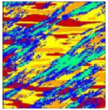


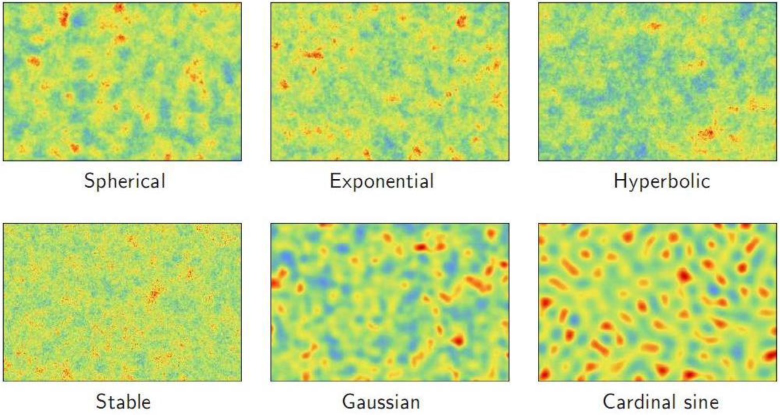
PluriGaussian Model used for simulating heterogeneous deposits

Multigaussian framework

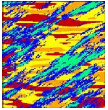
- Multigaussian provides an optimal framework for various simulations models:
  - Spectral method
  - Turning bands method
  - Sequential method
- Able to:
  - Operate on "continuous" variables
  - Simulate most of the known covariances / variograms
  - Honor conditioning data (through kriging)

Multigaussian framework

Able to simulate most of covariances / variograms



Courtesy from Ch. Lantuejoul



From continuous to categorical

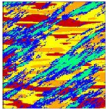
How to simulate categorical variable (facies) ?

- Turn the facies into numerical variable through some indicators and adapt the simulation method:

  SGS -> SIS

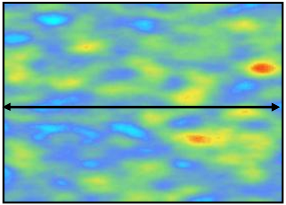
- Consider the facies as a transformed version of underlying Gaussian random function(s):

  Truncated Gaussian (TG) & Plurigaussian (PGS)

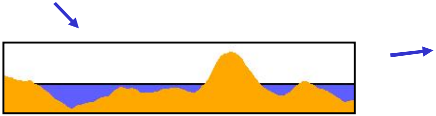


TRUNCATED GAUSSIAN & PLURIGAUSSIAN SIMULATIONS

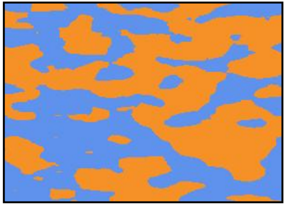
Truncated Gaussian Model



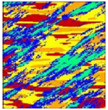
Stationary normalized Gaussian RF Y
Covariance $\rho(h)$ or $\gamma(h)$



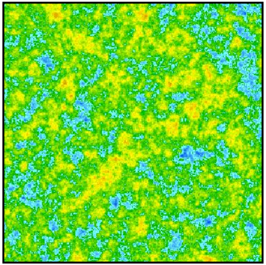
Threshold on the Gaussian RF



Random Set A
Proportions p
Covariances $K_A(h)$ or $\gamma_A(h)$



Proportions and thresholds



Simulation of the Gaussian RF Y

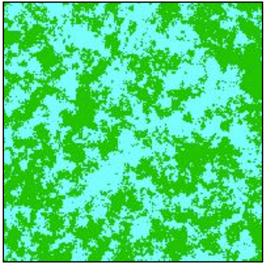
Considering the blue facies

G(Y)

