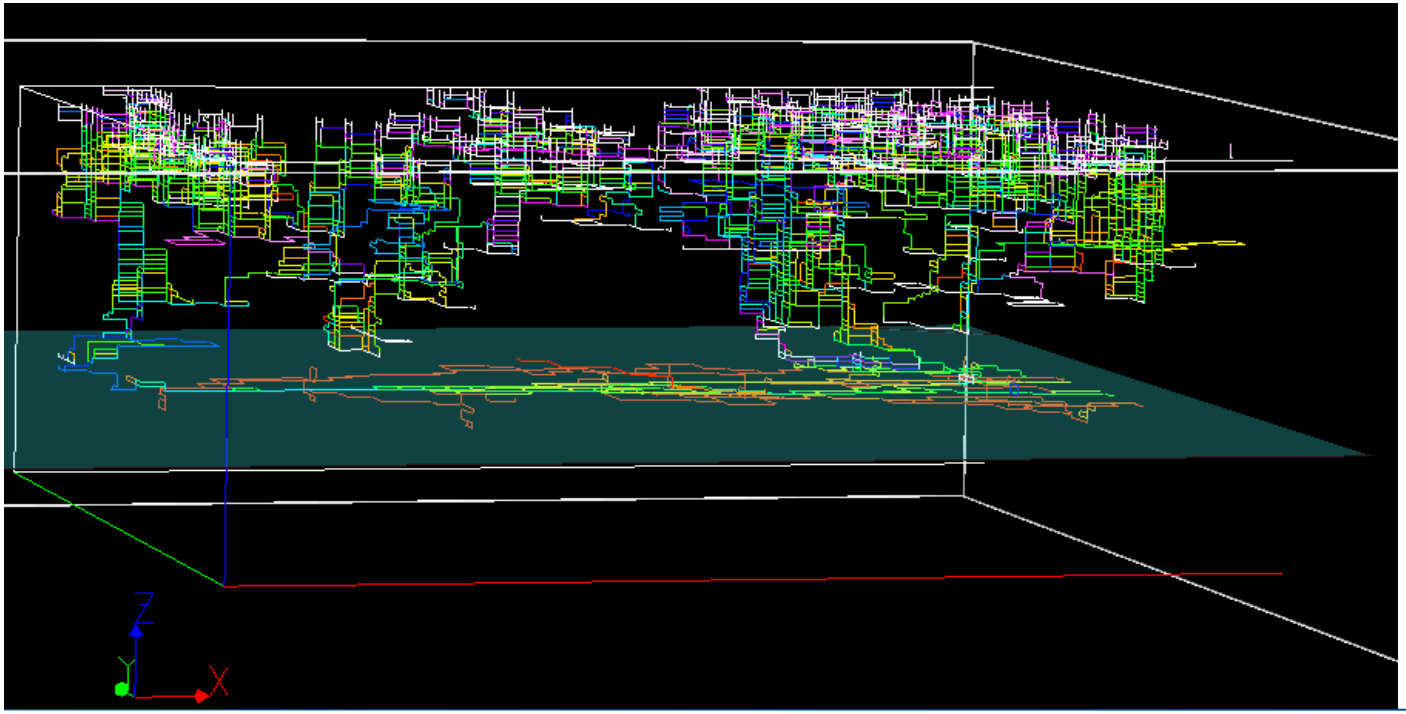


Conduit diameter evolution (m)

