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

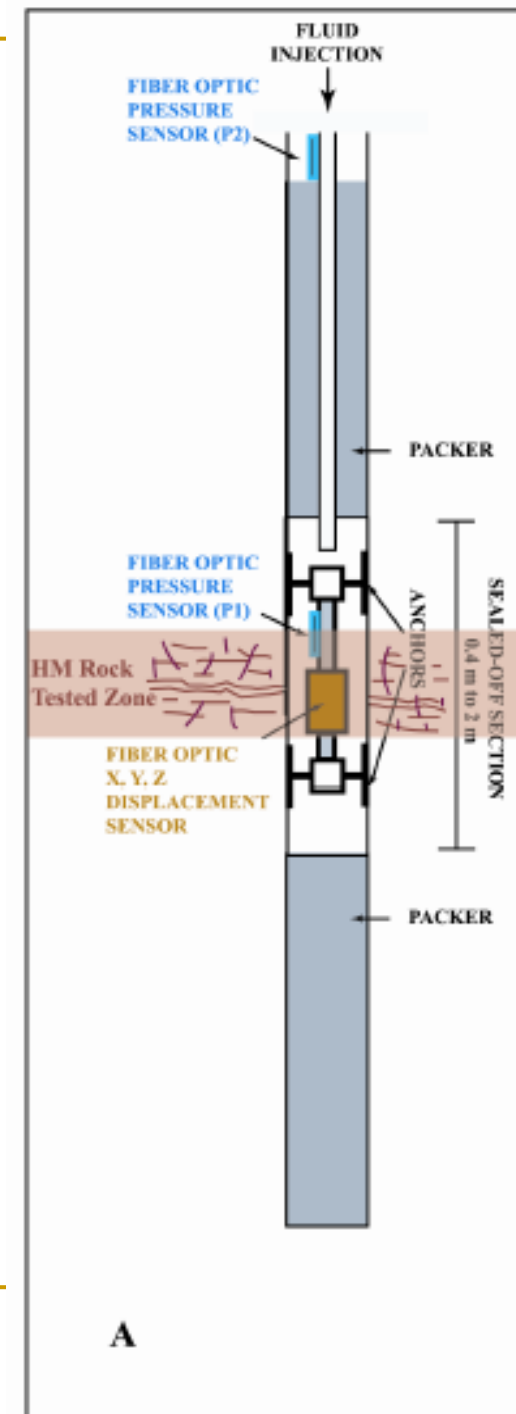


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Context

- HPPP – CO₂ 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

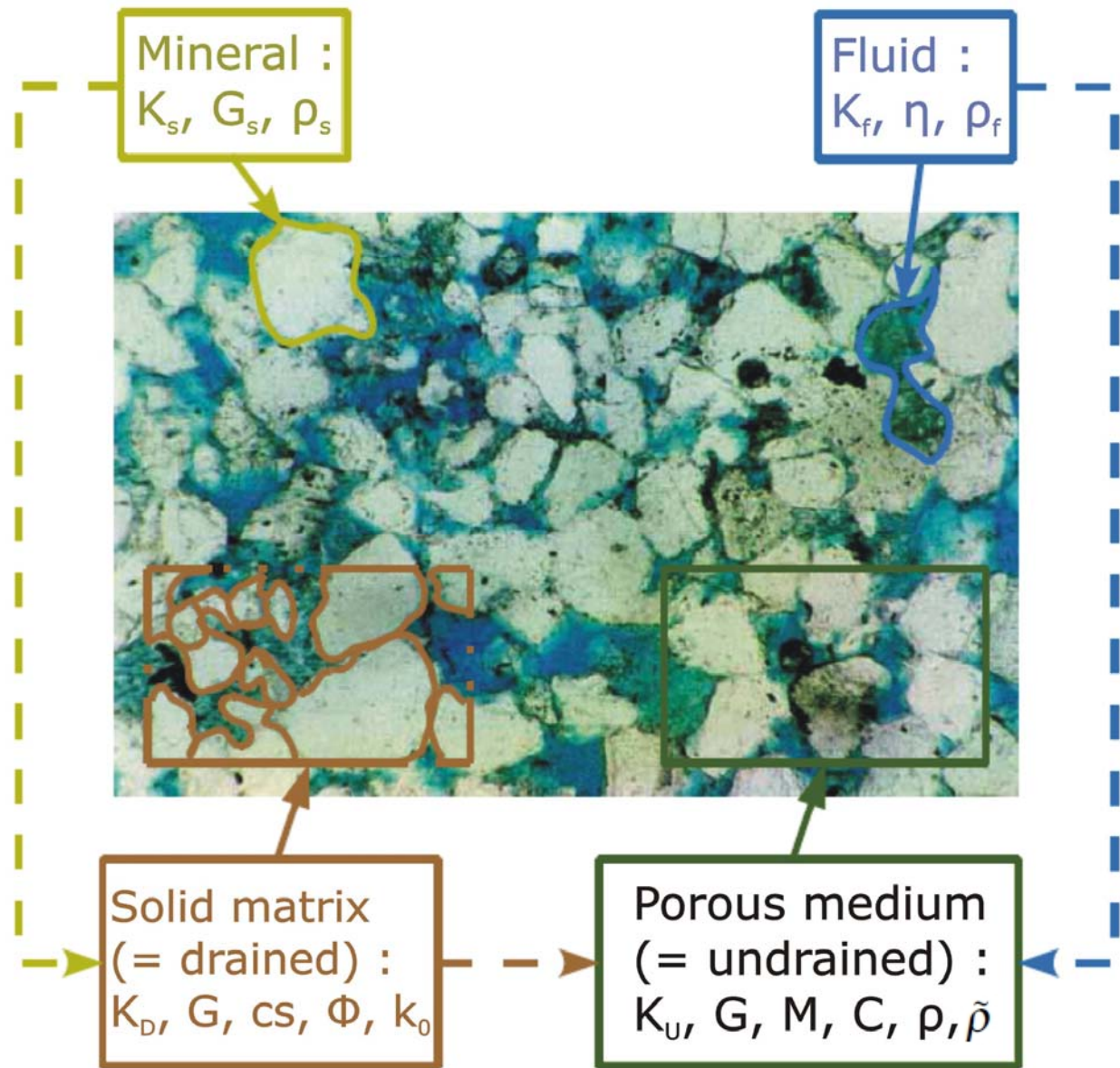
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Description of porous media

