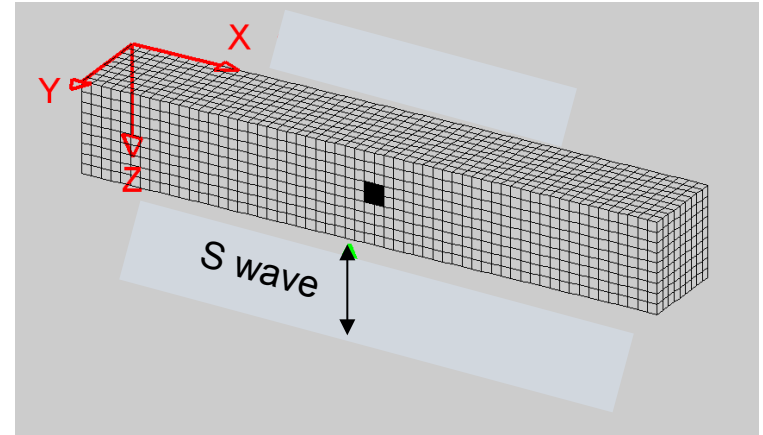
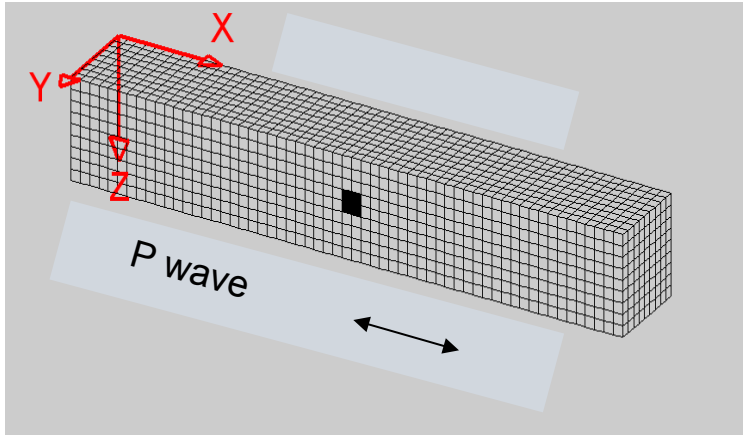
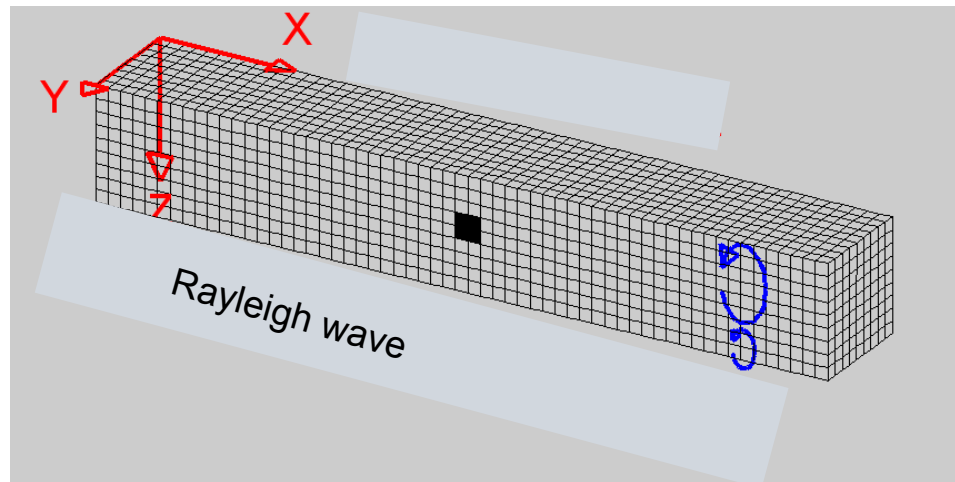


Seismic waves

Bulk waves P and S



Surface waves: Rayleigh waves





Mino Owari, 1891 (Koto)
Calabria, 1905,
Messina, 1908
San Francisco, 1906



Birdseye View of the Ruins of San Francisco.

Supplement to the San Francisco Examiner, May 13, 1906.

