Diplomado post-titulo en Sismologia

Curso de Madariaga
July 2017

Metodos para modelar la fuente sismica

- Source models
- Spectral models
- Stacking and backprojection
- Using Near field modelling with Axitra

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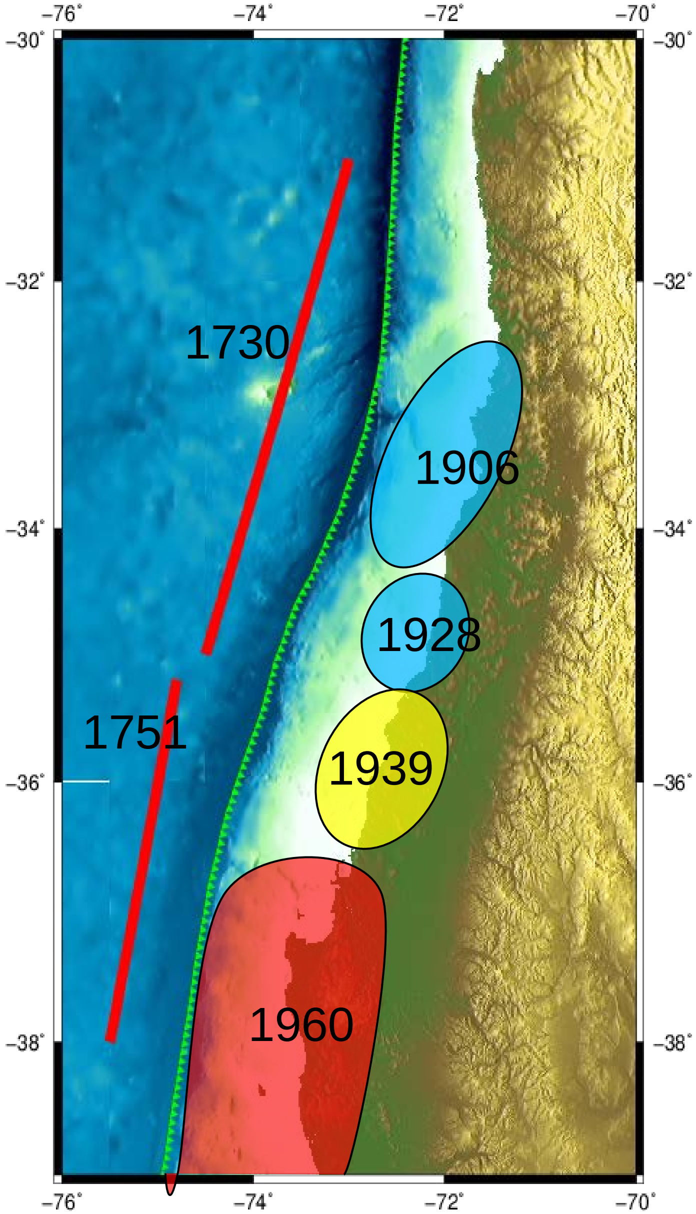
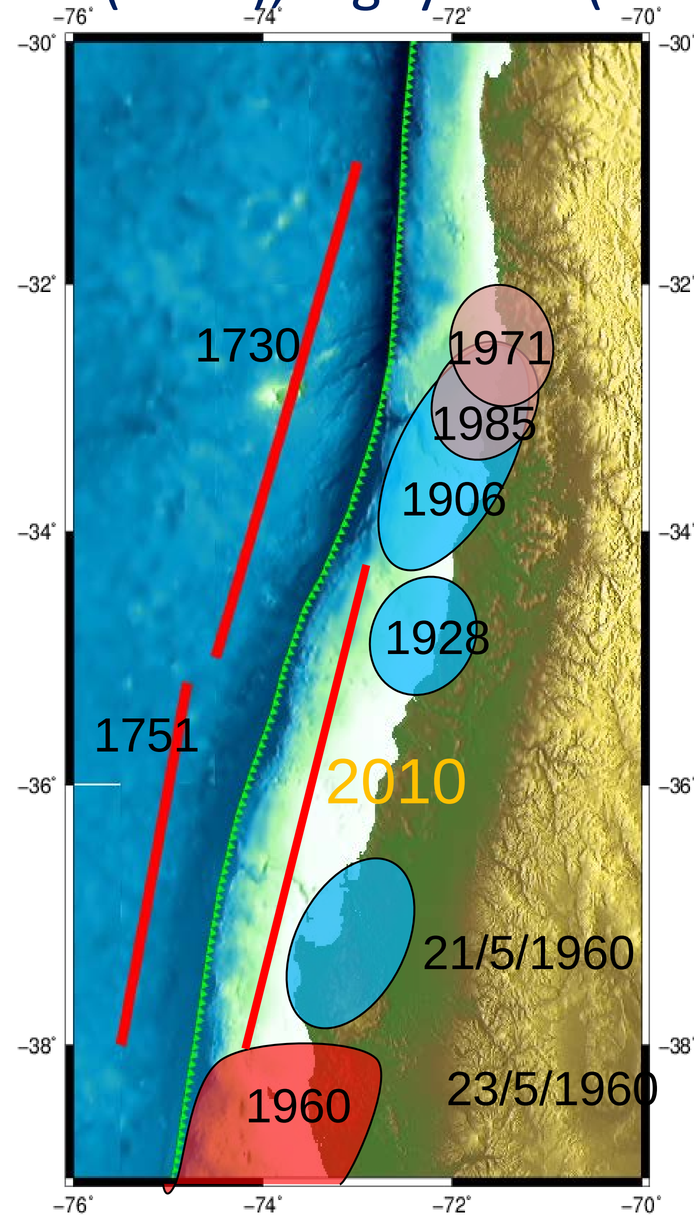
South Central Chile Gaps

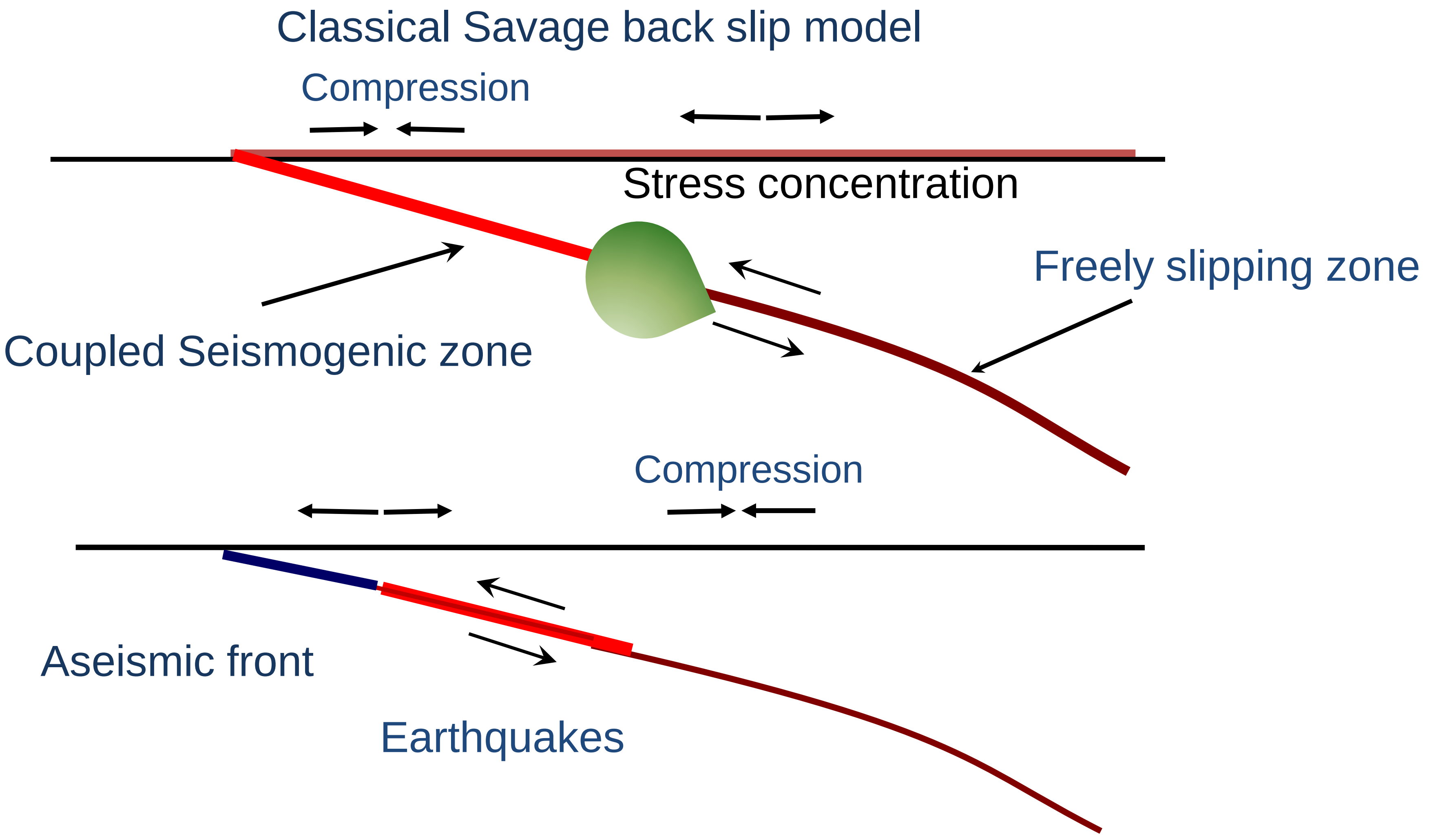
Kelleher et suivants



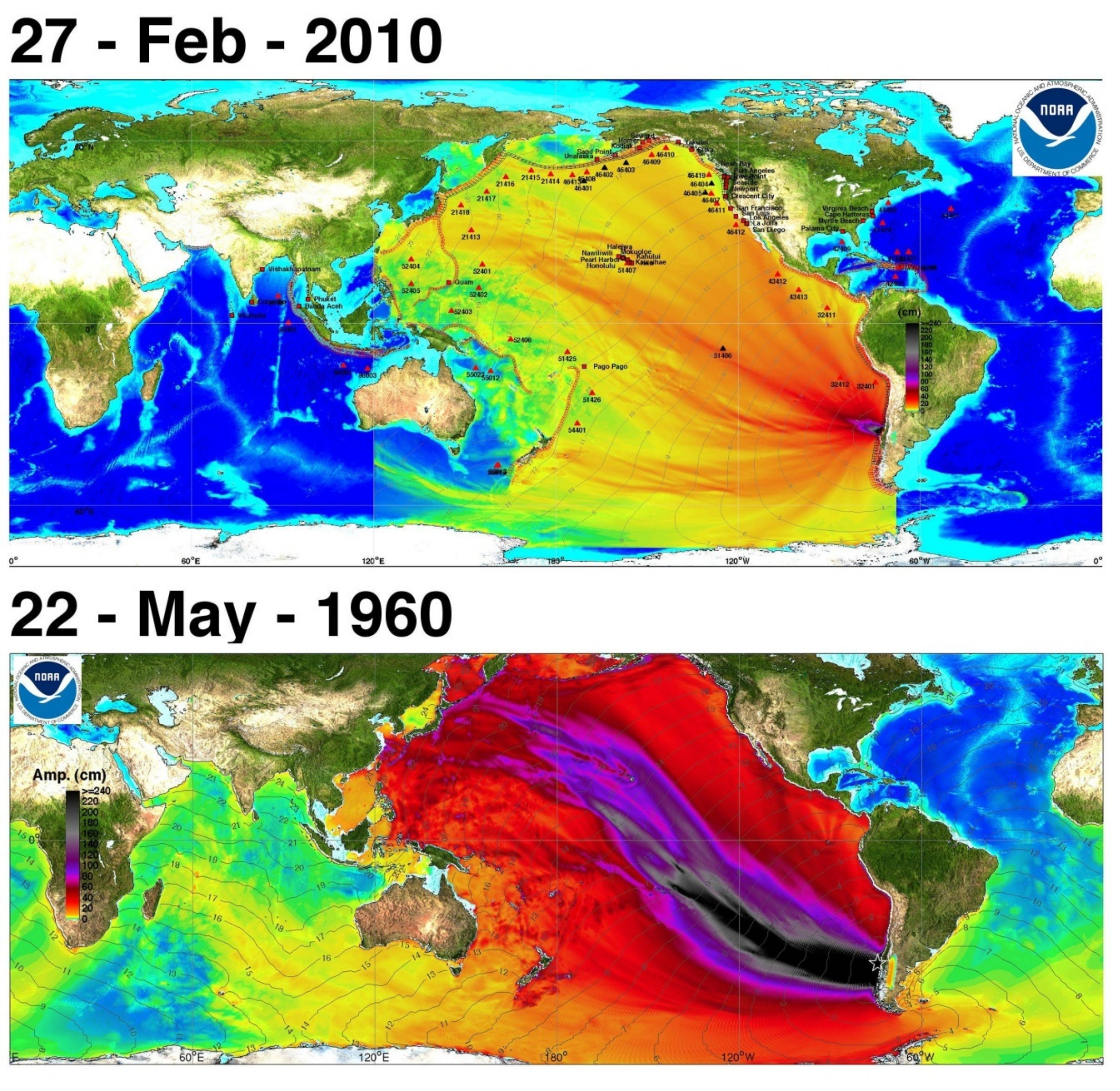
Beck et al (1998), Vigny et al (2011)