- Homogenization of fluid and solid phases

De Barros, 2007



Poroelastodynamics : Biot-Gassmann equations

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

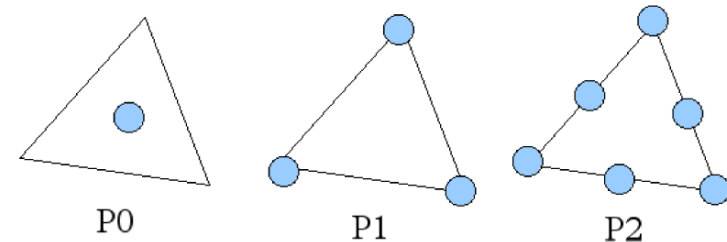
8 unknowns in 2D (5 in elastics) :

- 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 : $\mathbf{A} \cdot \mathbf{x} = \mathbf{b}$

Outline

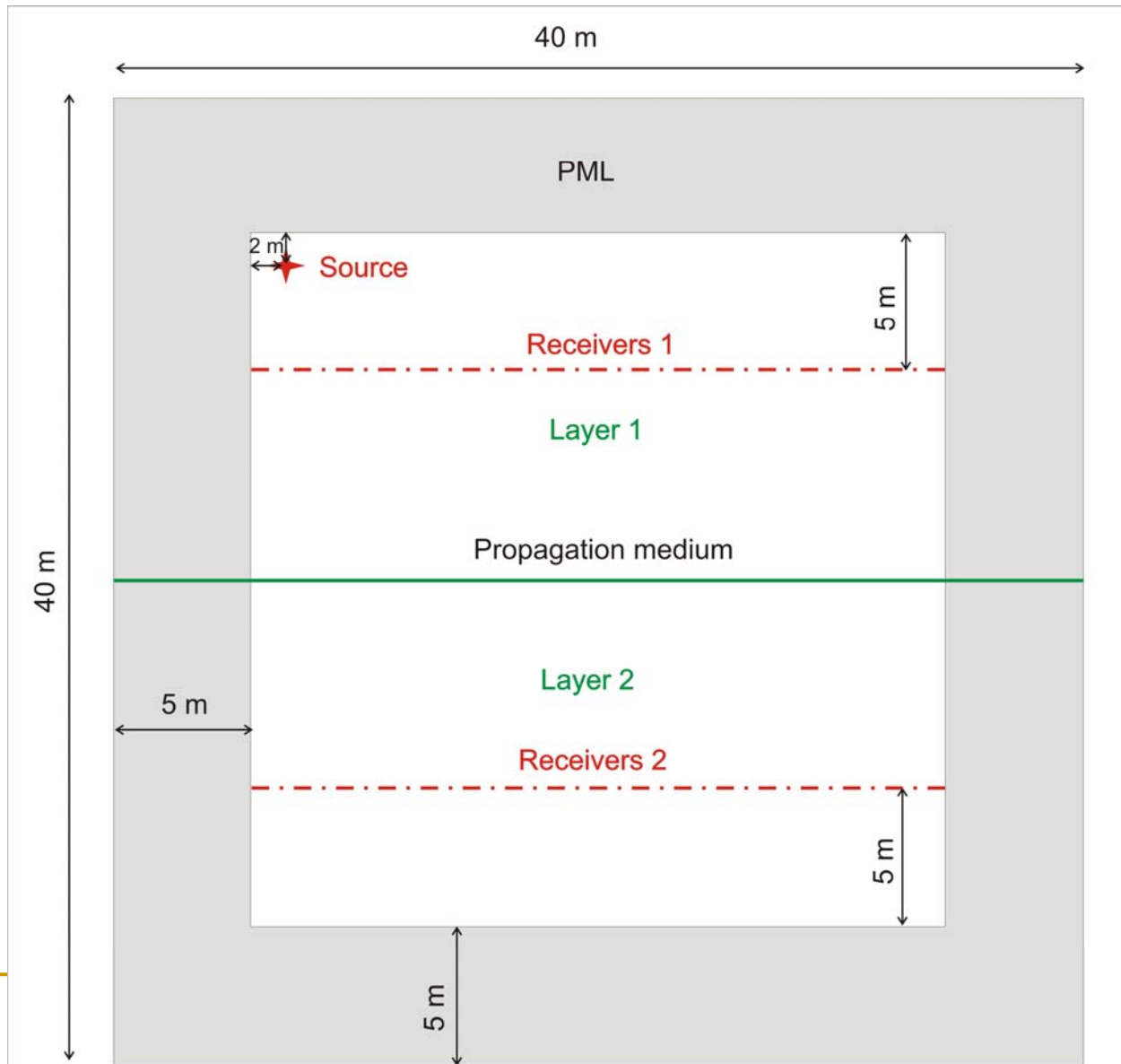
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Validation in stratified media

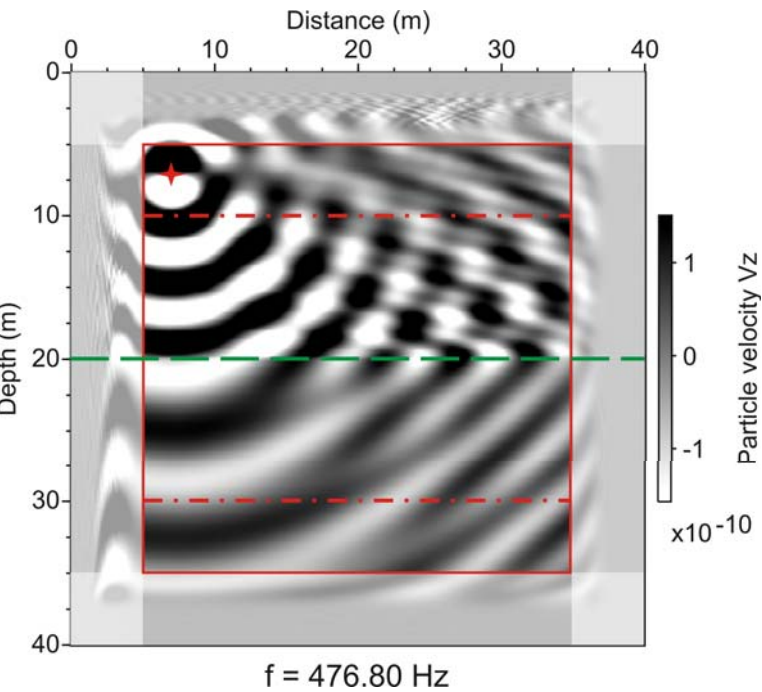
- Explosive source : Ricker with a central frequency of 200 Hz
- Frequency band : from 1 to 600 Hz
- Two-layers medium :

