Conférence Internationale Aquifères de socle : le point sur les concepts et les applications opérationnelles – La Roche sur Yon 2015

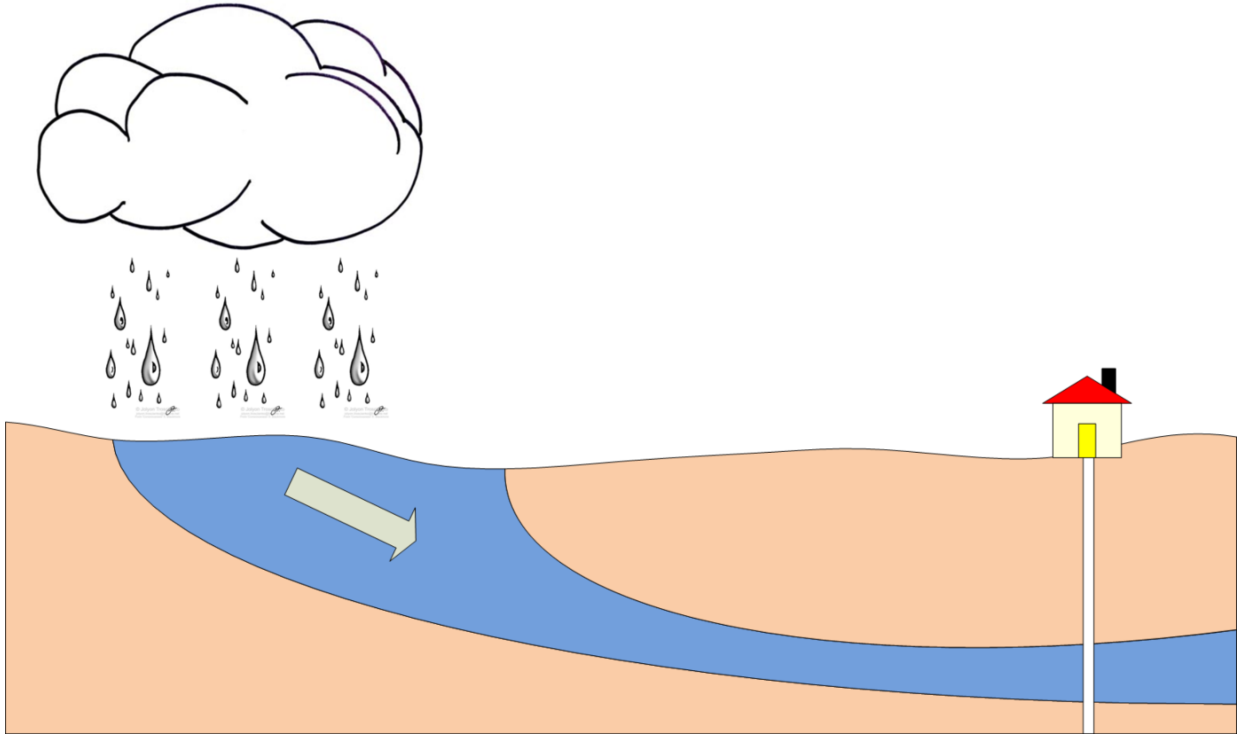
Prédiction des temps de renouvellement dans les aquifères de socle à partir des données de datation des eaux

Assessing renewal time in hard rock aquifers from groundwater age data

Pauline Rousseau-Gueutin , Jean-Raynald de Dreuzy, Jean Marçais, Sarah Leray, Olivier Bour, Luc Aquilina, Virginie Vergnaud-Ayraud

« Groundwater age »

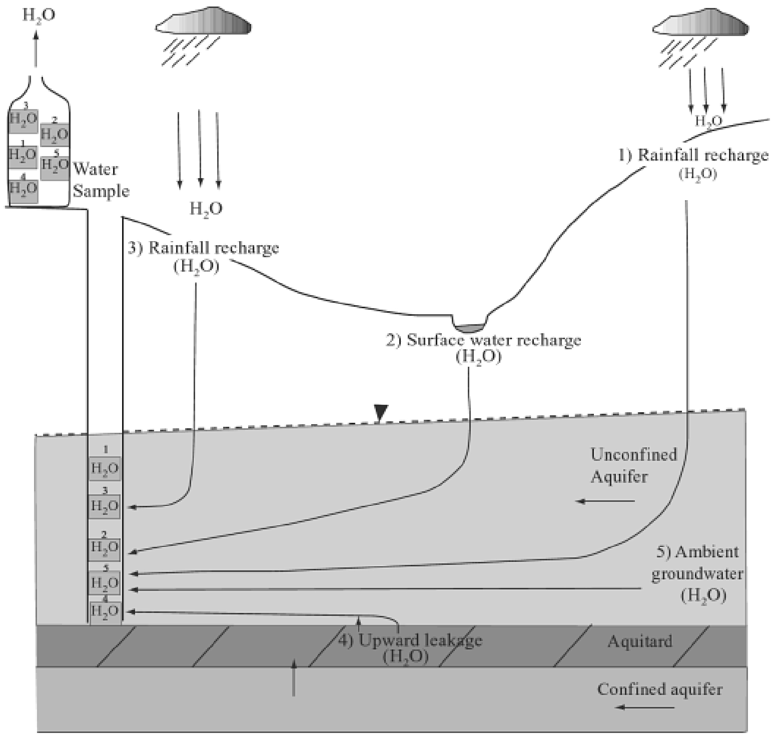
- Time since precipitation has entered groundwater system → use of environnemental tracers



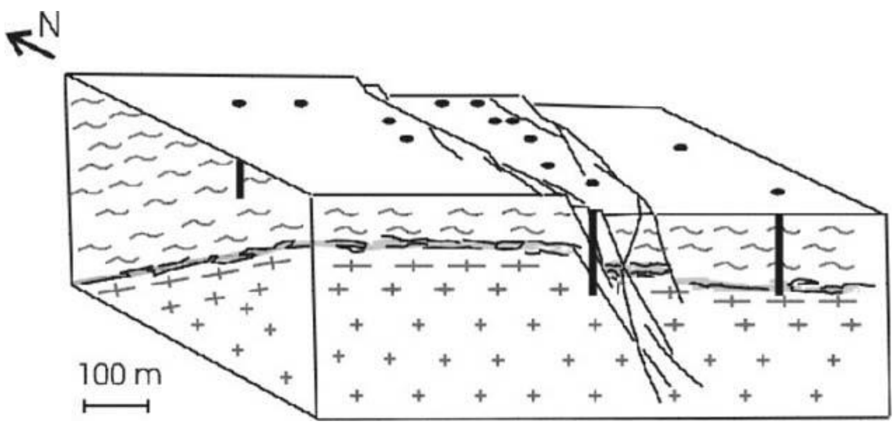
Massoudieh, 2016

« Groundwater age »

- Dispersion in the aquifers and mixing when sampling



Kazemi et al. 2006

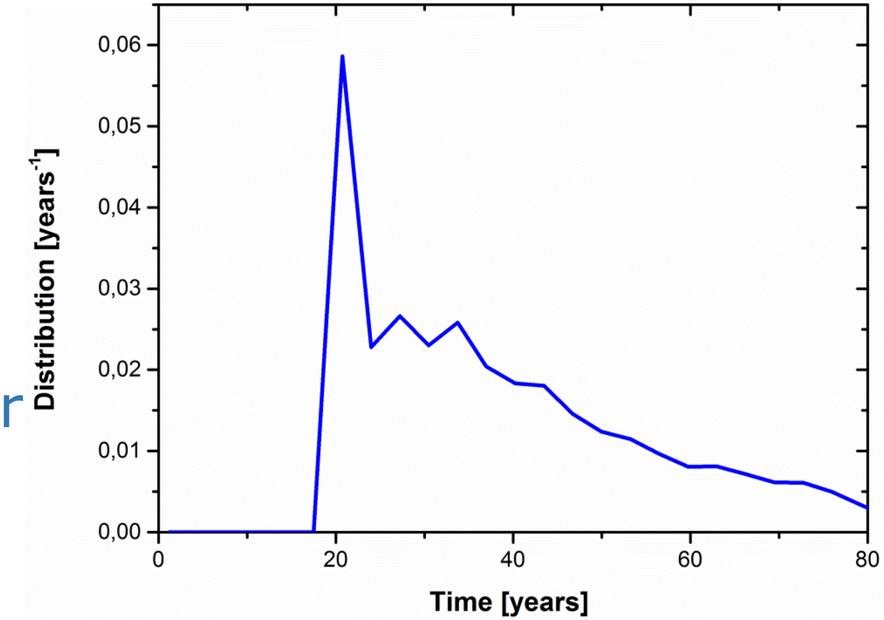


Le Borgne et al. 2006

« Groundwater age »