Seismic coupling in subduction zones

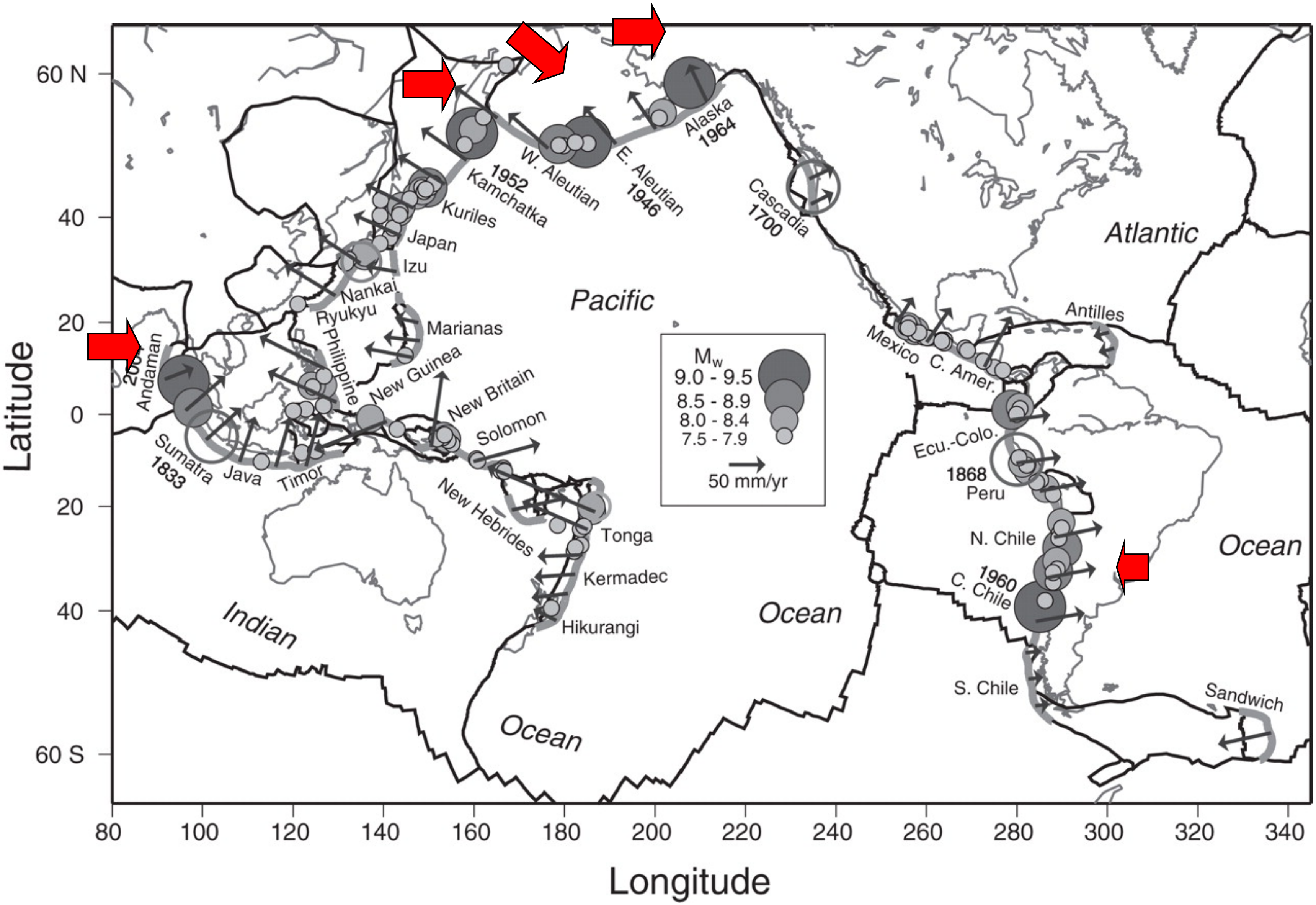


Que es un gran terremoto ?
Tsunamis de 1960 y 2010



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

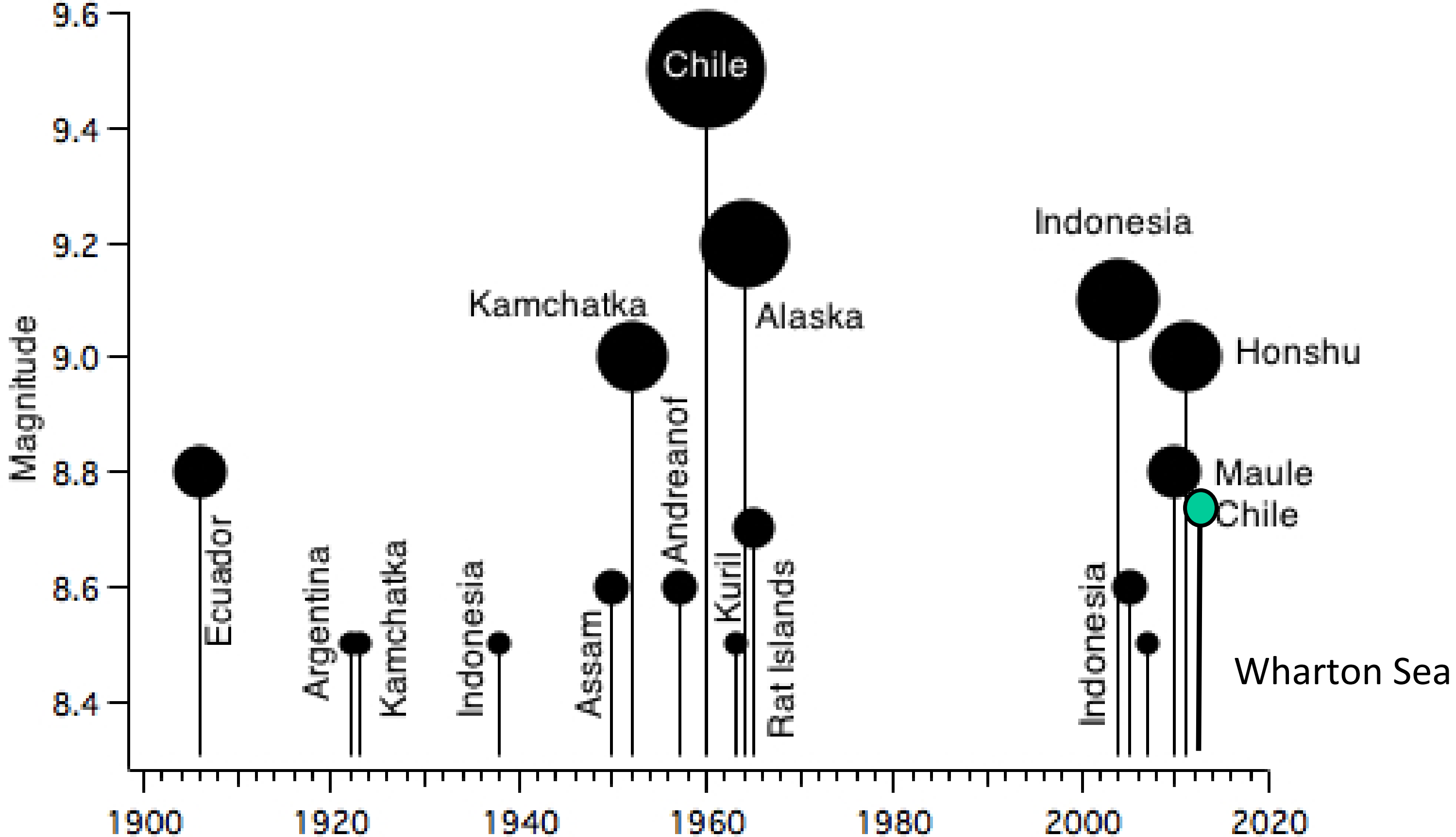
Grandes sismos historicos



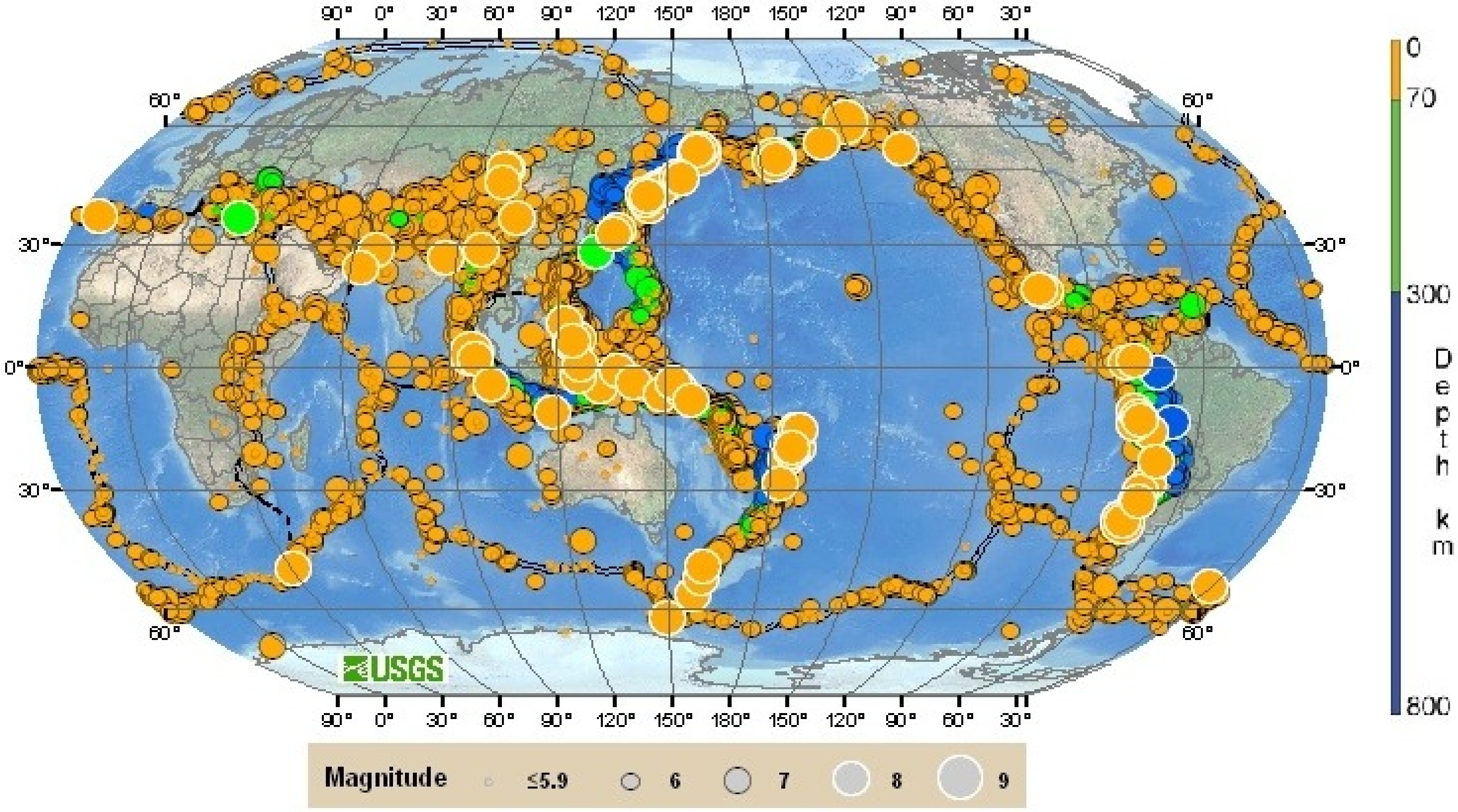
Los mayores sismos desde 1900

Chile	22 Mai 1960	9 .75	38.2 S	73.1 W
Prince Williams Alaska	28 mars 1964	9.3	61 .9 N	147.6 W
Sumatra	26 Décembre 2004	9.1	3.30 N	95.8 E
Kamtchaka	4 Novembre 1952	9.0	52.8 N	160.1 W
Tohoku-oki	11 Mars 2011	9.0	38.3 N	142.5 E
Chile	27 Février 2010	8.8	35.6 S	72 W
Wharton Sea	11 Avril 2012	8.8	3.5 S	92.8 E
Colombia Ecuador	31 janvier 1906	8.8	1.0 N	81.5 W
Andreanoff, Alaska	9 Mars 1957	8.6	51.6 N	175.4 W
Rat Island, Aleutiennes	4 février 1965	8 .7	51.2 N	178.5 S

La sismicidad es aleatoria e imprevisible

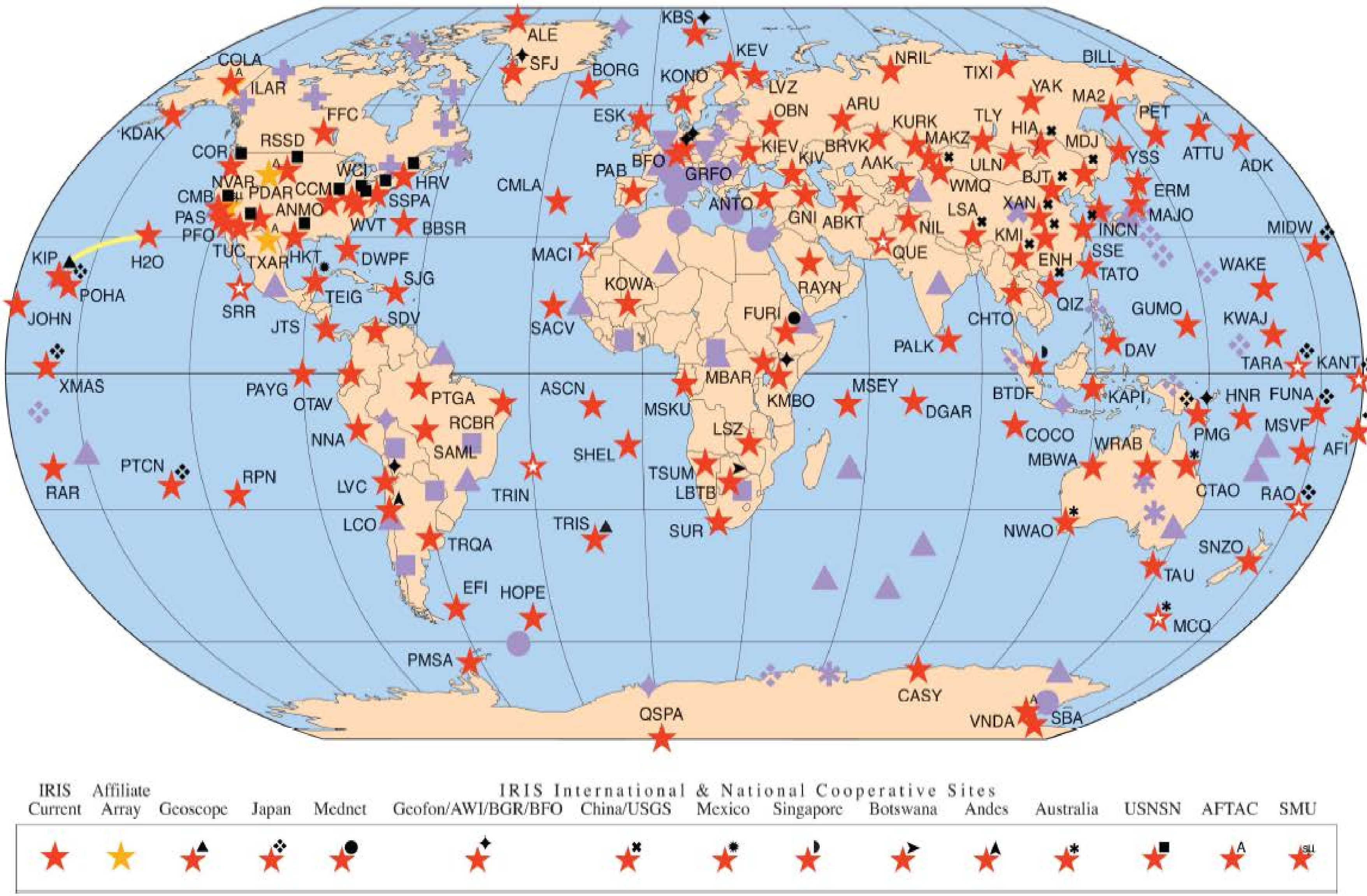


Seismicity of the world 1990-2010, Mw>5



Observation de terremotos por la Red Global
Mayoritariamante Broad Band

Eos, Vol. 85, No. 23, 8 June 2004



¿Qué es un terremoto ? II

Landers 28 juin 1992

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

Faults are everywhere. Some of them are now inactive, Others produce earthquakes.