	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

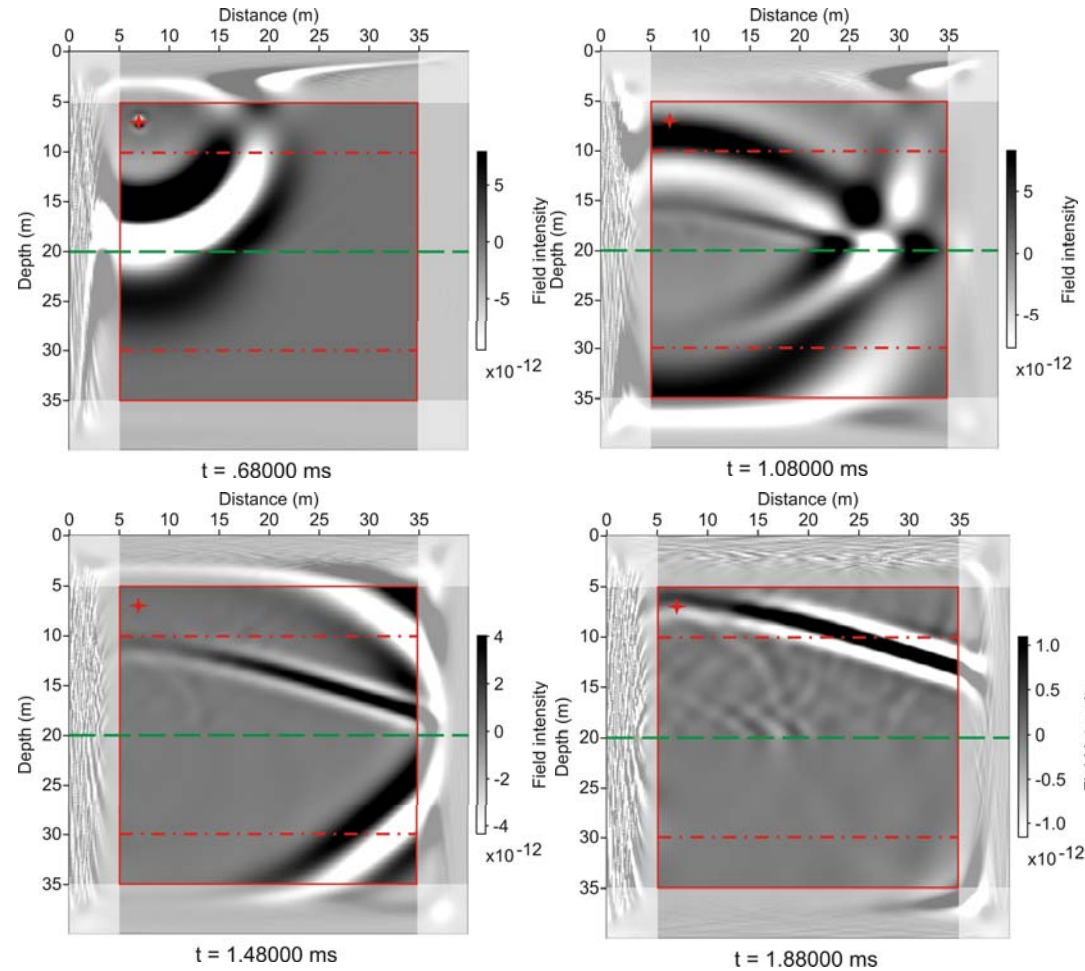


2D maps : V_z



$f = 476.80 \text{ Hz}$

Frequency



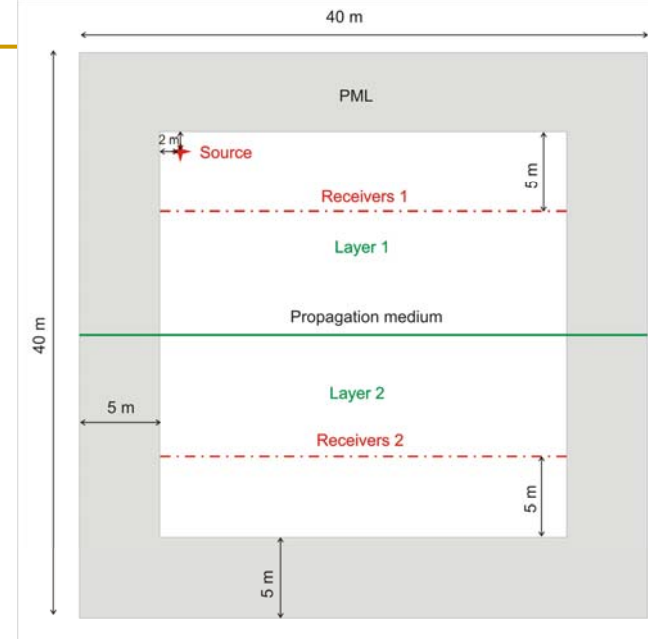