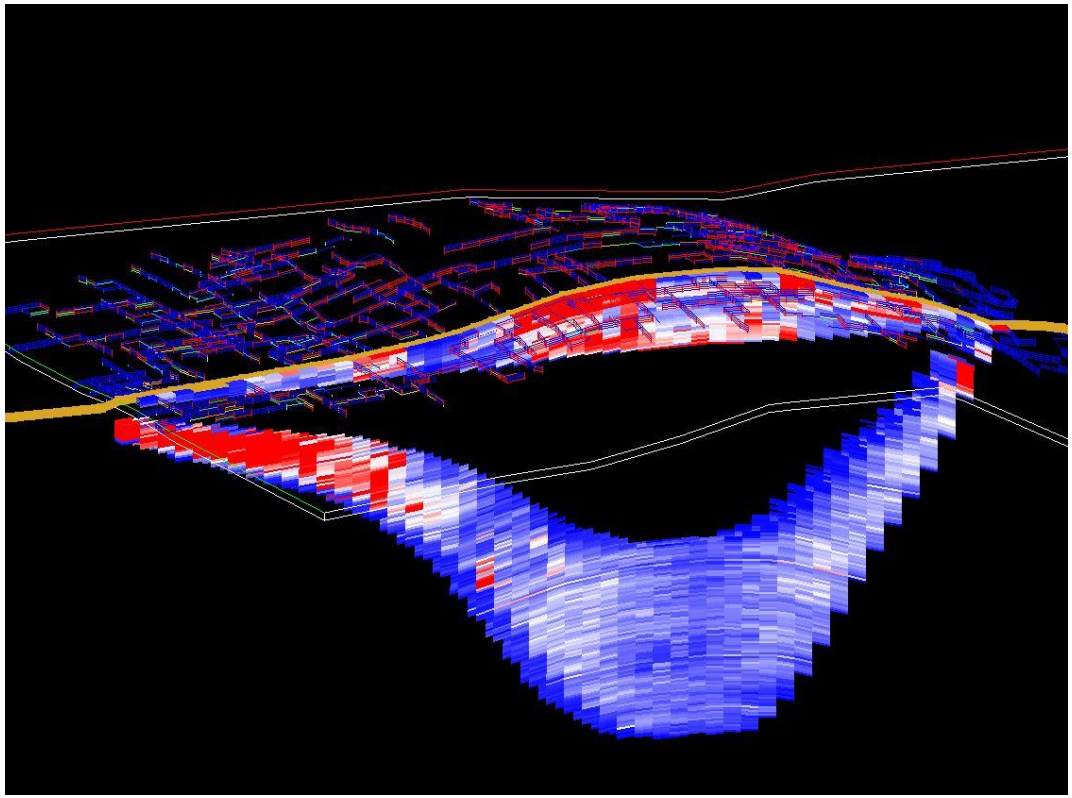


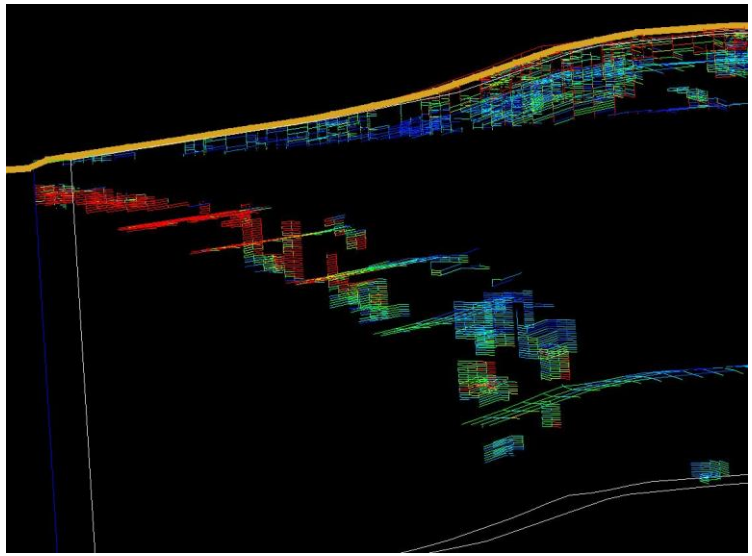
The development of karstic conduits uses pre-existing fractures and beddings