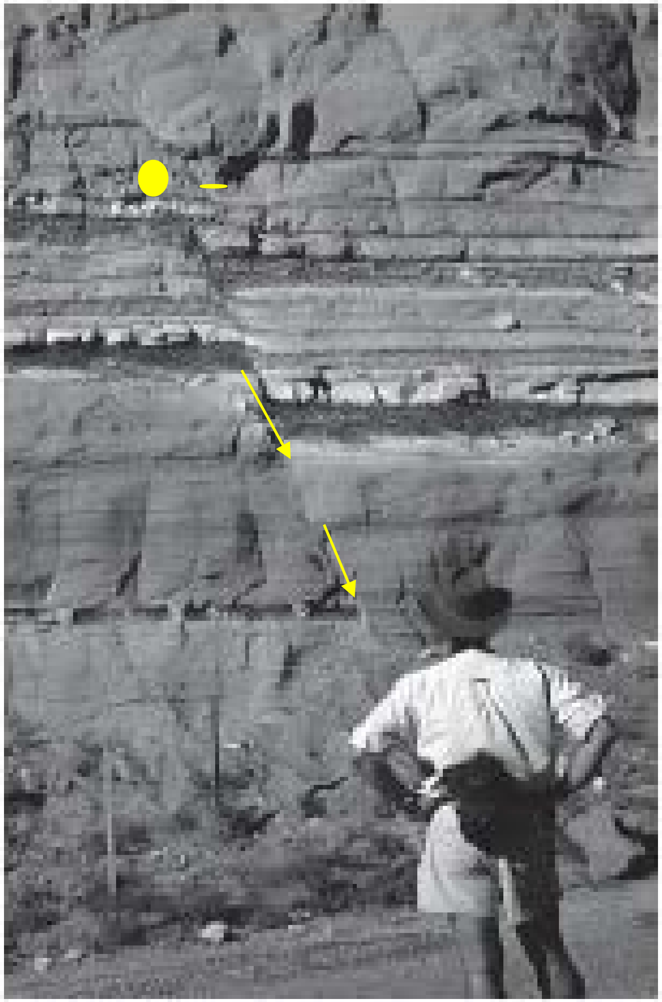
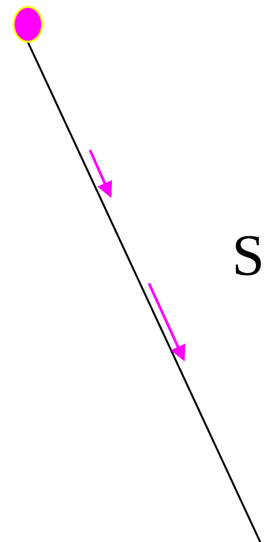


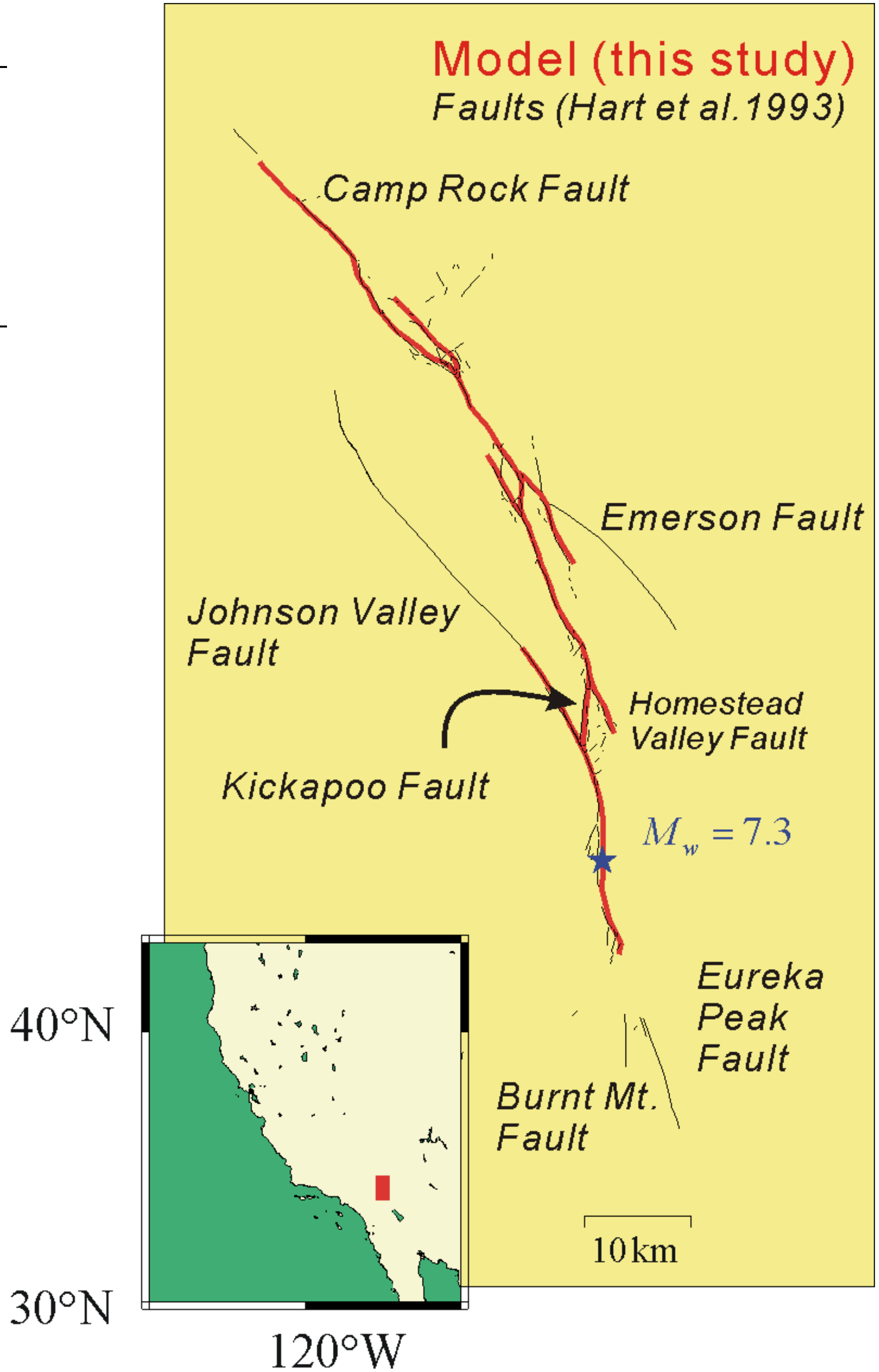
Fig. 11.9. Photograph of a bounded normal fault in Utah showing variations in the amount of displacement accommodated along the fault.



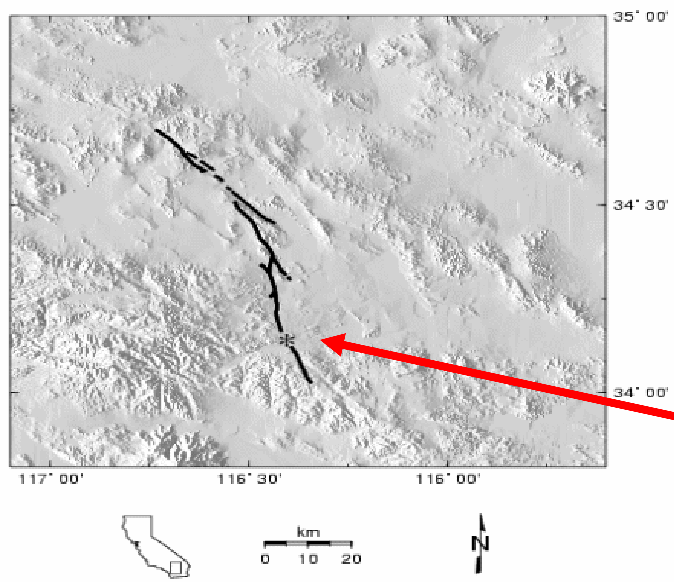
Slip is larger near center

Geometry of Landers fault system

Figure shows the fault traces (Hart et al., 1993) which ruptured during the 1992 earthquake, *and those which did not break then*



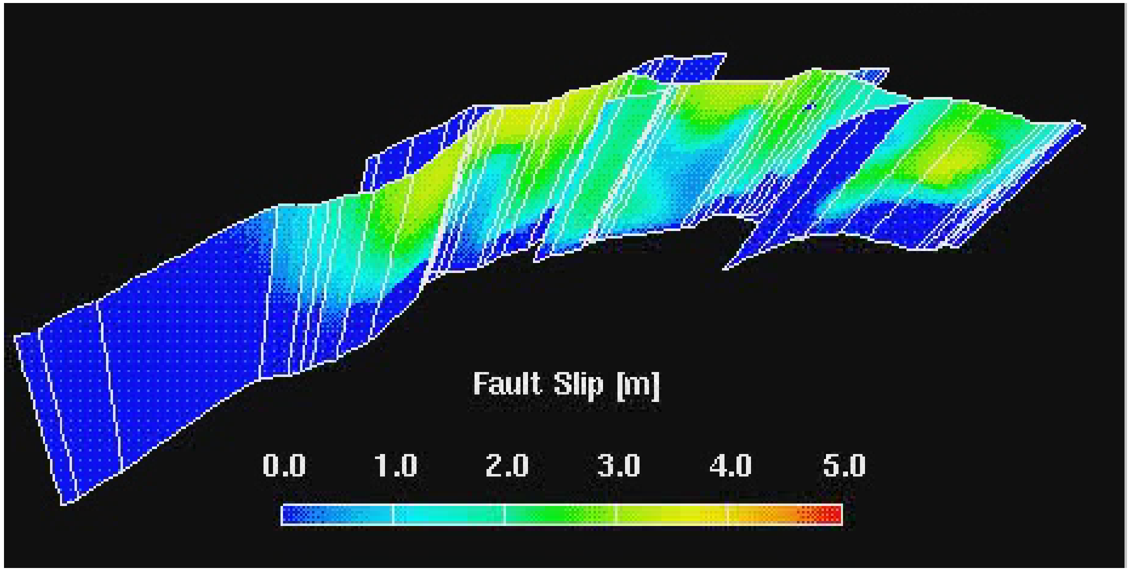
Earthquakes as dynamic shear ruptures



Pre-existing Fault system in the Mojave desert

Epicenter

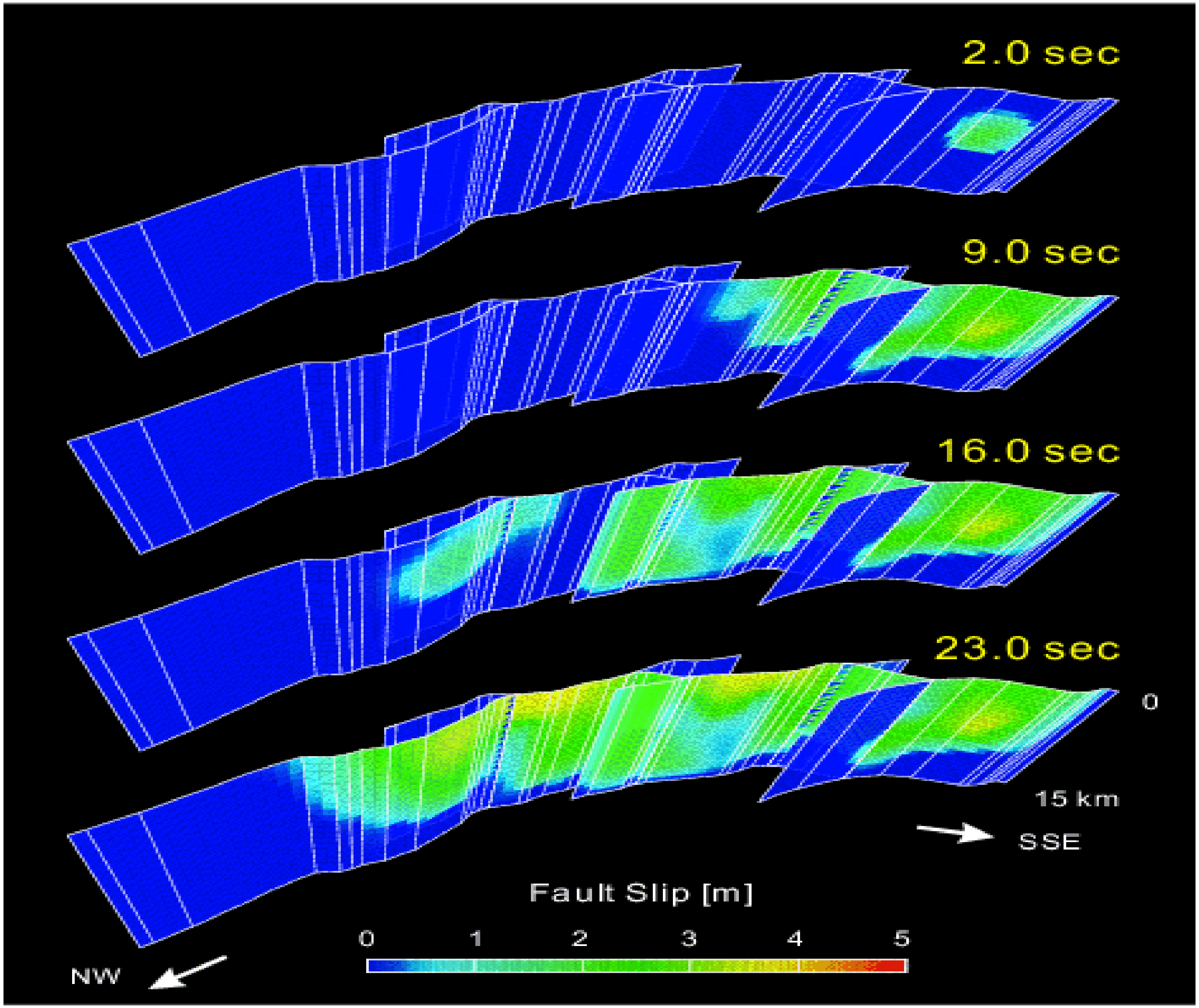
Final slip observed on the fault as determined from Geology, Geodesy and Seismology