Time

Seismograms : V_z

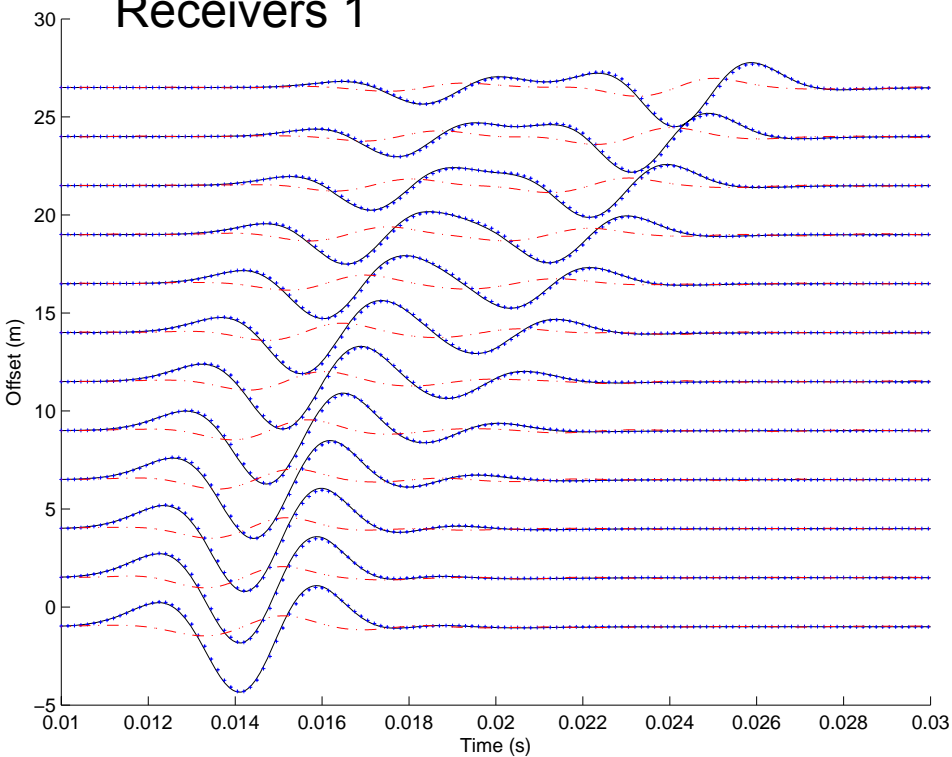
Semi-analytical solution

DGP0

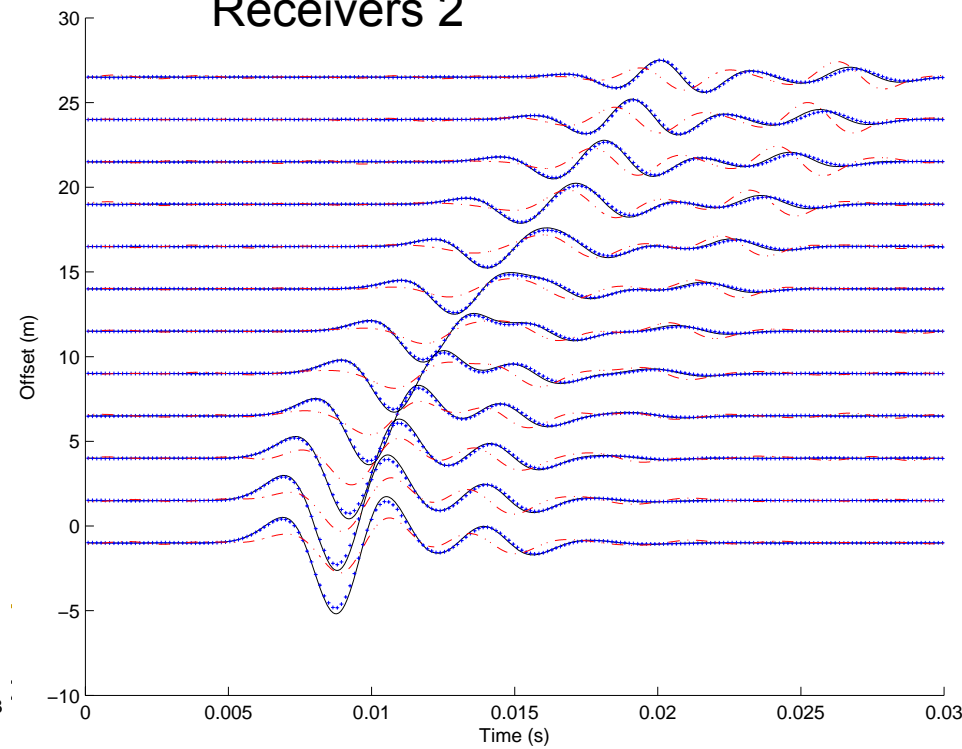
Residual * 5



Receivers 1



