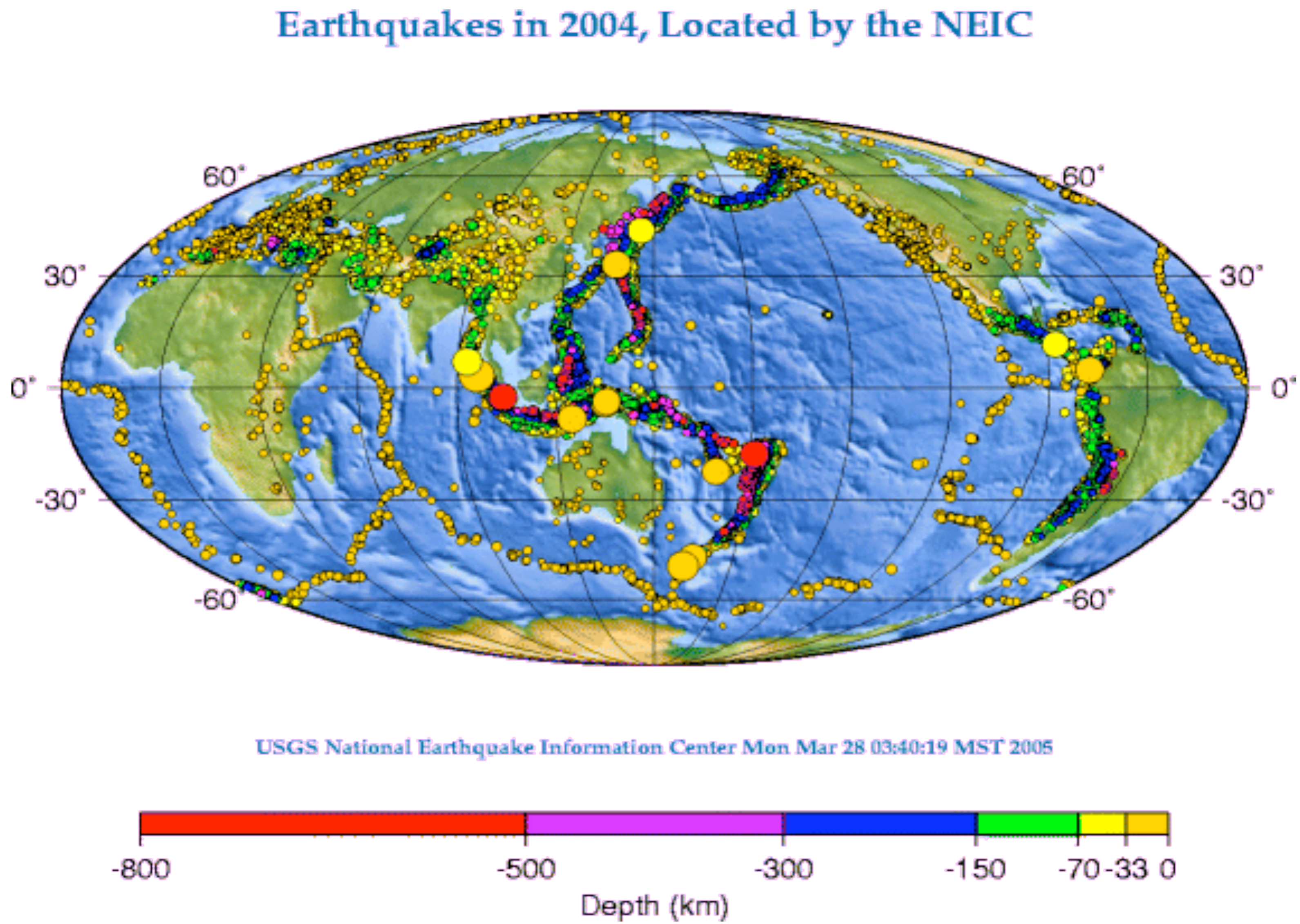
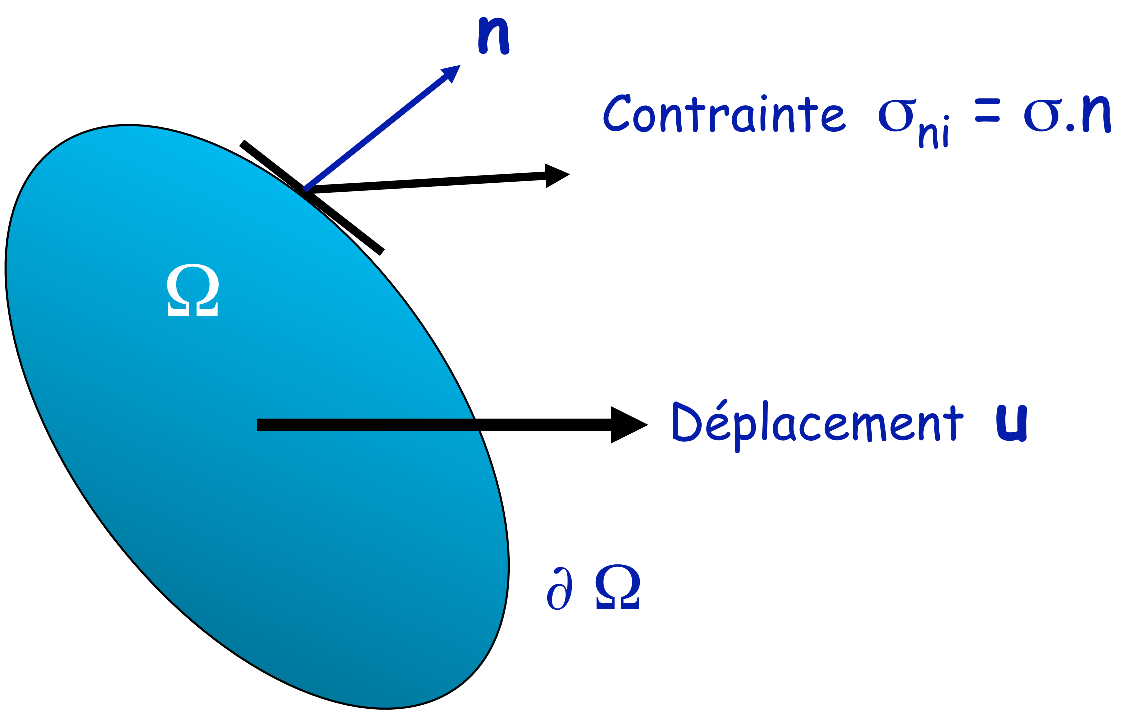
http://www.geologie.ens.fr/~madariag/Exposes.html

Sismicité de 2004



Equations des ondes élastiques



Équation de mouvement

$$\rho \frac{\partial^2 \mathbf{u}}{\partial x^2} = \nabla \bullet \sigma + \mathbf{f}$$

Sources

Équation de l'élasticité

$$\boldsymbol{\sigma} = \lambda \nabla \bullet \mathbf{u} + \mu \left(\nabla \mathbf{u} + \nabla^T \mathbf{u} \right)$$

The elastic wave equation

Equation of elastic waves in a finite inhomogenous medium neglecting anisotropy for convenience.