Modèle ENS (Peyrat, Aochi, Olsen, Madariaga)

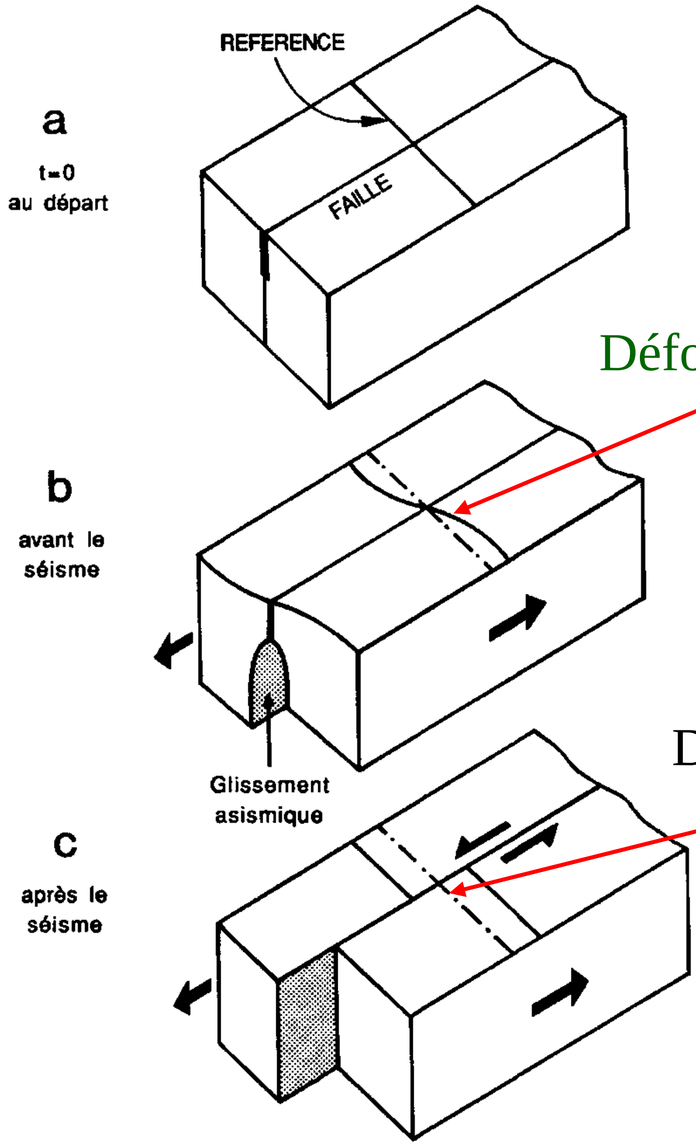
Propagacion de la ruptura del sismo de Landers

Aochi et al 2002



¿Què es un terremoto? III

Modelo del rebote sismico



Situation algunos dias despuès del sismo

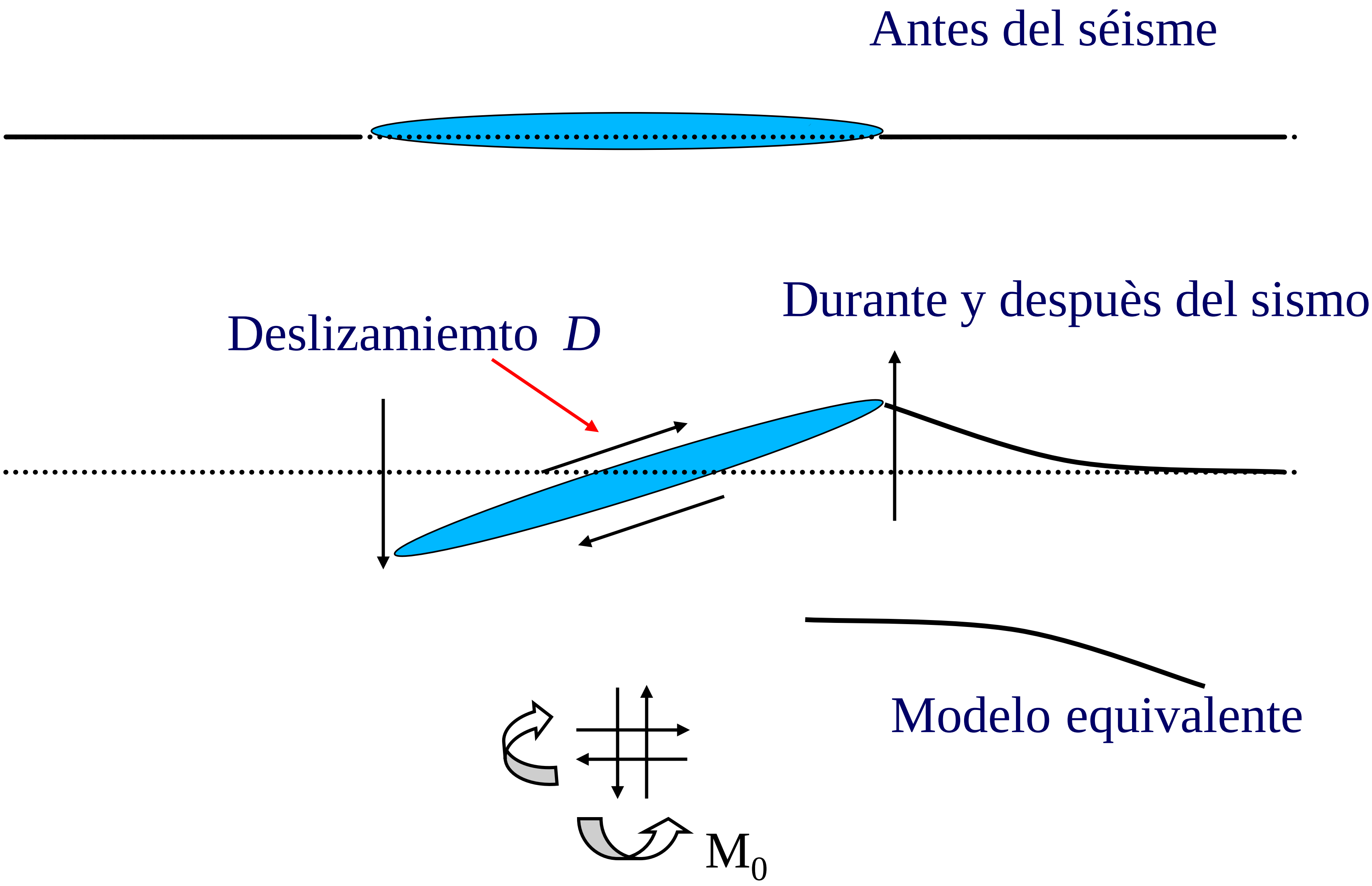
Déformation présismica

Situation intermedia

Deslizamiento sismico

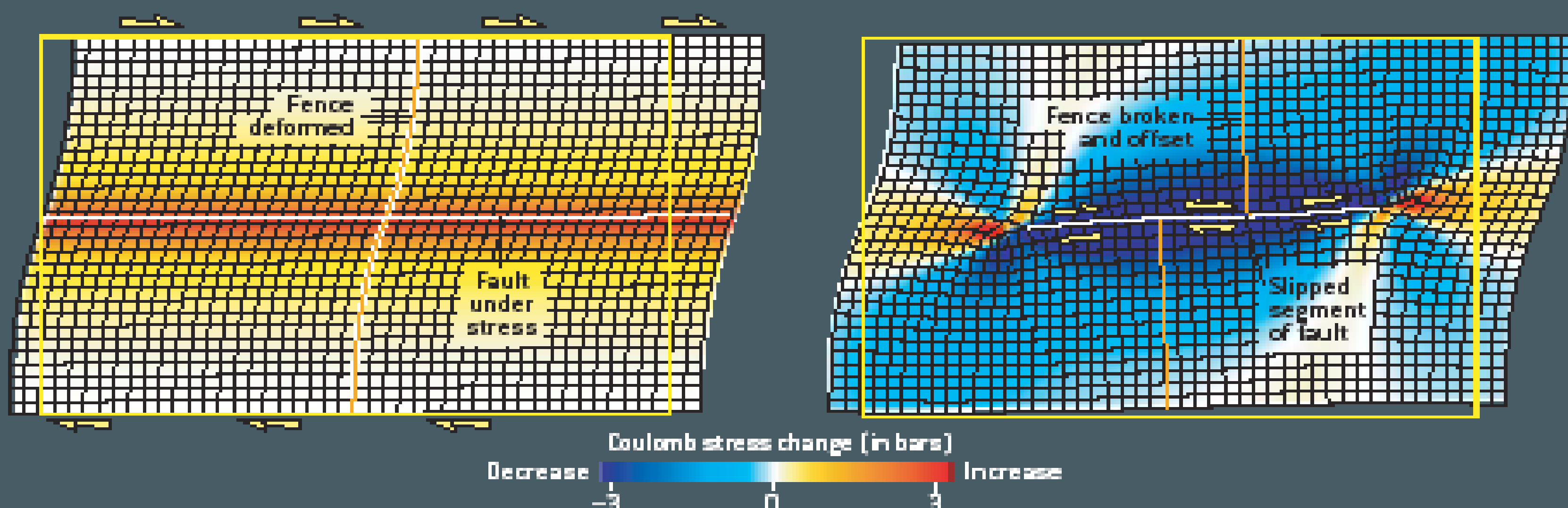
Situacion algunos dìas despuès del sismo siguiente

Modèlo de ruptura sismica (dislocation)



STRESSED OUT

BUILDUP AND RELEASE of the stress that accumulates slowly as the earth's tectonic plates grind past one another mark the cycle of all great earthquakes. Along Turkey's North Anatolian fault [*white line*], the land north of the fault is moving eastward relative to the land to the south [*yellow arrows*] but gets stuck along the fault. When the stress finally overcomes friction along the fault, the rocks on either side slip past one another violently. A catastrophic example of this phenomenon occurred on August 17, 1999, when a magnitude 7.4 shock took 25,000 lives in and around the city of Izmit. Calculations of stress before and after the Izmit earthquake [*below*] reveal that, after the shock, the so-called Coulomb stress dropped along the segment of the fault that slipped but increased elsewhere. —*R.S.S.*



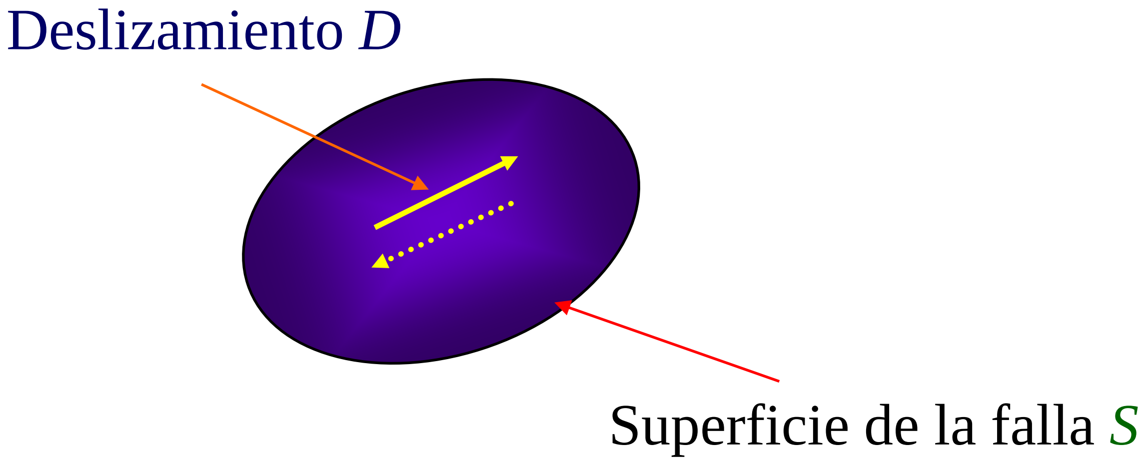
BEFORE THE EARTHQUAKE

The segment of the North Anatolian fault near Izmit accumulated significant stress [*red*] during the 200 years since its last major stress-relieving shock. An imaginary deformed fence and grid superimposed over the landscape illustrate this high stress. Squares along the fault are stretched into parallelograms [*exaggerated 15,000 times*], with the greatest change in shape, and thus stress, occurring closest to the fault.

