# *Fracturation électro-hydraulique des roches*

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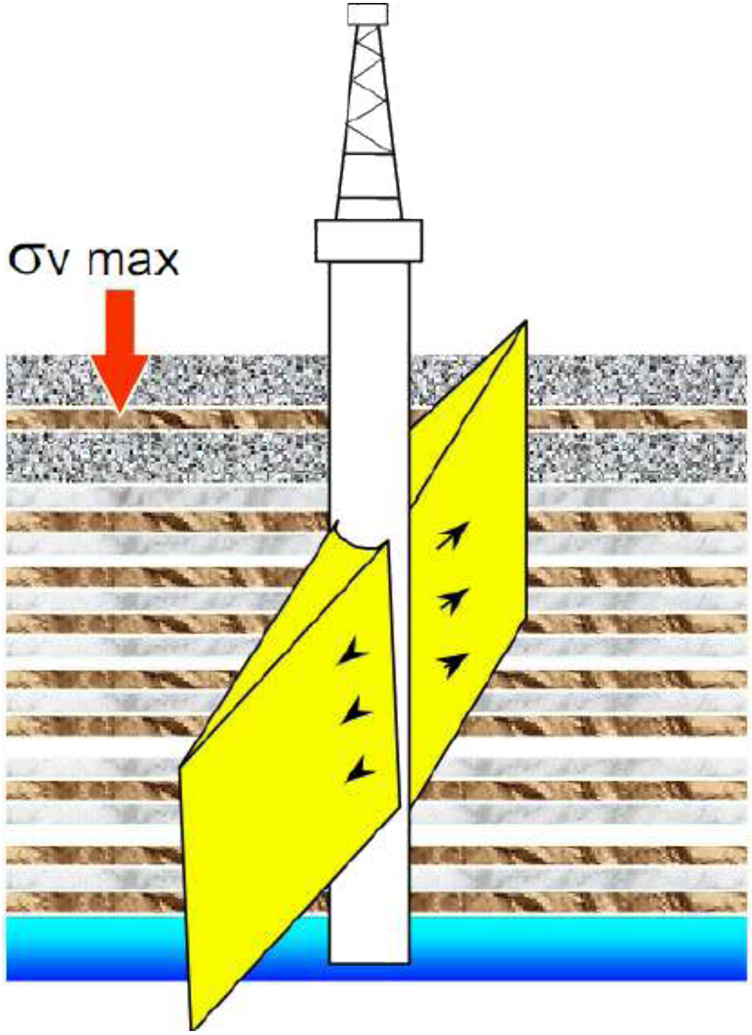
**CFMR, Paris 16/10/2014**

# Context

- Extract fossil ressources from tight rocks

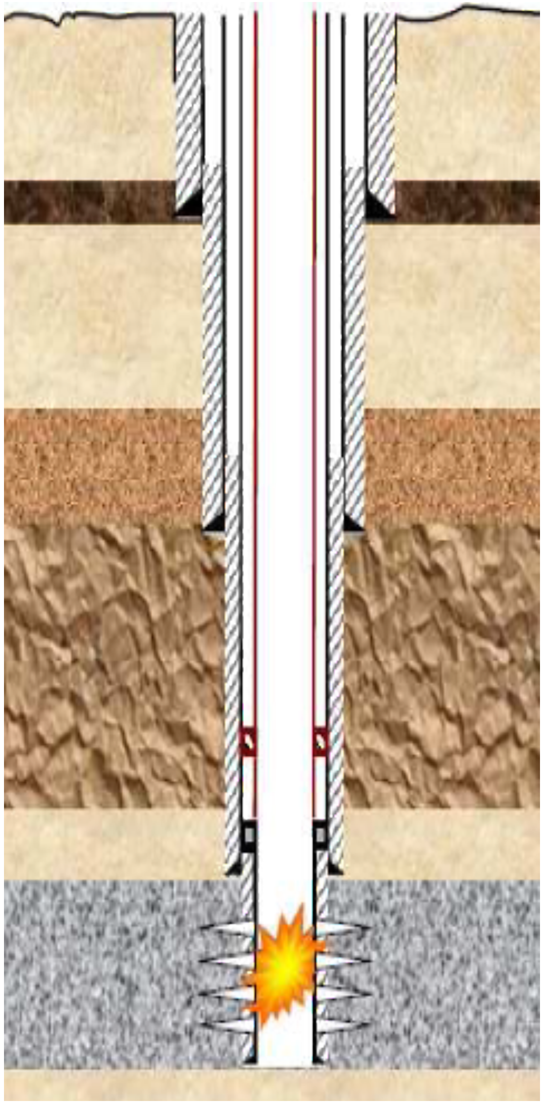


# Context

- Extract fossil ressources from tight rocks

- Alternative to hydraulic fracturing = dynamic loads

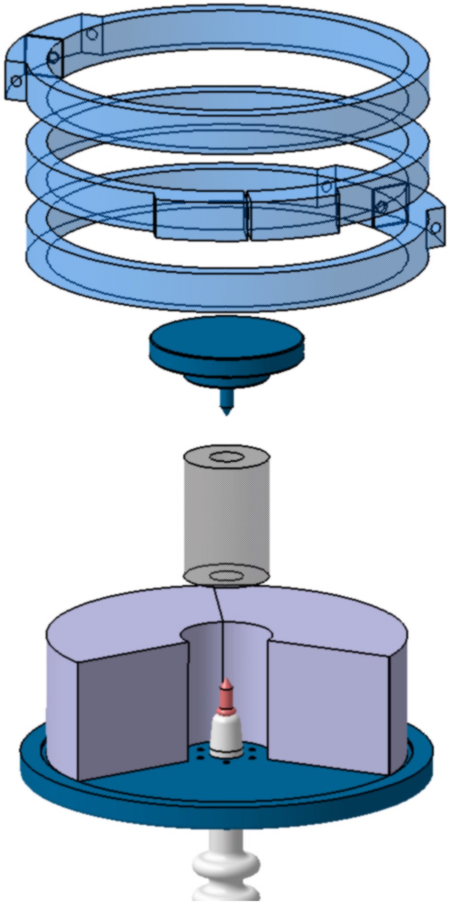
- Dynamic wave generated by electrical discharge