There are two ways to pose the problem

Classical text-book equation

$$
\begin{aligned}
\rho \frac{\partial^2}{\partial t^2} \mathbf{u} &= \nabla \cdot \sigma + \mathbf{f} \\
\sigma &= \lambda \nabla \cdot \mathbf{u}\, \mathbf{I} + \mu \left[(\nabla \mathbf{u}) + (\nabla \mathbf{u})^T \right] + \mathbf{m}_0,
\end{aligned}
$$

velocity-stress formulation of linear elastodynamics (Madariaga, 1976, Virieux, 1986):

$$
\begin{aligned}
\rho \frac{\partial}{\partial t} \mathbf{v} &= \nabla \cdot \sigma + \mathbf{f} \\
\frac{\partial}{\partial t} \sigma &= \lambda \nabla \cdot \mathbf{v}\, \mathbf{I} + \mu \left[(\nabla \mathbf{v}) + (\nabla \mathbf{v})^T \right] + \dot{\mathbf{m}}_0
\end{aligned}
$$

where $\mathbf{u}(\mathbf{x}, t)$ is the displacement

$\mathbf{v}(\mathbf{x}, t)$ is the particle velocity vector field.

$\sigma(\mathbf{x}, t)$ is the associated linear elastic stress tensor.

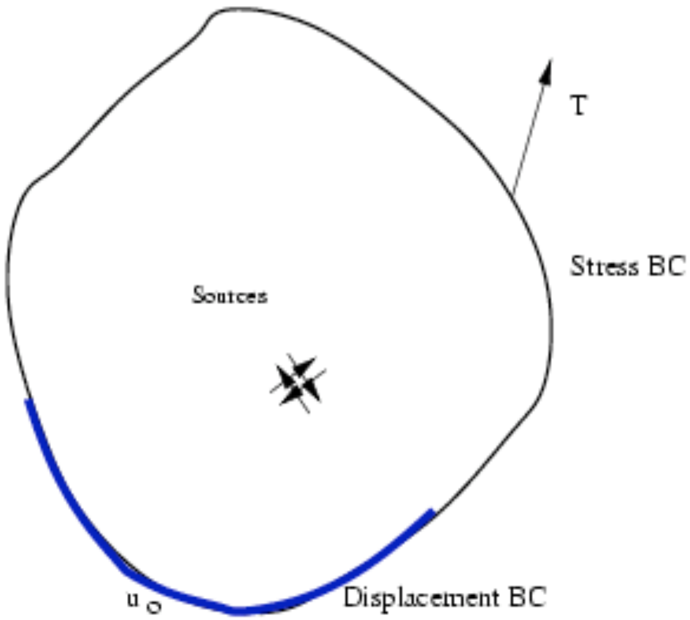
$\lambda(\mathbf{x})$ and $\mu(\mathbf{x})$ are Lamé's constants, and $\rho(\mathbf{x})$ is the mass density of the elastic medium.

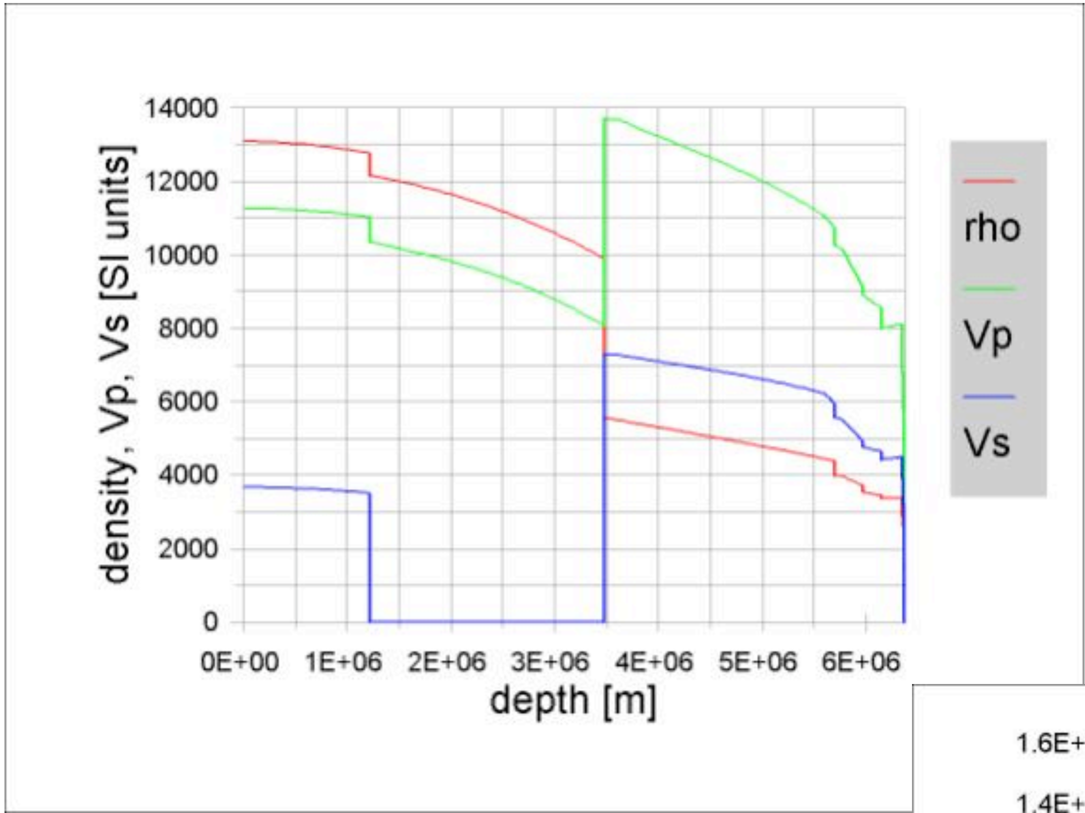
Finally, $\mathbf{f}(\mathbf{x})$ and $\mathbf{m}_0(\mathbf{x})$ are the force and seismic moment tensor source distributions.