- Dispersion in the aquifers and mixing when sampling

→ **Groundwater age = distribution of ages**



→ TTD translate groundwater age data to renewal time or flushing time

→ Partial knowledge of TTD with tracer concentration

Assessment of the TTD

- One of the approaches → Lumped Parameter Models
- Analytical solutions developped to represent the multi-scale and multi-factors diperssive processes

LPM's name	Expression
Dirac (*Piston Flow*)	$f_T(t) = \delta(t-T)$
Exponential (*Exponential*)	$f_T(t) = \frac{1}{T}\exp\left(-\frac{t}{T}\right)$
Inverse Gaussian (*Dispersion*)	$f_{(T,Pe)}(t) = \left(\frac{TPe}{2\pi t^3}\right)^{0.5} \exp\left(-\frac{Pe(t-T)^2}{2Tt}\right)$
Shifted Exponential (*Exponential Piston Flow*)	$f_{(T,t_0)}(t) = \begin{cases} \frac{1}{t_0}\exp\left(-\frac{t-(T-t_0)}{t_0}\right) & \text{for } t \geqslant T-t_0, \\ 0 & \text{otherwise.} \end{cases}$
Uniform (*Linear Piston Flow*)	$f_{(T,\epsilon)}(t) = \begin{cases} \frac{1}{\epsilon} & \text{for } T-\frac{\epsilon}{2} \leqslant t < T+\frac{\epsilon}{2}, \\ 0 & \text{otherwise.} \end{cases}$
Weighted sum of Diracs	$f_{(t_0,t_1,\omega)}(t) = \omega\delta(t-t_0) + (1-\omega)\delta(t-t_1)$
Shifted Inverse Gaussian	$f_{(T,Pe,t_0)}(t) = \begin{cases} \left(\frac{Pe(T-t_0)}{2\pi(t-t_0)^3}\right)^{0.5} \exp\left(-\frac{Pe(t-T)^2}{2(T-t_0)(t-t_0)}\right) & \text{fort } \geqslant t_0, \\ 0 & \text{otherwise.} \end{cases}$

Aims

- **What is the predictive capacity of the LPMs ?**
- Why constraining a groundwater model of a complex aquifer with tracer data?
- Are shallowly dipping fractured zones significant goundwater resource ?

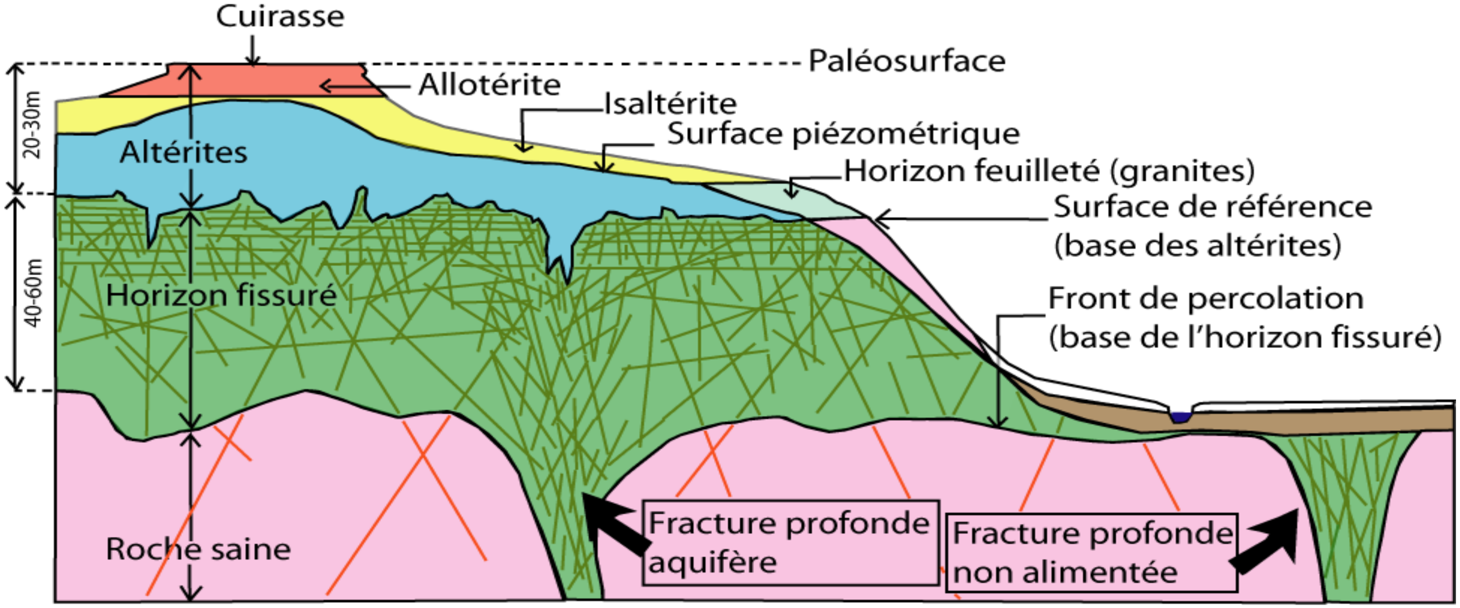
Methodology

- Highlights on shallowly dipping fractured zones productivity and application to the Ploemeur site
- Use of a numerical model at the Ploemeur site as virtual reality
  - Obtention of « information »
- Calibration of LPMs and comparison of the renewal times (predictions) from those LPMs and our reality

Productivity of Dipping Fractured Zones

Productive structures in HR aquifers

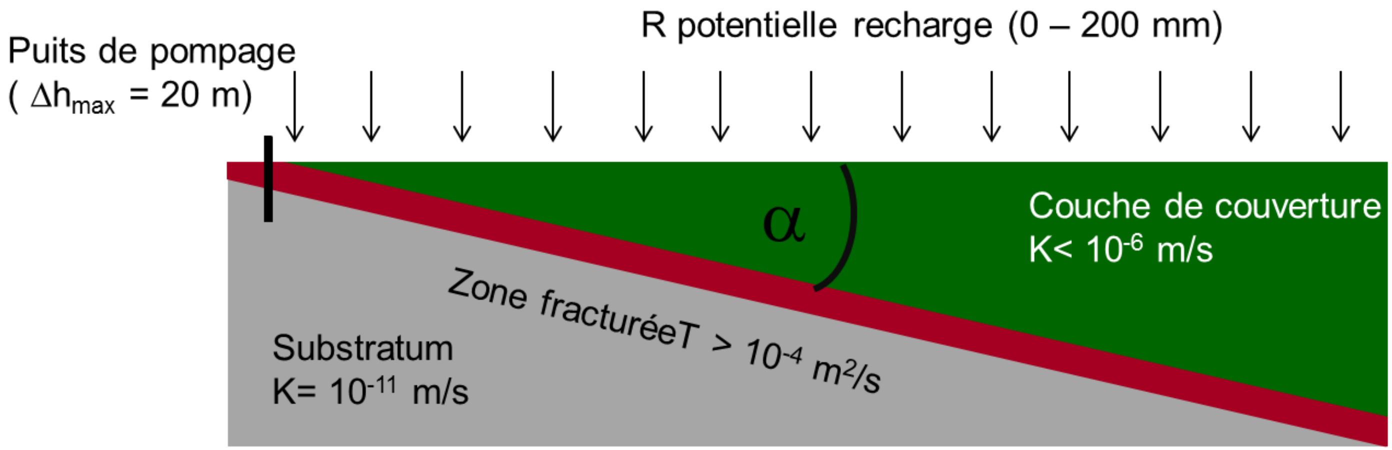
- Two main structures :