Receivers 2

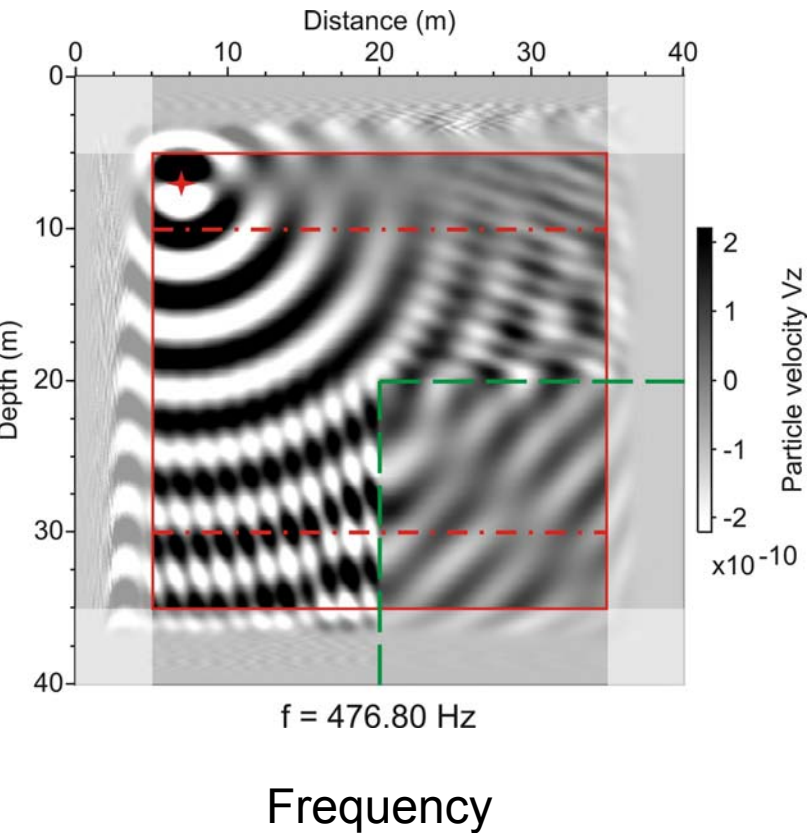


Outline

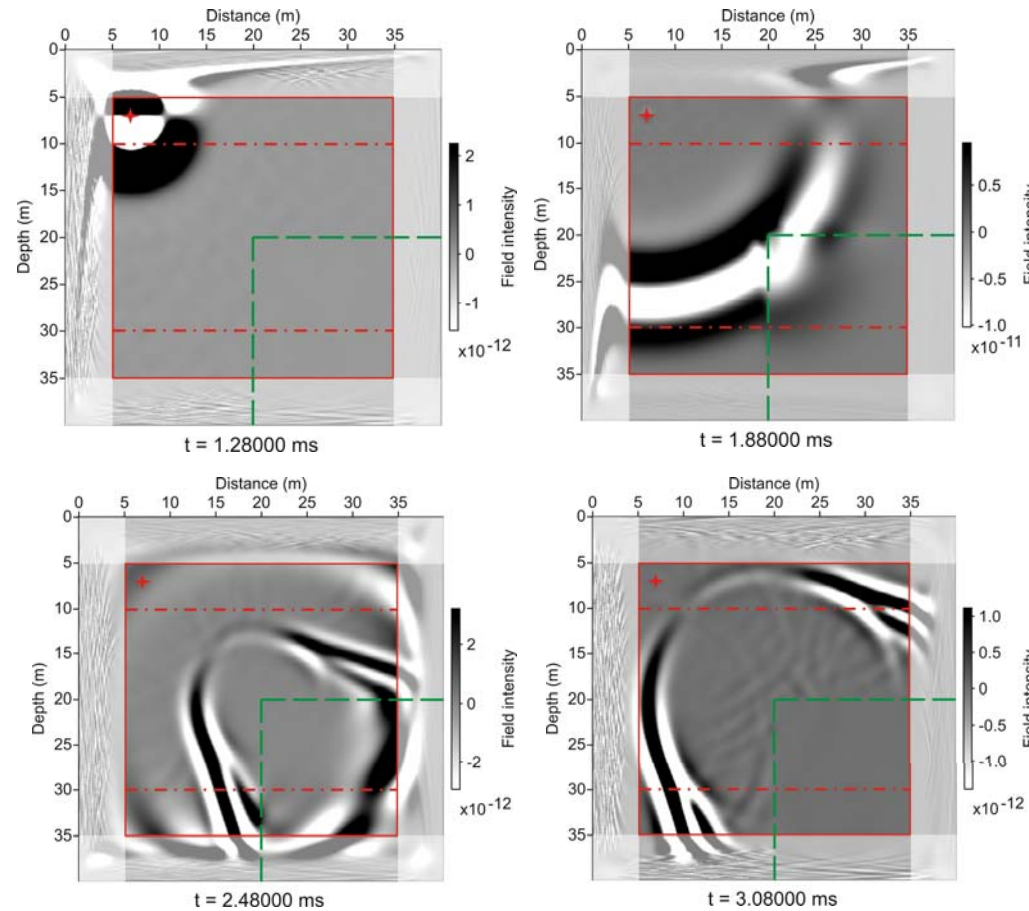
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Corner edge model :