Faults seen from the surface

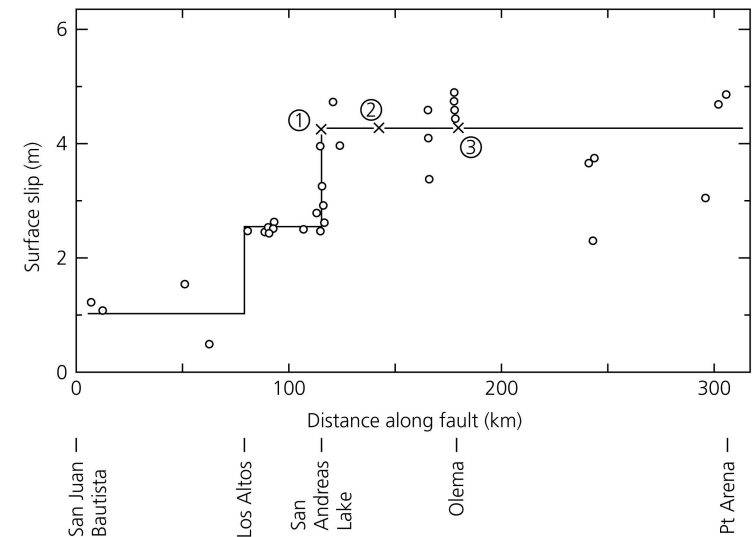
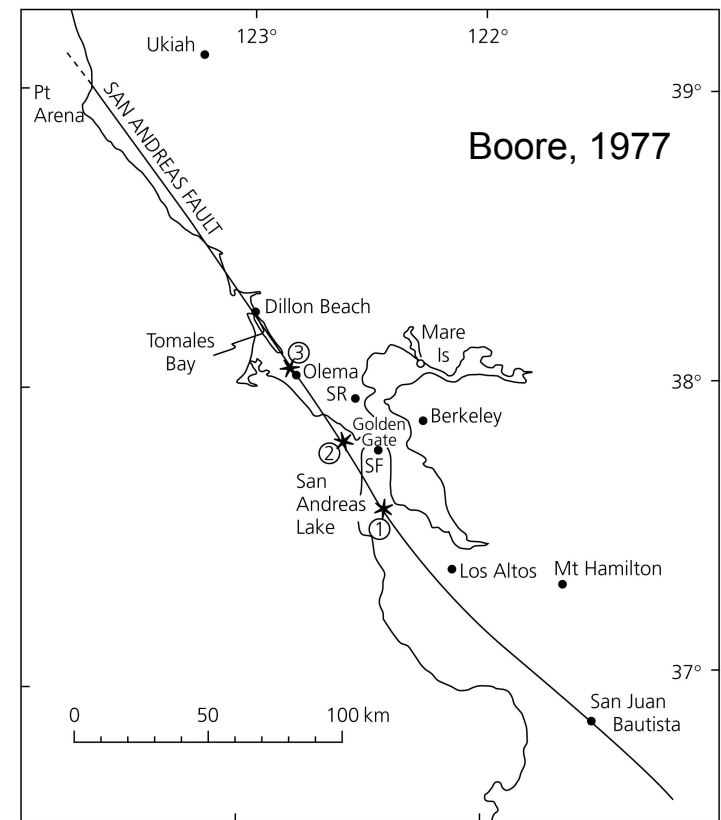