AFTER THE EARTHQUAKE

The earthquake relieved stress [*blue*] all along the segment of the fault that slipped. The formerly deformed fence broke and became offset by several meters at the fault, and the grid squares closest to the fault returned to their original shape. High stress is now concentrated beyond both ends of the failed fault segment, where the grid squares are more severely contorted than before the shock struck.

Définition de Momento sismico



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

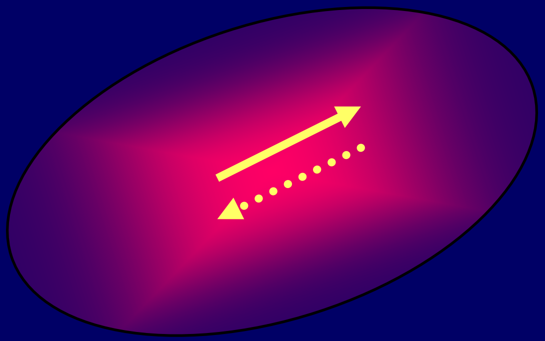
μ Constante elastica (modulo de cisalle)

Ley de escala de los terremotos (Aki, 1967)

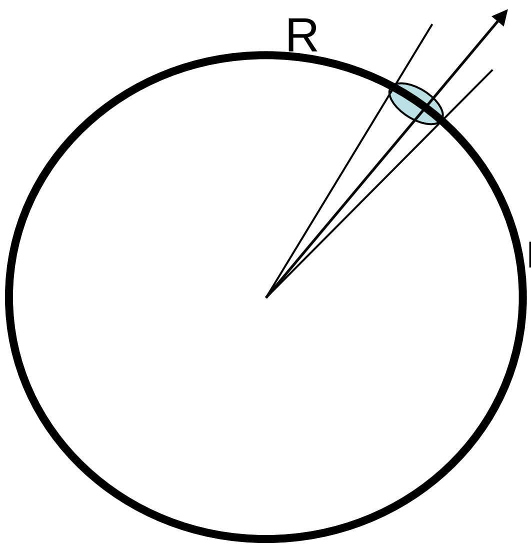
$$\log_{10} M_0(Nm) = 1.5M_w + 9.3$$

Magnitude (M_w)	Moment (Nm)	Longueur (km)	Durée (s)	Glissement (m)
10	10^{24}	1000?	300?	100?
9	3.10^{22}	300	100	30
8	10^{21}	100	30	10
7	3.10^{19}	30	10	3
6	10^{18}	10	3	1

Radiaciòn y mecanismo de foco



Ondes sphériques



Ondes P

$$\frac{1}{\alpha^2}\frac{\partial^2}{\partial t^2}\varphi = \nabla^2\varphi = \frac{1}{R^2}\frac{\partial}{\partial R}\left[R^2\frac{\partial\varphi}{\partial R}\right]$$

Solution space temps

$$\varphi(R,t) = \frac{1}{4\pi}\frac{1}{R}\; f\left(t - \frac{R}{\alpha}\right)$$

Divergence géométrique

Solution space Fourier

propagation

$$\varphi(R,\omega) = \frac{1}{4\pi}\frac{1}{R}\;\tilde{f}(\omega)\, e^{i\omega(t-R/\alpha)}$$

forme d'onde

Transformada de Fourier

Toda funcion del tiempo définida sobre la linea de tiempo *t*
Posede una transformada de Fourier definida en el espacio de frecuencias:

$$\tilde{f}(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$$

Su inverso se define como

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{f}(\omega) e^{+i\omega t} dt$$

En general $f(\omega)$ es complejo y tiene muchas propiedades importantes
Propiedad fundamental

$$\tilde{f}(0) = \int_{-\infty}^{\infty} f(t) dt$$

Ejemplos

	Funcion del tiempo	Tr de Fourier
Puerta		$\tilde{f}(\omega) = \frac{\sin \omega T}{\omega T}$
Triangulo		$\tilde{f}(\omega) = \left(\frac{\sin \omega T}{\omega T}\right)^2$
Exponencial	$f(t) = \frac{1}{\sigma} e^{-t/\sigma}$	$\tilde{f}(\omega) = \frac{1}{(1 + i\omega\sigma)}$
Brune	$f(t) = \frac{t}{\sigma^2} e^{-t/\sigma}$	$\tilde{f}(\omega) = \frac{1}{(1 + i\omega\sigma)^2}$

Radiacion sismica producida por una fuente puntual

Sea una fuerza vertical de intensidad f_0

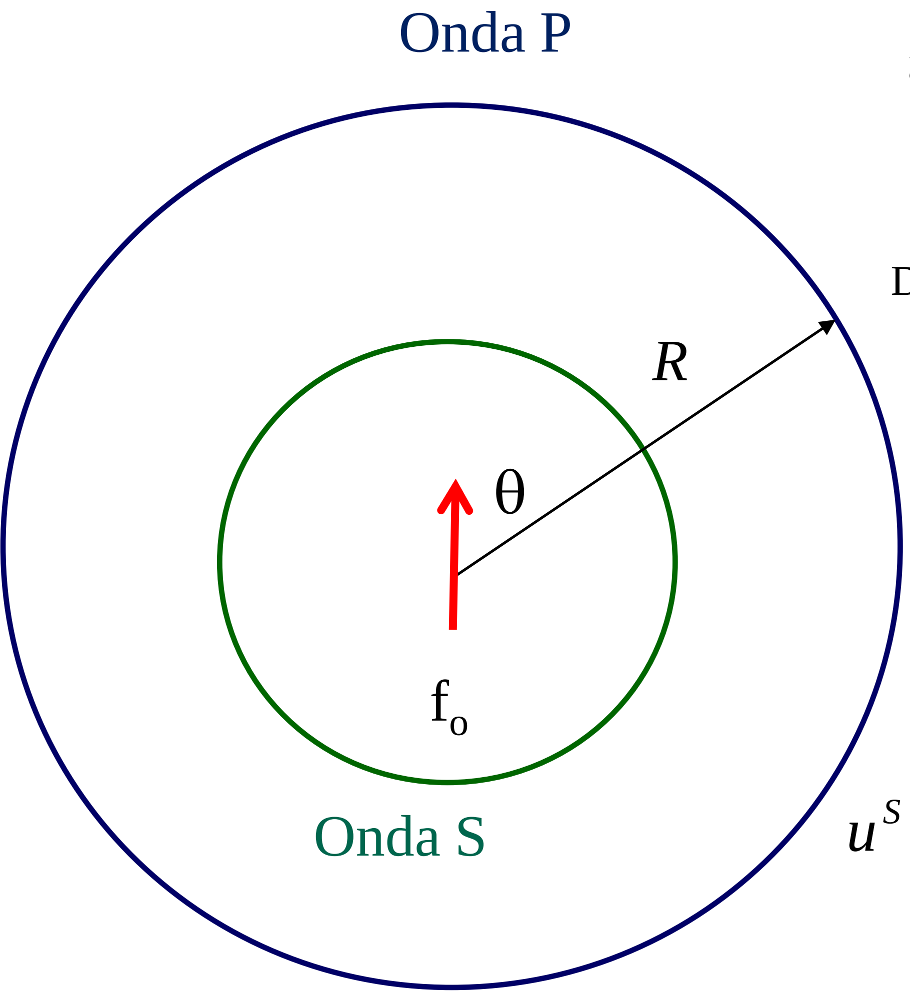


Diagrama de radiaciòn

$$u^P(R,t) = \frac{1}{4\pi\rho\alpha^2}\,\frac{1}{R}\,\mathcal{R}^P(\theta)\; f_0(t - R/\alpha)$$

Divergencia Geométrica

Señal sìsmico

$$\mathcal{R}^P = \cos\theta \qquad \mathcal{R}^S = \sin\theta$$

$$u^S(R,t) = \frac{1}{4\pi\rho\beta^2}\,\frac{1}{R}\,\mathcal{R}^S(\theta)\; f_0(t - R/\beta)$$

Sources mécaniquement acceptables

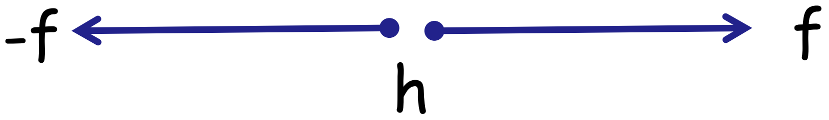
Une source d'origine interne doit satisfaire les deux conditions

$$\sum \mathbf{f} = 0$$

$$\sum \mathbf{f} \times \mathbf{r} = 0$$

. La somme des forces et de moments de ces forces doit être égal à zéro

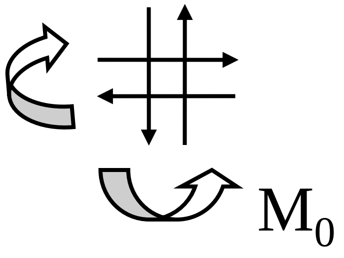
La source la plus simple est un dipôle linéaire qui représente une fissure en ouverture (un crack)



Fuente mecanicamente aceptable

Como ya vimos una falla produce un sistema de fuerzas
Consistente en

Cuatro fuerzas sin resultante de fuerza ni de momento



Calculemos la radiaciòn

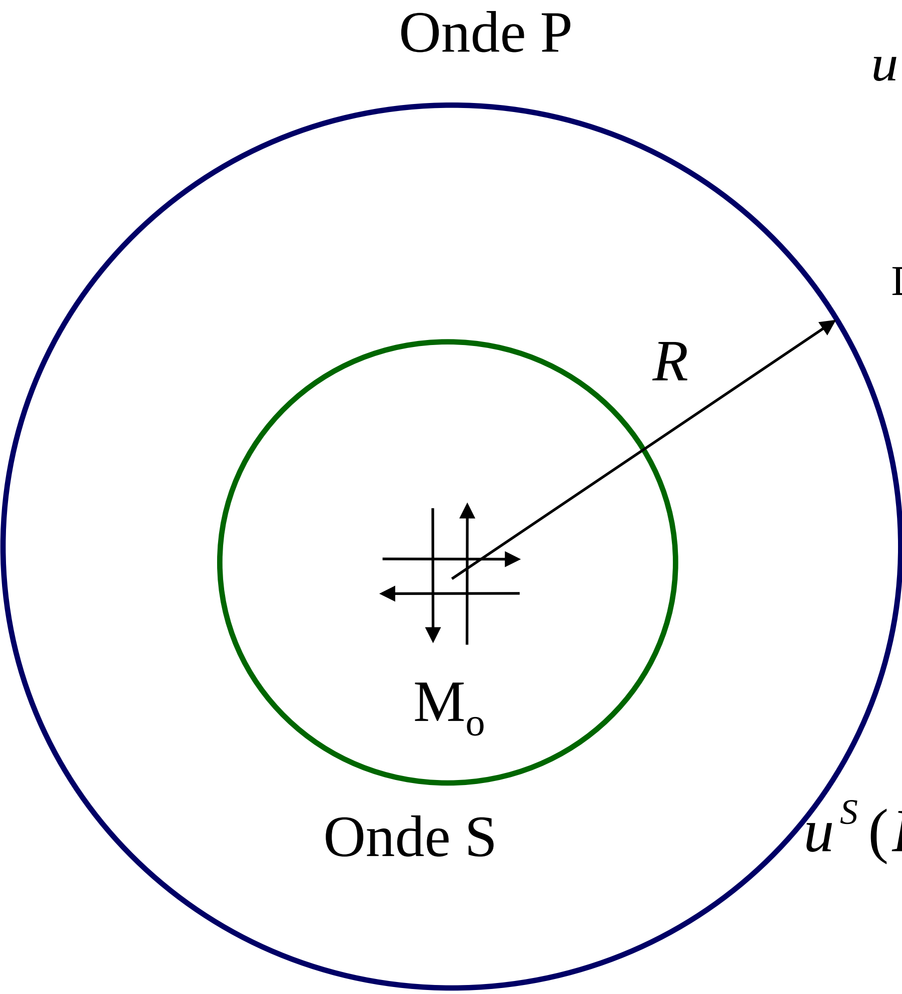
Radiacion sìsmica en un medio homogeneo

Diagramme de radiacion

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

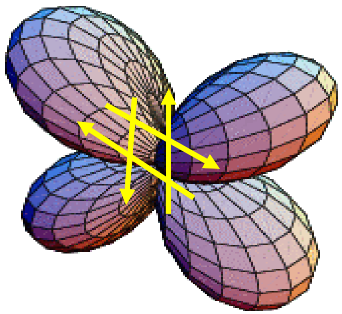
Divergencia Géométrica

Señal sìsmica



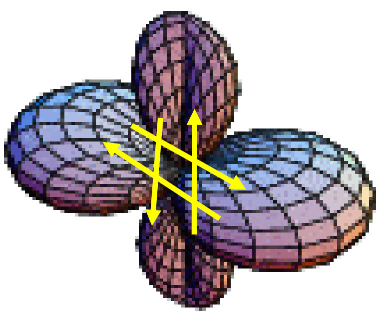
$$u^S(R,t) = \frac{1}{4\pi\rho\beta^3}\,\frac{1}{R}\,\mathcal{R}^S(\theta,\varphi)\,\dot{M}_0(t - R/\beta)$$

Diagrama de radiacion

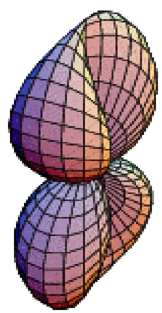


Radiacion de ondas P :

