UNIVERSITÀ DEGLI STUDI DI MILANO

Sediments' connectivity and transport properties

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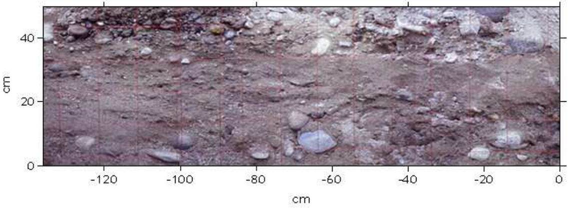
EGU General Assembly 2011

Motivation



- The hydrofacies heterogeneity at the fine scale controls water flow and contaminant transport at the macroscopic scale
- Which are the main factors affecting this process?
  - conductivity contrasts among different facies
  - relative abundance and number of different facies
  - connectivity of the most permeable facies

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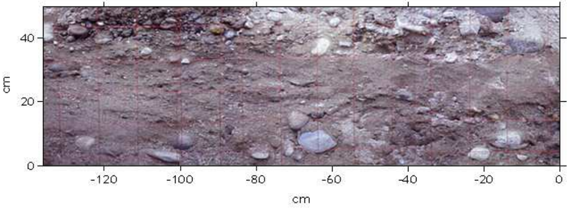

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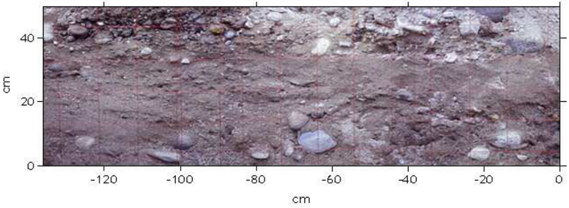

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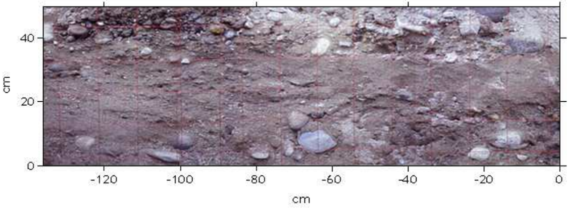

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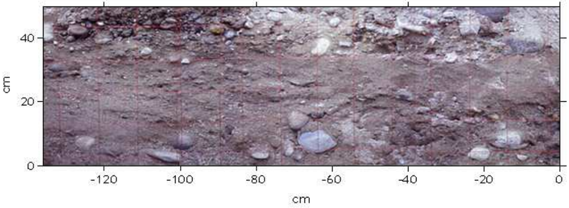

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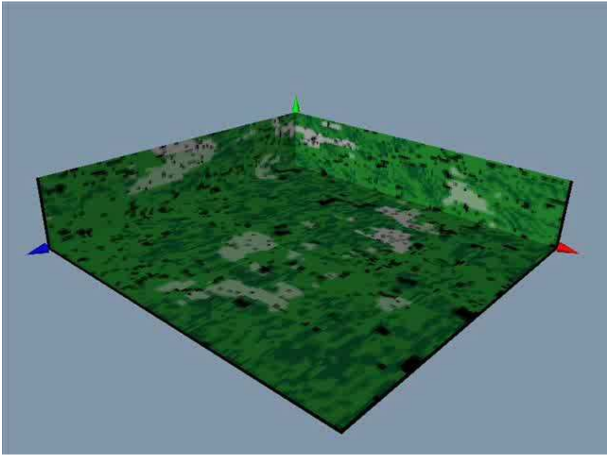
Motivation

Vassena et al., Hydrogeology J, 2010

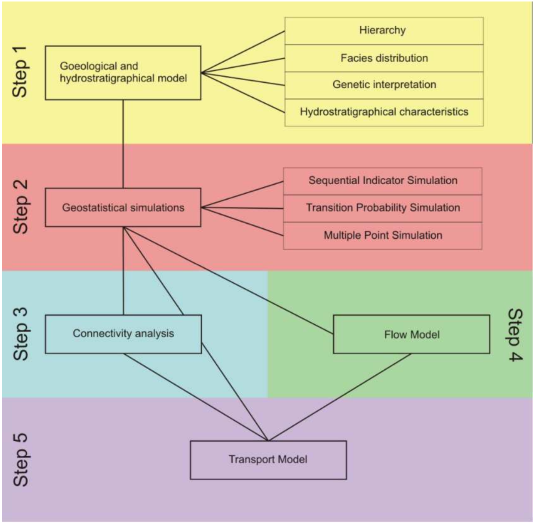
- presence of preferential flow paths (PFPs) has significant effects on
  - travel times
  - dispersion

$\Downarrow$

bimodal peaks of the breakthrough curves (BTCs)



Methodology



Case study

Dell'Arciprete et al., Adv. Water Resour., submitted

- A prismatic block of sediments (volume $\approx$ 100 m^3) dug in a quarry site into real sediments of the river Lambro basin (Northern Italy)