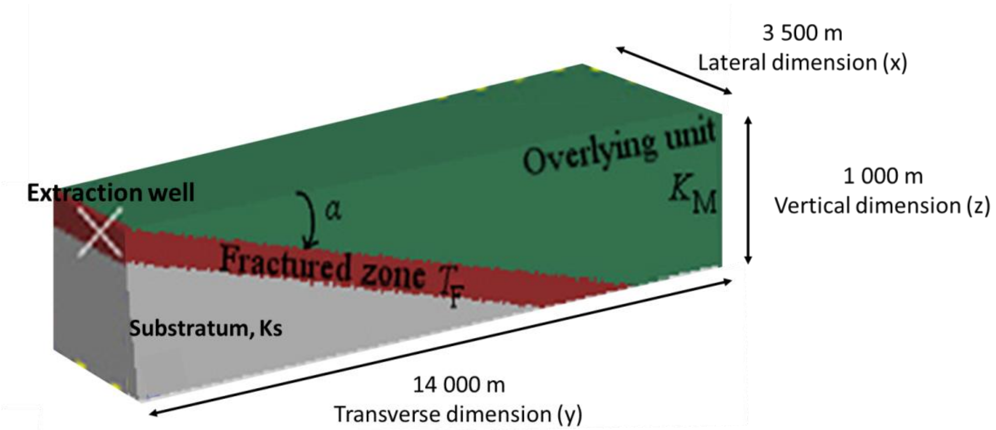


Wynns et al., 2005

- 3rd type → dipping fractured zones

Numerical modeling





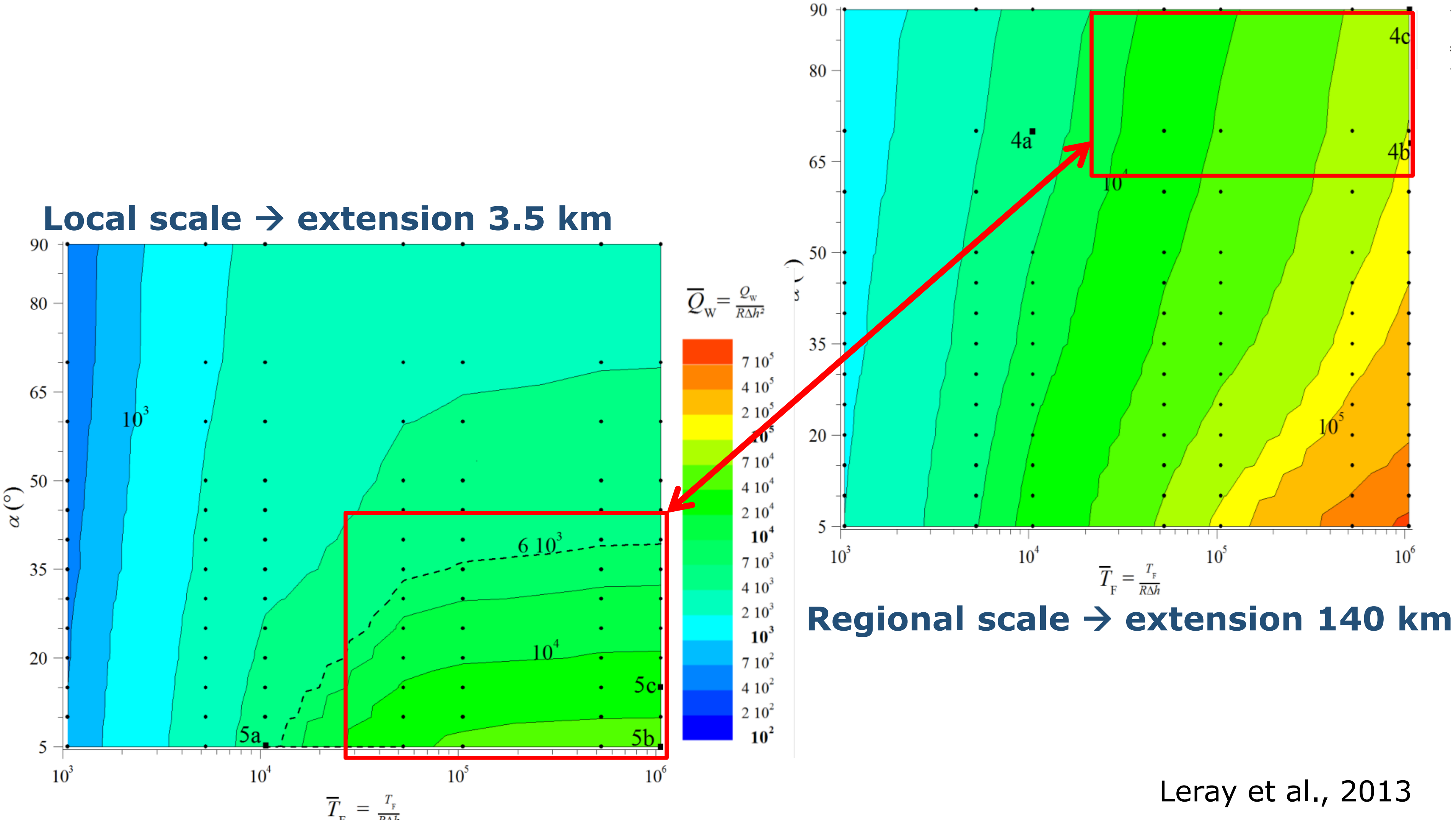
Steady state 3D simulations→ assessment of Q for a specific Δh

Tested parameters :

- Geometry
  - α and size of the system (3.5 and 140 km)
- Hydrogeology
  - T of the fracture zone and K of the overlying layer

