Wave propagation in 2D heterogeneous porous media : Discontinuous Galerkin method in (x,ω) domain

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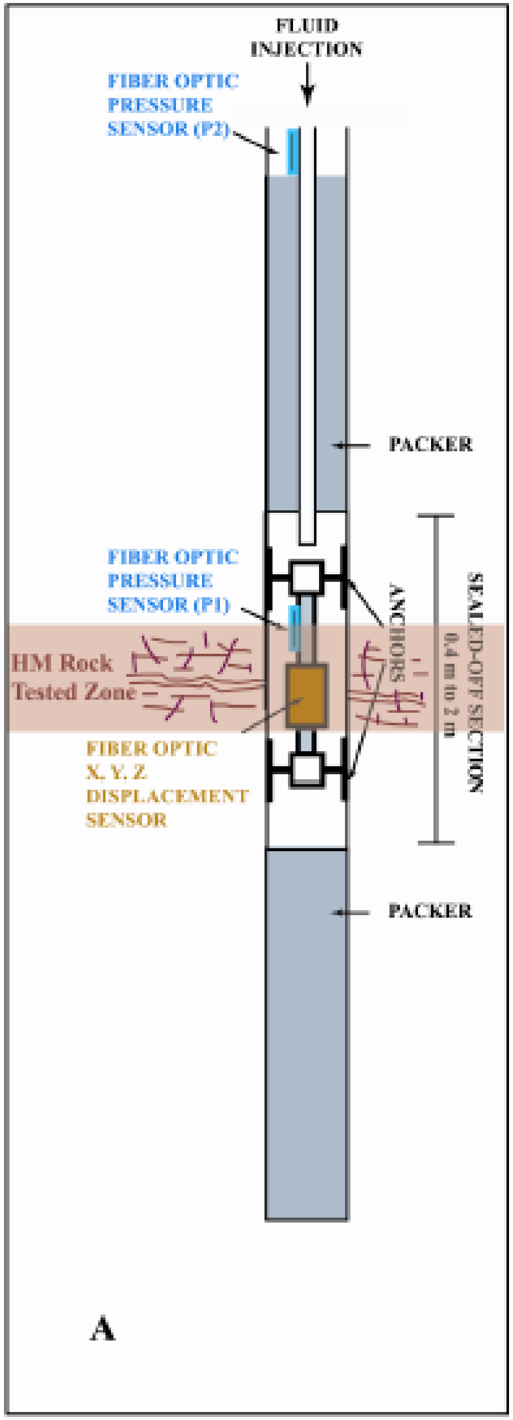
Context

- HPPP – CO_2 probe :
  - displacements and fluid pressure sensors
  - complex fluid pressure source
  - near field waves (Biot wave)



Outline

- Poroelastodynamics
- Validation in stratified media
- Heterogeneous media
- Biot wave influence

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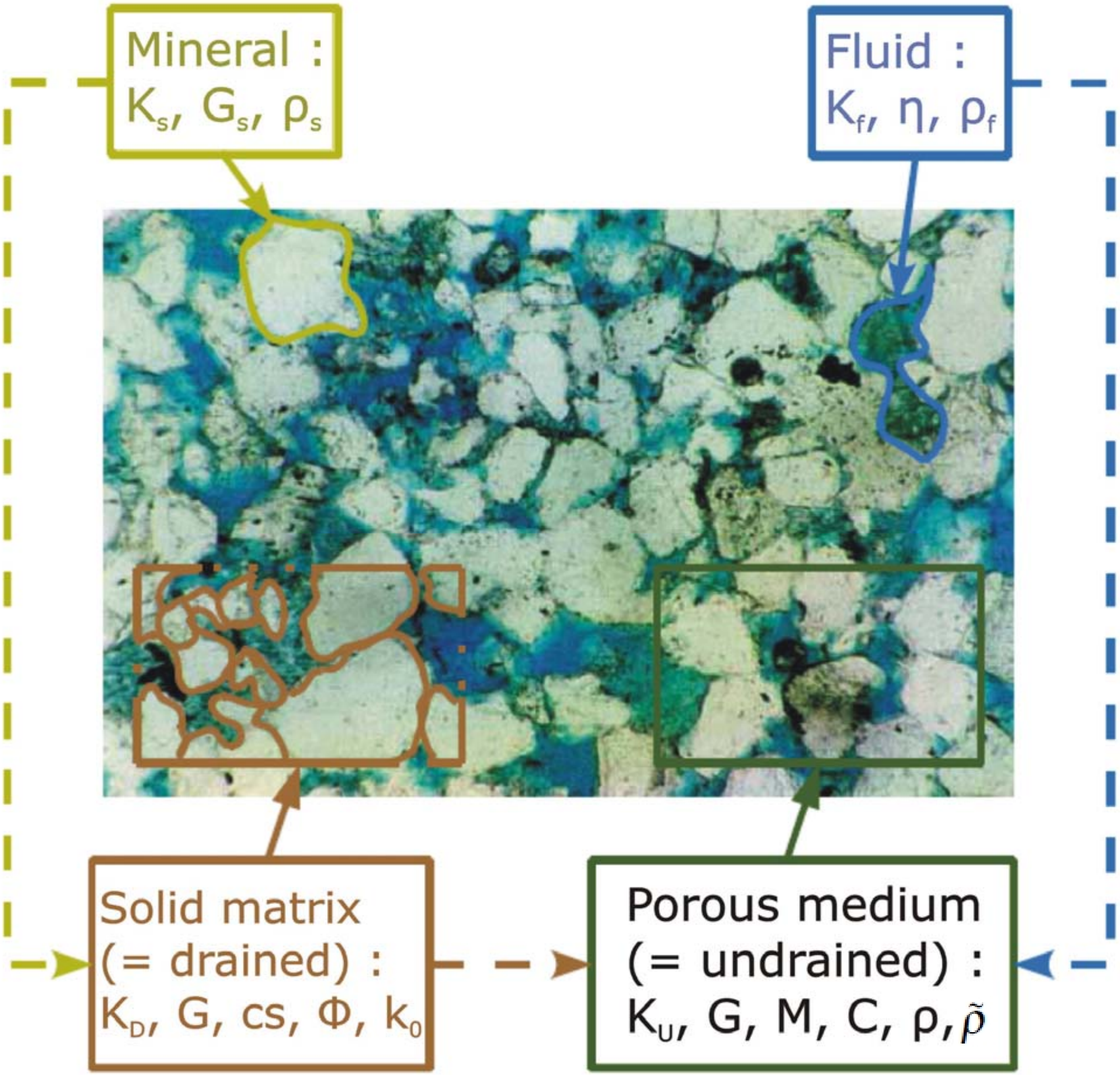
Description of porous media