V_z



Frequency



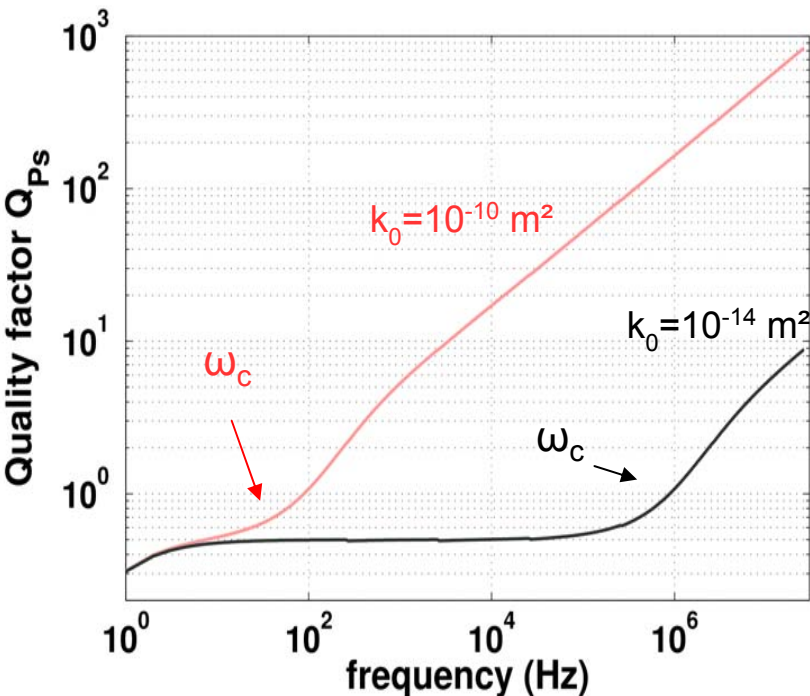
Time

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Biot wave and the flow resistance density term

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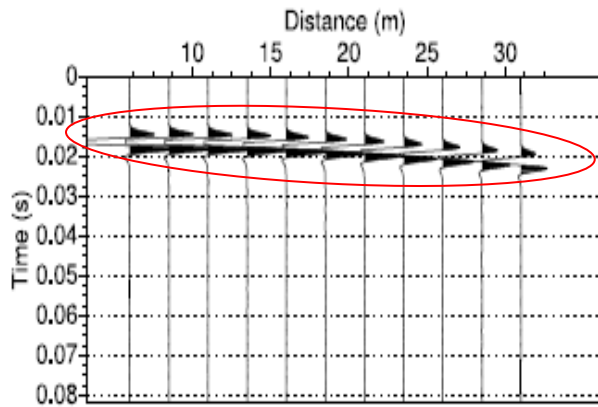
	Fluid viscosity η (Pa.s)	Permeability k_0 (m^2)	Cut-off frequency ω_c (Hz)	Biot wave behaviour
Medium 1	10^{-3}	10^{-11}	25 300	Diffusive
Medium 2	10^{-3}	10^{-9}	253	Intermediate
Medium 3	10^{-11}	10^{-11}	2,53	Propagative