*From fracture to fragmentation….*

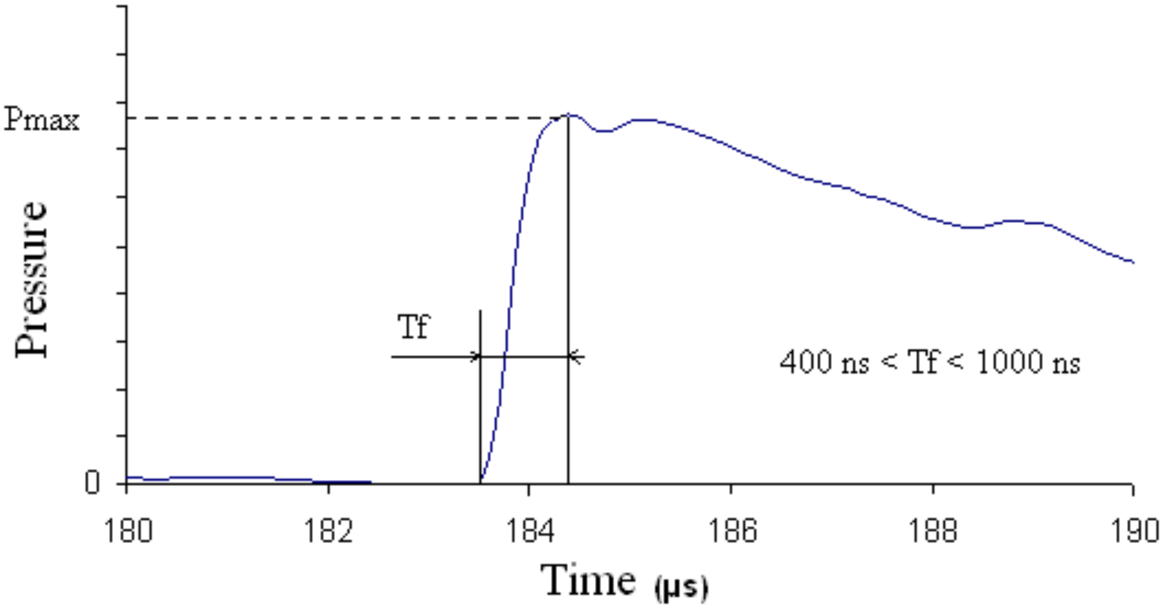
# Pulsed Arc Electro-Hydraulic Discharge Fracturing

## Experimental facility

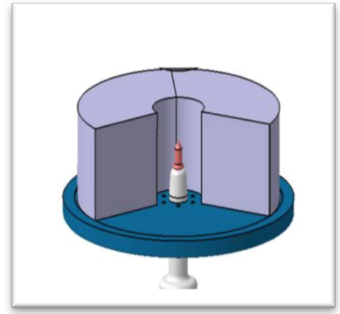



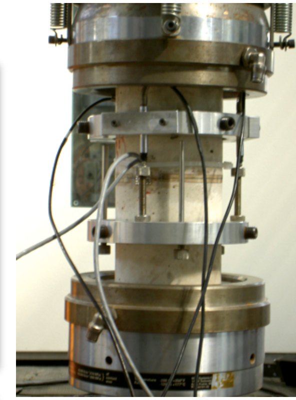
# Pulsed Arc Electro-Hydraulic Discharge Fracturing

## Experimental facility


# Coupling between damage and permeability

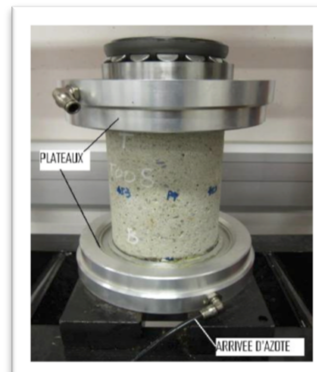





Fracture

↓

Permeability measurement

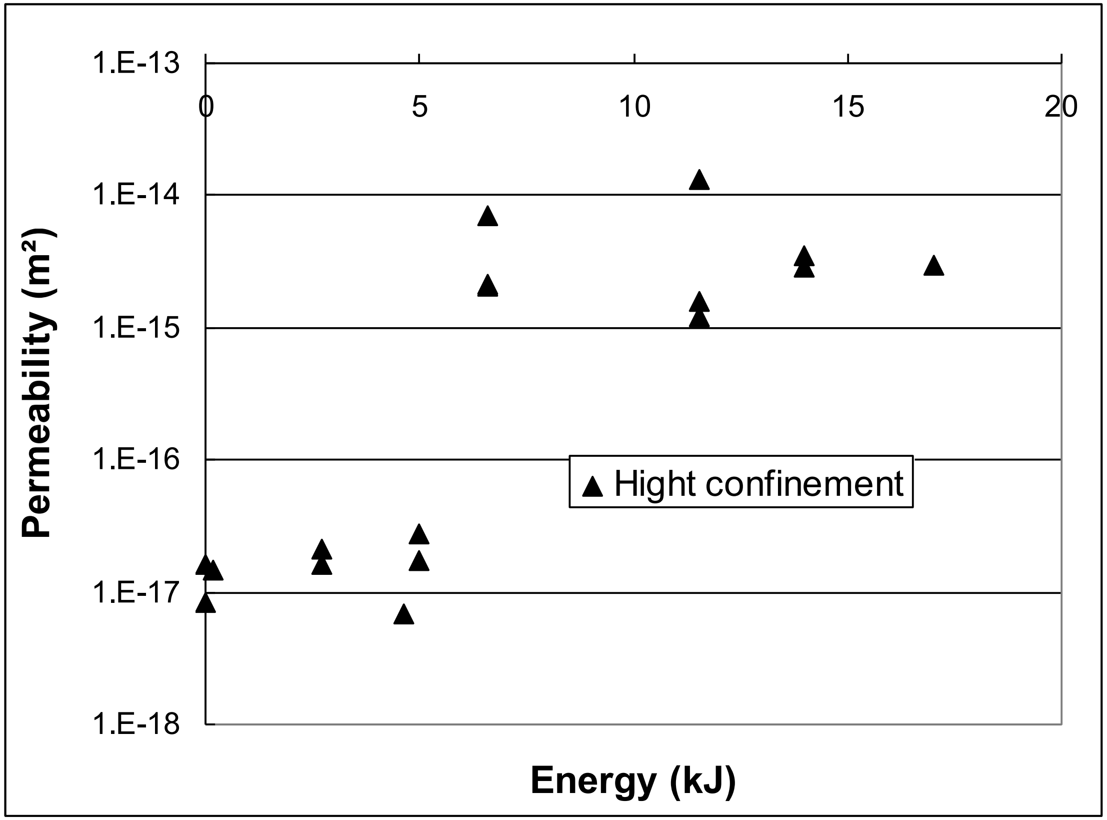


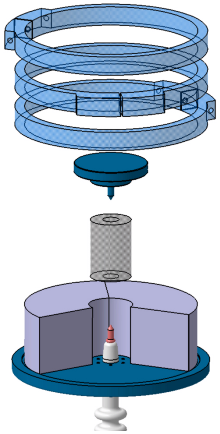

↓

PSD test
(mercury intrusion)