proportion →

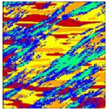
↑
threshold

$$A = \{x; Y(x) \leq s\}$$



Proportion ->Threshold

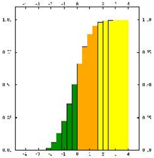
Facies Simulation

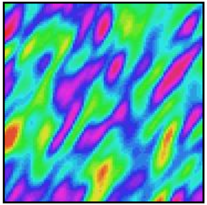


Several facies

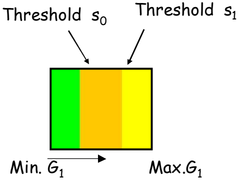
$p_2+p_1 = G(s_1)$

$p_1 = G(s_0)$

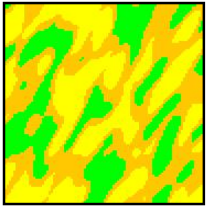




Gaussian RF



Lithotype rule

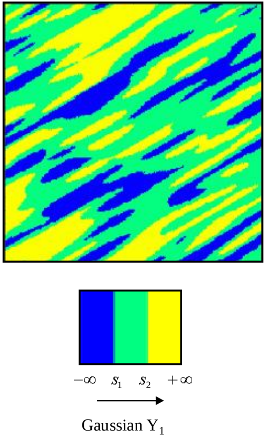


Facies Simulation

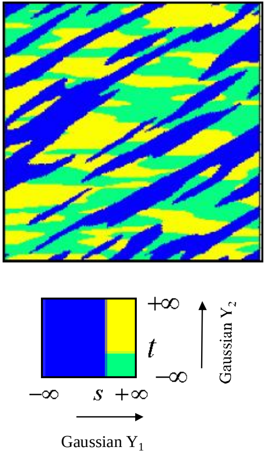
Use ONE underlying Gaussian RF to simulate several facies

From Mono to Plurigaussian

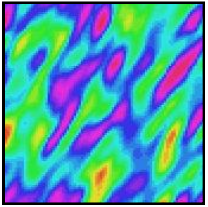
Mono-Gaussian



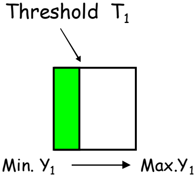
PluriGaussian

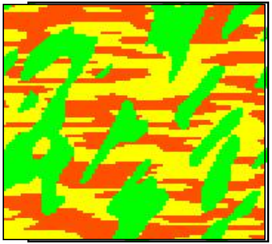


Three facies - Two gaussians

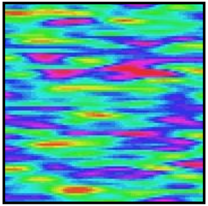


Gaussian (Y_1)

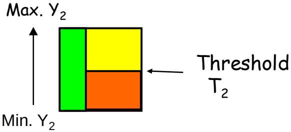




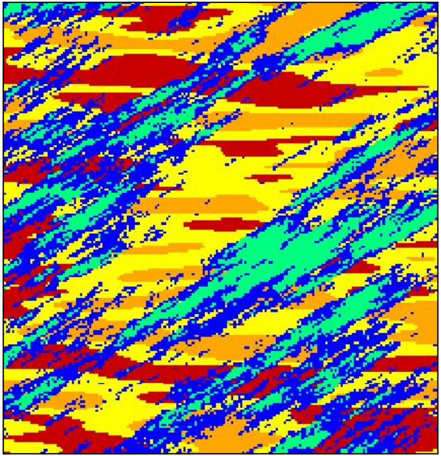
Facies Simulation



Gaussian (Y_2)

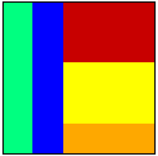


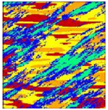
Several facies



Simulation with:

- 5 facies
- 2 Gaussian RF:
  - different covariances
  - different anisotropies





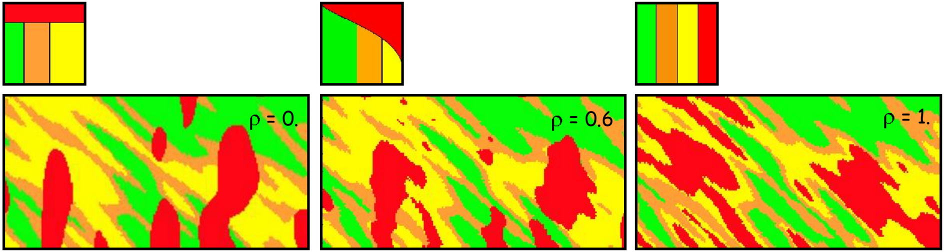
Other properties

- Non-stationarity
  - Use stationary underlying Gaussian random function
  - Consider non-constant proportions / thresholds