SV



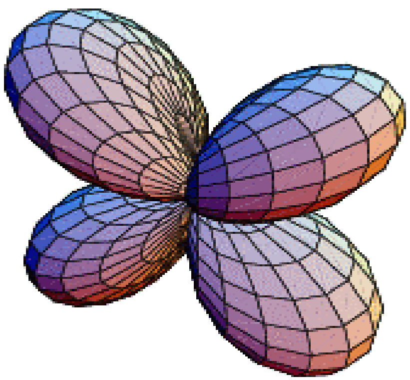
SH

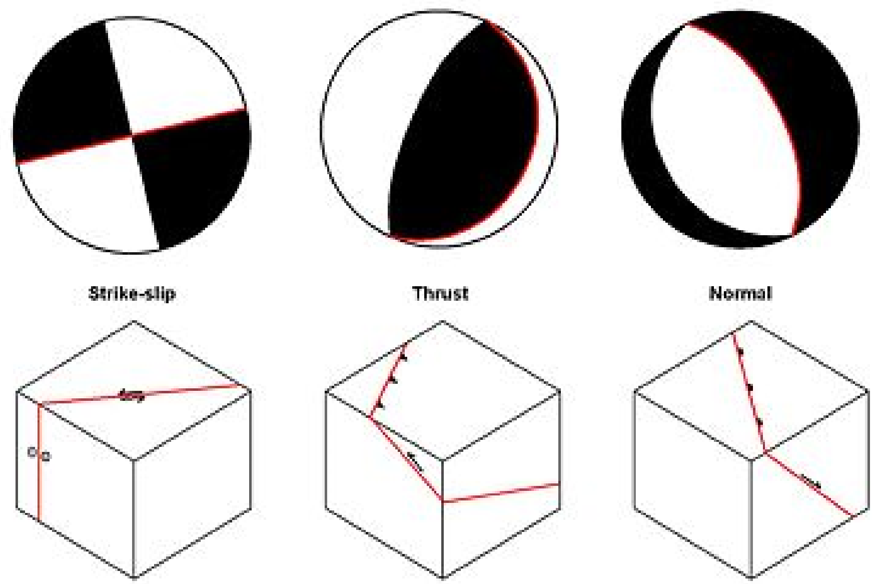


Radiacion de ondas S :

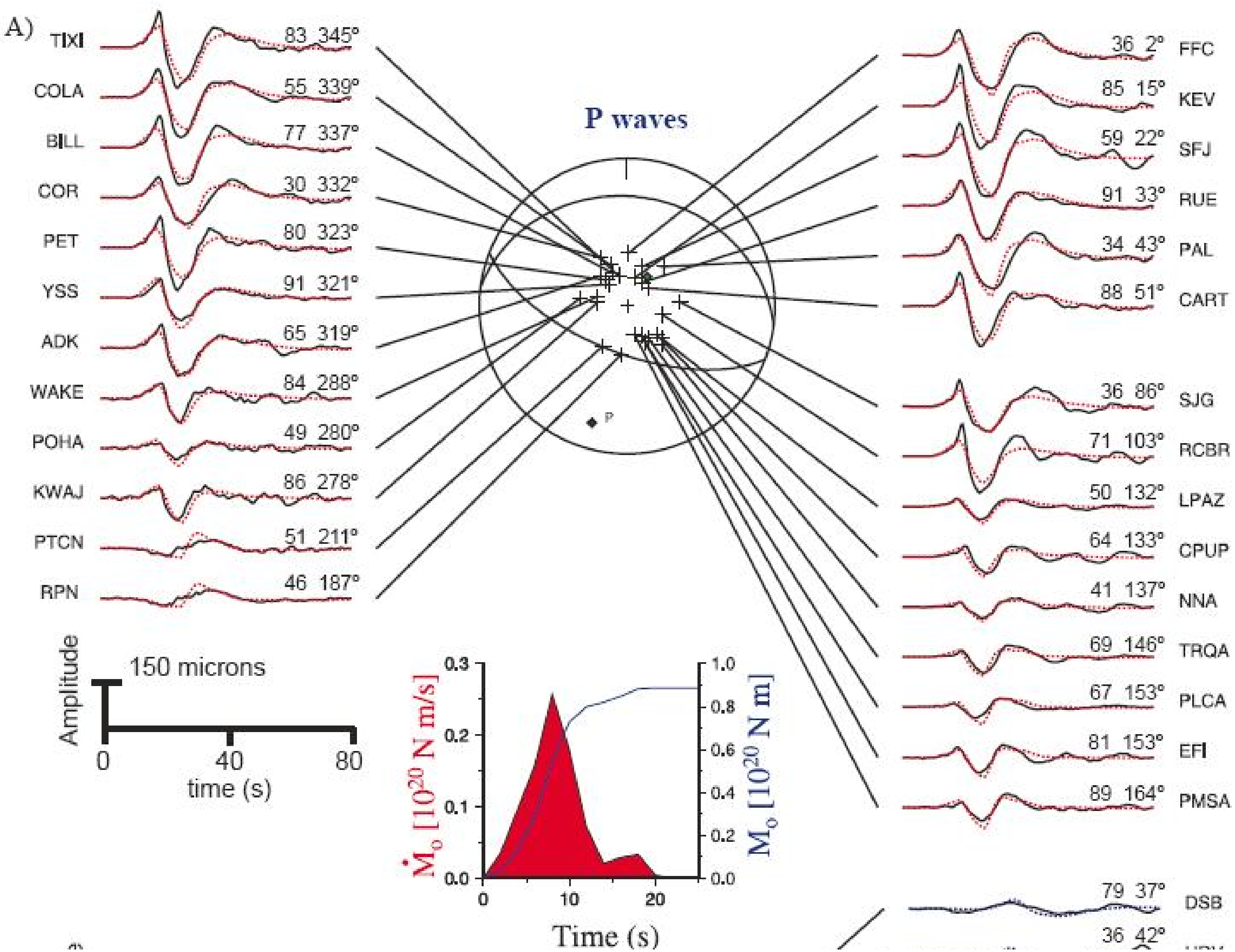
Mécanisme au foyer

Onde P

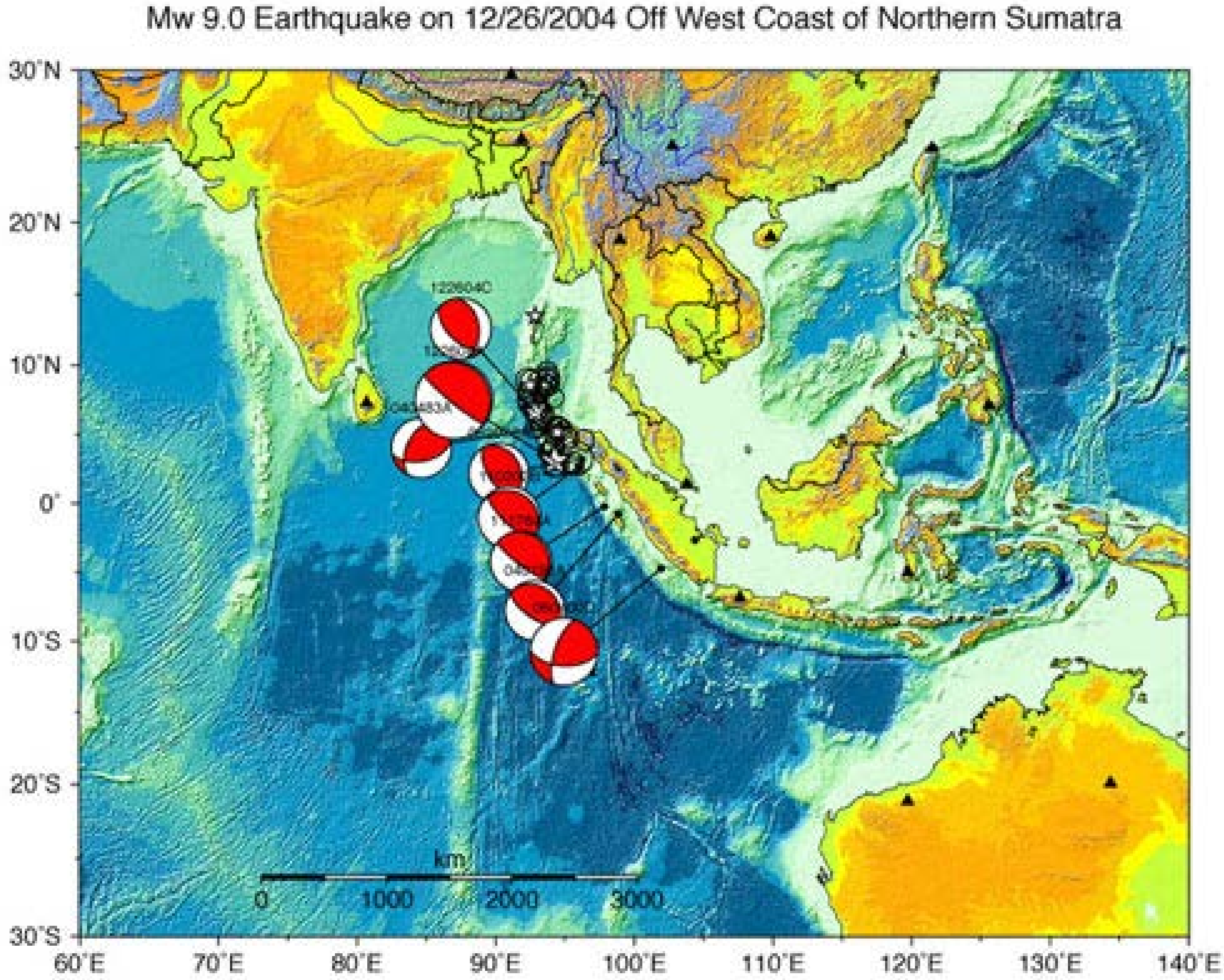




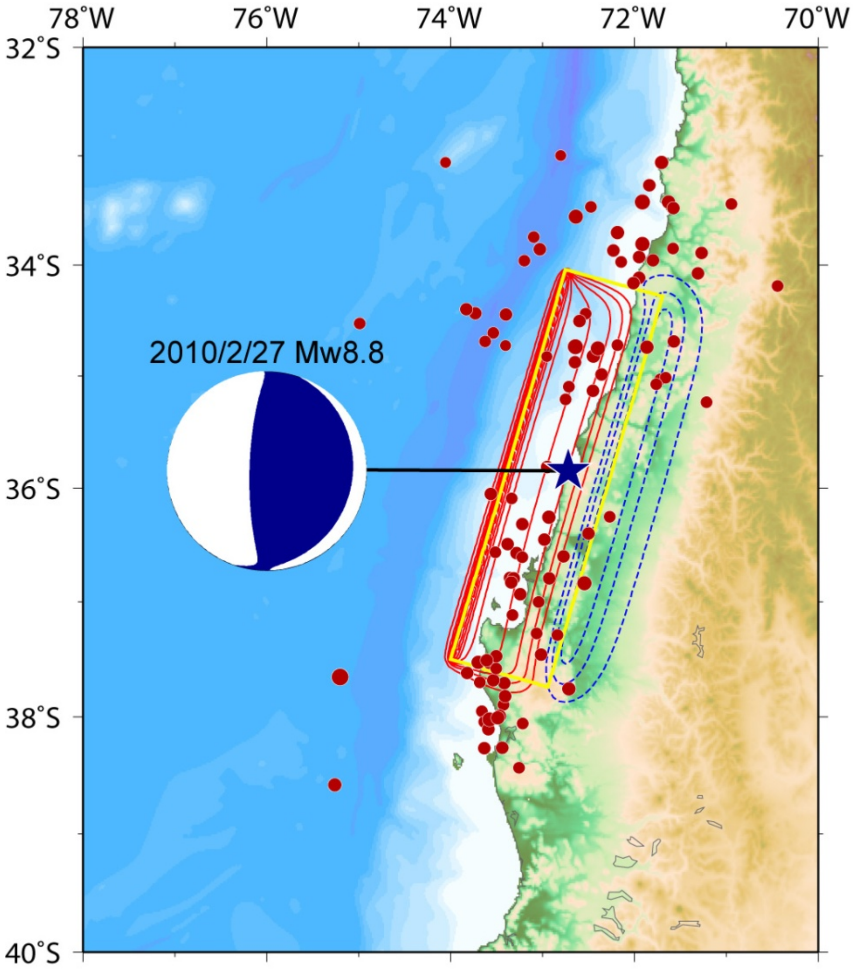
Types of 'beachball plot' associated with different fault end-members
(nodal plane in red parallel to fault)

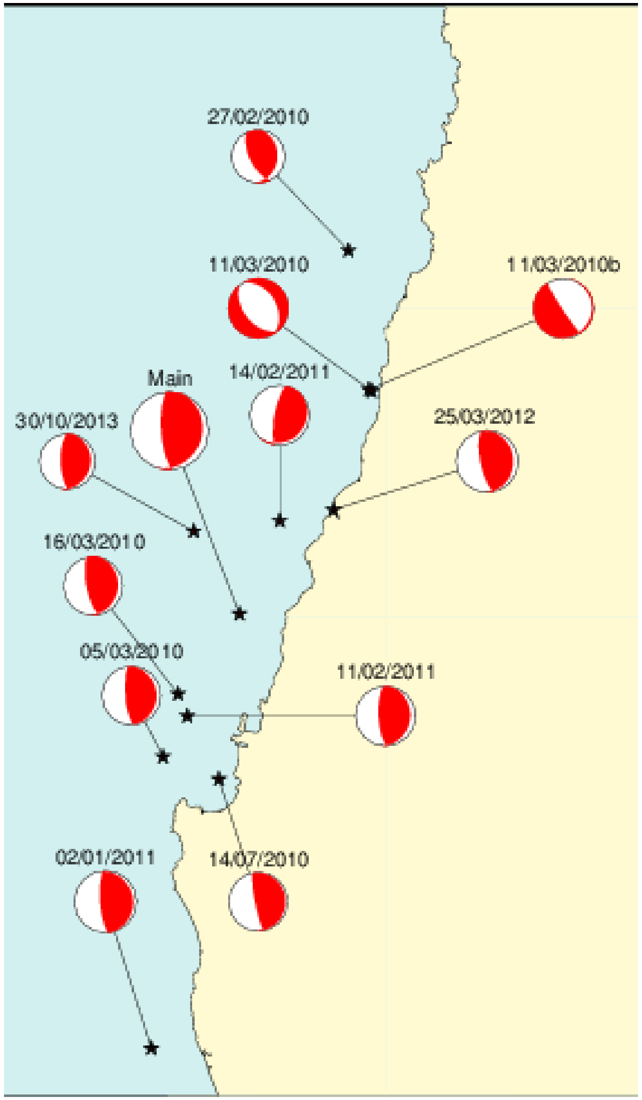

A)
P waves
TIXI 83 345°
COLA 55 339°
BILL 77 337°
COR 30 332°
PET 80 323°
YSS 91 321°
ADK 65 319°
WAKE 84 288°
POHA 49 280°
KWAJ 86 278°
PTCN 51 211°
RPN 46 187°
36 2° FFC
85 15° KEV
59 22° SFJ
91 33° RUE
34 43° PAL
88 51° CART
36 86° SJG
71 103° RCBR
50 132° LPAZ
64 133° CPUP
41 137° NNA
69 146° TRQA
67 153° PLCA
81 153° EFI
89 164° PMSA
79 37° DSB
36 42°
P
Amplitude
150 microns
0
40
80
time (s)
$\dot{M}_o$ [10^{20} N m/s]
M_o [10^{20} N m]
Time (s)
0.3
0.2
0.1
0.0
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20