- Homogenization of fluid and solid phases

De Barros, 2007



Poroelastodynamics : Biot-Gassmann equations

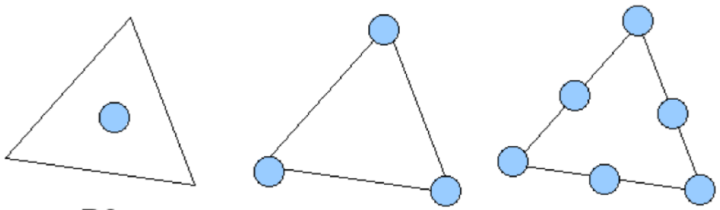
$$\begin{cases} \nabla . \boldsymbol{\tau} = -\,\omega^2\,(\rho\,\vec{u} + \rho_f\,\vec{w}) \\ \boldsymbol{\tau} = [K_U\,\nabla.\vec{u} + C\,\nabla.\vec{w}]\,\boldsymbol{I} + G\,[\nabla\vec{u} + (\nabla\vec{u})^t - 2/3\,\nabla.\vec{u}\boldsymbol{I}] \\ -P = C\,\nabla.\vec{u} + M\,\nabla.\vec{w} \\ -\nabla P = -\,\omega^2\,(\rho_f\,\vec{u} + \tilde{\rho}\,\vec{w}) \end{cases}$$

8 unknowns in 2D (5 in elastics) :

- displacements : solid u_x and u_z and relative fluid/solid w_x and w_z
- stresses τ_{xx}, τ_{zz} et τ_{xz} and fluid pressure P

Numerical method : Discontinuous Galerkin (DGM) in the (x , ω) domain

- Discontinuous finite element : fluxes between triangular cells
  - Mix interpolation orders
  - Complex interfaces and topography



- Frequency modelling :
  - Porous media rheology
  - Linear system to solve : **A . x = b**