- Conditioning to data:
  - based on simulations of underlying Gaussian random functions
  - Gaussian random functions can be conditioned to hard data
  - Translate facies data into Gaussian values (Gibbs sampler)
  - Possibility to handle hard and soft information

CORRELATED UNDERLYING GAUSSIAN RANDOM FUNCTIONS

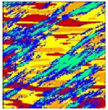
Correlated underlying GRF



The underlying gaussian RF are intrinsically correlated:

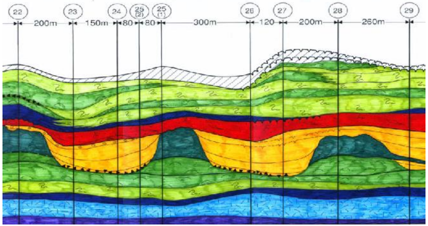
$$\begin{cases} Y_1(x) = Z_1(x) \\ Y_2(x) = \rho Z_1(x) + \sqrt{(1-\rho^2)}\; Z_2(x) \end{cases}$$

Z_1 and Z_2 not correlated



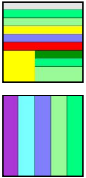
Correlated underlying GRF

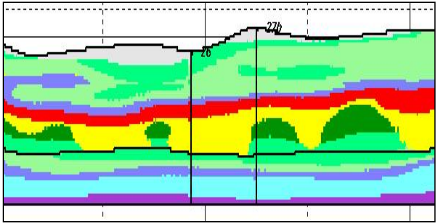
Paradox: algal mounds



Interpreted cross-section

- Non skeletal carbonate facies
- Quartz sand facies
- Skeletal bioclastic facies
- Algal mound facies (final stage)
- Algal mound facies (initial stage)
- Incipient algal mounds
- Intermediate facies
- Sponge facies
- Black laminated shales

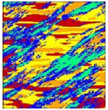




Simulation with correlated GRFs

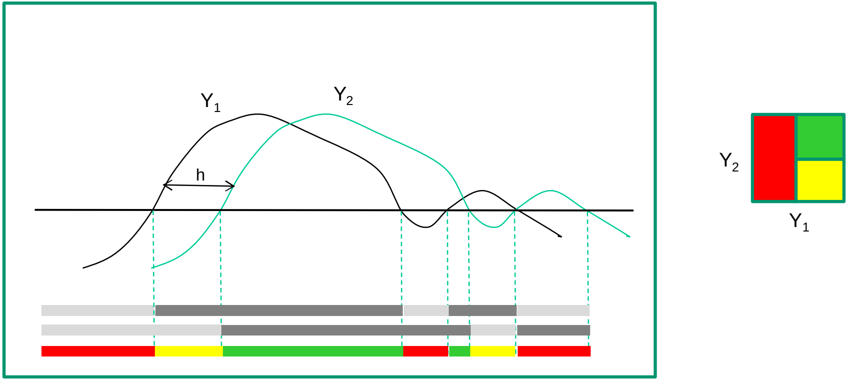
Courtesy from A. Galli et al.

SHIFTED PLURIGAUSSIAN SIMULATIONS



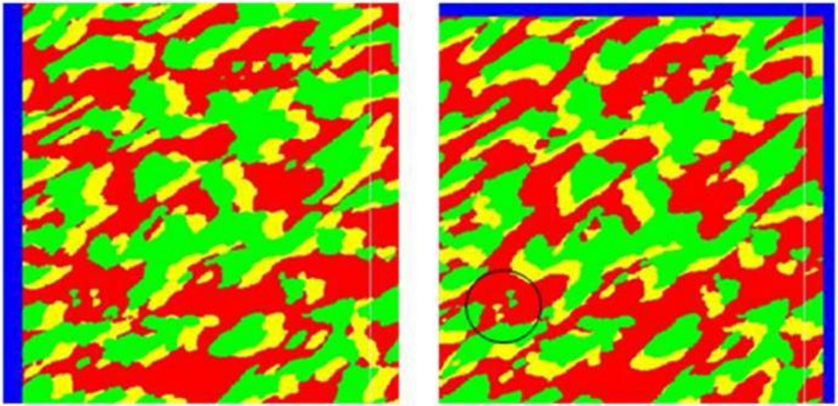
Shifted PGS

Y(x) designates the first GRF, the second GRF is given by Y(x+sh)