Productivity of the dipping structure equivalent to regional fault productivity

Local scale → extension 3.5 km

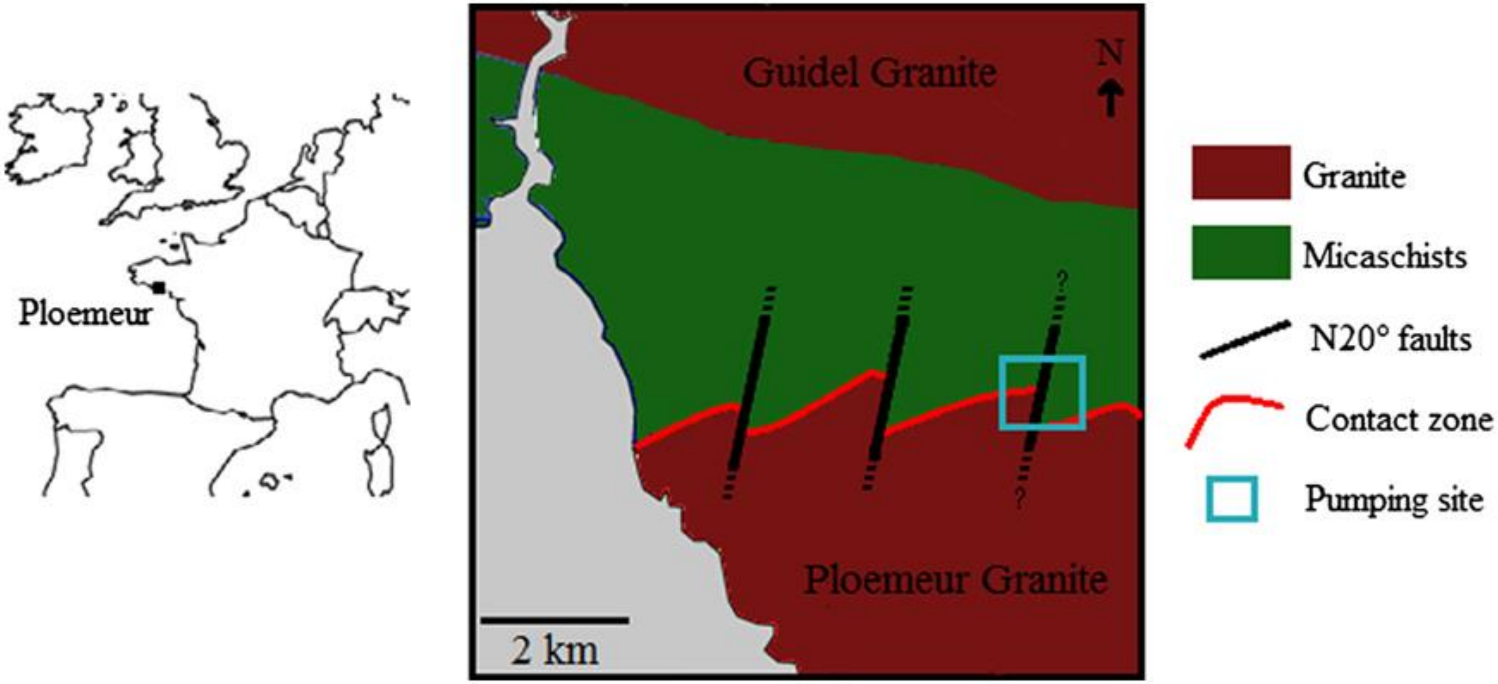


Regional scale → extension 140 km

Leray et al., 2013

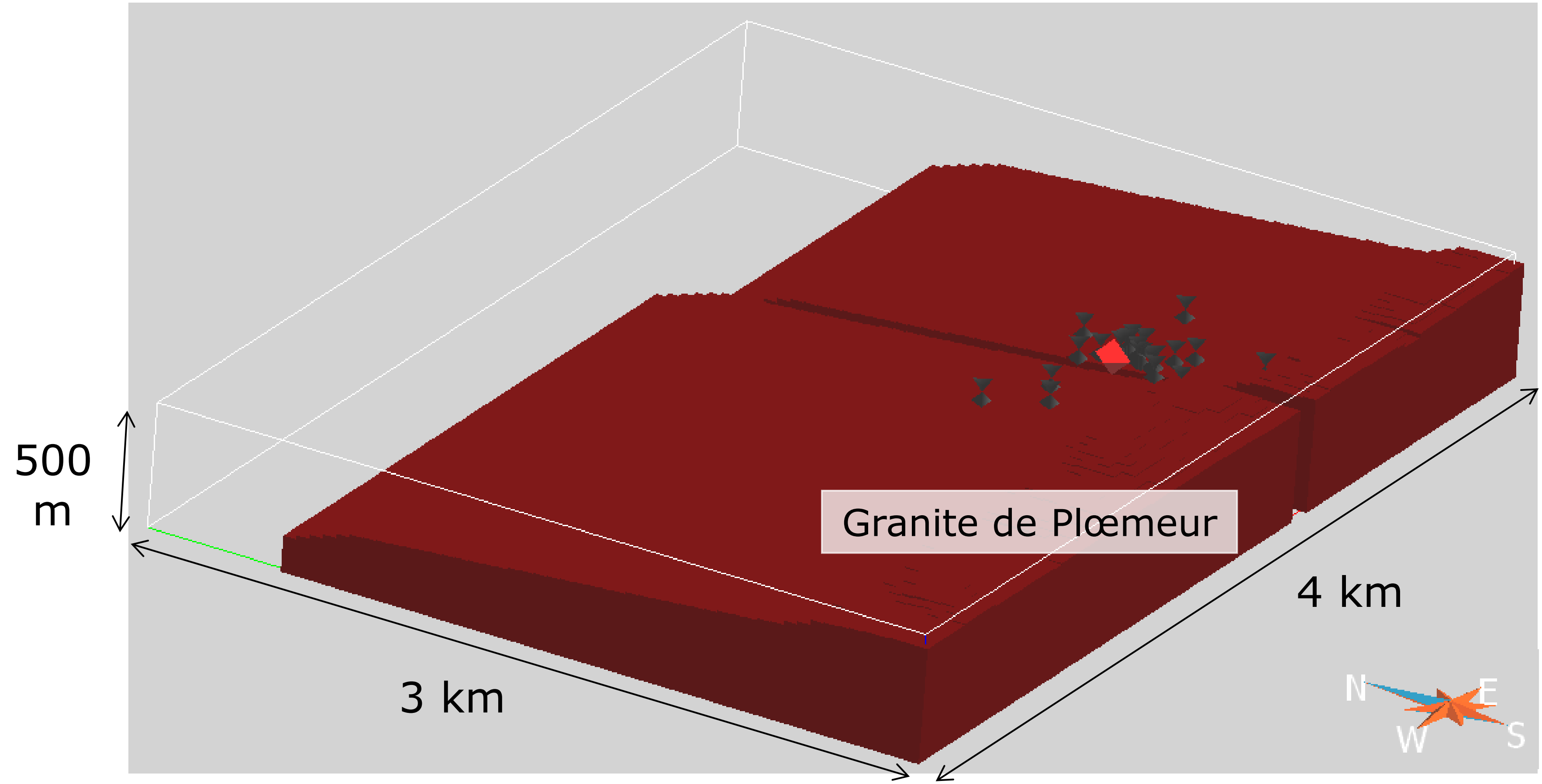
Numerical Modeling of the Ploemeur Aquifer