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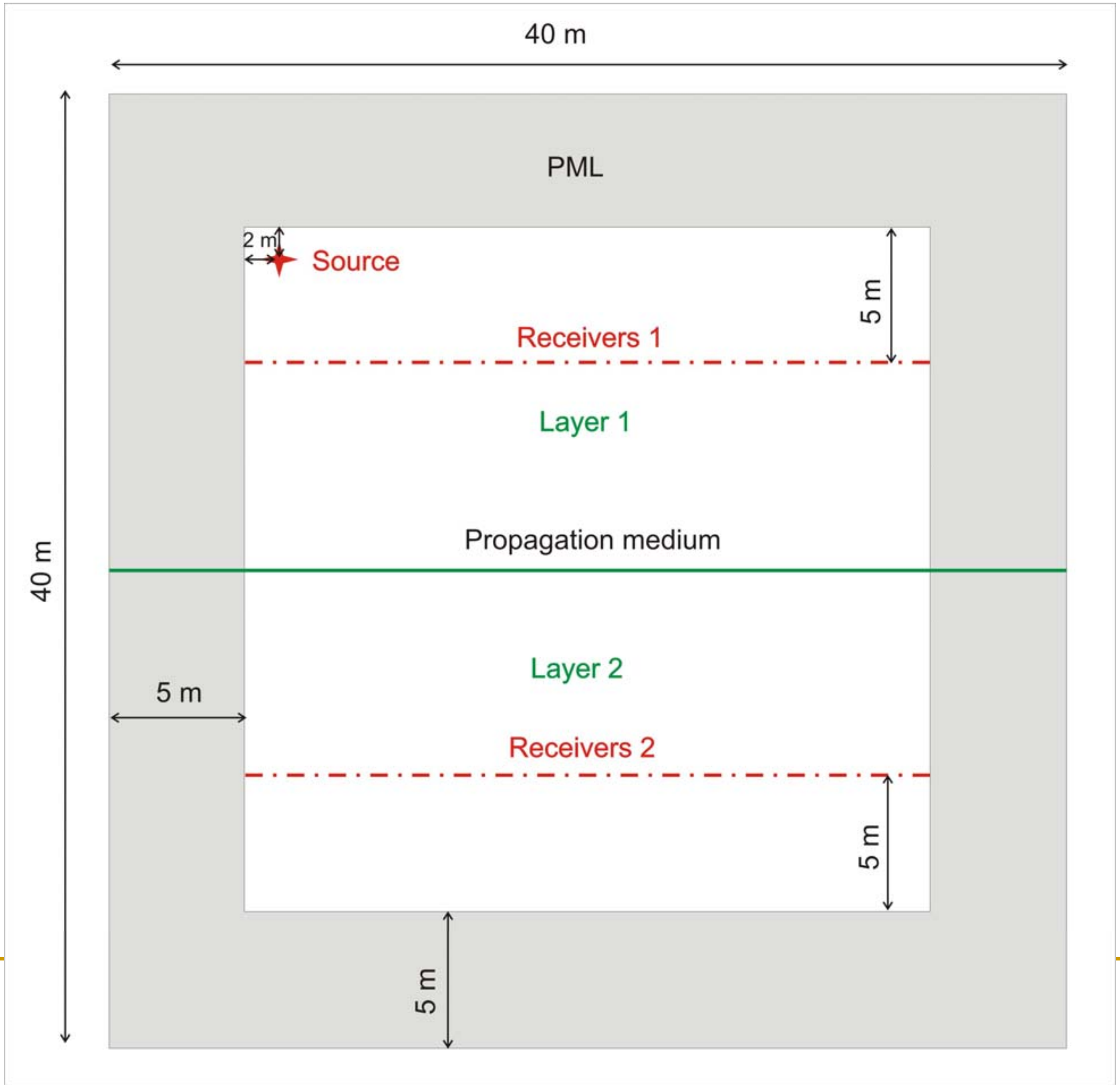
Validation in stratified media

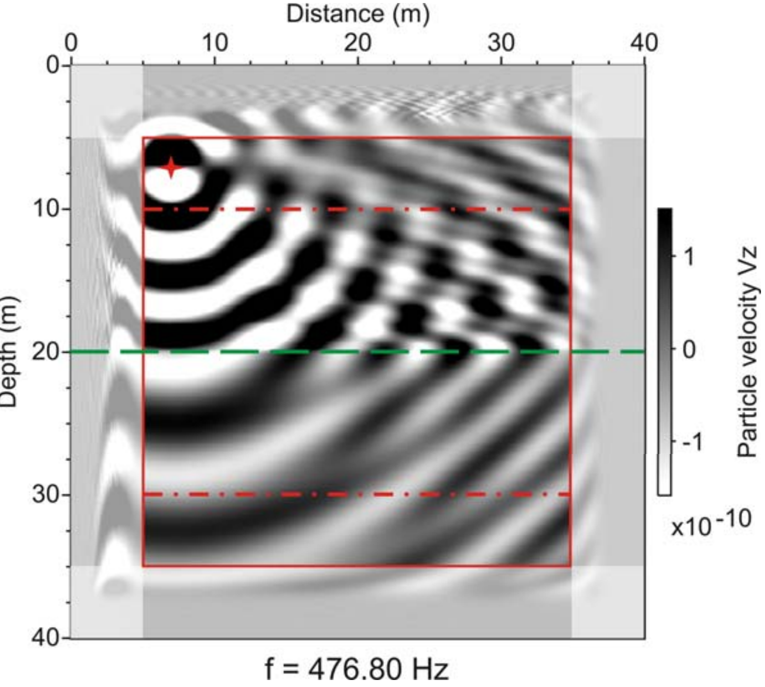
- Explosive source : Ricker with a central frequency of 200 Hz
- Frequency band : from 1 to 600 Hz
- Two-layers medium :