Shifted PGS

Two examples of shifted PGS

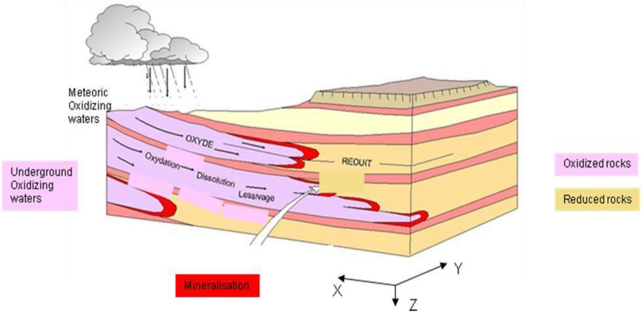


No systematic contact between yellow and green facies

SHADOWED PLURIGAUSSIAN SIMULATIONS

Shadowed PGS

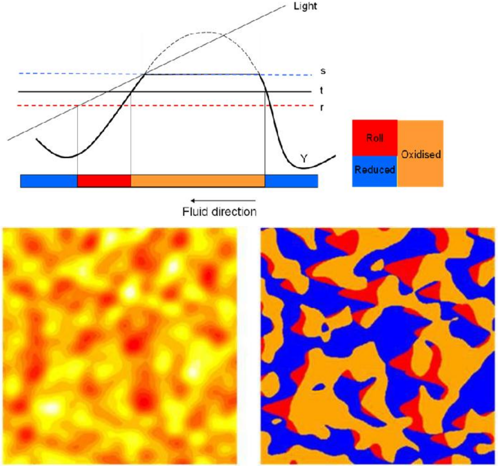
Simulation of Uranium roll-fronts

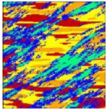


Courtesy from V. Langlais (AREVA)

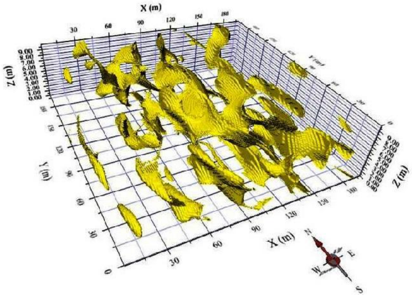
Shadowed PGS

- The first GRF is considered as the relief (truncated below “s”), the second GRF is the shadow (on the reference plane “r”)

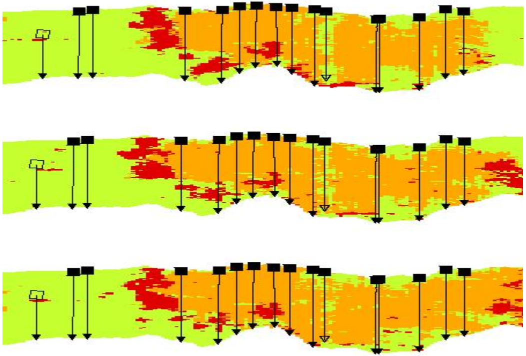




Shadowed PGS



Simulation of roll-fronts



3 conditional simulations

Courtesy from AREVA

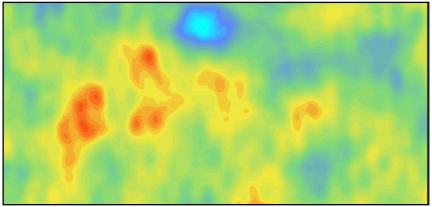
APPLICATIONS OF PGS

Applications

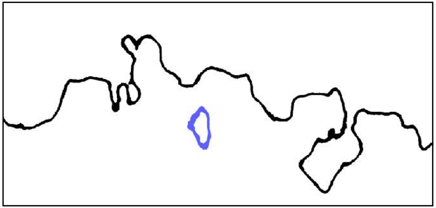
- The following illustrations are obtained by making specific choices for:
  - The covariances of the GRFs
  - The lithotype rule
  - The proportions and thresholds
  - The non-stationarity