1906 SAN FRANCISCO EARTHQUAKE (magnitude 7.8)

**~ 4 m of slip on 450 km of San Andreas
~2500 deaths, ~28,000 buildings
destroyed (most by fire)**

**Catalyzed ideas about relation of
earthquakes & surface faults**



SEISMIC CYCLE AND PLATE MOTION

Over time, slip in earthquakes adds up and reflects the plate motion

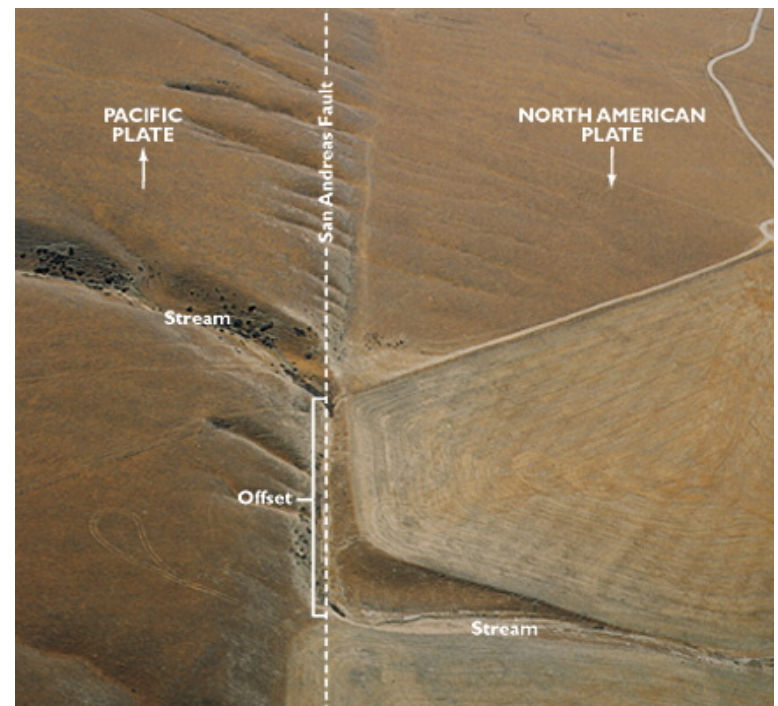
Offset fence showing 3.5 m of left-lateral strike-slip motion along San Andreas fault in 1906 San Francisco earthquake

~ 35 mm/yr motion between Pacific and North American plates along San Andreas shown by offset streams & GPS

Expect earthquakes on average every
 $\sim (3.5 \text{ m}) / (35 \text{ mm/yr}) = 100 \text{ years}$

Turns out more like 200 yrs because not all motion is on the San Andreas

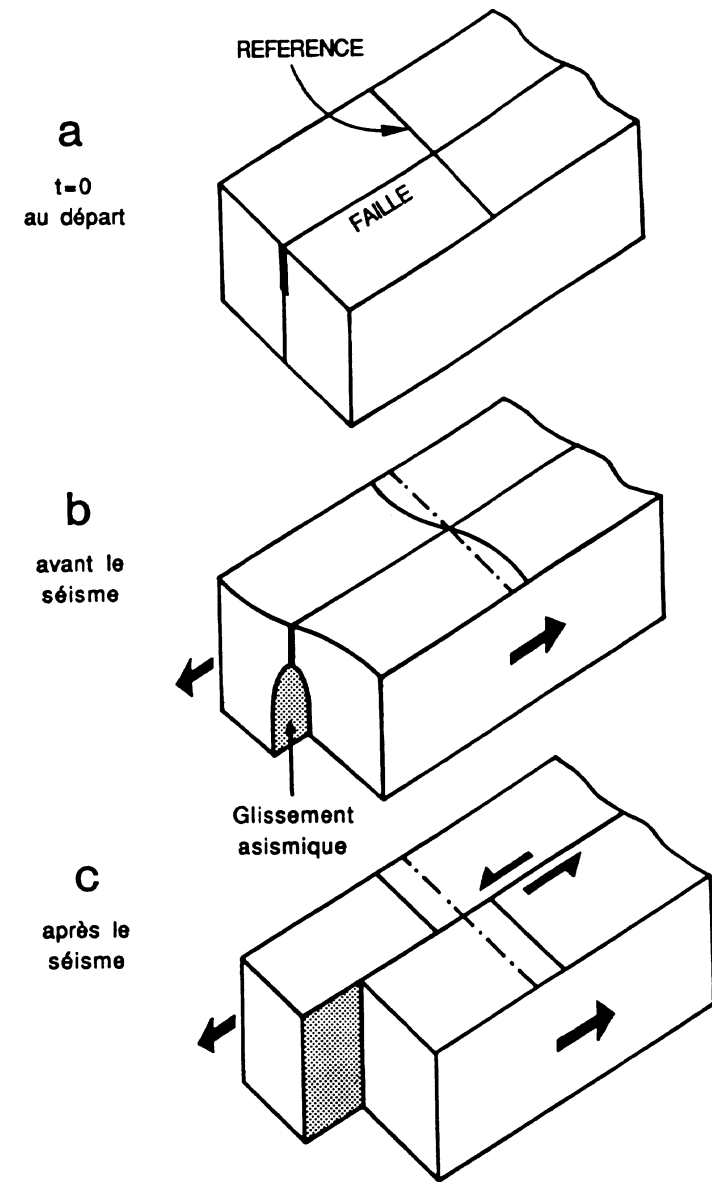
Moreover, it's irregular rather than periodic