	ϕ	k_0 (m^2)	ρ_f (kg/m^3)	ρ_s (kg/m^3)	K_s (GPa)	G_s (GPa)	K_f (GPa)	cs	η $(Pa.s)$	m
Layer 1	0.4	10^{-11}	1000	2700	30	21,67	2.2	20	0.001	1.5
Layer 2	0.1	10^{-14}	1000	2700	40	35	2.2	20	0.001	1.5

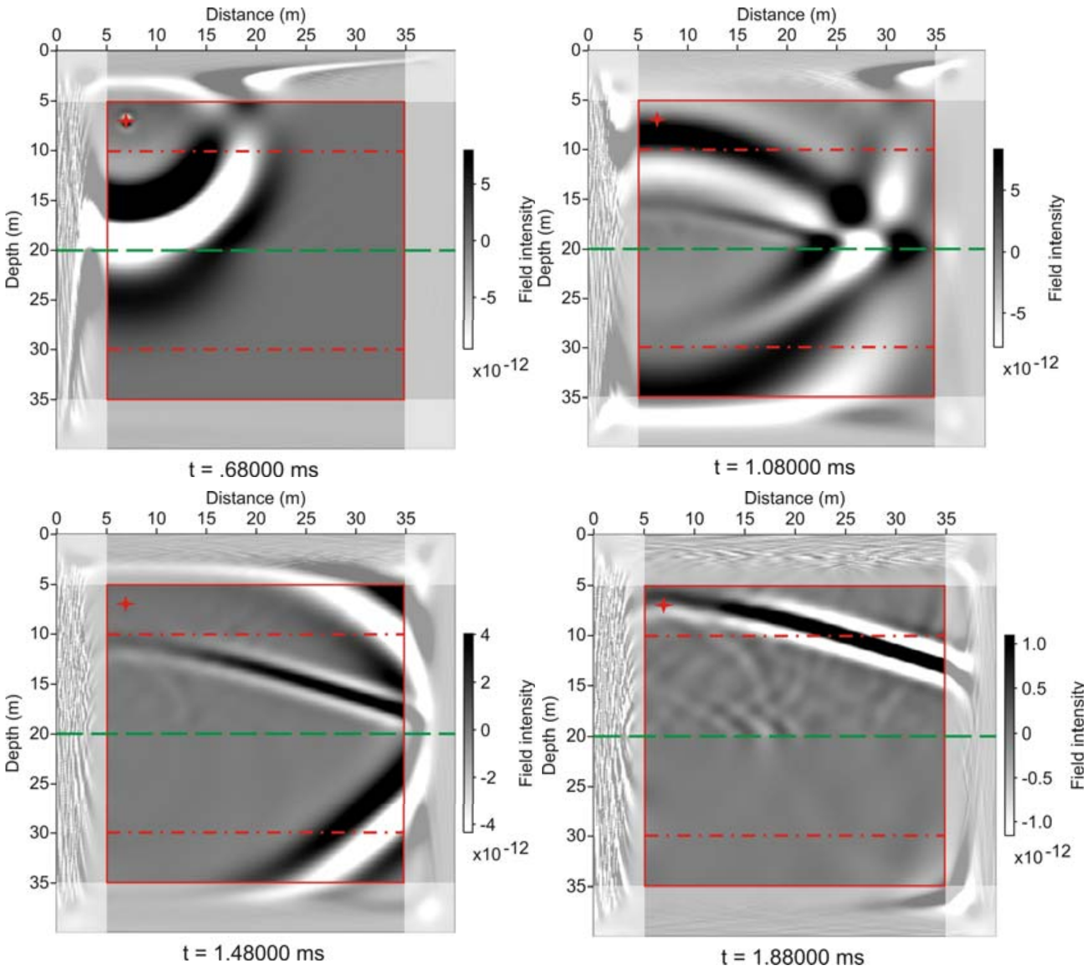