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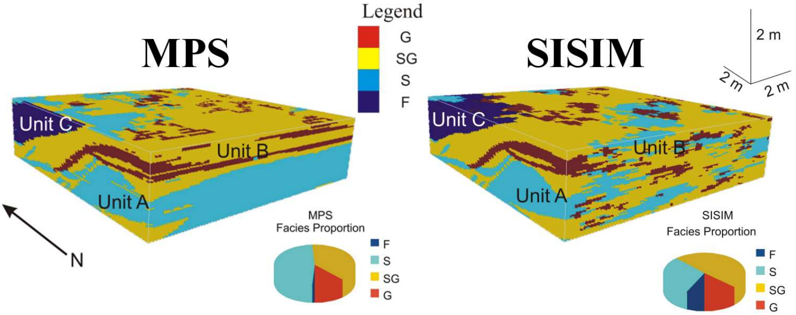
- A prismatic block of sediments (volume ≈ 100 m^3) dug in a quarry site into real sediments of the river Lambro basin (Northern Italy)
- Geological and hydrostratigraphical model
- Geostatistical simulation: 2 ensembles of 50 equiprobable realizations with two methods:



Connectivity

Vassena et al., Hydrogeology J, 2010

- Evaluation of hydrofacies connectivity indicators for the different realizations:
  - **Intrinsic connectivity** of the facies p:

$$C_p^* = P[\mathbf{x} \leftrightarrow \mathbf{y} |\ \mathbf{x} \in \Omega_p,\ \mathbf{y} \in \Omega_p,\ \mathbf{x} \neq \mathbf{y}]$$

$$\approx \frac{\#\ \text{connected pairs of the facies } p}{\#\ \text{pairs of the facies } p}$$

Connectivity

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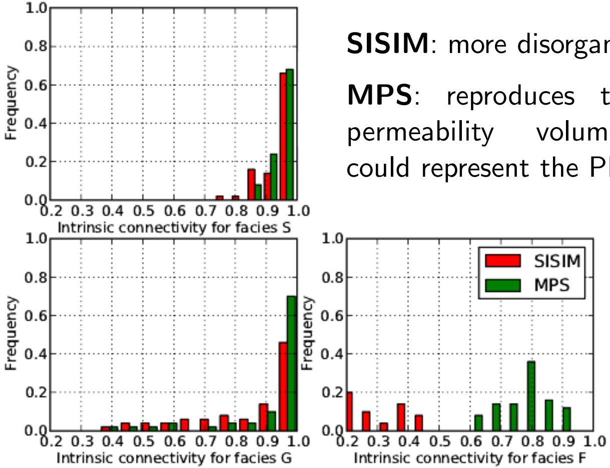


SISIM: more disorganized

MPS: reproduces the high-permeability volumes that could represent the PFPs

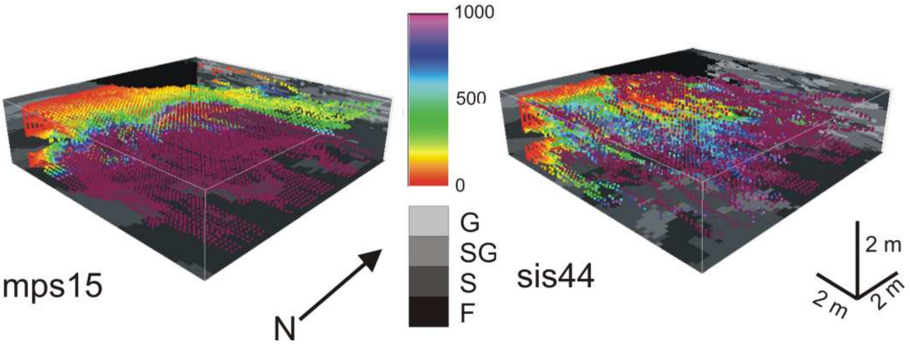
Flow and transport modeling

- Numerical experiments of convective transport of a non-reactive solute:
  - flow field computed with a flow model for steady state saturated flow
  - convective transport modelled with a particle tracking technique

Numerical experiments

Dell'Arciprete et al., Adv. Water Resour., submitted

- The numerical experiments simulate the evolution of a non-reactive tracer for a plume istantaneously injected through the inflow boundary (number of particles injected $\approx$ 4000)



Single Domain Model (SDM)

Vassena et al., Hydrogeology J, 2010

- heterogeneous porous medium → equivalent homogeneous porous medium

ADE

$$\frac{\partial C_F}{\partial t} = -v\frac{\partial C_F}{\partial l} + D\frac{\partial^2 C_F}{\partial l^2}$$

- Initial Condition:
  initially no solute in the domain

$$C_F(l,0) = 0, \quad l > 0$$

- Boundary Conditions:
  instantaneous injection of M $[\mathrm{kg/m^2}]$

$$C_F(0,t) = 2Mq^{-1}\delta(t), \quad t \geq 0$$

$$\lim_{l\to+\infty} C_F(l,t) = 0, \quad t \geq 0$$

Laplace Transform method ⇓

$$C_F(l,t) = \frac{M}{q}\frac{l}{\sqrt{4\pi D t^3}}\exp\left[-\frac{(l-vt)^2}{4Dt}\right]$$