# Dynamic load – Shock wave

## Effect of a single shock wave

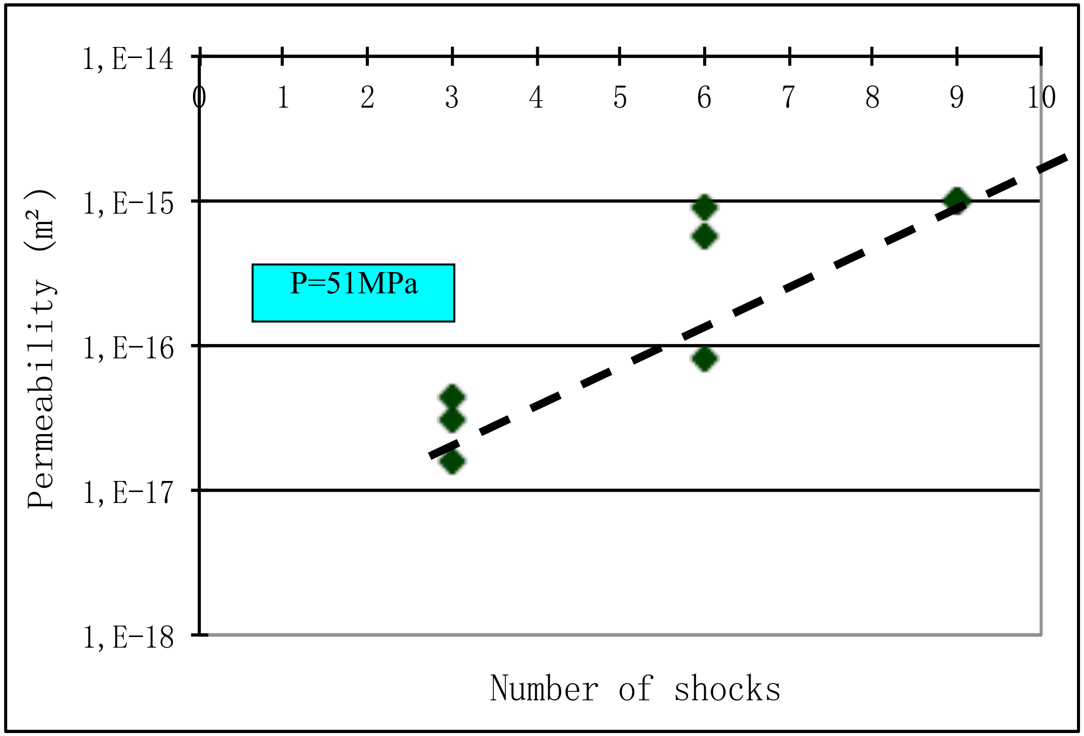


***Confinement : eq. to 2200 m***

# Dynamic load – Shock wave

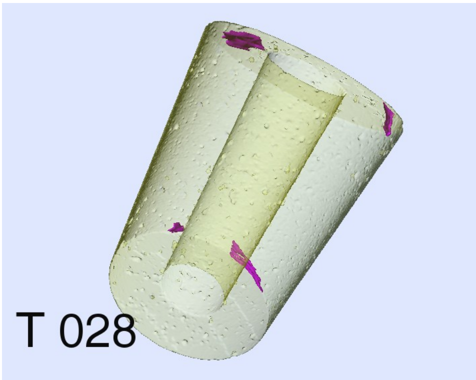
## Multiple shocks

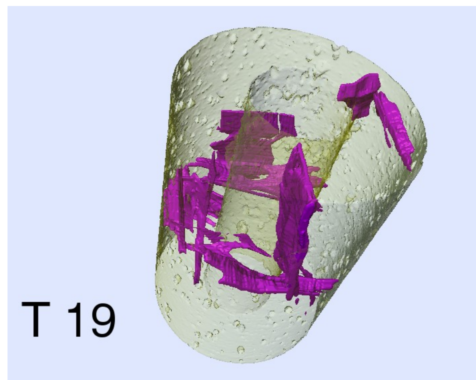

Confinement : equivalent to 2200 m

# Dynamic load – Shock wave

## Multiple shocks

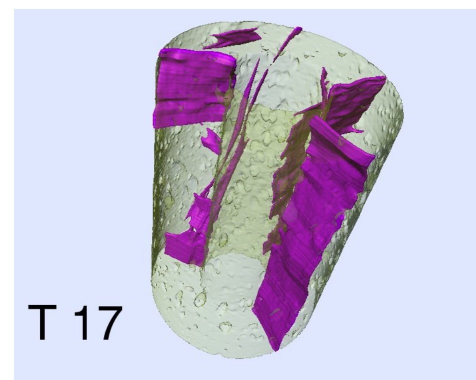



Permeability $10^{-17}$ m




Permeability $10^{-16}$ m

Permeability $10^{-15}$ m




Confinement : equivalent to 2200 m

# Computational model

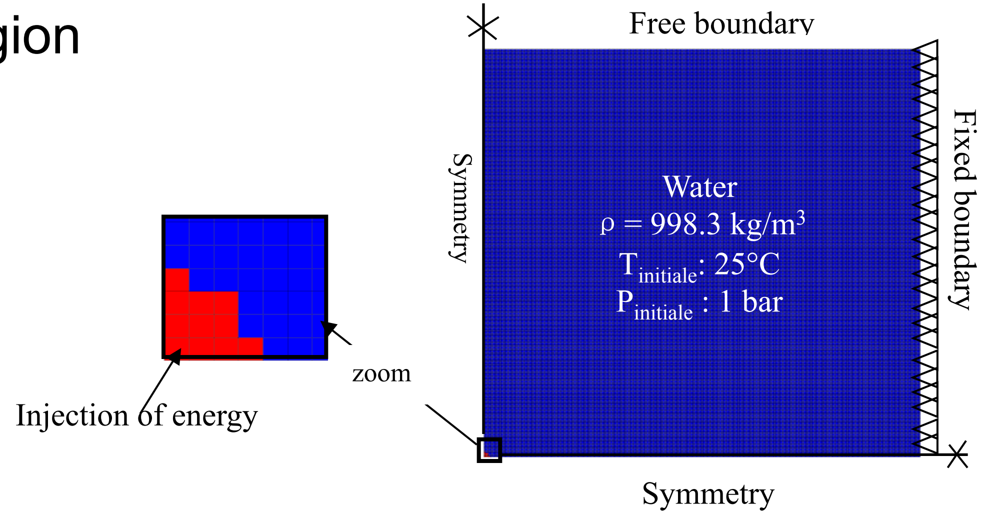
- Generation of the shock wave
- Induced damage in the reservoir
- Growth of permeability due to damage