Validation in stratified media



2D maps : Vz

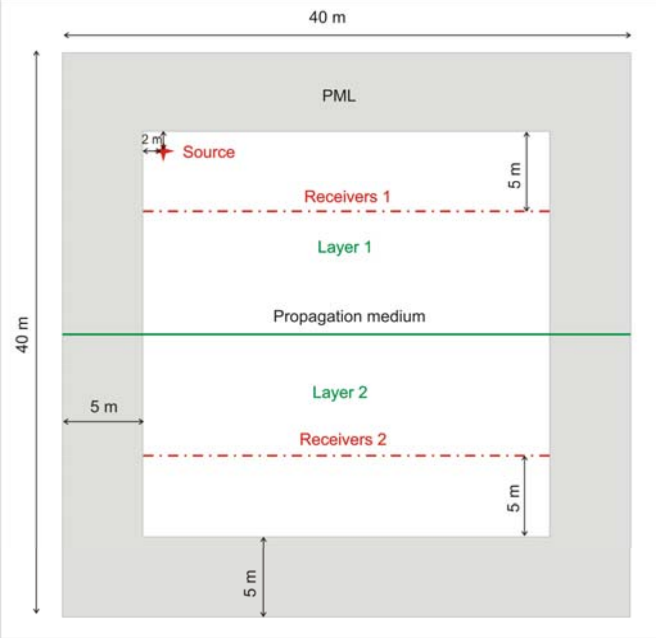


Frequency

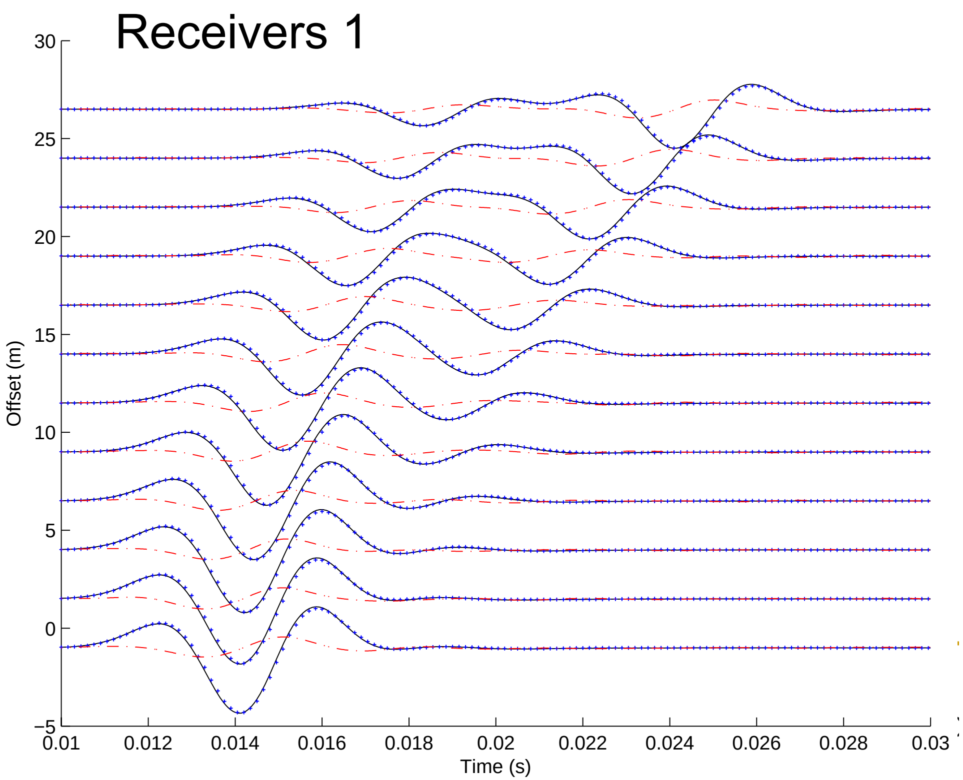


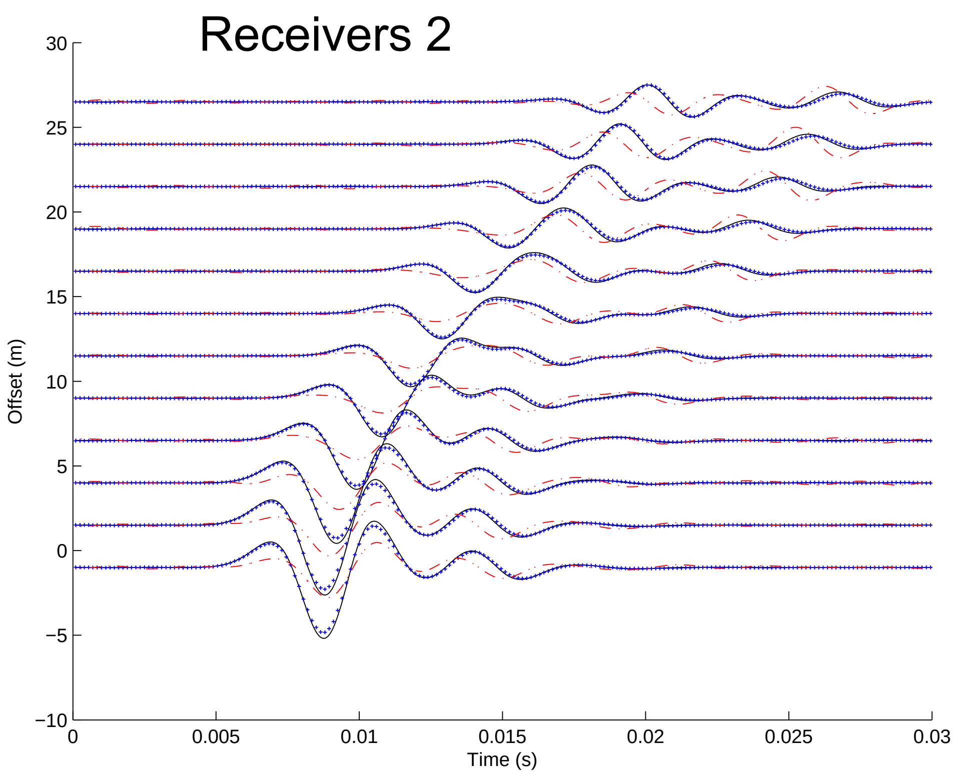
Time