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Dual Domain Model (DDM)

Baratelli et al., Transp. Por. M, 2010

- heterogeneous porous medium → **two overlapping domains**:

  (H) fast domain (High hydraulic conductivity)

  (L) slow domain (Low hydraulic conductivity)

- the two domains are considered as **disconnected** (no water or solute exchange) → two independent ADEs

- the solute flux in each domain is given by the SDM solution

- the total solute flux is the **weighted sum of the solute fluxes** in each domain (weighted over the volume fraction of each domain)

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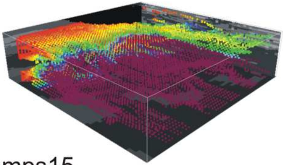
Transport modeling

Dell'Arciprete et al., Adv. Water Resour., submitted



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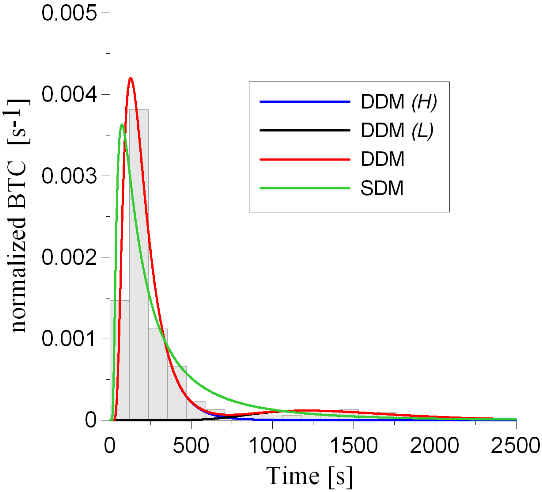

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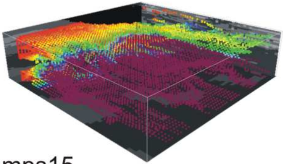

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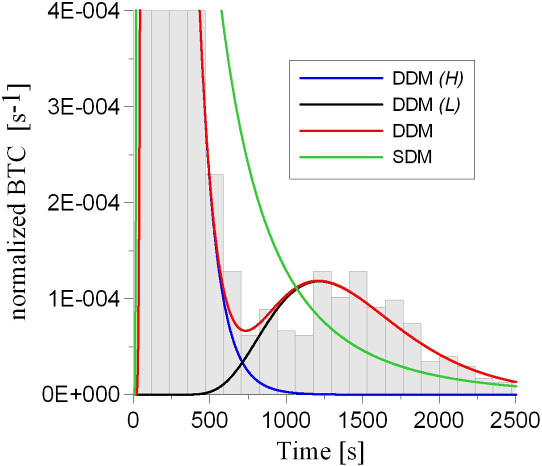

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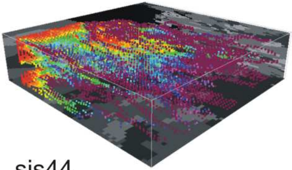

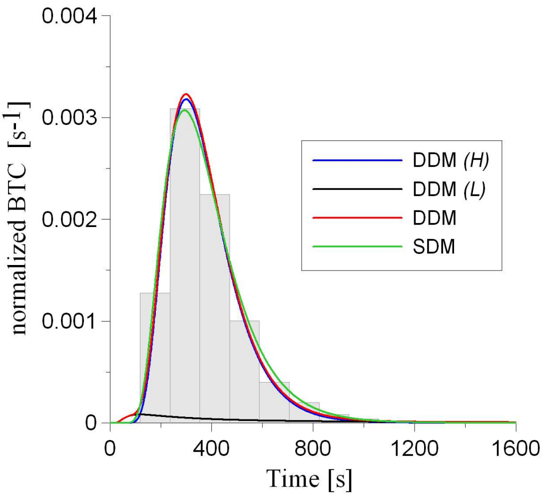

Conclusions

- The relevance of the **DDM** with respect to the **SDM** is in agreement with the results of the **connectivity analysis**:
  - the fit of the experimental data is greatly improved in those cases where the presence of preferential flow paths was evidenced by the connectivity analysis
- The DDM permits to describe the effects of the presence of preferential flow paths on the transport of solutes (**bimodal peaks** in the BTC)
- Dual domain models can be effectively applied...
  - ...even to media with **small hydraulic conductivity contrasts**
  - and at different scales:

    $\approx$ 10 m^3 [Baratelli et al., Transp. Por. M, 2010]

    $\approx$ 100 m^3 [Dell'Arciprete et al., Adv. Water Resour., submitted]

Outlook

- Improvement of the DDM:
  - exchange term
  - multi-domain model
- Quantify the relation between facies connectivities, transport parameters (velocity, dispersion coeffcient) and the ‘duality’ of the porous medium.

Thank you!