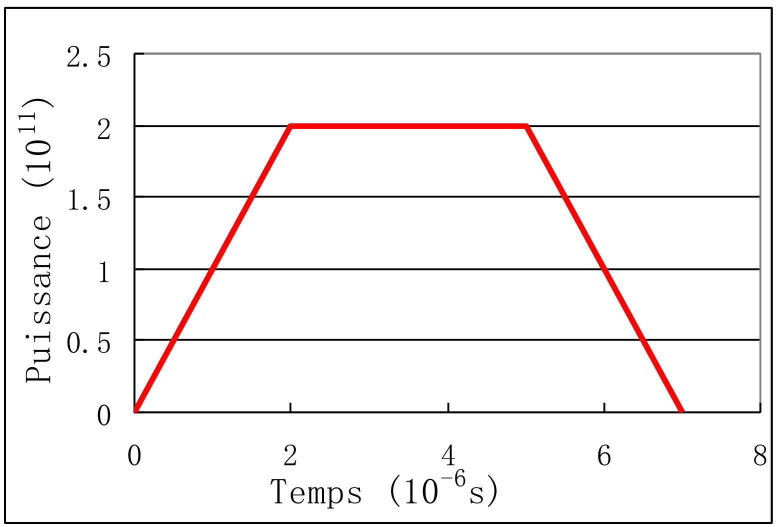
→

- Simulation of the experiments
- Model « reservoir » simulations

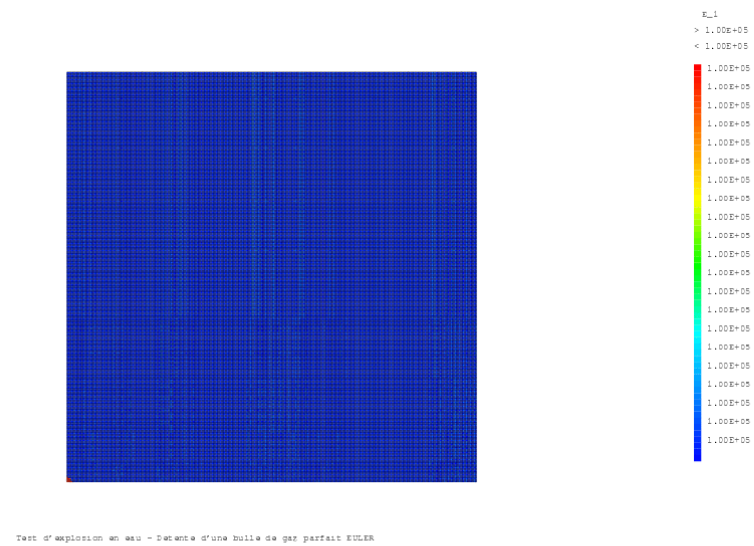
# Generation of the shockwave in water

- Injection of energy in small region (between the electrodes)
- Rely on the EOS of water




*Electrical power injected P(t)*



Pressure wave

# Constitutive modelling

- Based on continuum damage mechanics
- Anisotropic damage
- Crack closure effect
- Rate dependent response

*Desmorat et al. 2007*

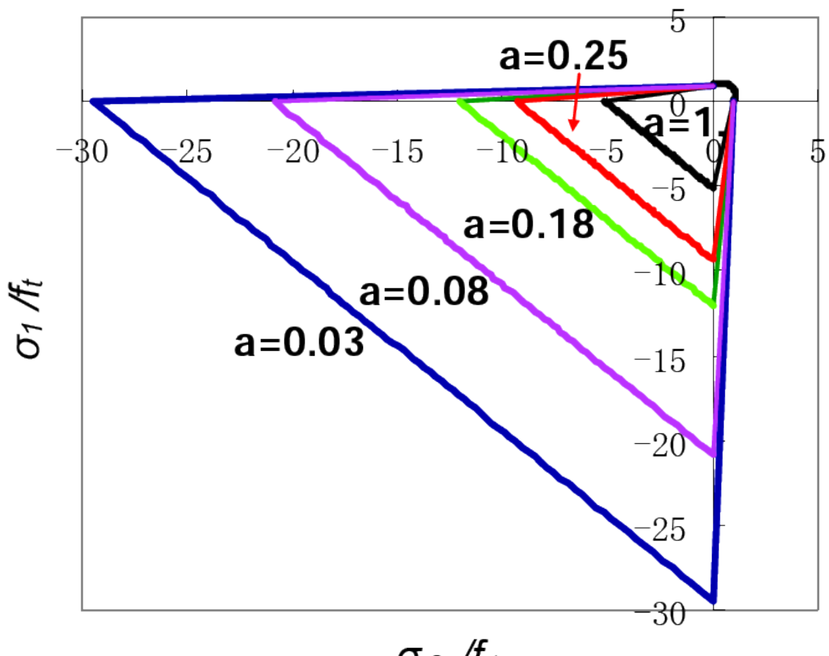
$$\varepsilon = \frac{1+\nu}{E}\tilde{\sigma} - \frac{\nu}{E} tr\tilde{\sigma}.I$$

$$\tilde{\sigma} = \left[(1-D)^{-1/2}\sigma^D(1-D)^{-1/2}\right]^D + \frac{1}{3}\left[\frac{\langle tr\sigma\rangle_+}{1-trD} + \langle tr\sigma\rangle_-\right].I$$

$$f = \hat{\varepsilon} - \kappa(D)$$

$$\hat{\varepsilon} = \sqrt{a\langle\varepsilon\rangle_+ : \langle\varepsilon\rangle_+ + \frac{1-a}{(1-2\nu)^2}\langle Tr\varepsilon\rangle_+^2}$$

$$\langle\varepsilon\rangle_+ : \langle\varepsilon\rangle_+ = \sum_{i=1}^{3}\langle\varepsilon_i\rangle^2$$