ZONATION IN THE EPIGENIC (METEORIC/PLATEAU) KARST



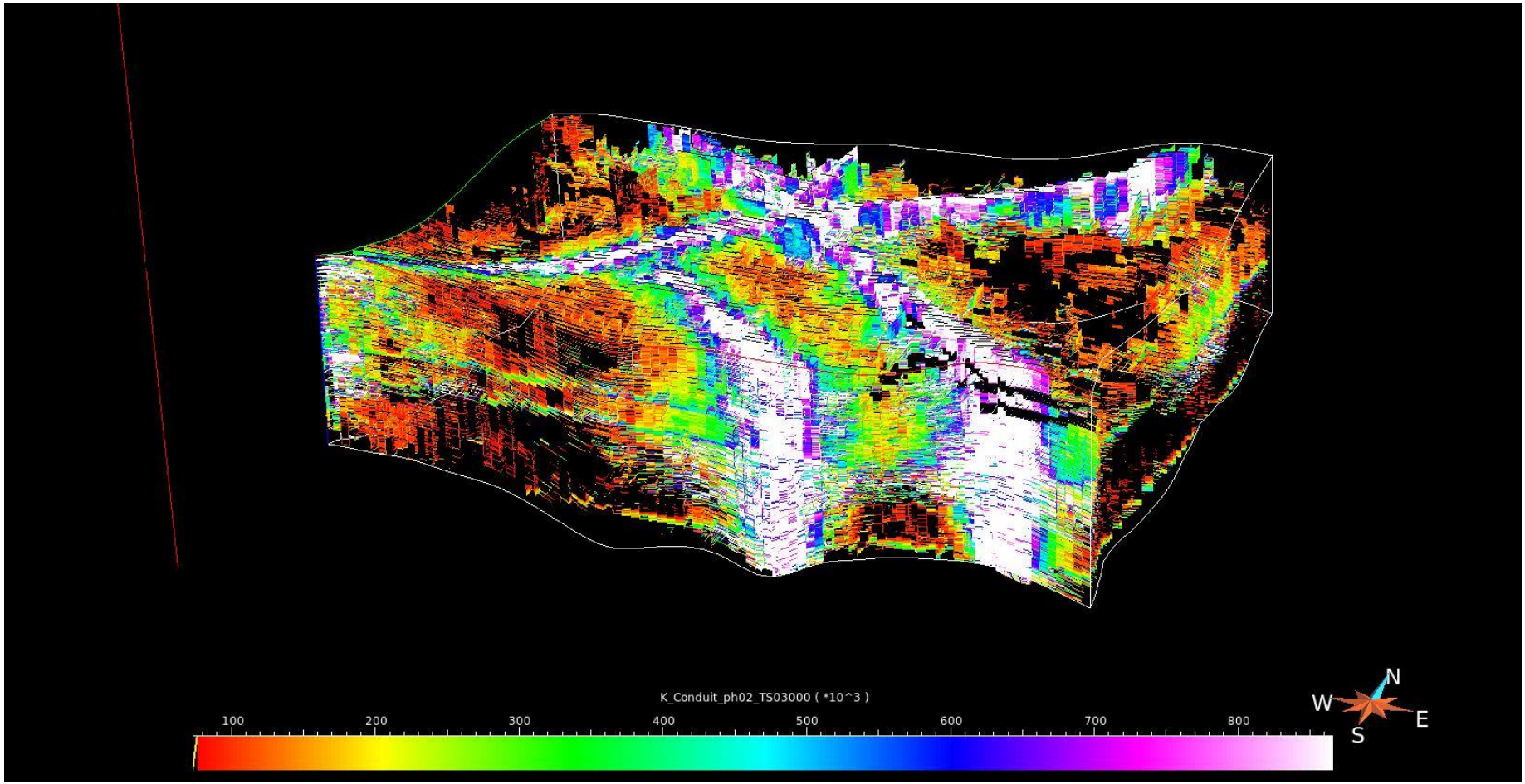
ISLAND KARST : DISSOLUTION IN THE MIXING ZONE



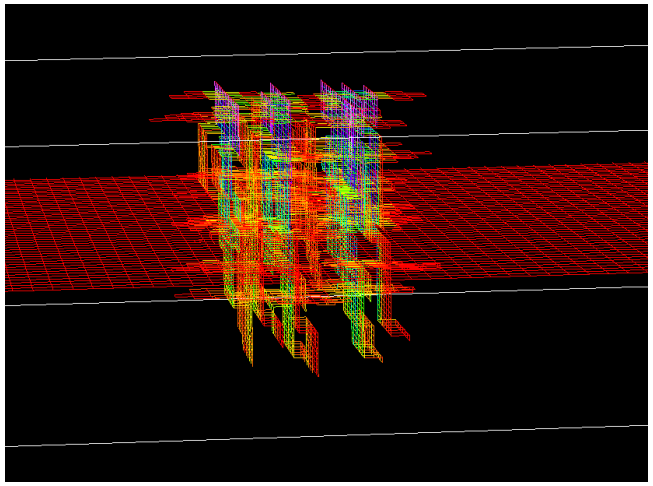


Dissolution or dolomitisation can occur in the mixing zone (fresh water lens). **gOdiag™** reproduces these effects in both the matrix and in discontinuities.