Boundary conditions

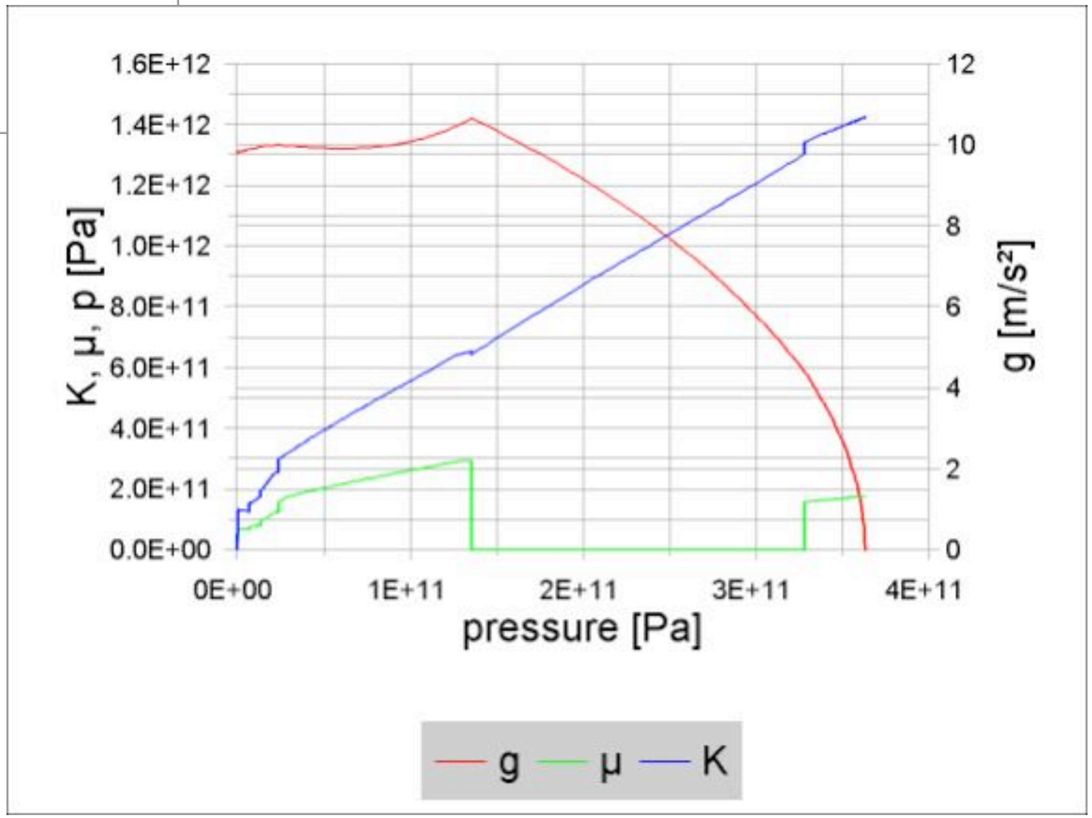
We solve the elastodynamic equations together with following Boundary conditions:

- Radiation conditions far from the sources in infinite media
- Stress boundary conditions on the Earth's surface ($\sigma \cdot \mathbf{n} = T$)
- Displacement (Dirichlet) boundary conditions ($\mathbf{u} = \mathbf{u}_0$)
- Mixed boundary conditions (Dynamic support, radiative, perfectly matched, etc)




14000
12000
10000
8000
6000
4000
2000
0
0E+00
1E+06
2E+06
3E+06
4E+06
5E+06
6E+06
depth [m]
density, Vp, Vs [SI units]
rho
Vp
Vs

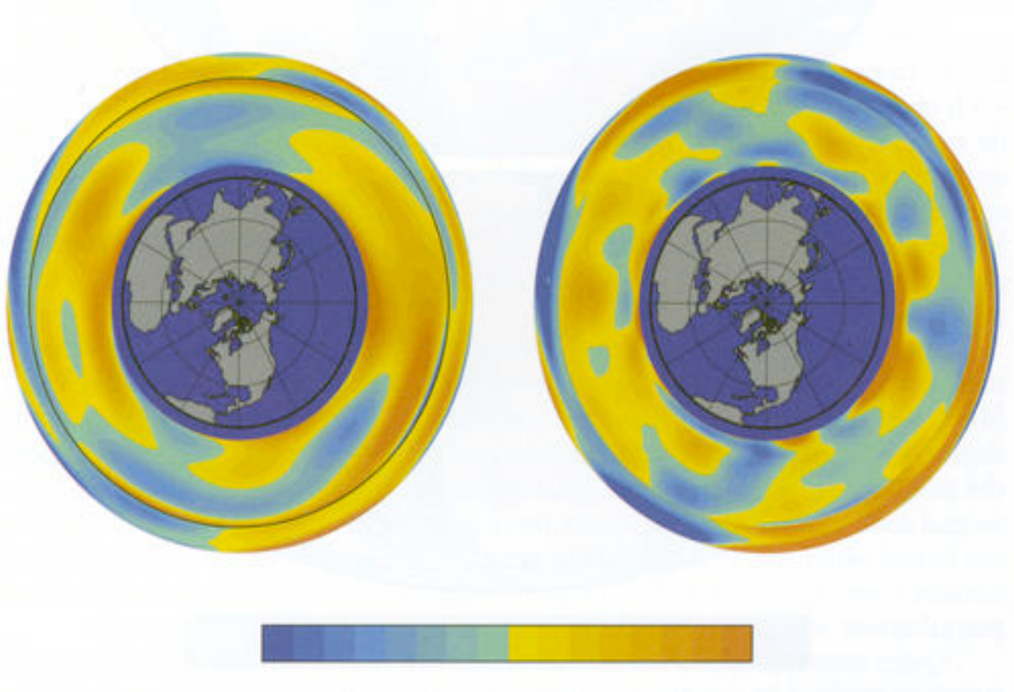
PREM !


1.6E+12
1.4E+12
1.2E+12
1.0E+12
8.0E+11
6.0E+11
4.0E+11
2.0E+11
0.0E+00
K, μ, p [Pa]
12
10
8
6
4
2
0
g [m/s²]
0E+00
1E+11
2E+11
3E+11
4E+11
pressure [Pa]
g
μ
K

Le premier modèle latéralement hétérogène M84C

Proposé par Dziewonski et Woodhouse (1985)
Ce modèle contient des harmoniques d'ordre < 8