Biot wave

P-wave

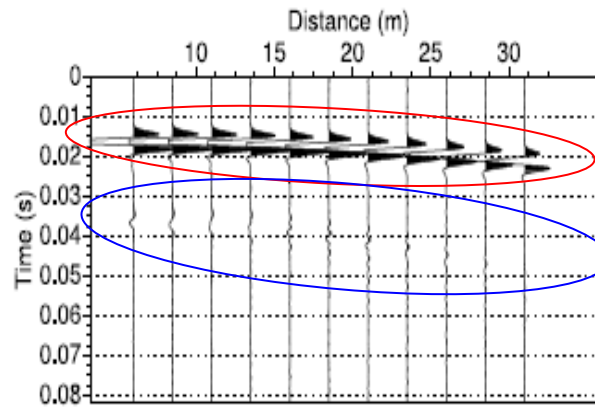
Biot wave

Medium 1 : diffusive



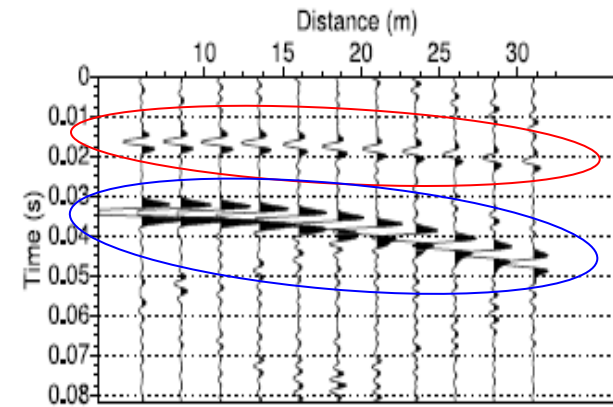
Vertical solid displacement V_z

Medium 2 : intermediate

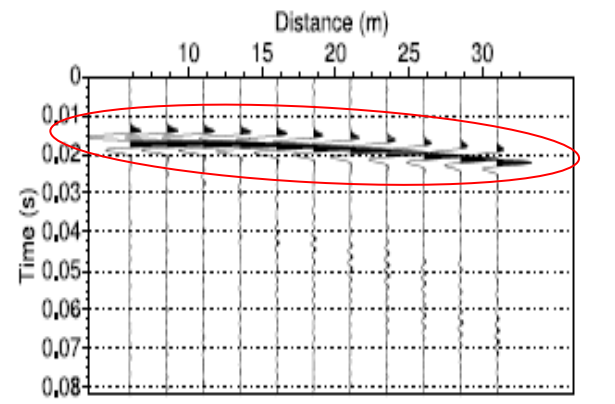


Vertical solid displacement V_z

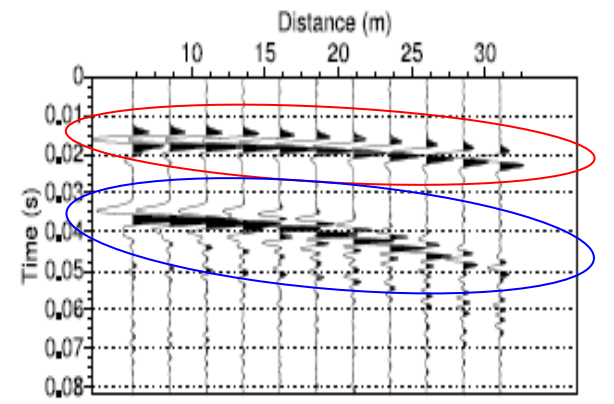
Medium 3 : propagative



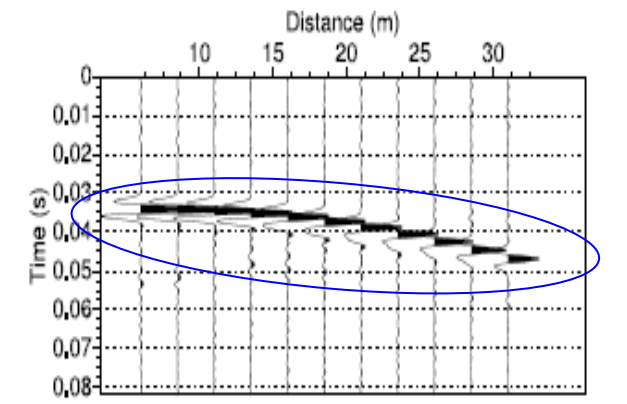
Vertical solid displacement V_z



Vertical relative fluid/solid displacement W_z



Vertical relative fluid/solid displacement W_z



Vertical relative fluid/solid displacement W_z

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