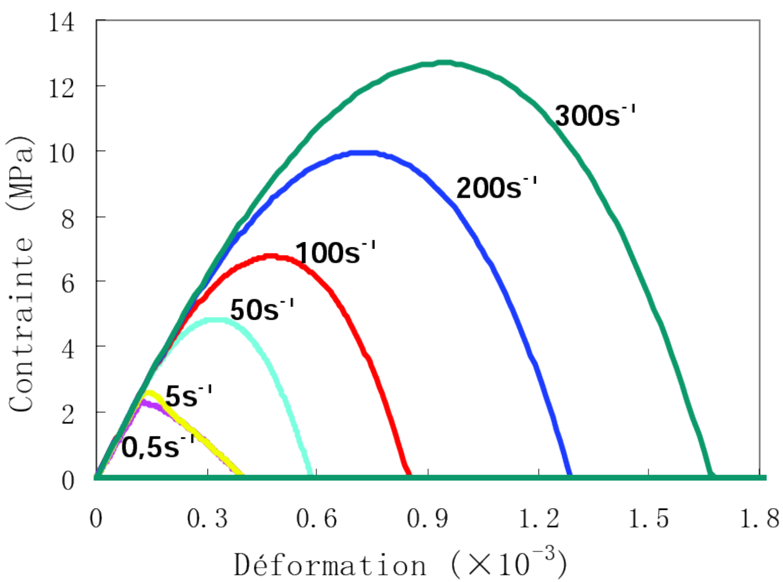


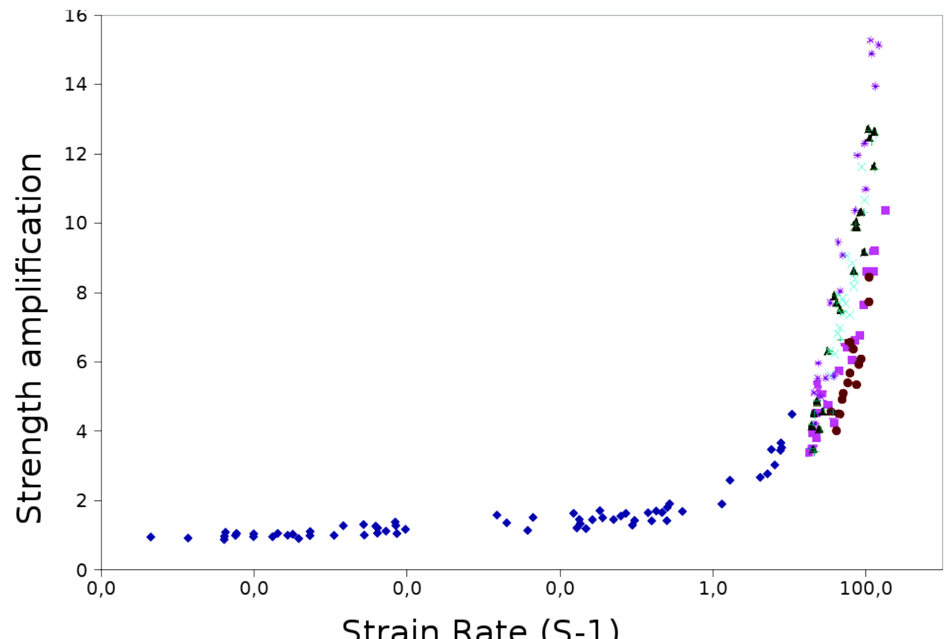
# Rate dependent formulation

Classical rate dependent formulation

$$\dot{D}_i = \dot{\lambda}\frac{\langle \varepsilon_i \rangle}{\varepsilon_I}$$

$$\dot{\lambda} = \frac{1}{m}\langle \frac{f}{k_0} \rangle^n$$

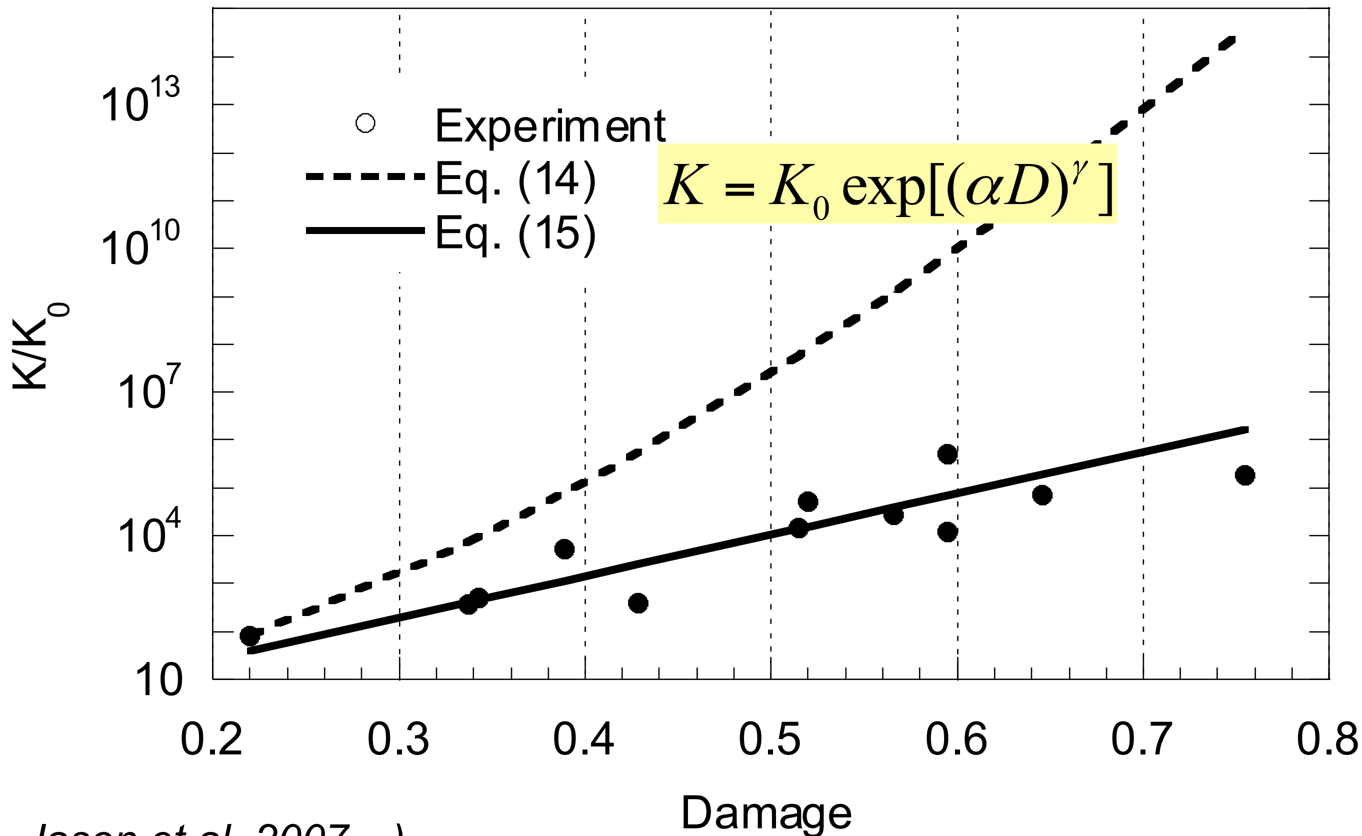


# Evolution of permeability

Permeability is indexed on damage growth

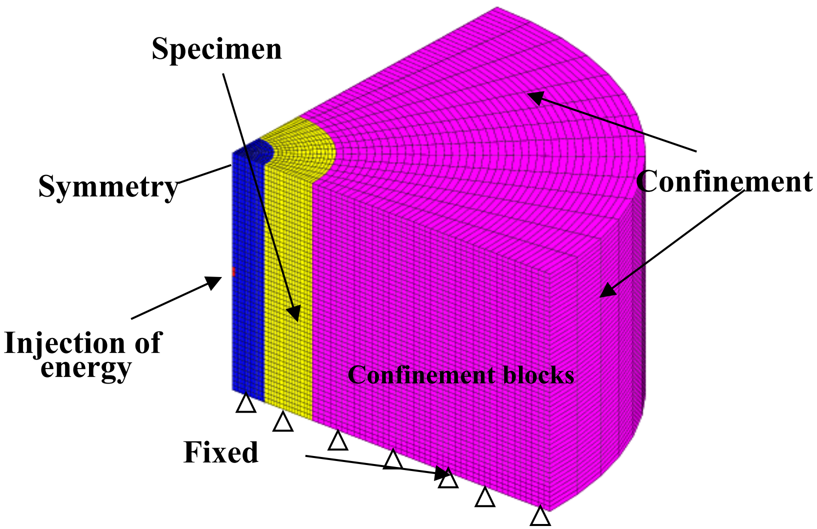
$$K = K_0 10^{8,67D-0,3} \qquad D \geq 0,035$$
$$K = K_0 \qquad D \leq 0,035$$



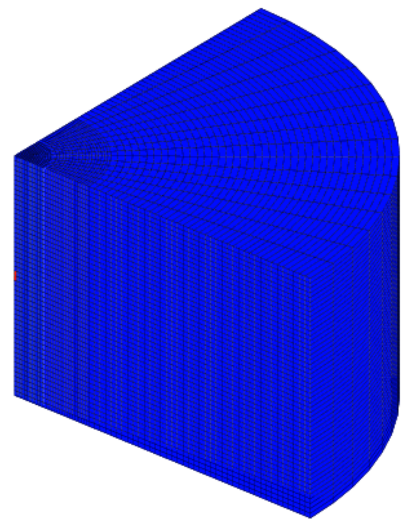