Perturbation des P



Perturbation des S

-4%

4%

D'après Dziewonski et al, 2000

Internal Boundary conditions

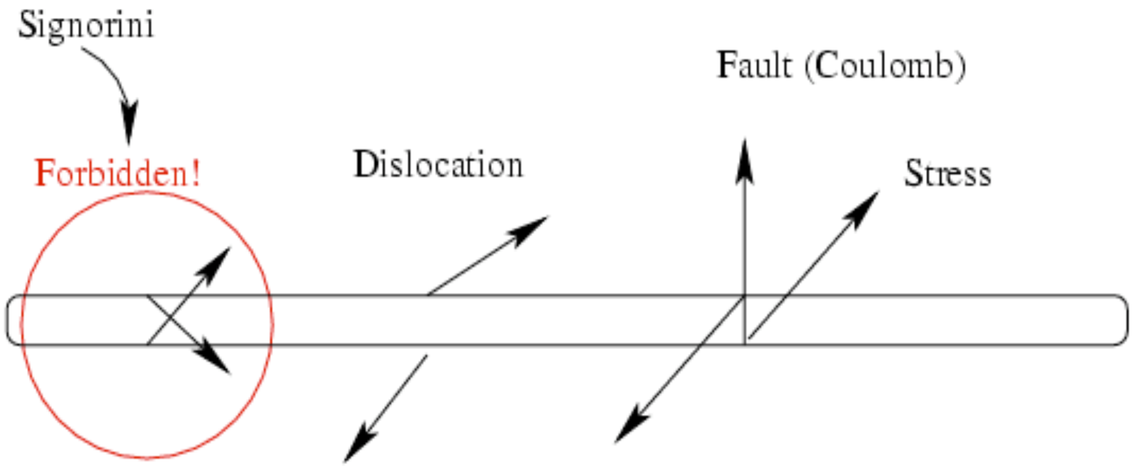
At internal discontinuities we apply the following

- Continuity of stress and velocities (or displacements) at elastic-elastic boundaries
- Continuity of normal stress and normal velocity
  and zero shear stress at elastic-fluid boundaries

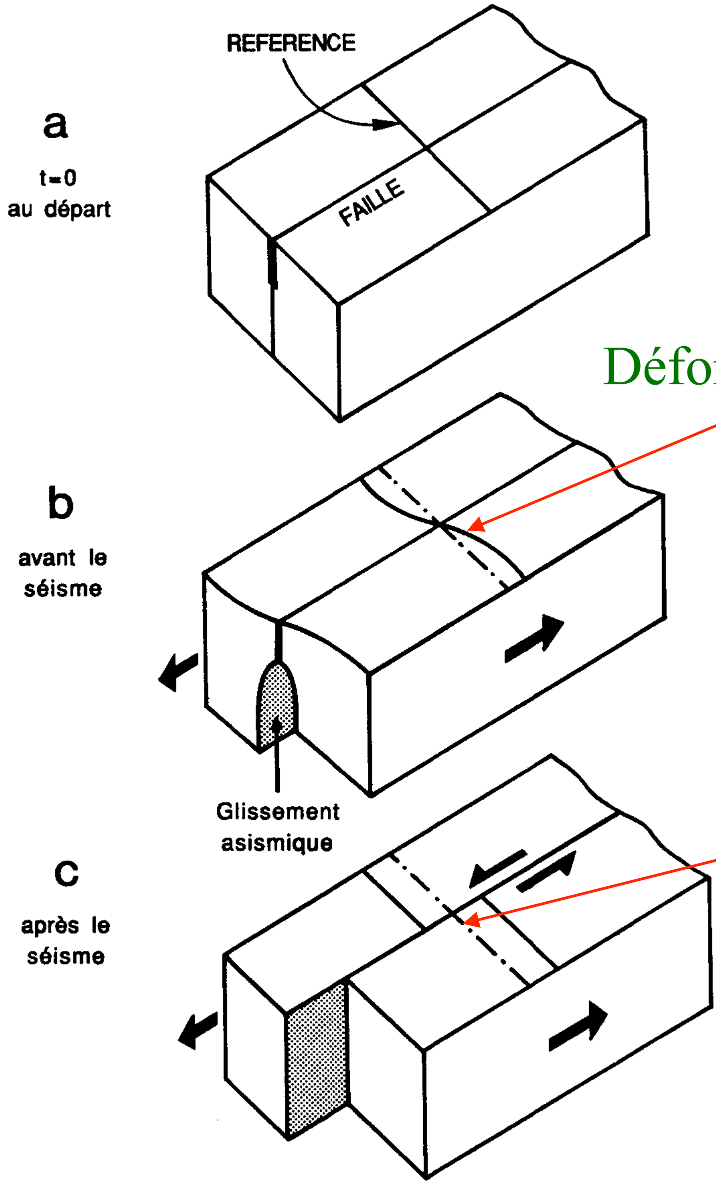
Internal Boundary conditions

There are two types of discontinuities

- Displacement discontinuities (dislocations)
- crack boundary conditions at faults