Ploemeur site



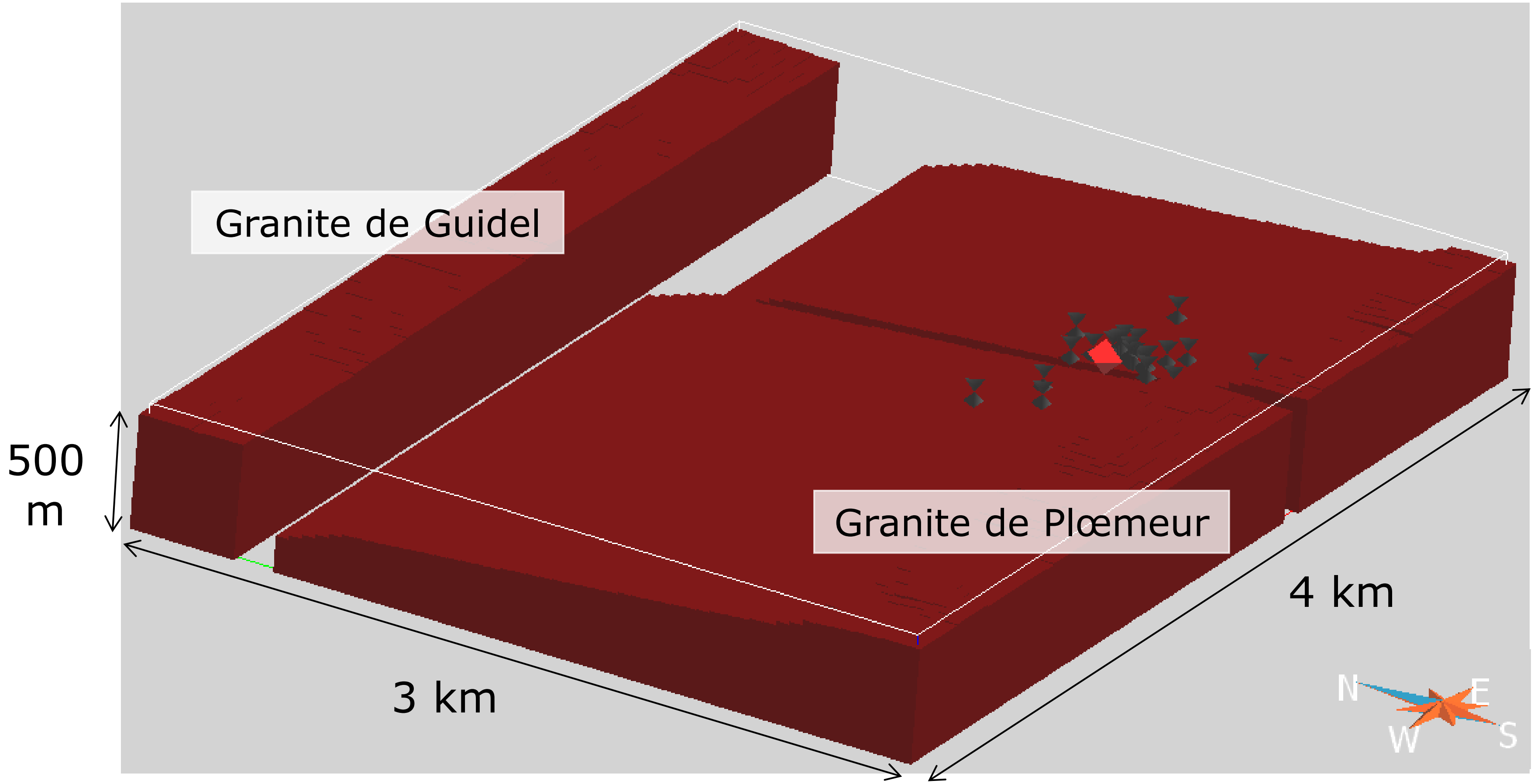
- Aquifer with a high productivity ($110 m^3/h$)
  →cannot be explained by saprolites or fault