Subduccion: Dominio tipico ce fallas inversas



Fallas inversas y una normal en Chile central rèplicas del Maule

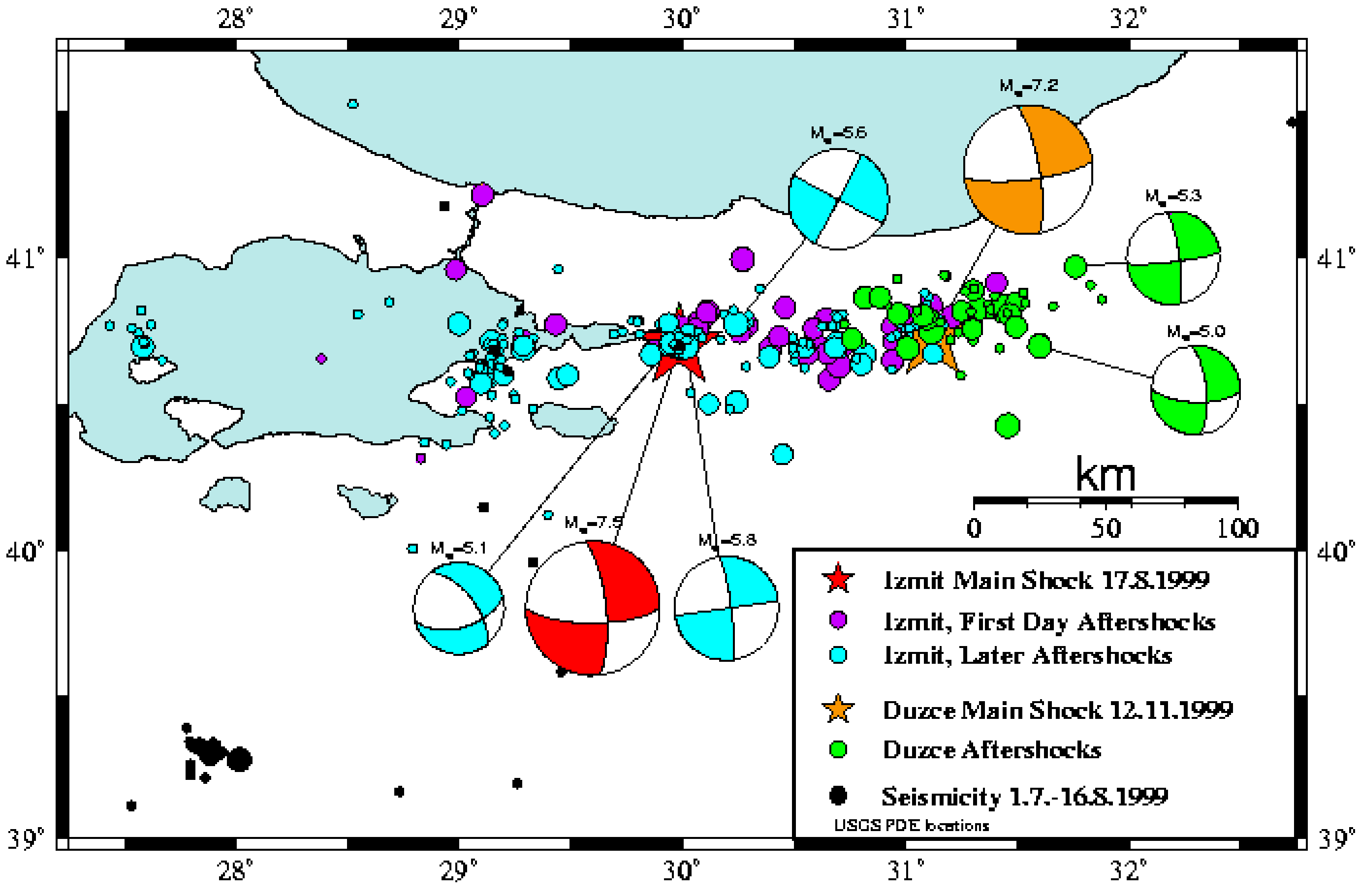




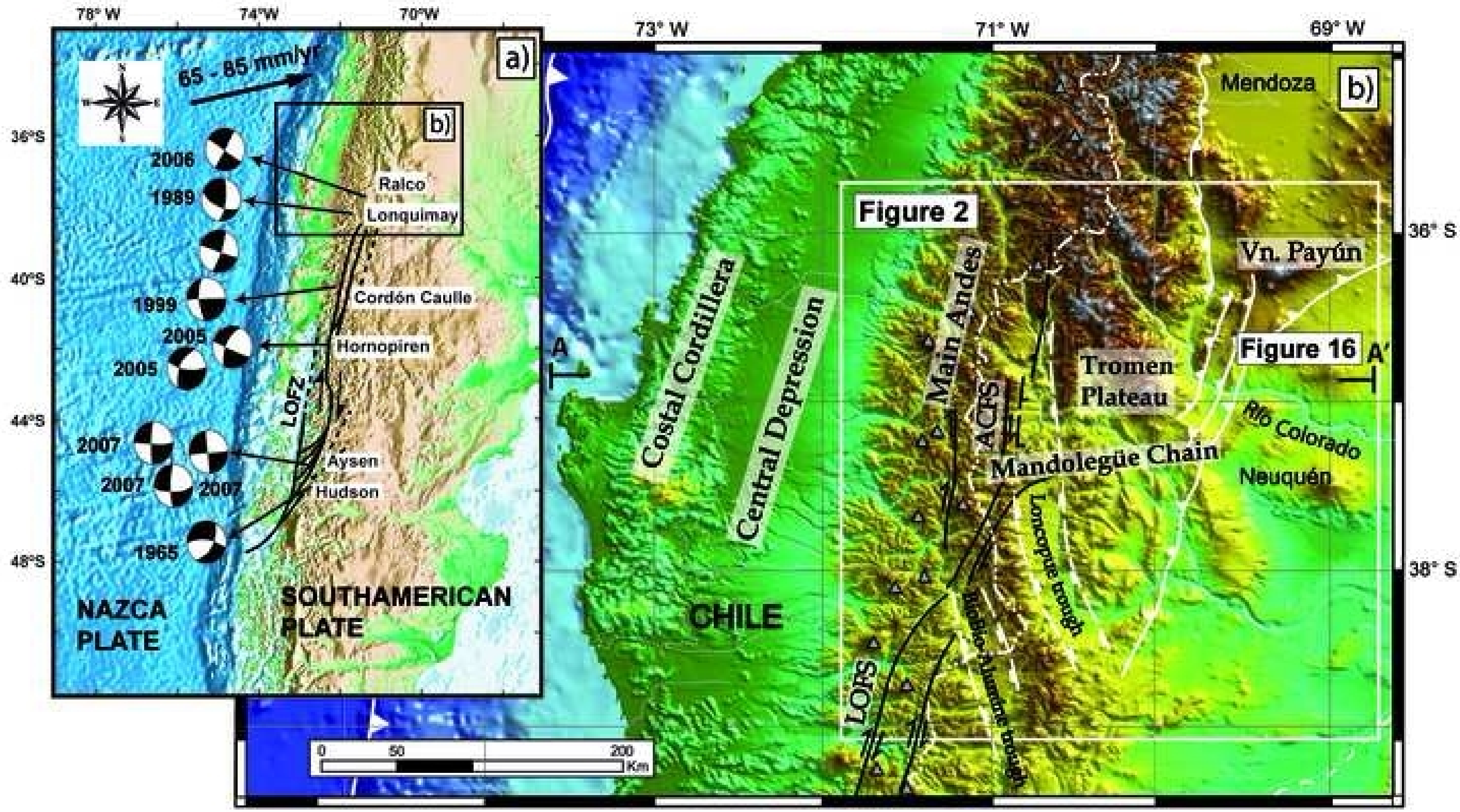
Dominio tipico de fallas de rumbo (strike slip)