Modèle du rebond sismique



Situation quelques jours après un séisme

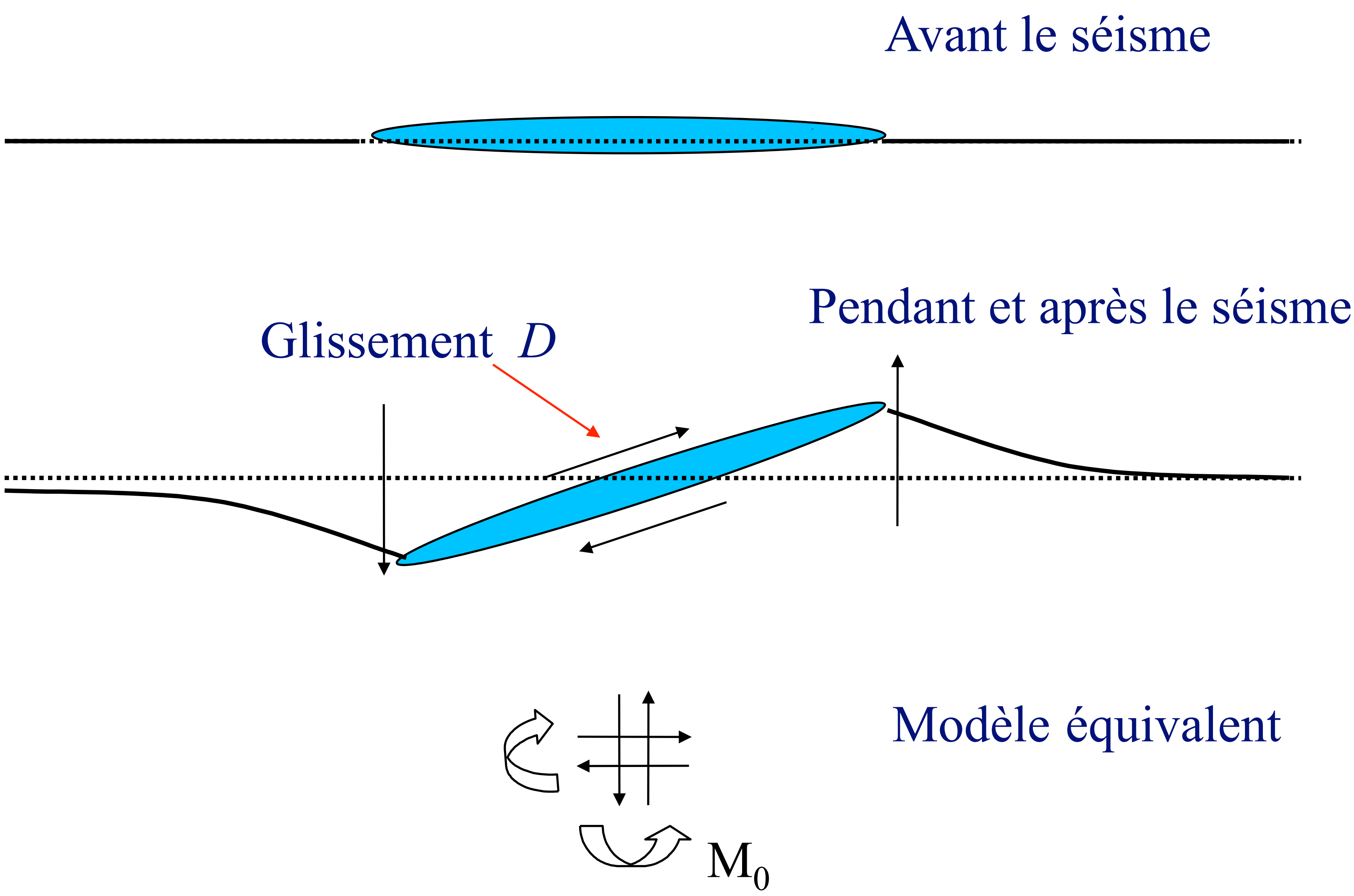
Déformation présismique

Situation à mi parcours

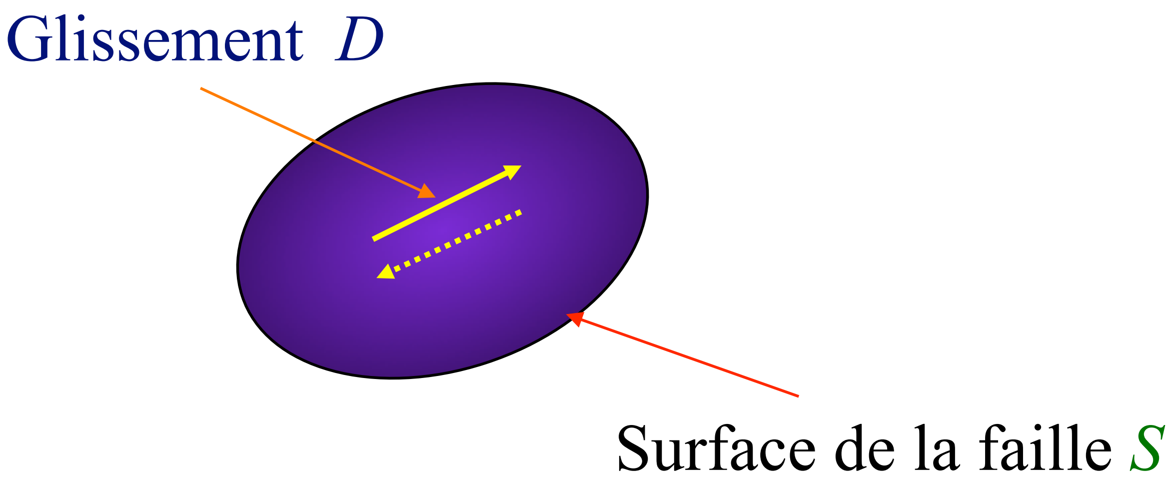
Glissement sismique

Situation quelques jours après le séisme suivant

Modèle de rupture sismique (dislocation)



Définition de Moment sismique



$$M_o = \mu \; D \, S$$

μ Constante élastique

Rayonnement sismique dans milieux homogène

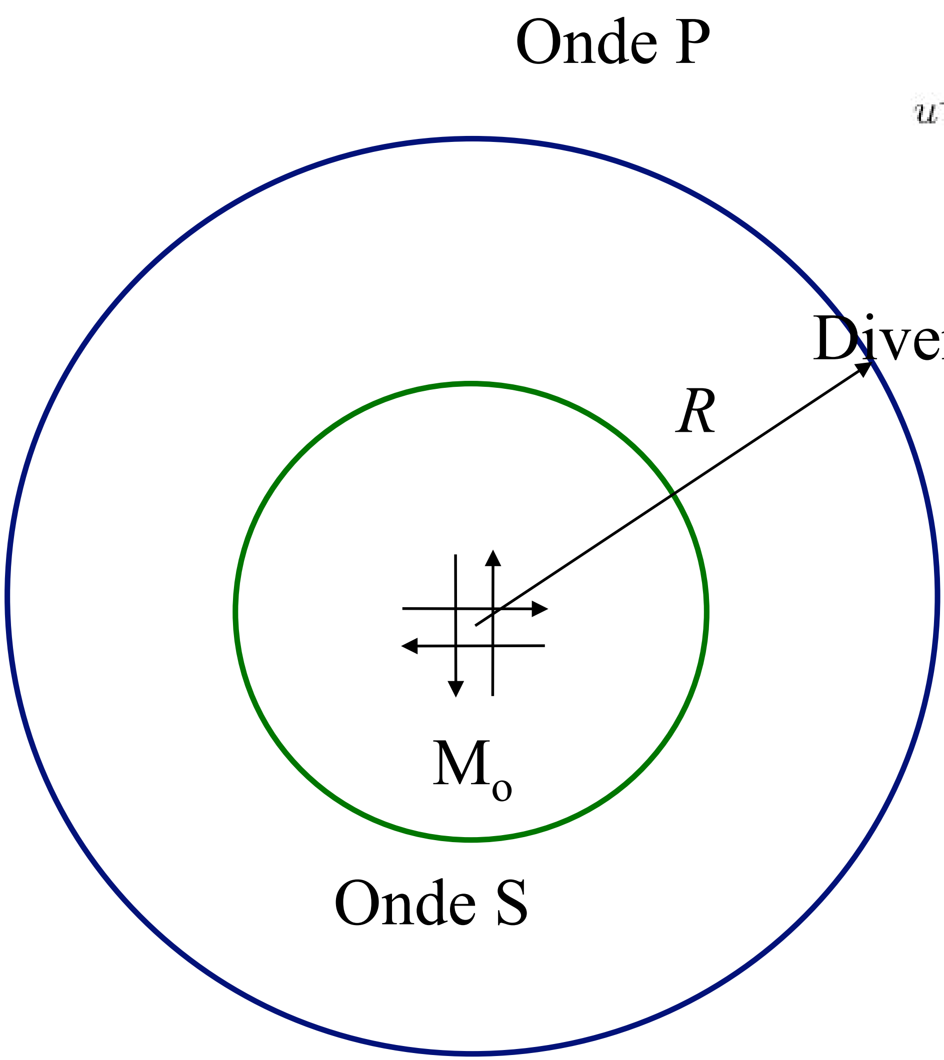


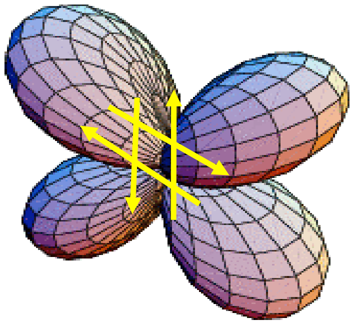
Diagramme de rayonnement

$$u^P(R,t) = \frac{1}{4\pi\alpha^3} \quad \frac{1}{R} \quad \mathcal{R}^P(\theta,\phi) \quad \dot{M}_0(t - R/\alpha)$$