Hydrogeological model



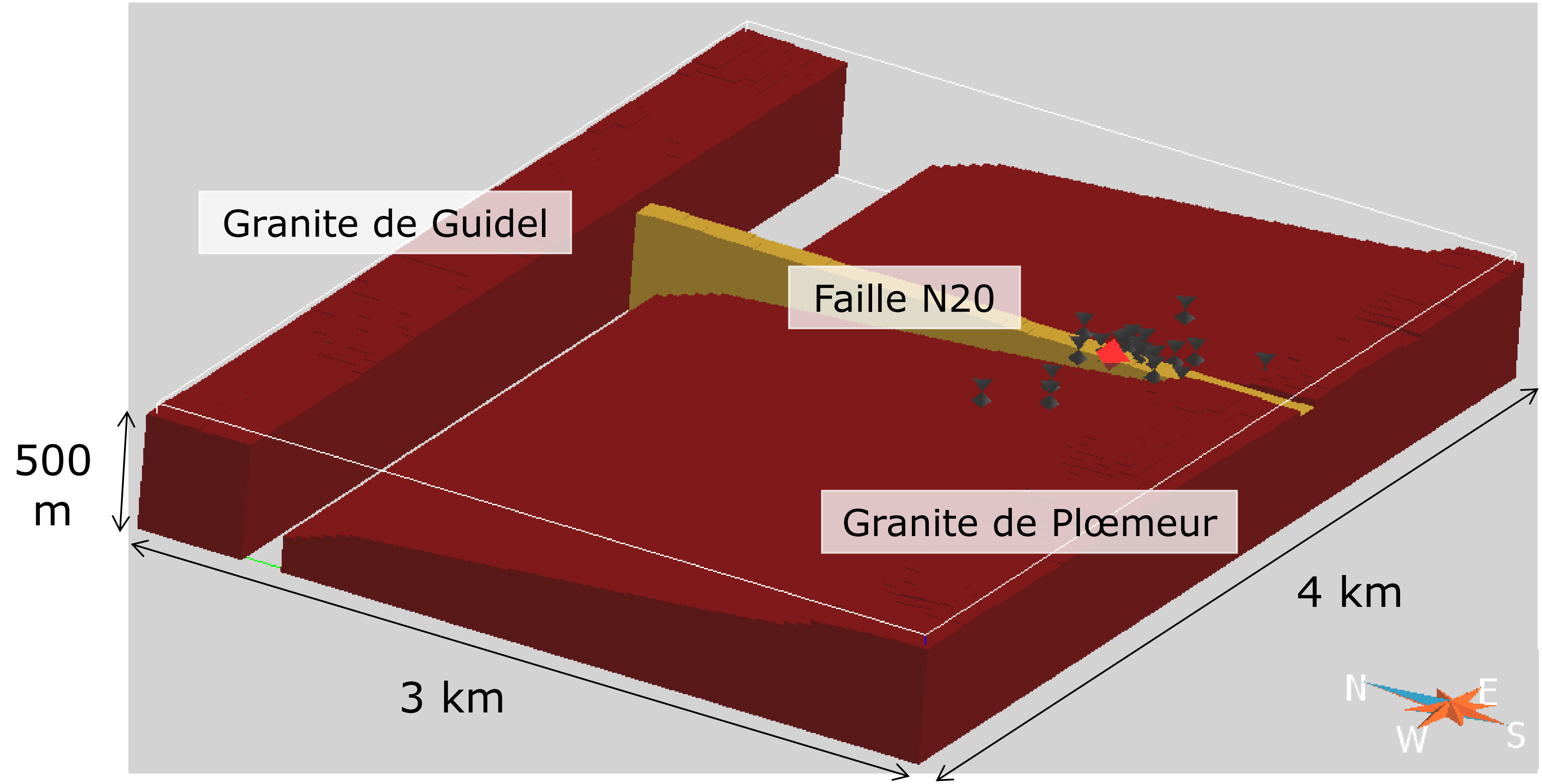
Leray, 2012

Hydrogeological model



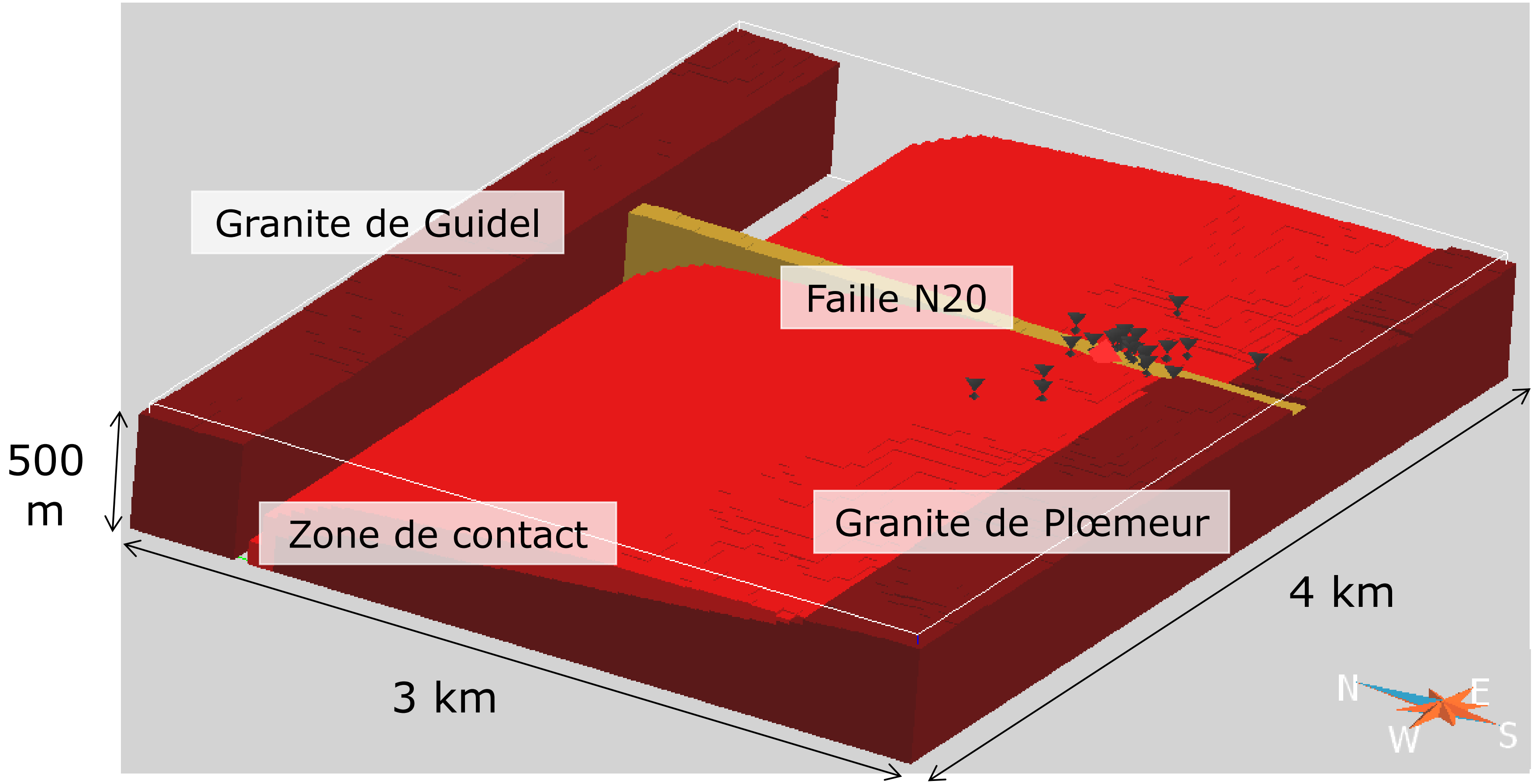
Leray, 2012

Hydrogeological model



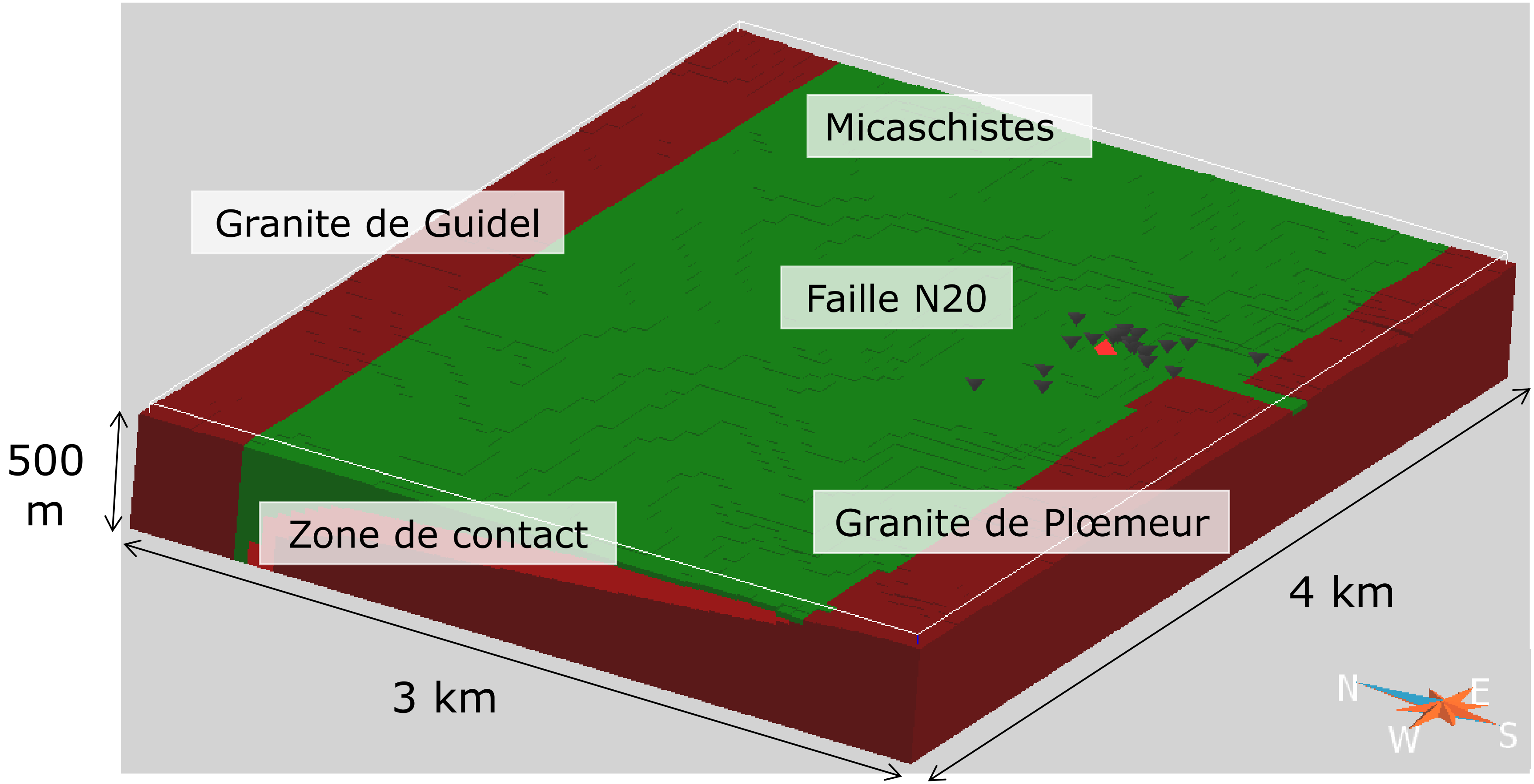
Leray, 2012

Hydrogeological model



Leray, 2012

Hydrogeological model



Leray, 2012

Model calibration

- Piezometry
  - Contact zone transmissivity
  - Recharge
- CFC-12 concentration at the well
  - Global volume of the aquifer= structure + porosity
  - TTD

Model calibration

- Piezometry
  - Contact zone transmissivity
  - Recharge

- CFC-12 concentration at the well
  - Global volume of the aquifer= **structure** + porosity
  - TTD

↓

Crucial information for complex aquifers

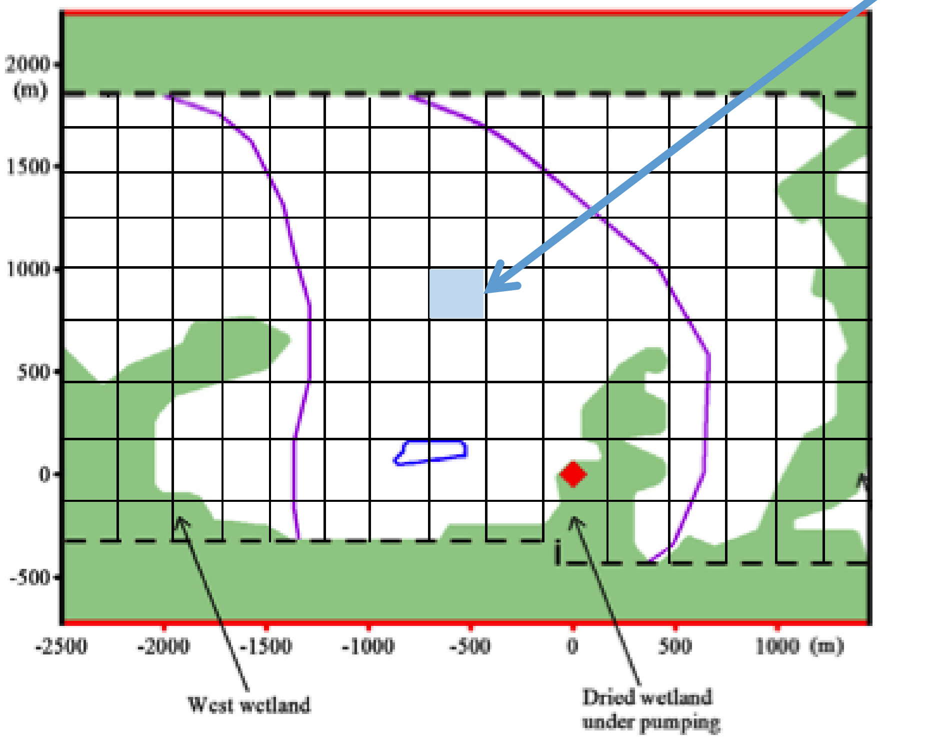
Model calibration

- Piezometry
  - Contact zone transmissivity
  - Recharge

- CFC-12 concentration at the well
  - Global volume of the aquifer= structure + porosity
  - TTD