Elastic rebound

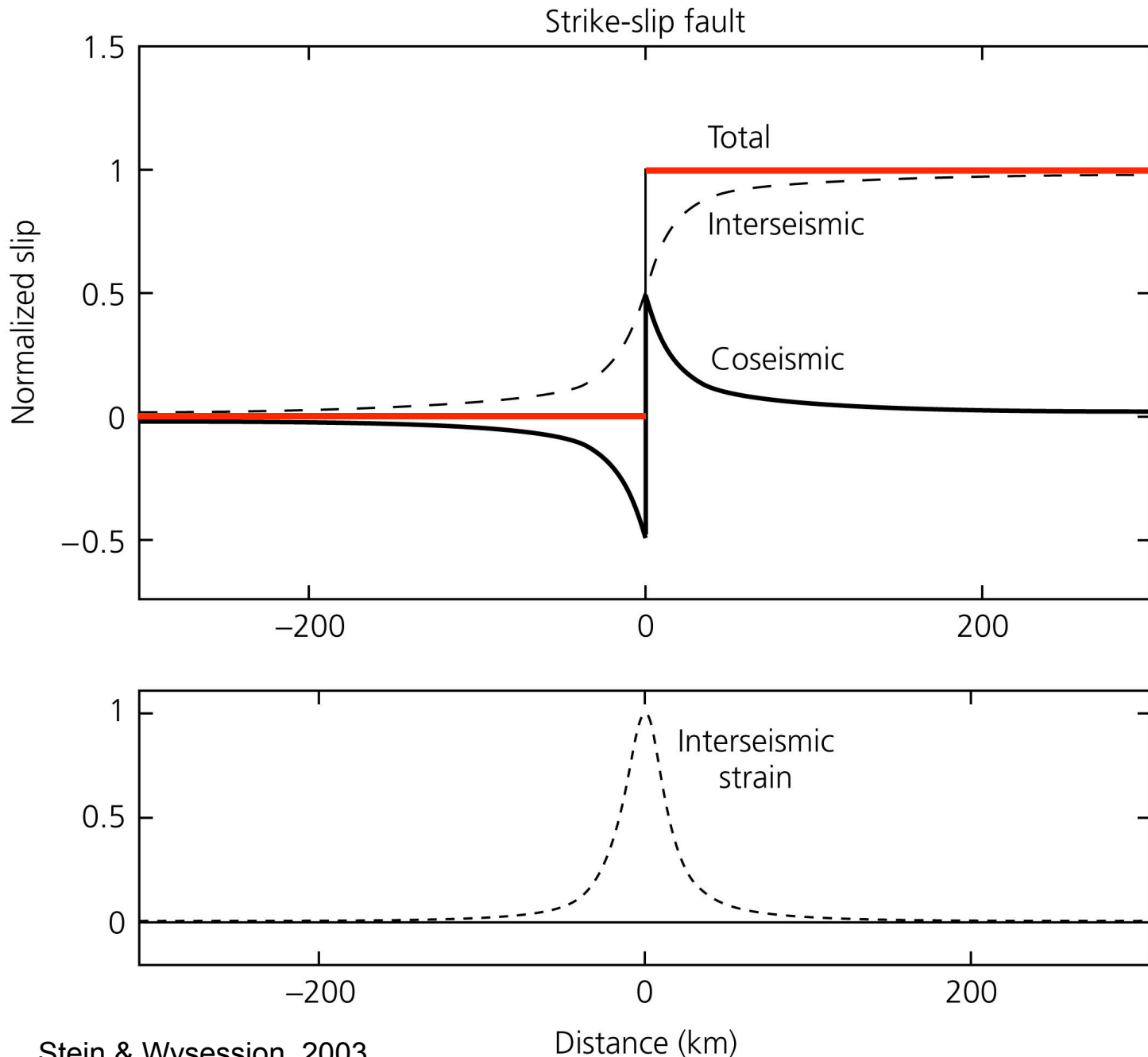


This fence running across the San Andreas fault in Marin County was offset 8.5 ft in the 1906 San Francisco earthquake as the land on the far side of the fault moved to the right.



Sources : Kramer, Geotechnical Earthquake Engineering (haut, gauche)
Bolt, Earthquake and Geological Discovery, 1993 (bas, gauche)
Madariaga et Perrier, Les tremblements de terre, 1991 (droite)

Figure 4.5-12: Coseismic and interseismic slips and strains.