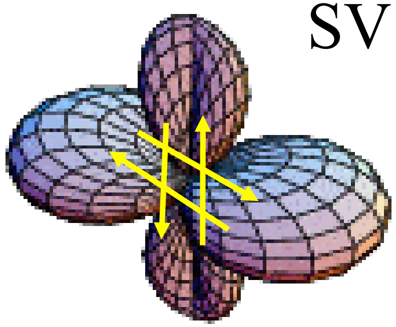
Divergence Géométrique   Signal sismique

$$u^S(R,t) = \frac{1}{4\pi\beta^3} \quad \frac{1}{R} \quad \mathcal{R}^S(\theta,\phi) \quad \dot{M}_0(t - R/\beta)$$

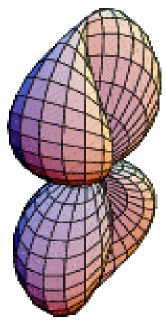
Diagramme de rayonnement



Rayonnement des ondes P :



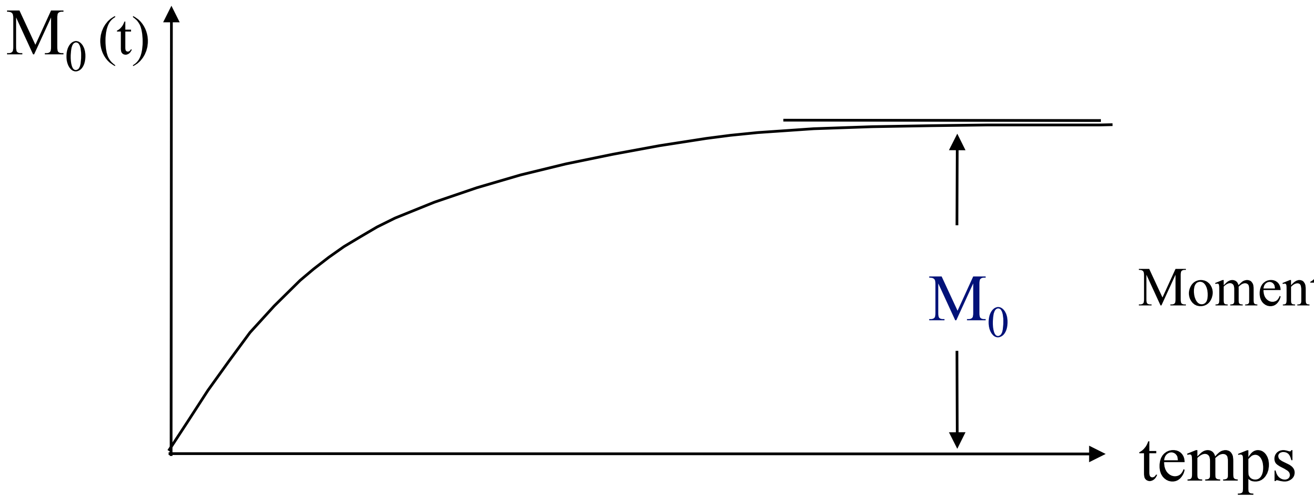
SV



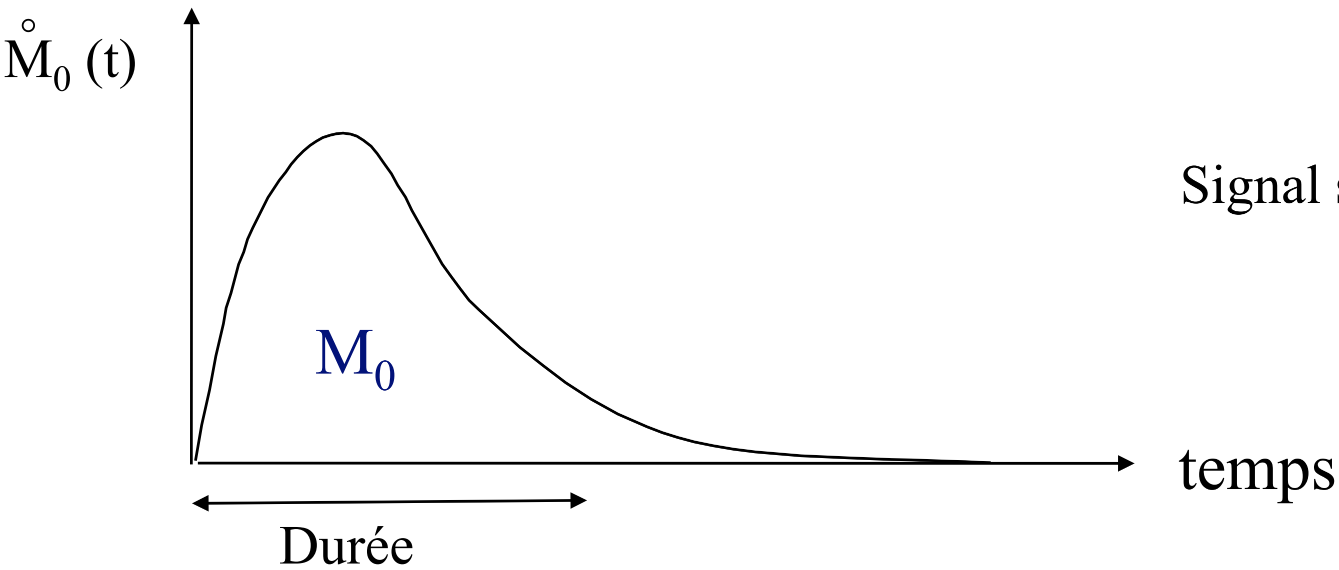
SH

Rayonnement des ondes S :