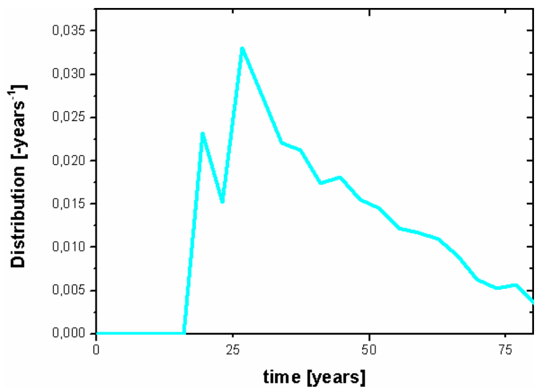
This model = our « reality »

Sampling « observations data »



Reference « observations » :

- Transit time distribution :



- Tracer concentrations

Concentration = field observations

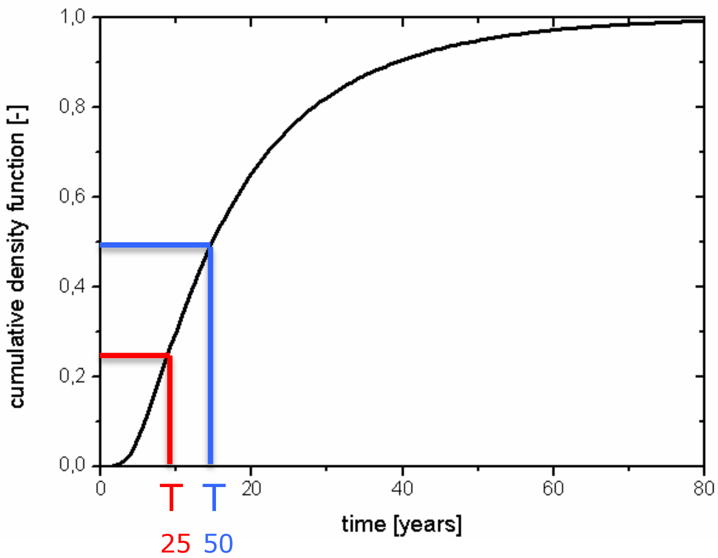
LPMs and Virtual Reality Predictions

Calibration of the LPMs

- Assessment of the LPMs parameters from our « observations ».
  - **Number of tracer = Number of the LPM**
  - 1 parameter LPM → CFC-11
  - 2 parameters LPM → CFC-11 et ^{85}Kr
  - 3 parameters LPM → CFC-11 et ^{85}Kr et SF_6
- Goodness of fit → estimation of residual

Predictions

- Renewal time of the aquifers → time required for 25 and 50% to be renewed

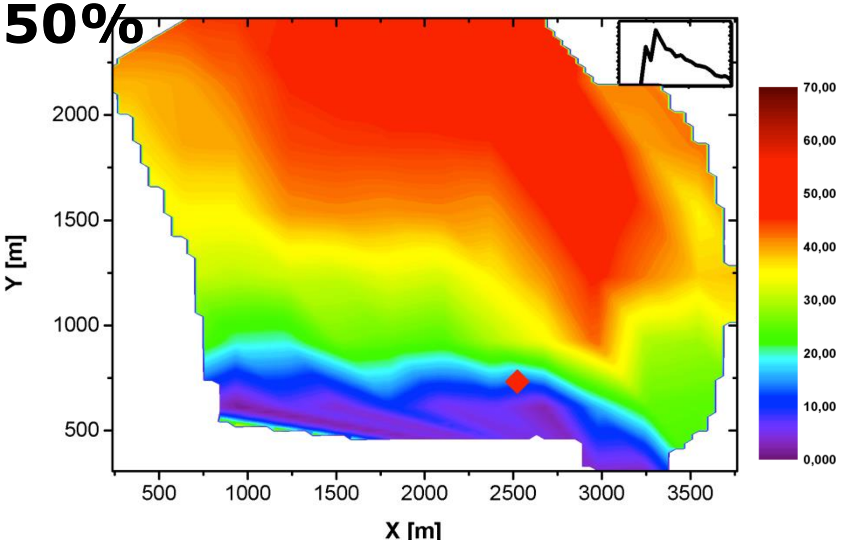


- Comparison of the predictions obtained from the LPMs and the reference TTD (our « reality »)

Quality of predictions (1 LPM)