*(Bary 1996, Jason et al. 2007…)*

# Computational model

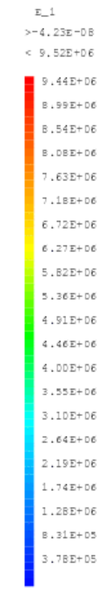
*Model*




*Wave propagation*



Medium confinement:
1500 m



Test d'explosion en eau - Detente d'une bulle de gaz parfait

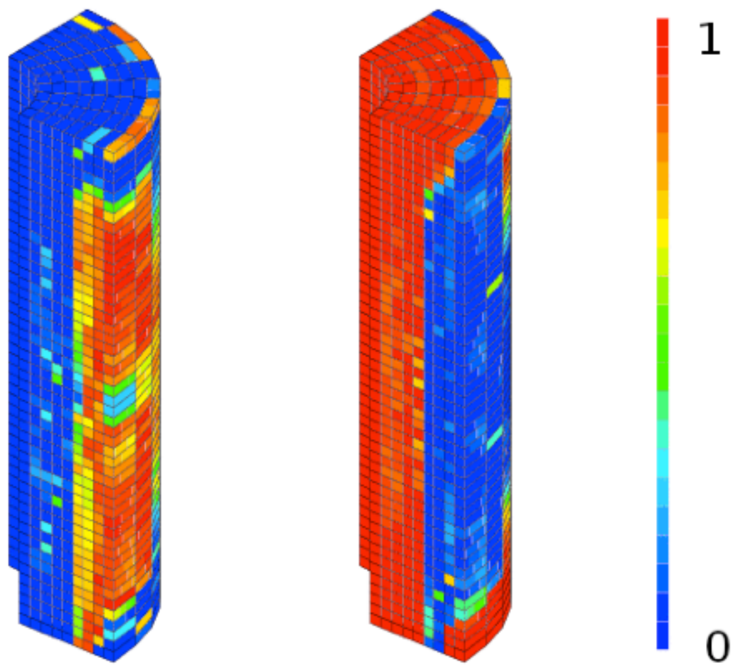
## ➢Different confinement levels

*Surface level : $P_{ax}$=2MPa, $P_{rad}$ =2MPa*

*Medium confinement : $P_{ax}$=19.5MPa, $P_{rad}$ =9.1MPa*

*High confinement : $P_{ax}$ =40MPa, $P_{rad}$ =25MPa*

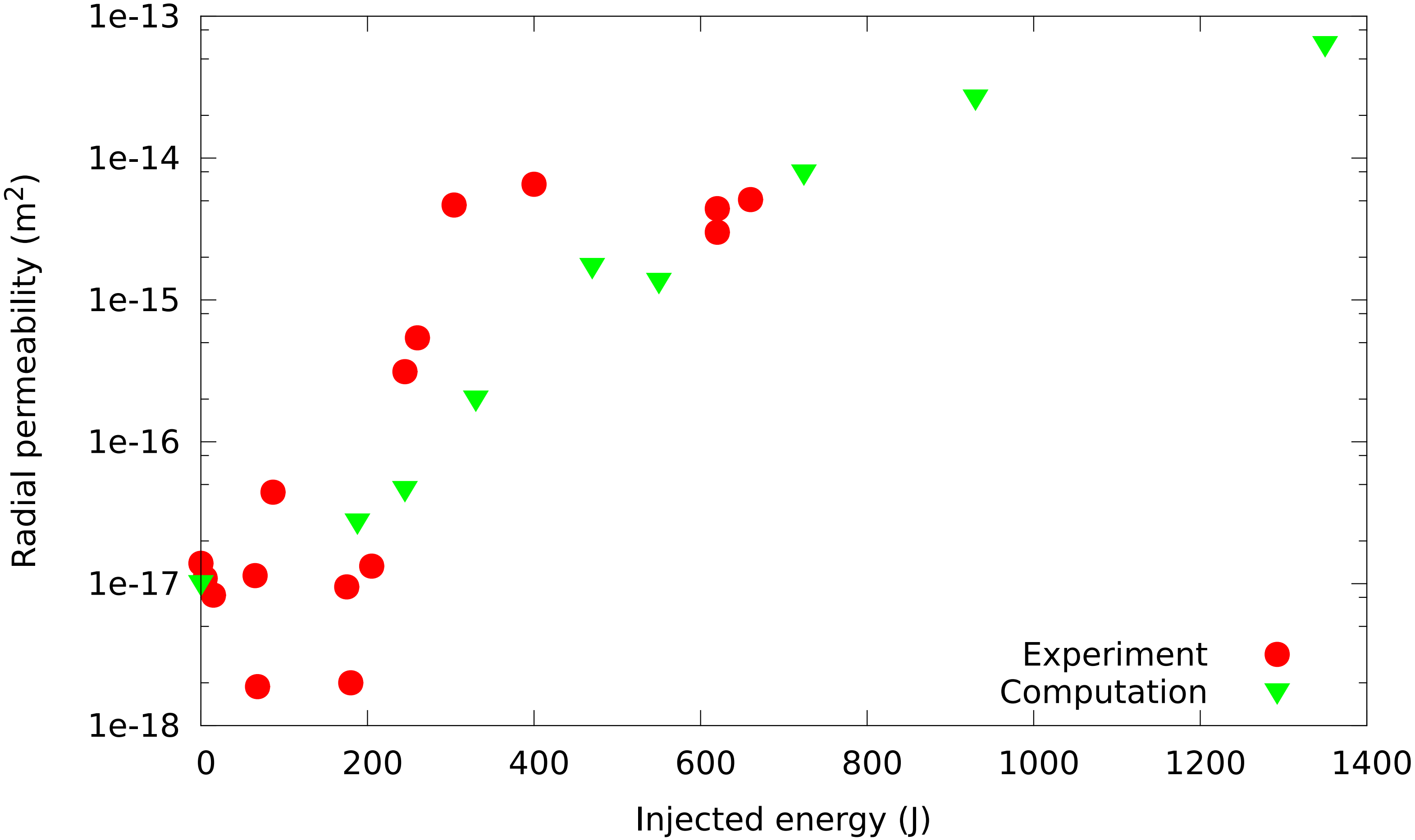
# Evolution of damage / Evolution of permeability