Rayonnement sismique



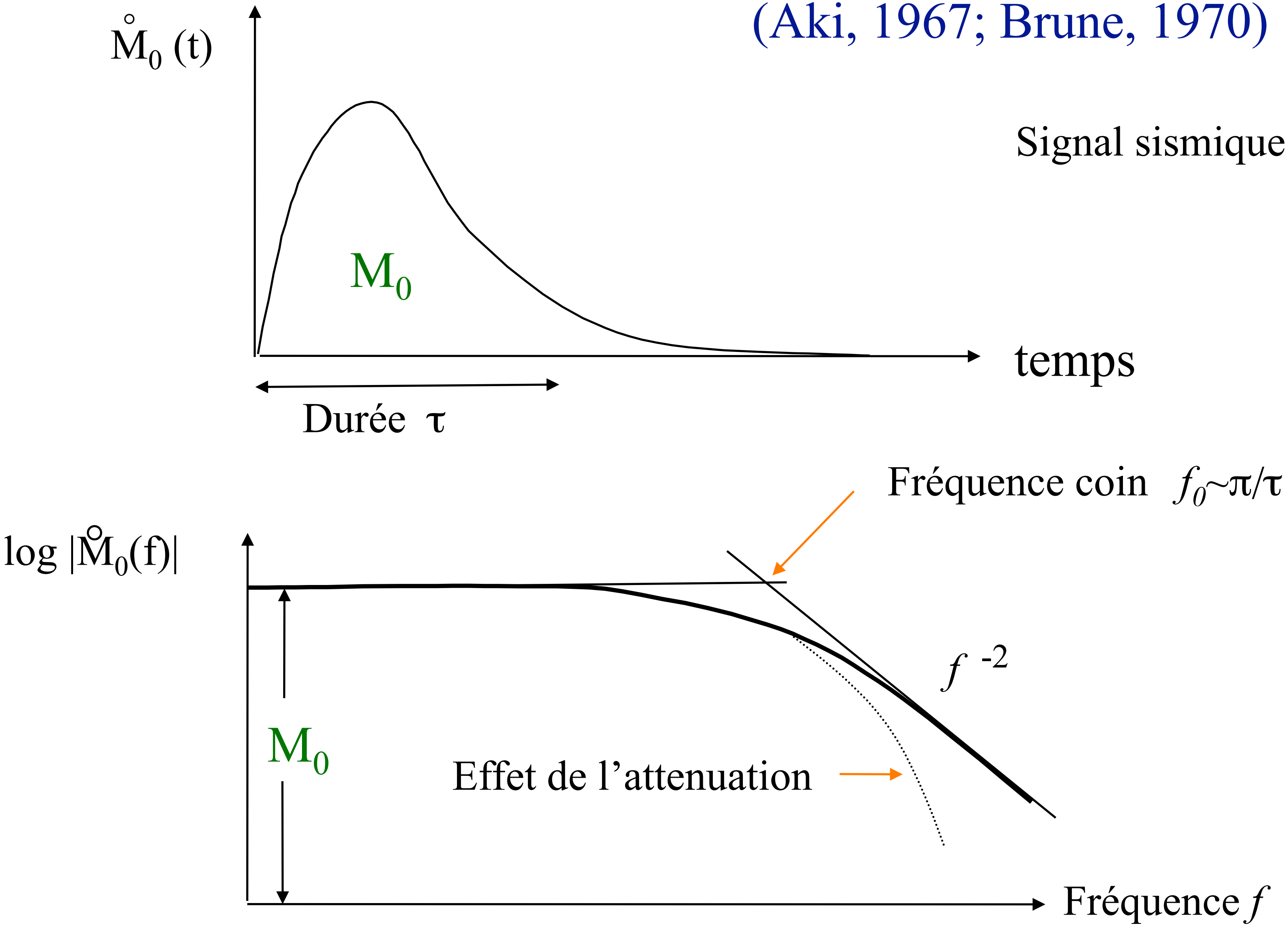
Moment sismique final



Signal sismique

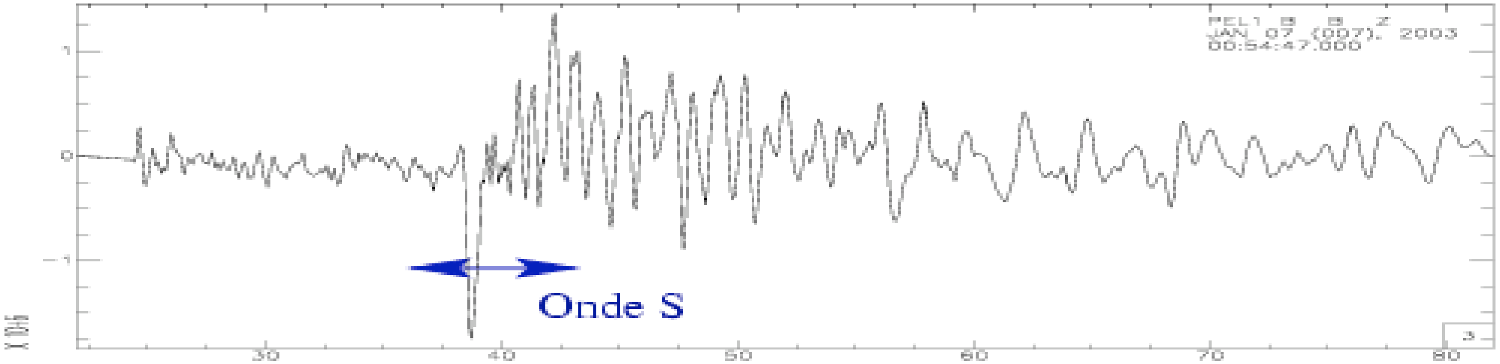
Formes universelles du signal et son spectre de Fourier

(Aki, 1967; Brune, 1970)