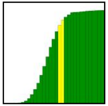
PGS Illustrations

Narrow threshold interval

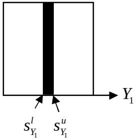


Simulation: meander & oxbow lake





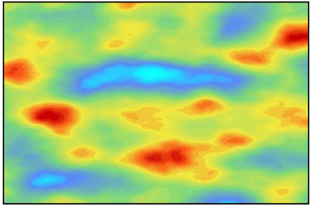
Lower & upper thresholds



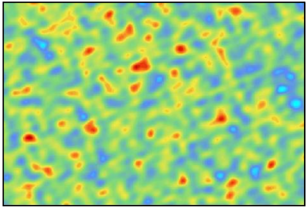
Lithotype Rule

A meandering river

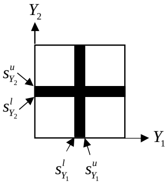
Definition of a Complex Random Set



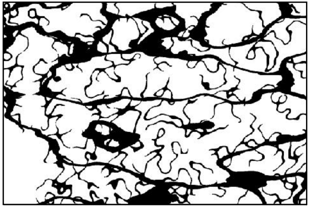
Long range GRF



Short range GRF



Lithotype Rule

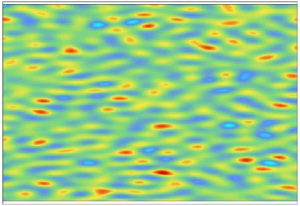


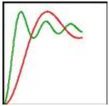
Mixed scale texture

Tidal channel on tidal flat, Coos Bay, Oregon

PGS Illustrations

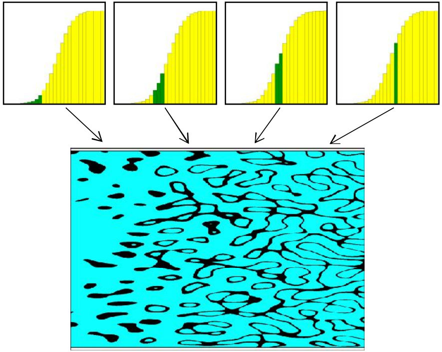
Non-stationary threshold interval





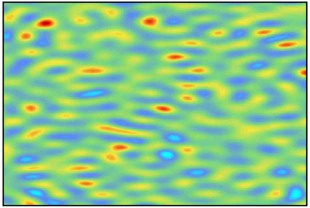
One stationary GRF with anisotropic periodic variogram

Constant proportion - Non-stationary thresholds



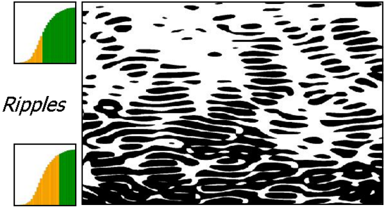
PGS Illustrations

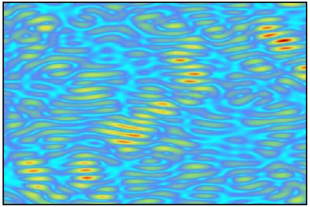
Non-stationary threshold interval



Anisotropic periodic GRF Y_0

Ripples

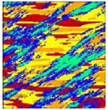




Y_1 = Gradient of Y_0

Ripples on tidal flat, SE Alaska

JOINT SIMULATION OF TWO PHENOMENA: BI-PGS

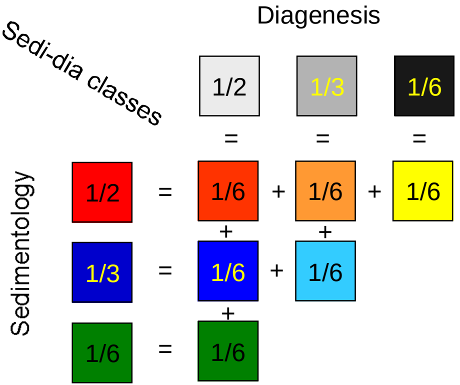


Introduction

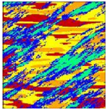
Simulate heterogeneities :