Seismograms : Vz



Semi-analytical solution
DGP0
Residual * 5





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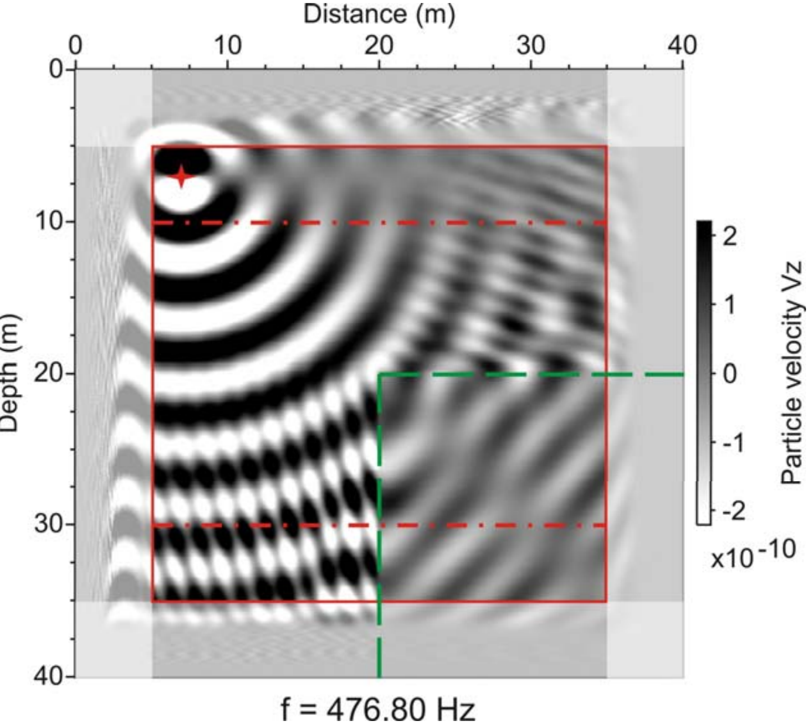
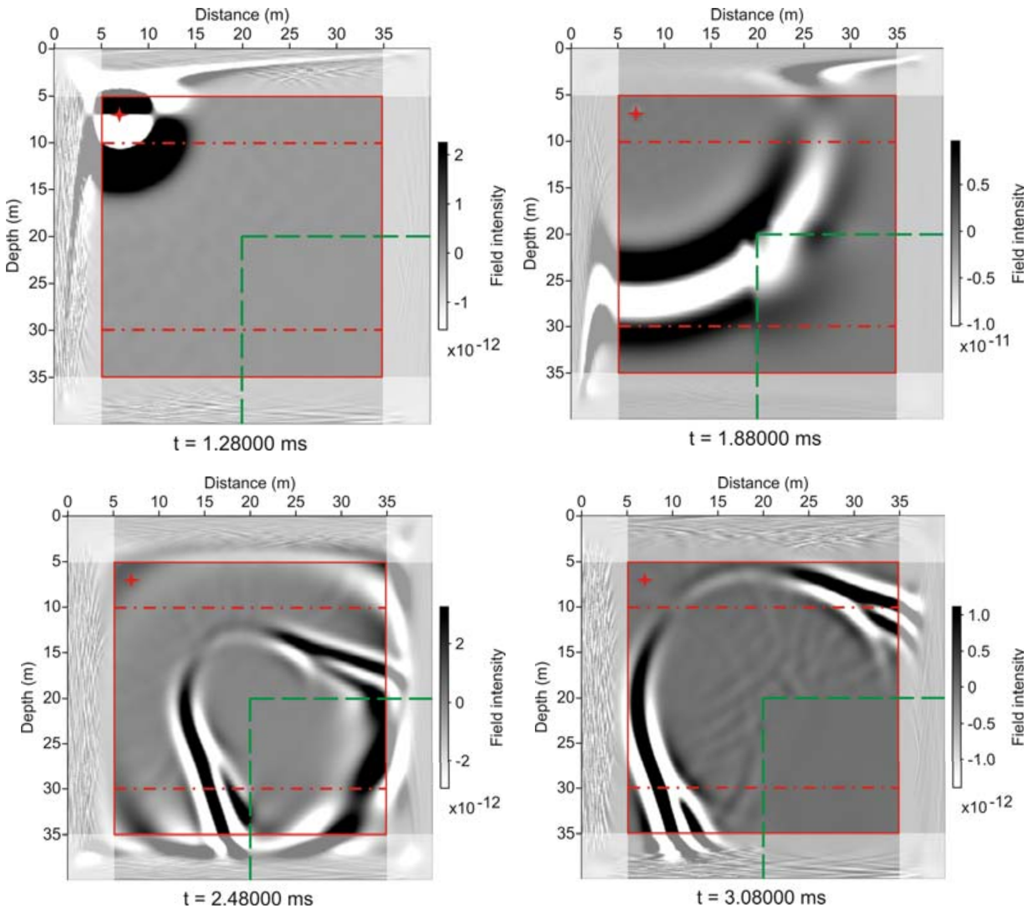
Corner edge model : Vz