Radial Tangential

Medium confinement (1500 m),
vertical stress = 19.5 Mpa, confinement stress = 9.1 MPa

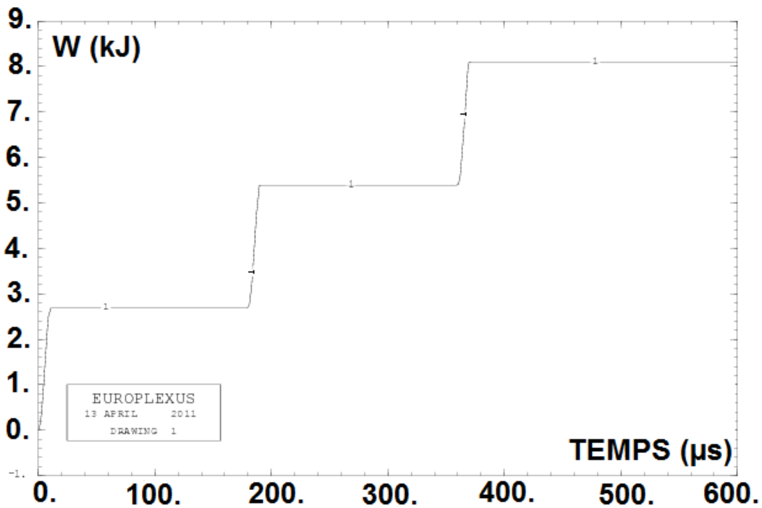
# Evolution of damage / Evolution of permeability



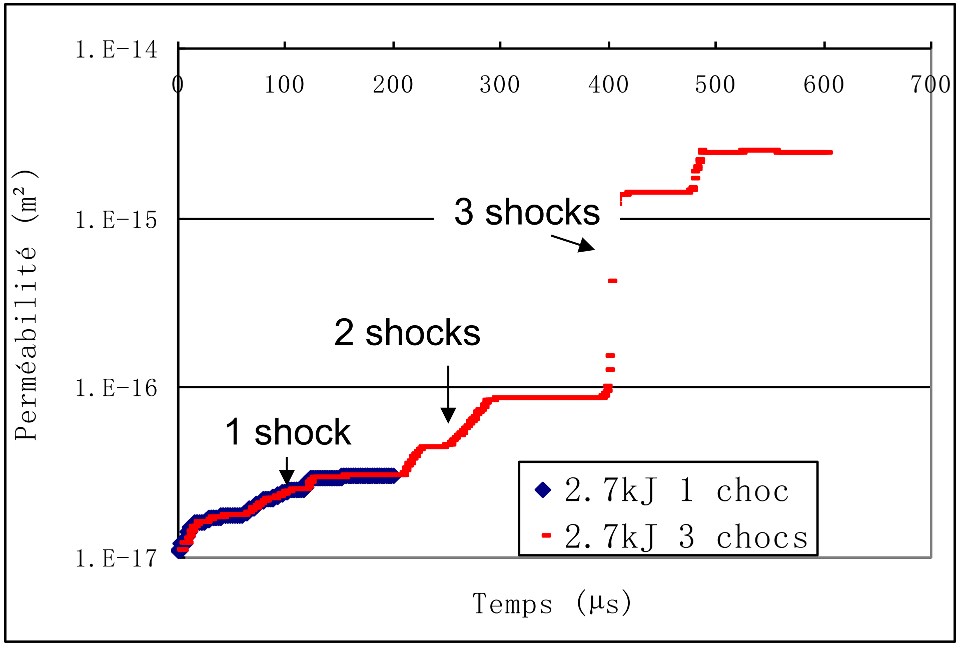

Medium confinement (1500 m),
vertical stress = 19.5 Mpa, confinement stress = 9.1 MPa