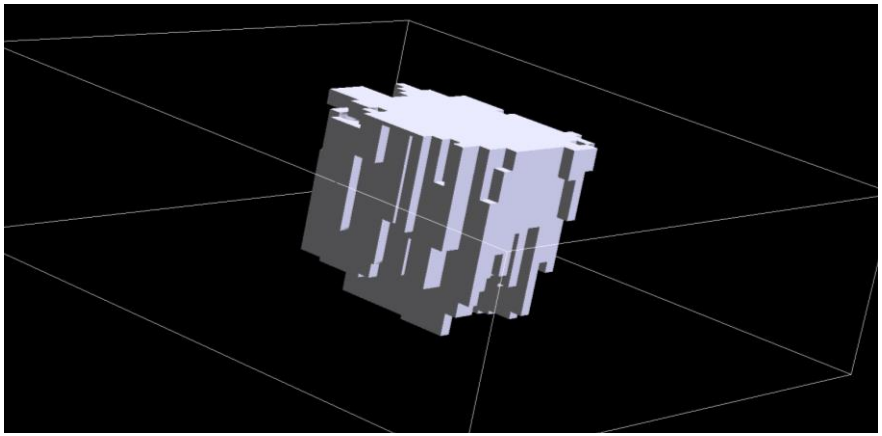
HYPOGENIC KARST : HYDROTHERMAL PROCESS



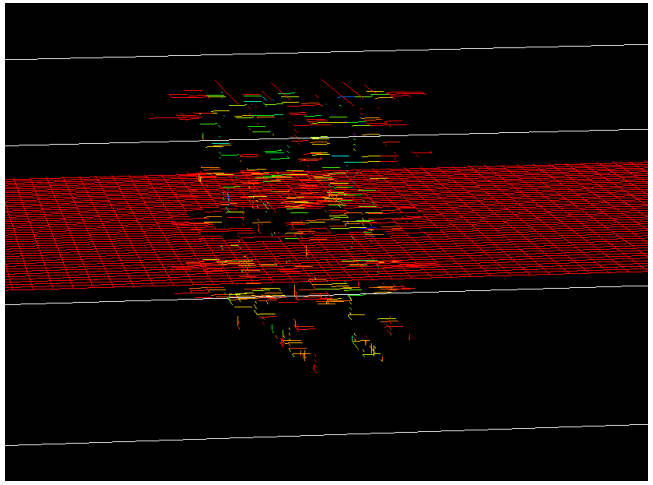
COLLAPSE MODELLING

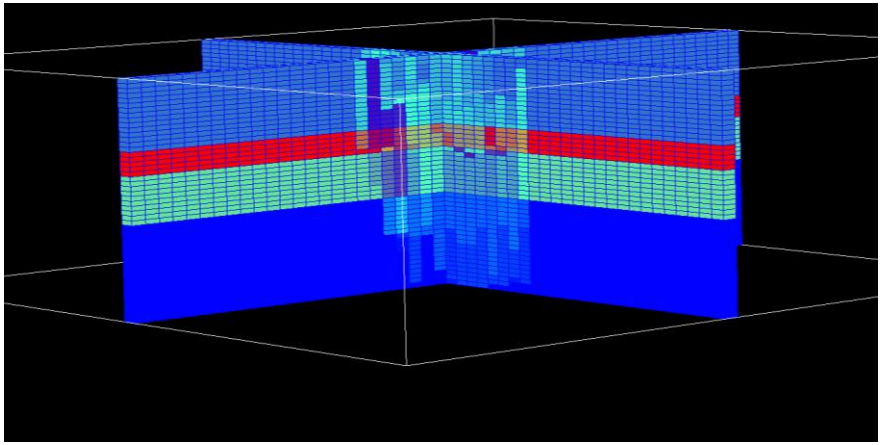


Conduits diameter



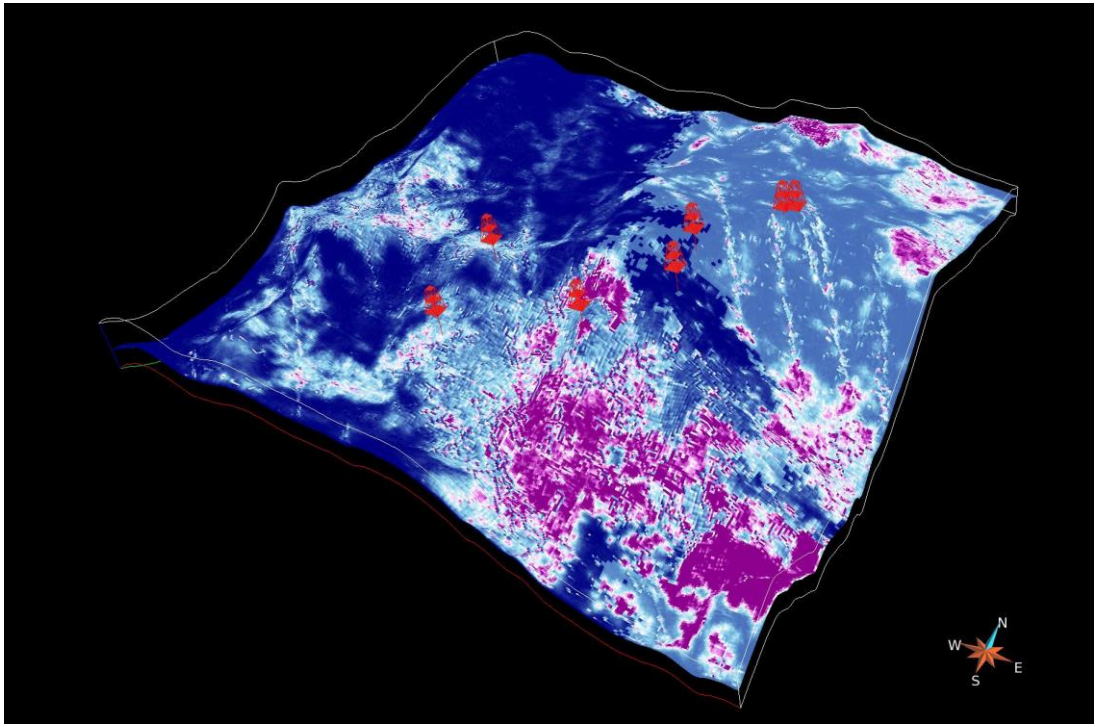
Collapse zone





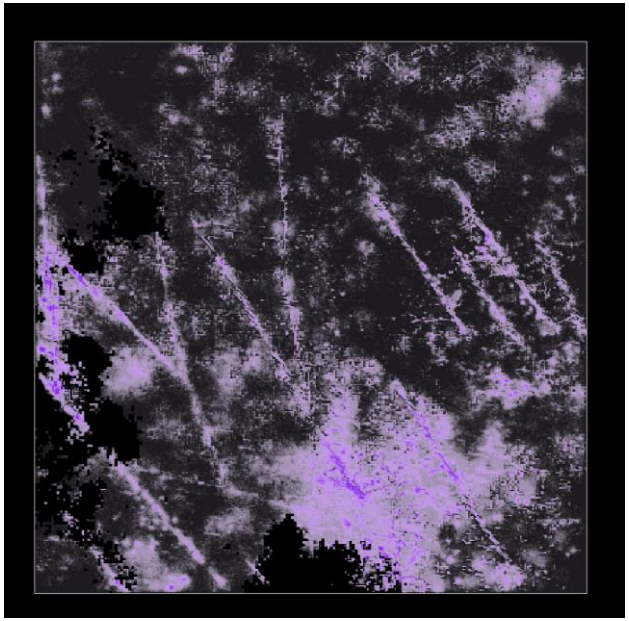
Permeability after collapse

GODIAG™, NOT ONLY FOR KARST MODELLING



The dolomitisation process leads to considerable changes in reservoir properties.

Its reconstitution by **gOdiag™** is a key for a correct modeling of reservoir properties.



When fractures drive dolomitisation, pre-existing heterogeneity controls the mineralogy change.

CONCLUSIONS

- **gOdiag™** mimics the reactive transport through the use of a cellular automaton
- **gOdiag™** is multi-reactions, multi-stages, multi-phenomena, and can be coupled with forward stratigraphic modelling
- **gOdiag™** generates realistic heterogeneity of karstic systems
- **gOdiag™** allows the testing of robustness of geological hypotheses
- **gOdiag™** improves the reliability of models for fluids flows simulations