Frequency



Time

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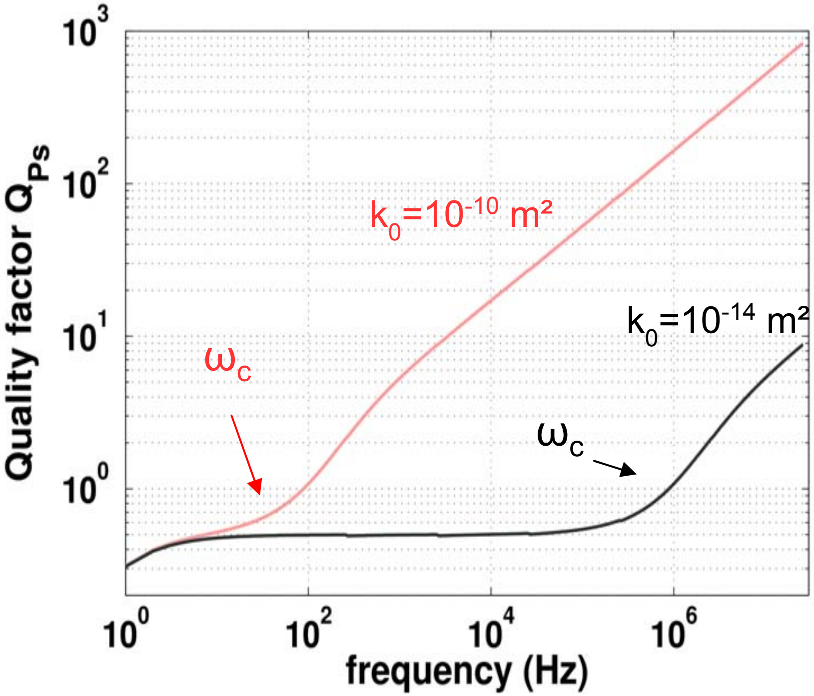
Biot wave and the flow resistance density term

- Fluid flow modelised by a generalised Darcy law
- The cut off frequency wc separates two different behaviours for the Biot wave
- Low frequency : strongly attenuated => non propagative wave, fluid-diffusion wave
- propagative wave in the high frequency domain



De Barros, 2007

$$k(\omega) = \frac{k_0}{\sqrt{1 - i\frac{4}{n_J}\frac{\omega}{\omega_c}} - i\frac{\omega}{\omega_c}}$$

$$\omega_c = \frac{\eta}{\rho_f F k_0}$$

$$\tilde{\rho} = \frac{i\eta}{\omega \; k(\omega)}$$

Parameters

$$\omega_c = \frac{\eta}{\rho_f F k_0}$$

ϕ	k_0 (m^2)	ρ_f (kg/m^3)	ρ_s (kg/m^3)	K_s (GPa)	G_s (GPa)	K_f (GPa)	cs	η $(Pa.s)$	m
0.4	10^{-11}	1000	2700	30	21,67	2.2	20	0.001	1.5

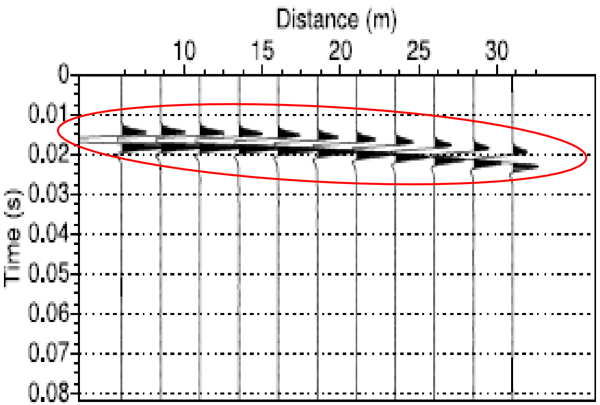
	Fluid viscosity η (Pa.s)	Permeability k_0 (m^2)	Cut-off frequency ω_c (Hz)	Biot wave behaviour
Medium 1	10^{-3}	10^{-11}	25 300	Diffusive
Medium 2	10^{-3}	10^{-9}	253	Intermediate
Medium 3	10^{-11}	10^{-11}	2,53	Propagative