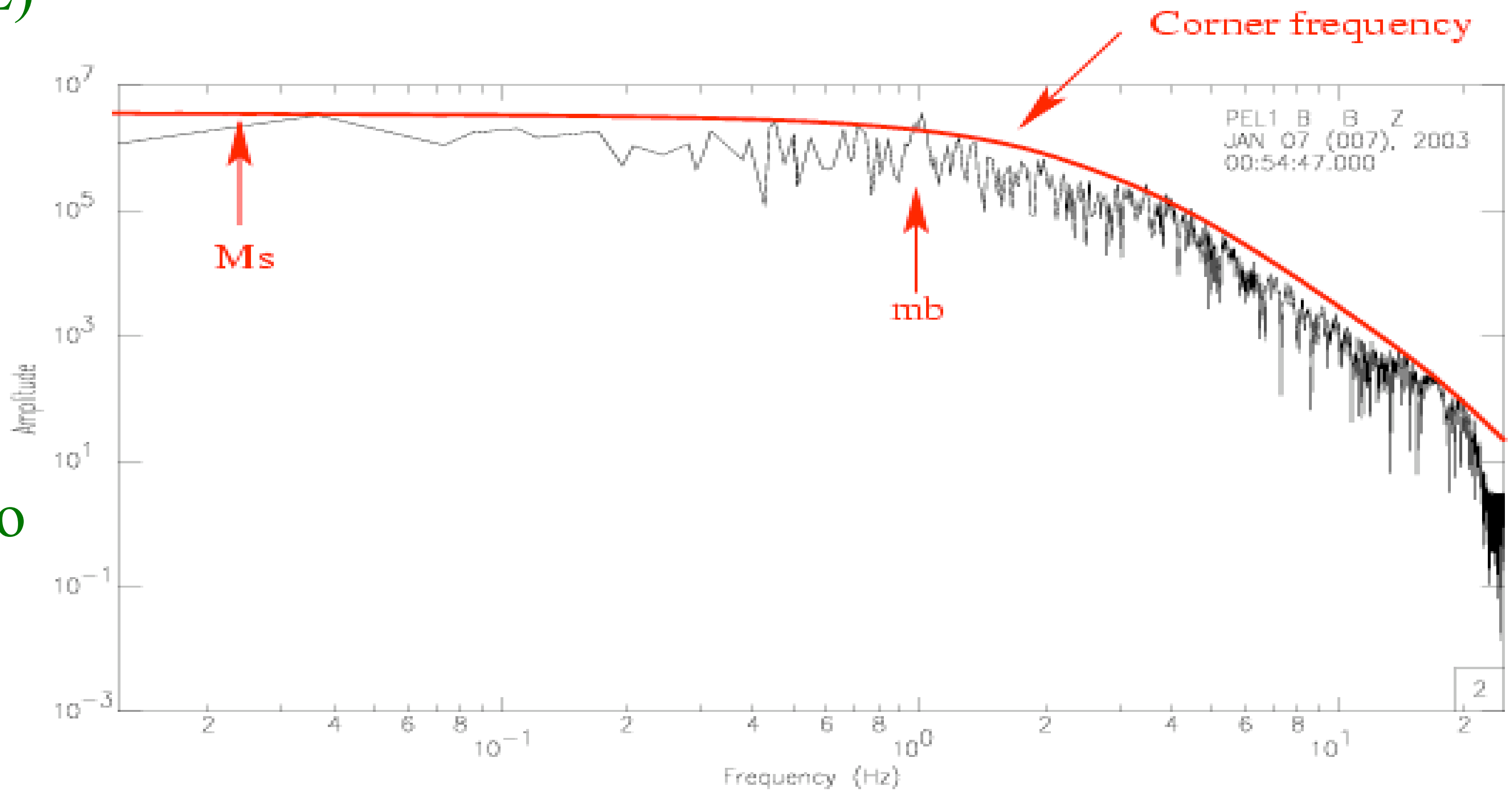


Example de spectre sismique

Enregistrement à Peldehue (GEOSCOPE)

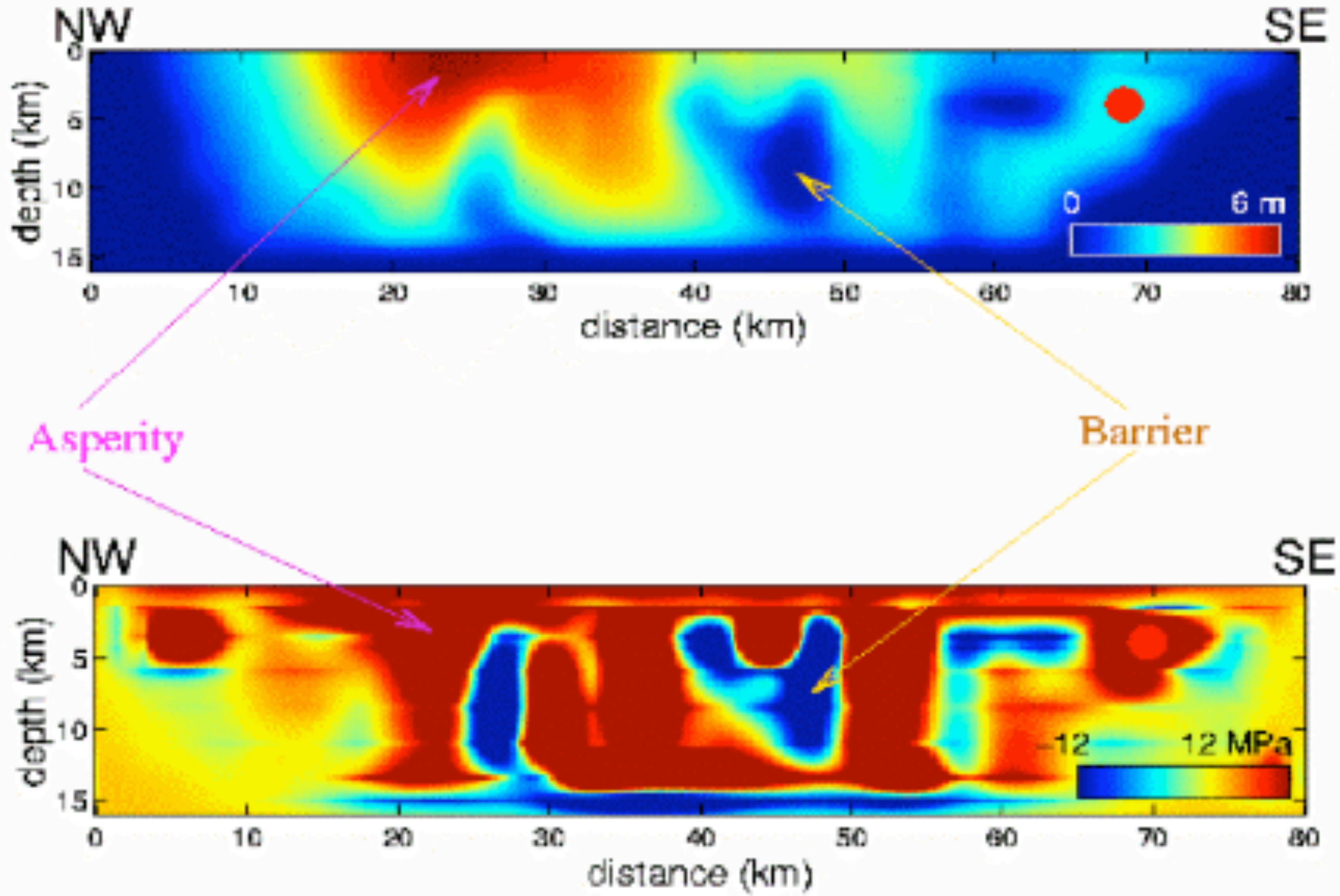


Séisme du 07/01/03 à 90 km sous Santiago



Landers Earthquake 28 June 1992

Slip on the Fault (Wald and Heaton, 1994)



Stress drop computed from slip (OMA, 1997)

Sumatra - Andaman Islands Earthquake (M_W=9.0),

Global Displacement Wavefield from the Global Seismographic Network

NSF IRIS USGS