Evolution of damage / Evolution of permeability

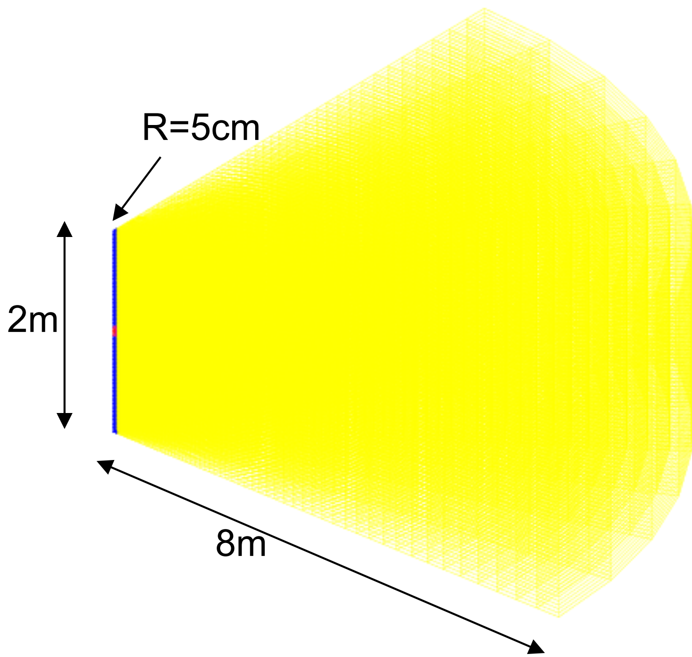
*Repeated shocks*



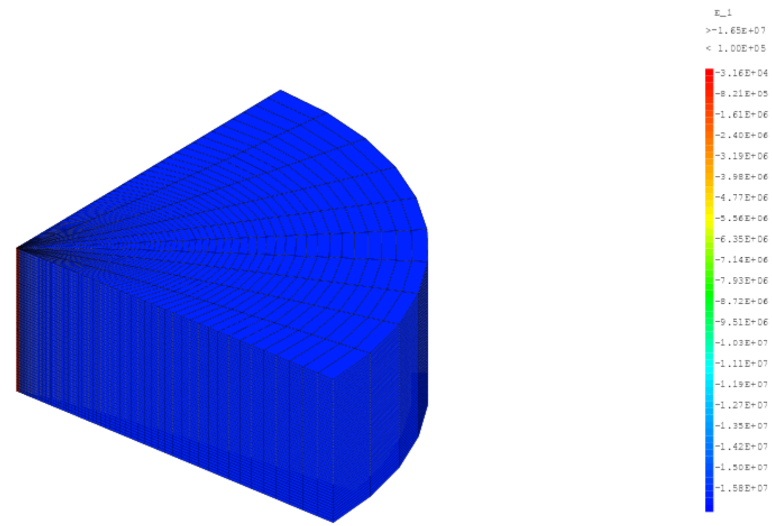

*Evolution of permeability*



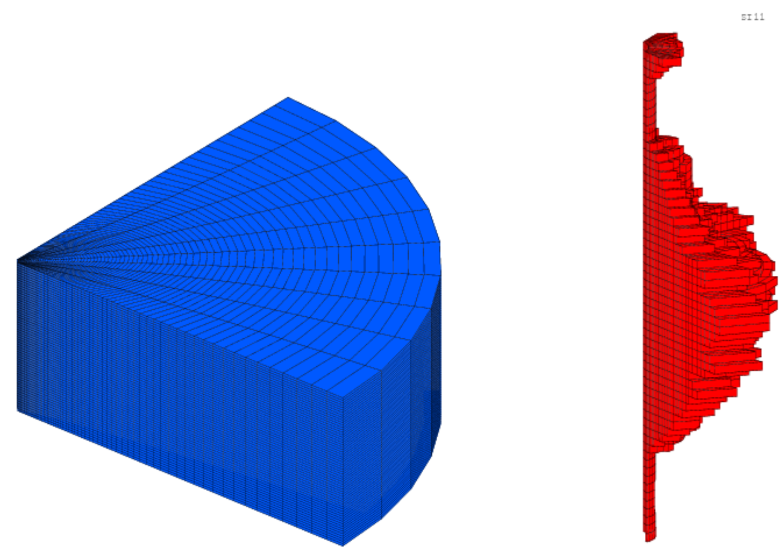
# Simulation on a representative problem




*Geometry*



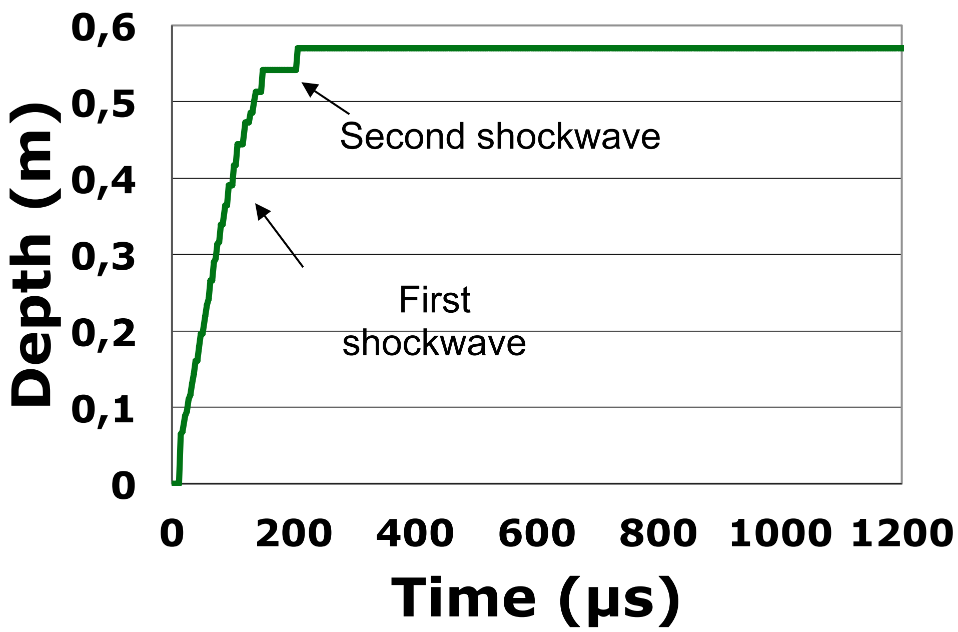

*Pressure*



*Damage (450kJ)*

# Simulation on a representative problem

## Damaged depth with time




## Damaged elements

# Concluding remarks

***Design and experiment a potential alternative methodology to hydraulic fracturing:***

- Describing damage of mortar and rocks due to dynamic loads : anisotropic damage, crack closure, rate dependent effects
- Modelling the anisotropic evolution of permeability

**Comparisons with experiments**

**Evaluation on representative geometries**

# Aknowledgments

## Readings

Electrohydraulic shock wave generation as a means to increase intrinsic permeability of mortar, O. MAUREL, T. REES, M. MATALLAH, A. De FERRON, W. CHEN, C. LABORDERIE, G. PIJAUDIER-CABOT, A. JACQUES, F. REY-BETHBEDER, Cement and Concrete Research, Vol. 40, pp. 1631-1638, 2010.

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Experimental study on an alternative oil stimulation technique for tight gas reservoirs based on dynamic shock waves generated by Pulsed Arc Electrohydraulic Discharges, W. CHEN, O., MAUREL, T. REESS, A. SYLVESTRE de FERRON, C. La BORDERIE, G. PIJAUDIER-CABOT, F. REY-BETBEDER, A. JACQUES, J. Petroleum Engrg., Vol. 88-89, pp. 67-74, 2012.

Simulation of damage - permeability coupling for mortar under dynamic loads, W. CHEN, C. La BORDERIE, O., MAUREL, G. PIJAUDIER-CABOT, F. REY-BETBEDER, Int. Num. Anal. Meth. Geomechanics, Vol. 38, pp. 457-474, 2014.

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