Biot wave

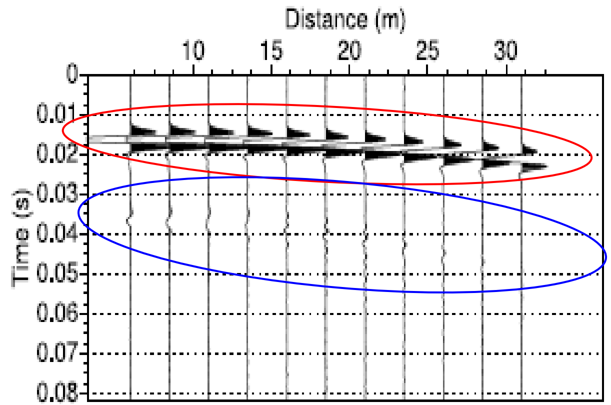
P-wave

Biot wave

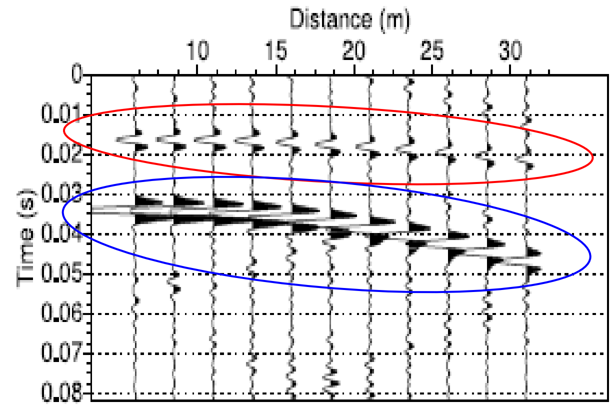
Medium 1 : diffusive | Medium 2 : intermediate | Medium 3 : propagative



Vertical solid displacement Vz



Vertical solid displacement Vz



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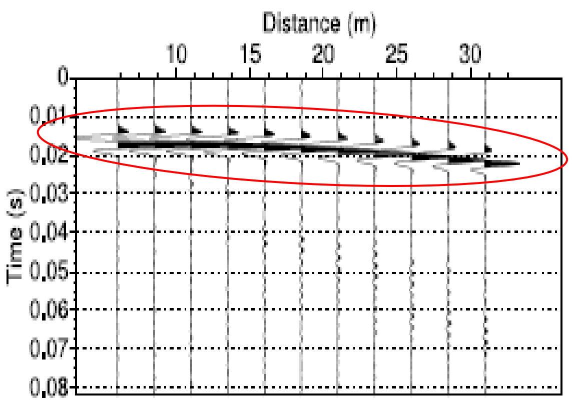
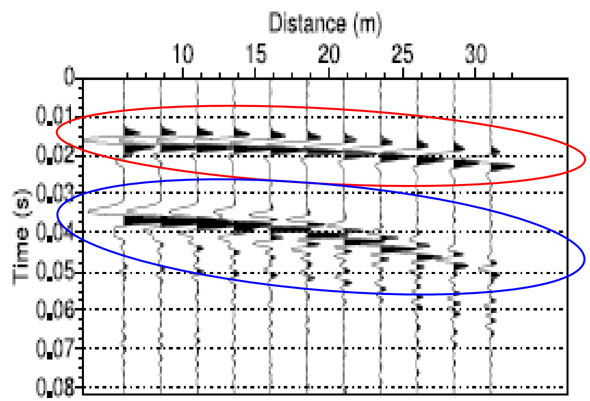
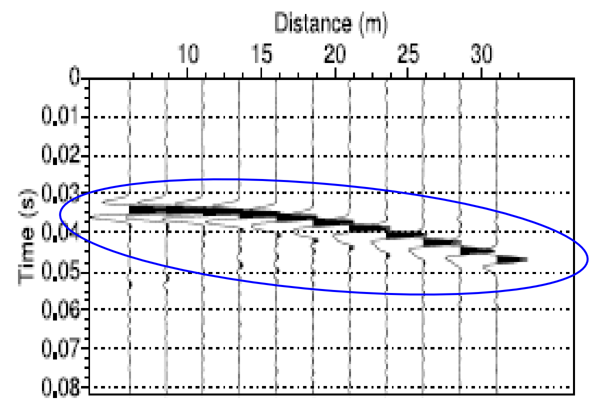


Vertical relative fluid/solid displacement Wz



Vertical relative fluid/solid displacement Wz



Vertical relative fluid/solid displacement Wz

Conclusions

- Tool of modelling for wave propagation in poroelastic media :
  - Efficiency Discontinuous Galerkin Method : HP adaptivity
    - Complex topography and interfaces, fractured media
    - Mesh facilities : local refinement, mix of interpolation orders
  - Advantages of frequency modelling :
    - Fluid/solid interactions frequency dependent
    - Poro-visco-elastodynamics
    - Inversion strategy in frequency
- Perspectives :
  - Near field for HPPP source
  - Energy repartition at interfaces
  - Imaging with FWI