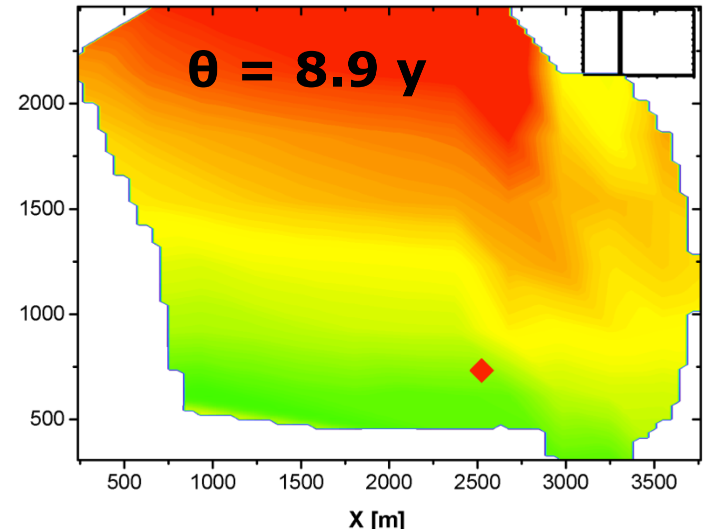
Marçais et al., 2015

50%

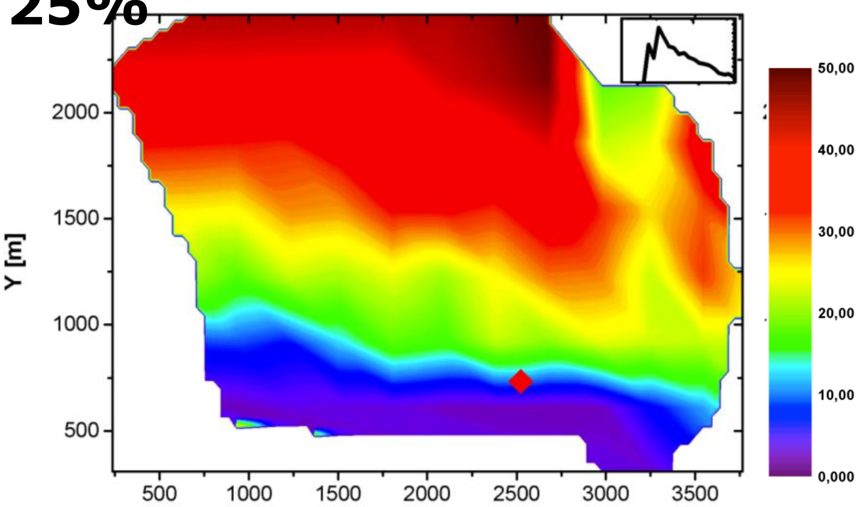


Dirac

Rcal = 0%

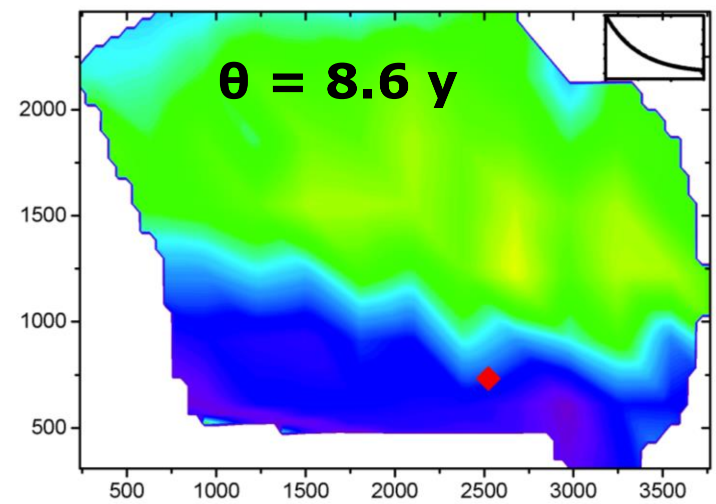


25%



Exponential

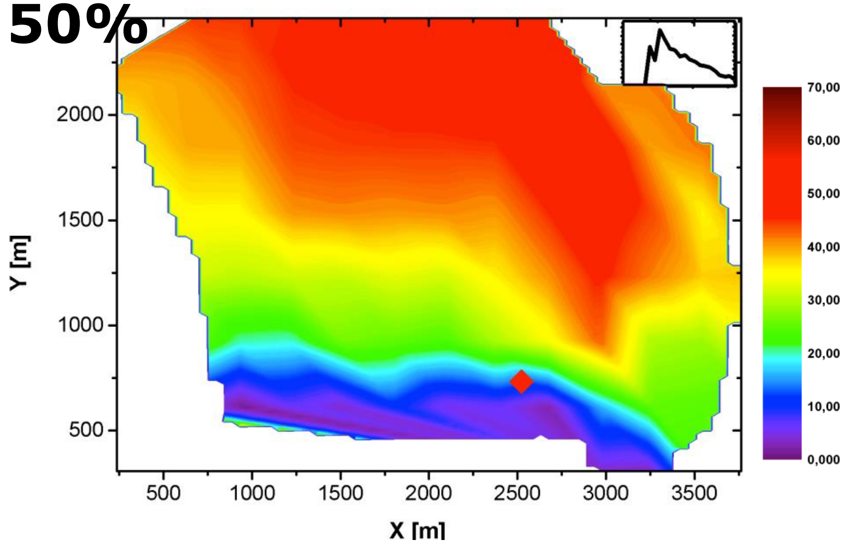
Rcal = 99%



Quality of the predictions (1 LPM)

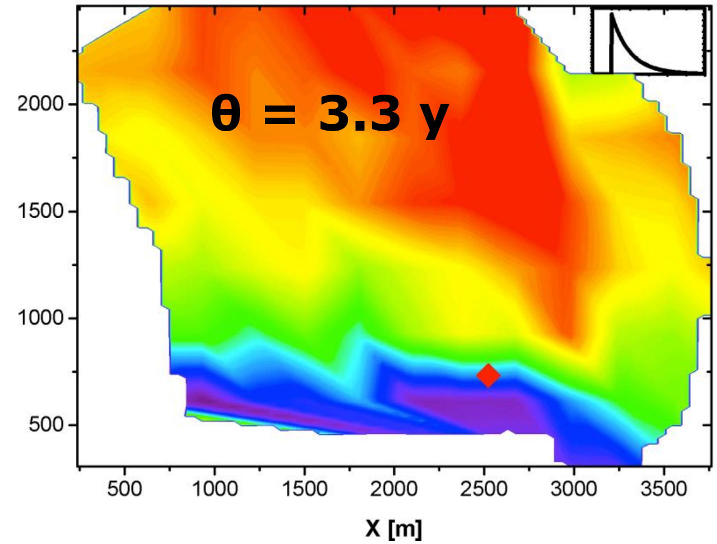
Marçais et al., 2015

50%

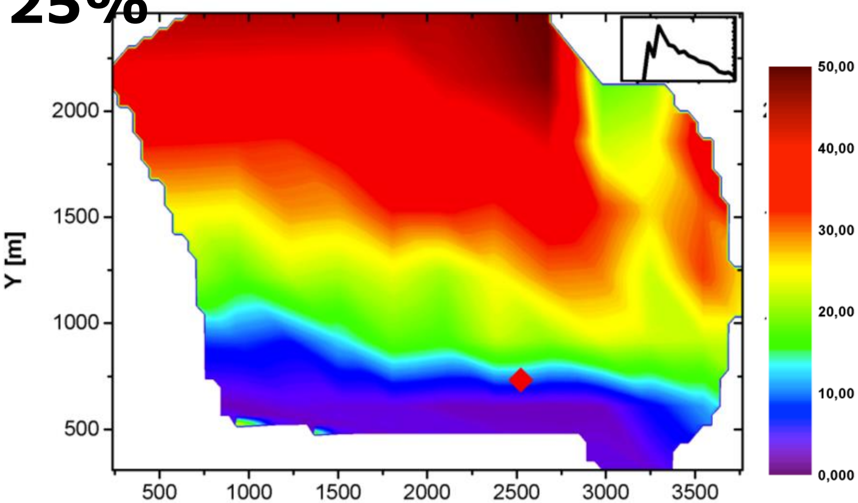


Exponential shifted

Rcal = 3.8%

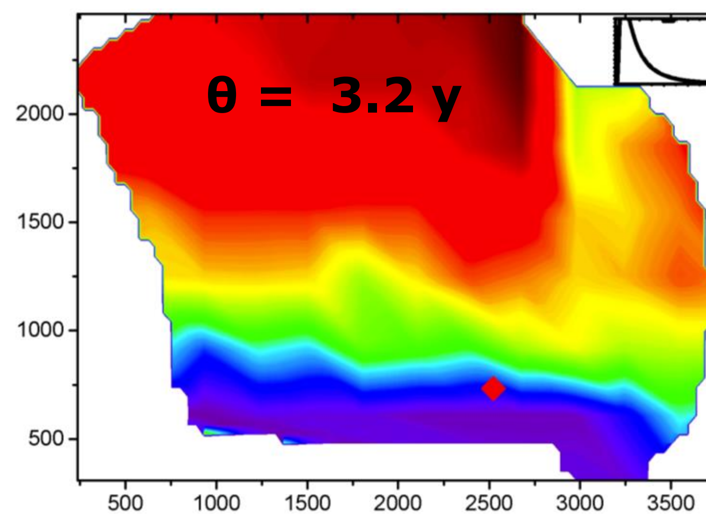


25%



Inverse Gaussian

Rcal = 1.1%



Conclusions

- Dipping fractured zones = significant resources~equivalent to regional scale fault
  - Tracer concentrations to constrain the aquifer structure

- Predictive capacity of the LPMs:
  - Do not only depend on the goodness of fit (ex. Dirac)
  - High dependancy to the **likelyhood** of the LPM (ex. Exponential)
  - Need at least **two tracers** with sufficiently different atmospheric concentration chronicles to use a **LPM broad and relatively smooth**
  - More details on the distribution provided by additional tracer data not necessary for our purposes

→2 tracer concentrations + LPMs → good predictions

THANK YOU!