- Two indicators reflecting two linked processes:
  - Sedimentology
  - Diagenesis
- Conditioned by heterotopic data set:
  - All samples have Sedimentology information
  - Only few have Diagenesis index

Joint proportions

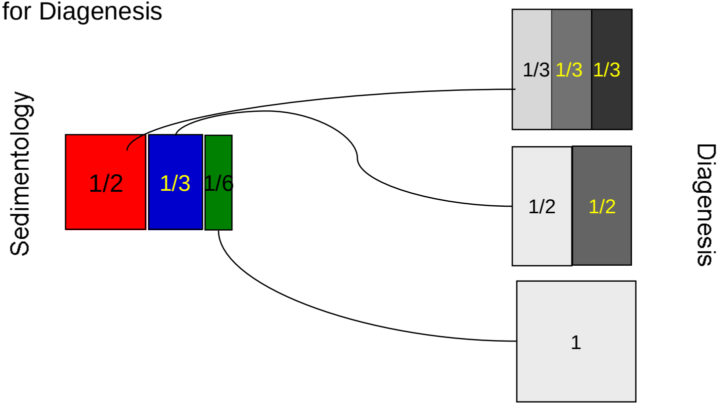


Proportions of
- Sedimentology facies
- Diagenesis indices
- Sedimentology-Diagenesis classes



Bi-Plurigaussian Simulation

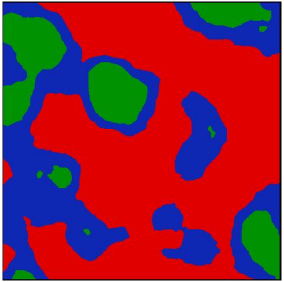
Two step process:
- PGS_1 for Sedimentology
- PGS_2 for Diagenesis