Faille Nord Anatolienne en Turkie

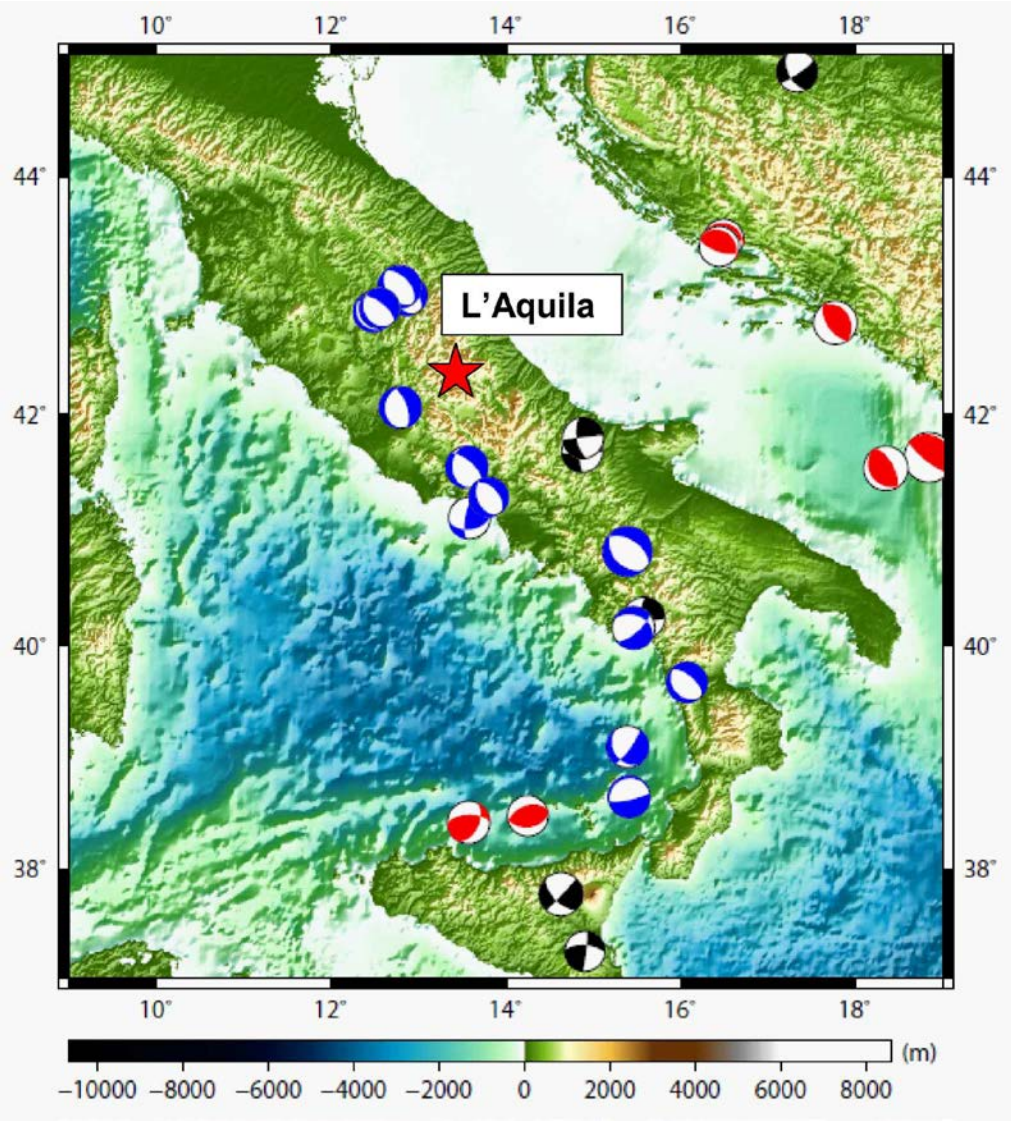
Séisme d'Izmit 17 Août 1999



Dominio tipico de fallas de rumbo (strike slip)
Falla de Liquiñe Ofqui



Dominio tipico de fallas normales
Italia central



Radiación sísmica y forma de ondas

Radiacion sísmica en un medio homogéneo

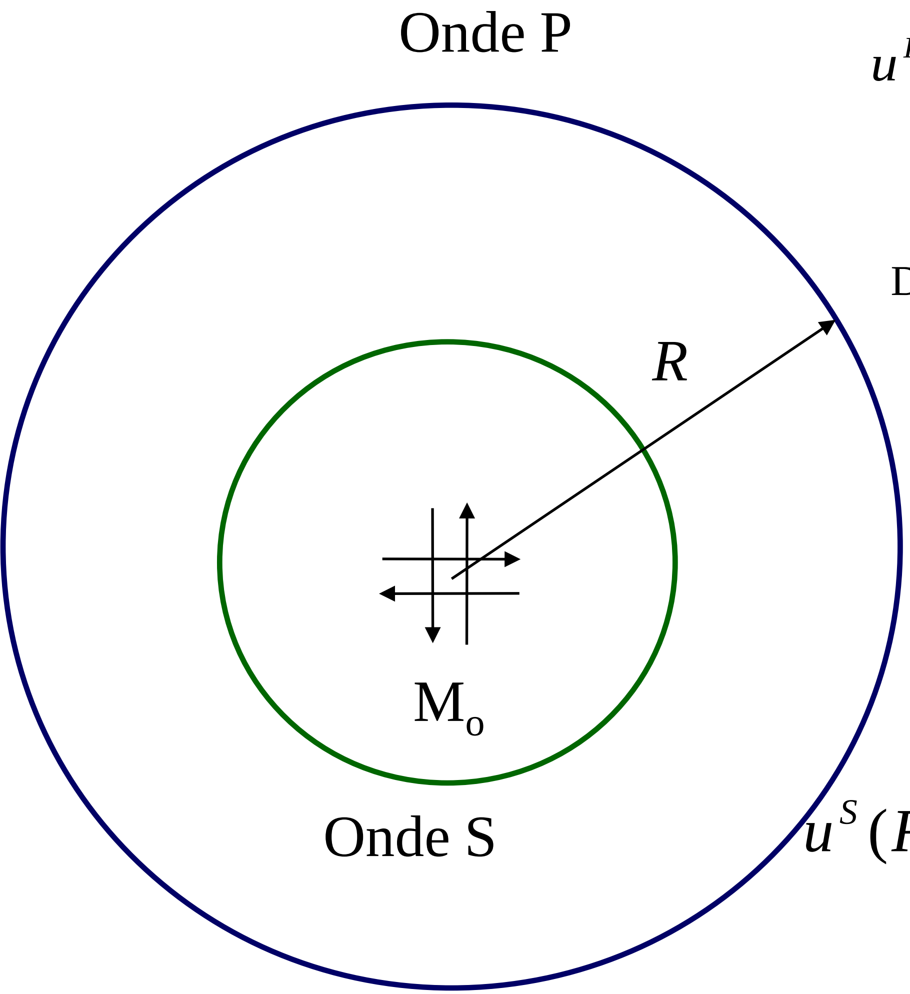


Diagrama de radiación

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

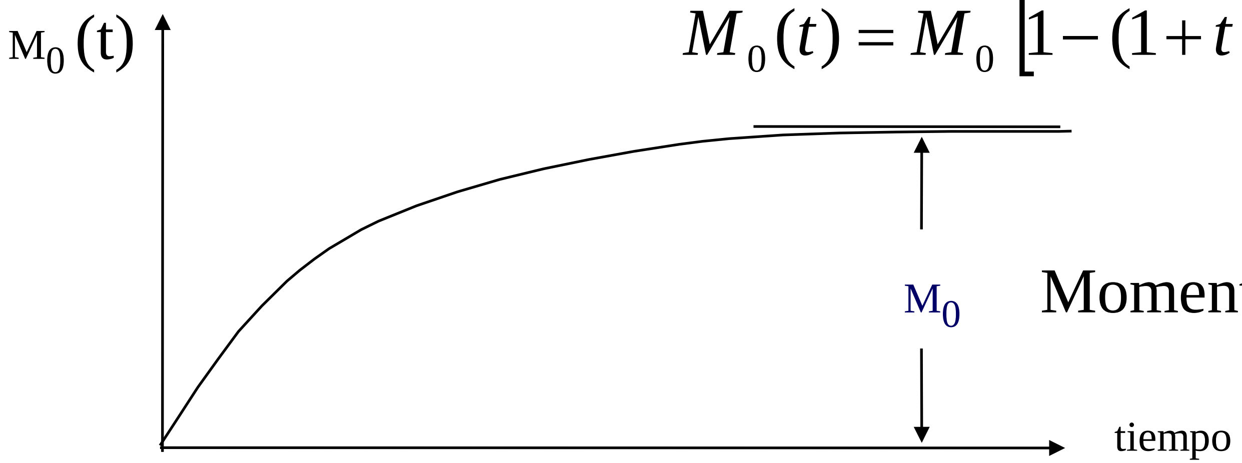
Divergencia Geométrica

Señal sísmica

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

Radiación sísmica Modelo de Brune

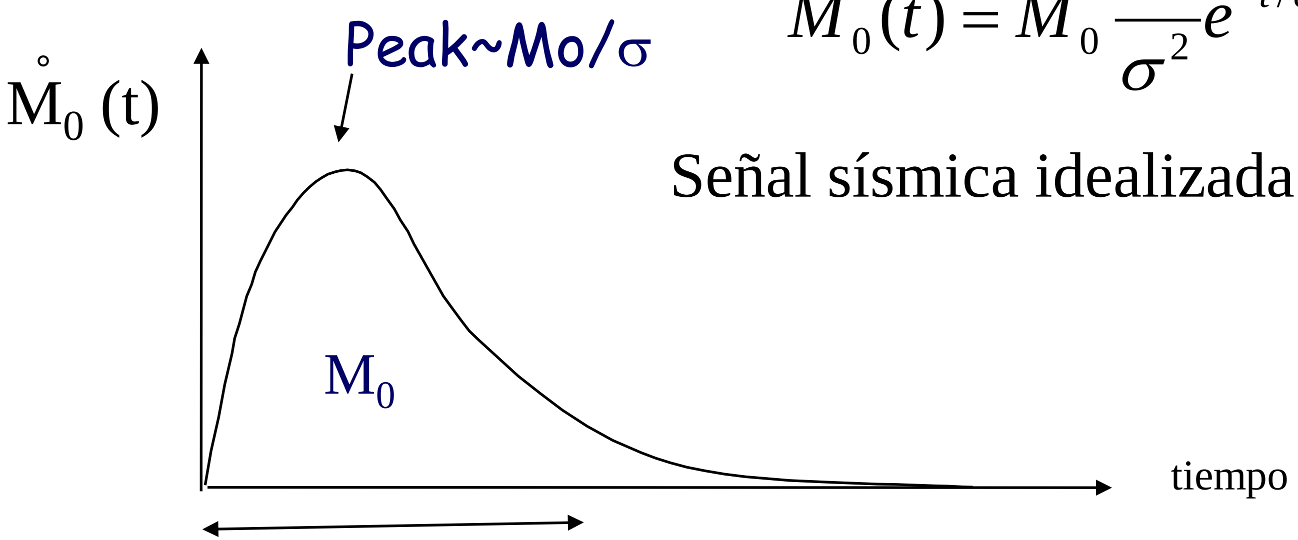
$$M_0(t) = M_0\left[1-(1+t/\sigma)e^{-t/\sigma}\right]H(t)$$



Momento Sísmico final

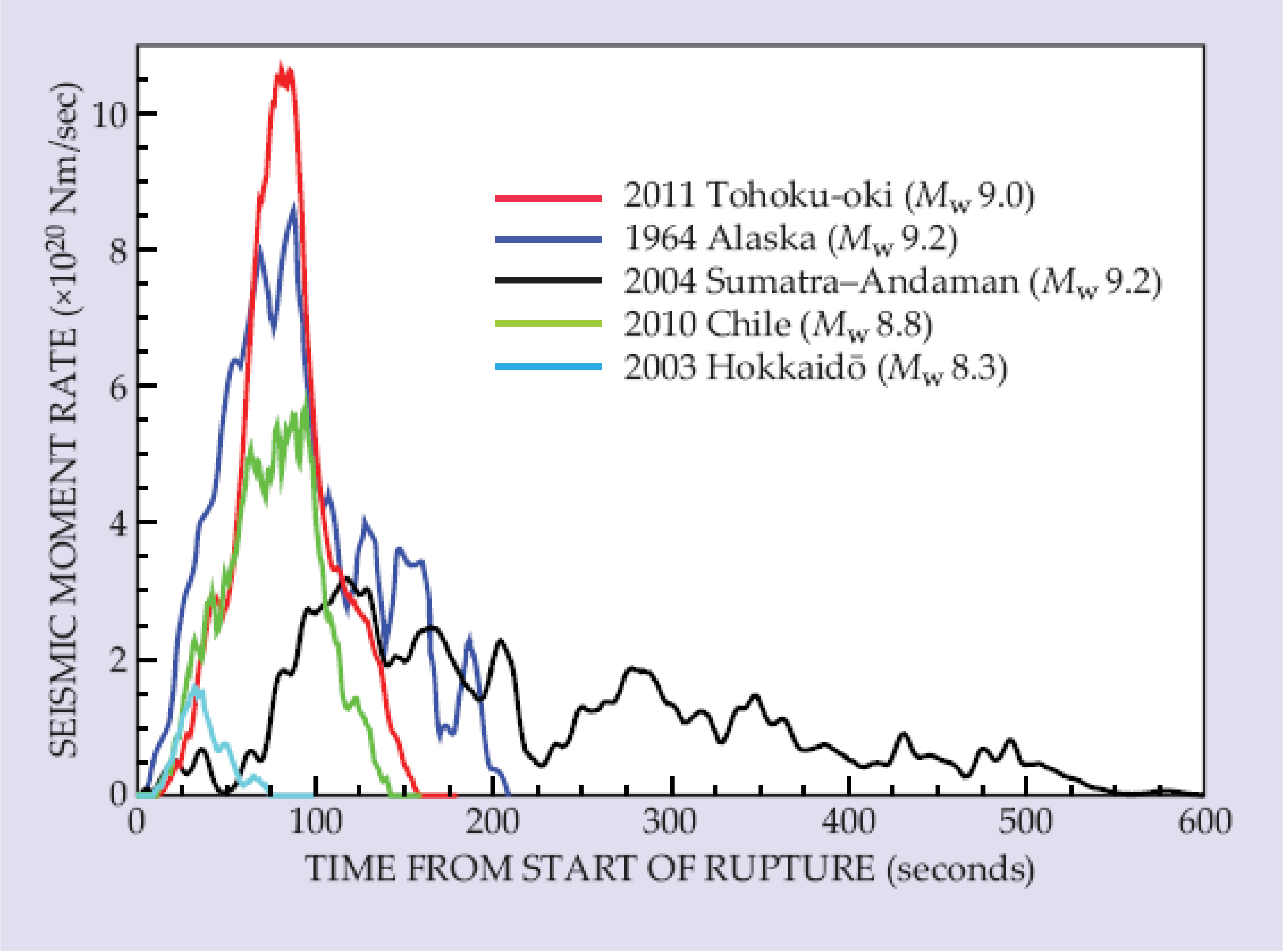
$$\dot{M}_0(t) = M_0\frac{t}{\sigma^2}e^{-t/\sigma}H(t)$$

Señal sísmica idealizada (pulso de Brune)

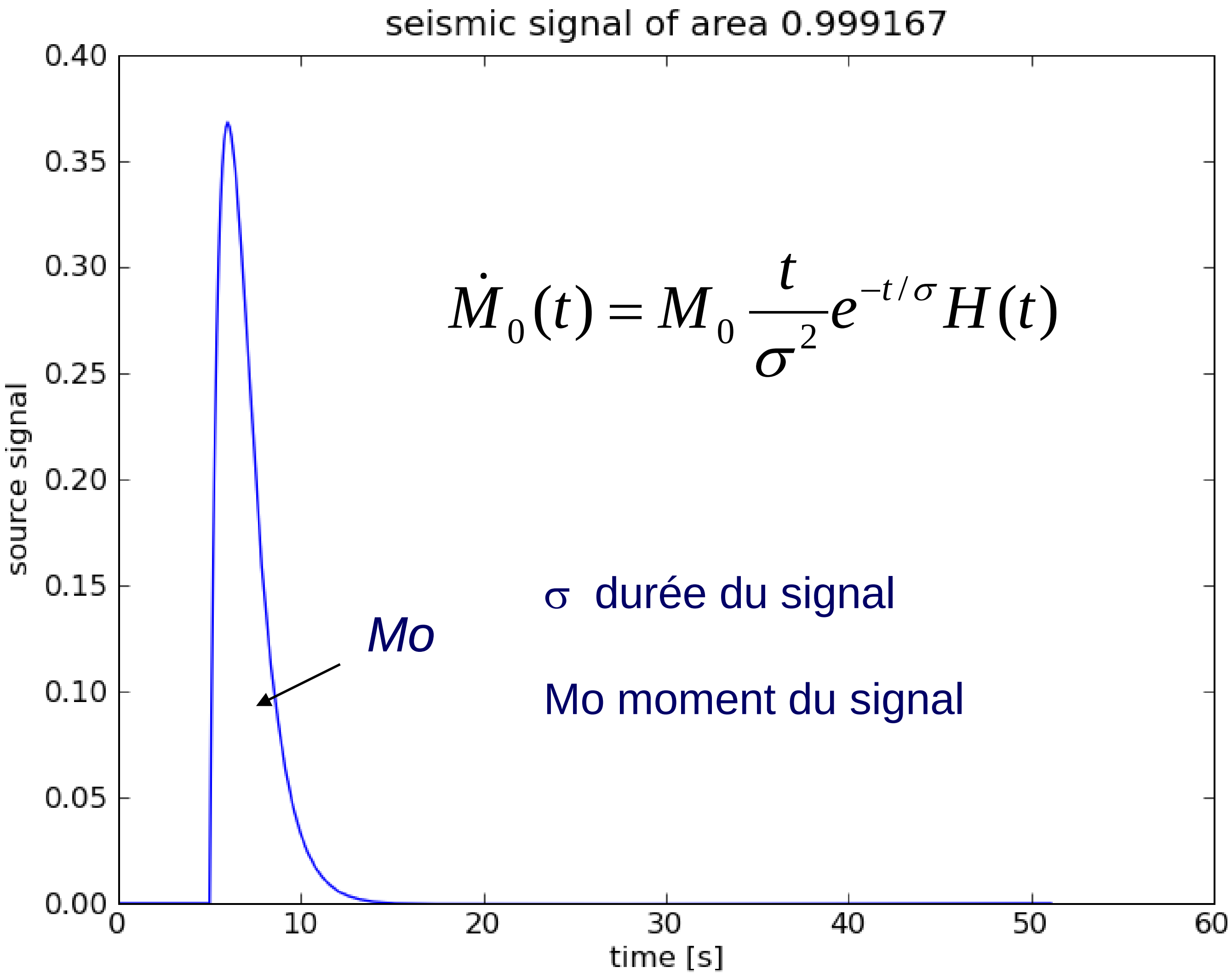


Duración ~ σ

Funciones temporales de la fuente (STF) de los mayores sismos recientes



La señal de Brune (1970)



$$\dot{M}_0(t) = M_0 \frac{t}{\sigma^2} e^{-t/\sigma} H(t)$$

σ durée du signal

Mo moment du signal

El espectro sìsmico de Brune (1970)

$$M_0(f) = M_0 \frac{f_0^2}{f_0^2 + f^2}$$