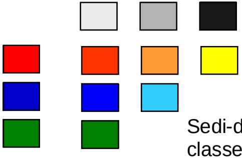


Proportions of Diagenesis are conditional to Sedimentology facies

Bi-Plurigaussian Simulation

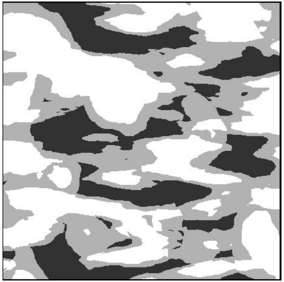
Sedimentology

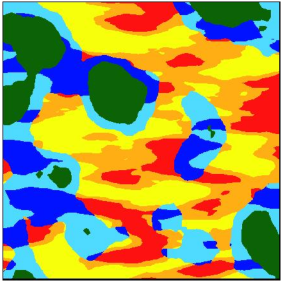




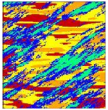
Sedi-dia classes

Diagenesis



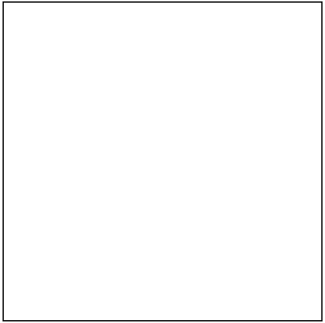


Final conditional simulation



Heterotopic Data Set

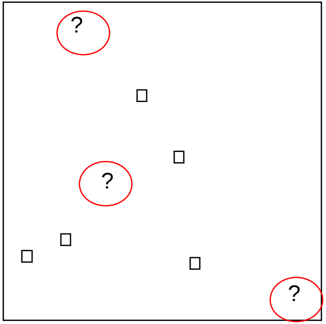
Bivariate categorical information



Sedimentology

9 data

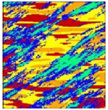
3 facies



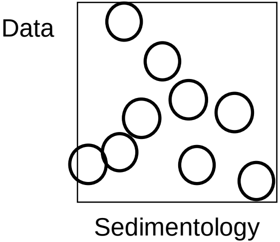
Diagenesis

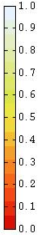
6 data

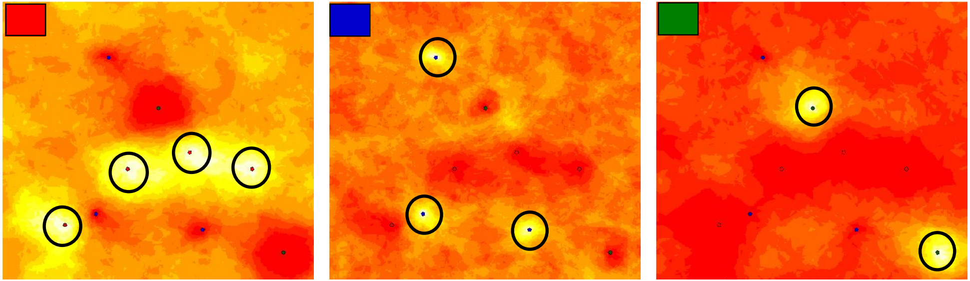
3 indices

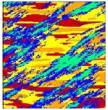


Probability of the sedimentary facies

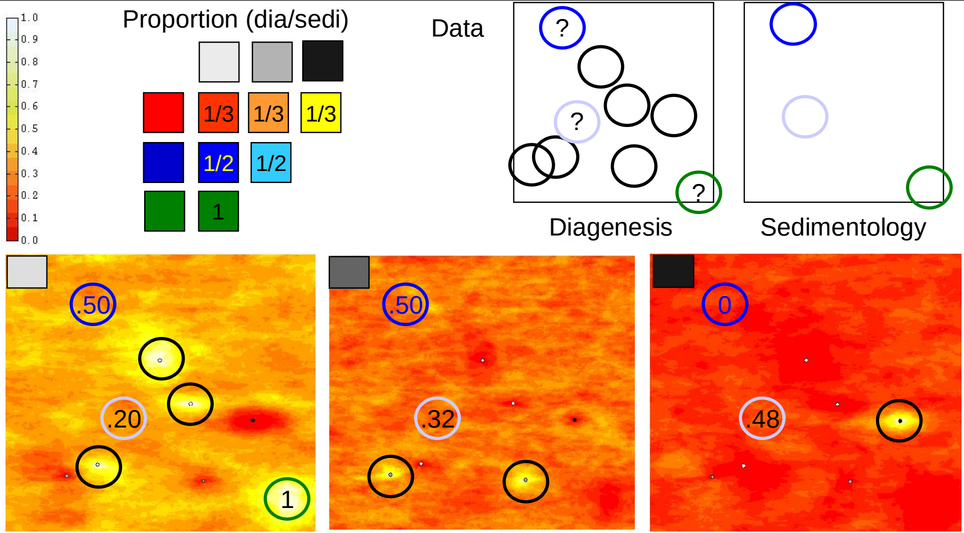








Probability of the diagenetic index



References

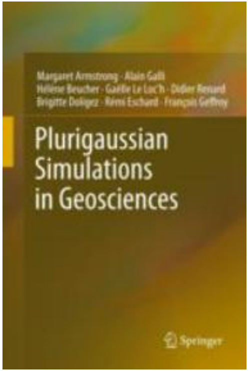
- Download **PluriDemo** package for:
  - Variography
  - PuriGaussian
  - Pluri-Sets

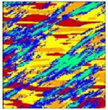
From:

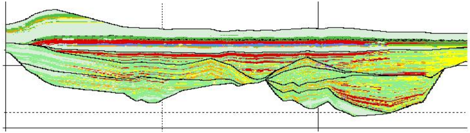
http://www.geosciences.mines-paristech.fr/web/en/organization/presentation-of-the-group-2/main-projects/pluridemo/projet-pluridemo

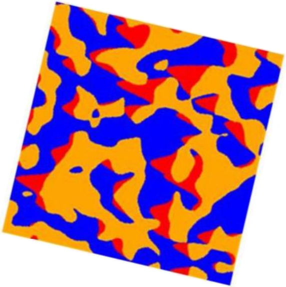
- **Plurigaussian Simulations in Geosciences, 2nd edition**

  Armstrong, M., Galli, A., Beucher, H., Loc'h, G., Renard, D., Doligez, B., Eschard, R., Geffroy, F.









Thank you for your attention