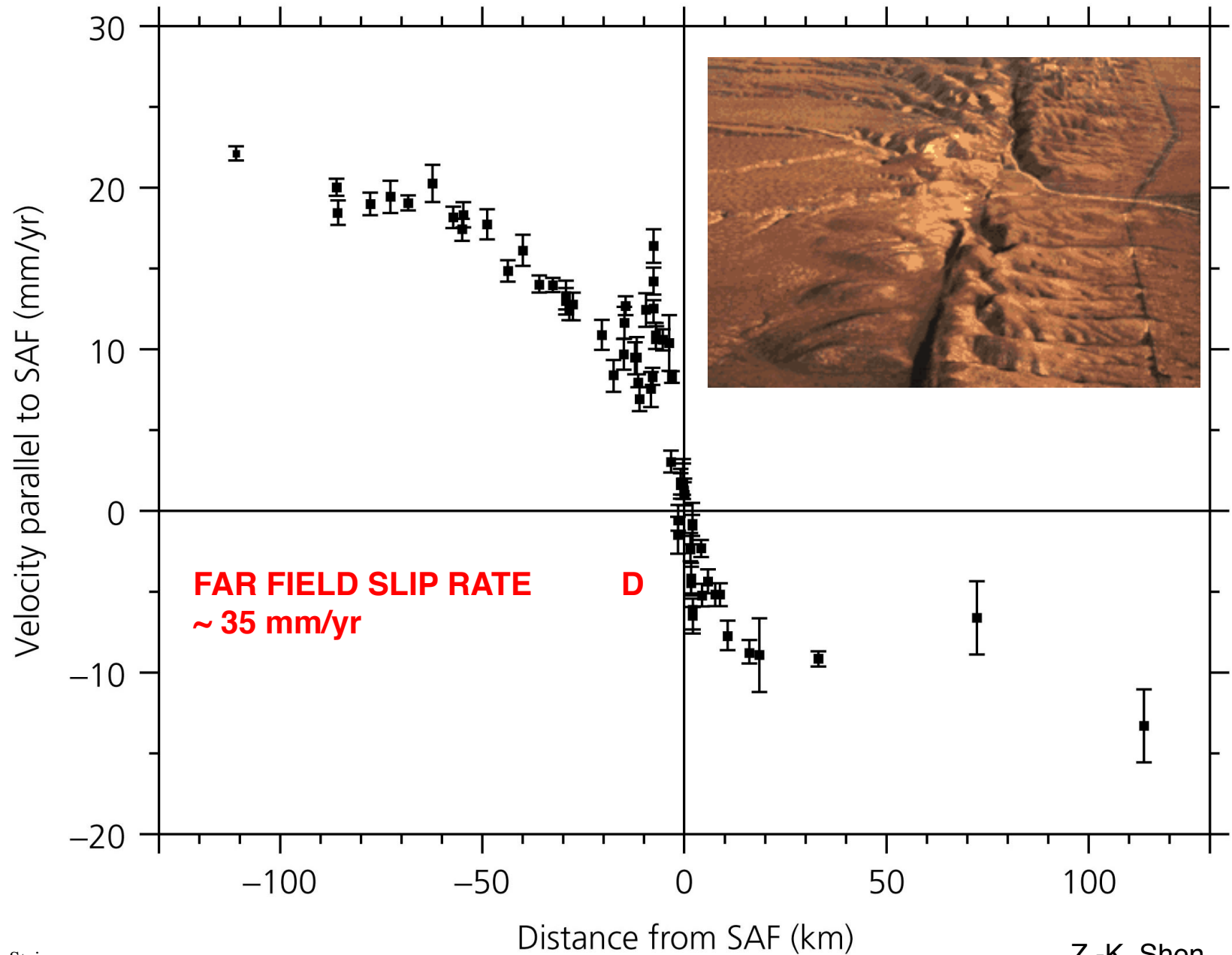


Large earthquakes release all strain accumulated on locked fault between earthquakes

Coseismic and interseismic motion sum to plate motion

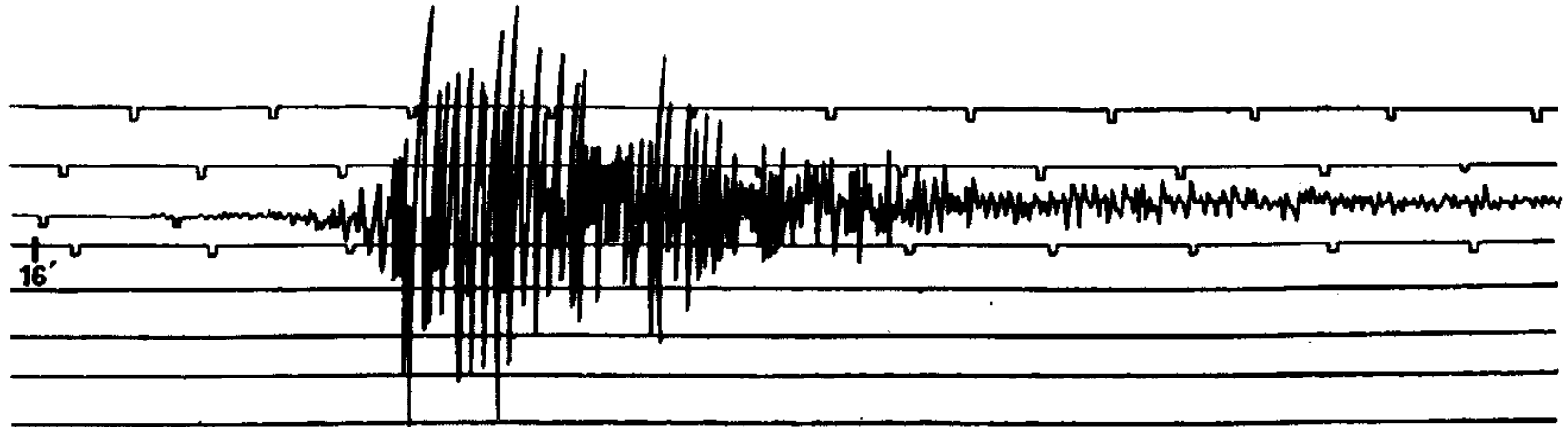
Interseismic strain accumulates near fault

Figure 4.5-13: Fault-parallel horizontal interseismic motion across the San Andreas fault.



Source : S. Stein

Seismograms 1888 von Reuber-Paschwitz



Séisme de Lambesc (11 juin 1909)

Portion principale du sismogramme obtenue à l'Observatoire du Parc-Saint-Maur
(composante E-W) lors du tremblement de terre du 11 juin 1909 (première secousse)

Cette portion va de 21h 16mm à 21h 26mm

WIECHERT de 1000 kg, $T_0 = 12s$, amplification : 230

WIECHERT

Fabriqués en 1904 et 1909 à Göttingen (Allemagne).

Ils ont fonctionné à Strasbourg de 1904 à 1968.

Système complet d'enregistrement du mouvement du sol : un sismomètre pour enregistrer deux composantes horizontales, et un sismomètre pour enregistrer la composante verticale.



Horizontal :

- masse 1000 kg
- période 8 s

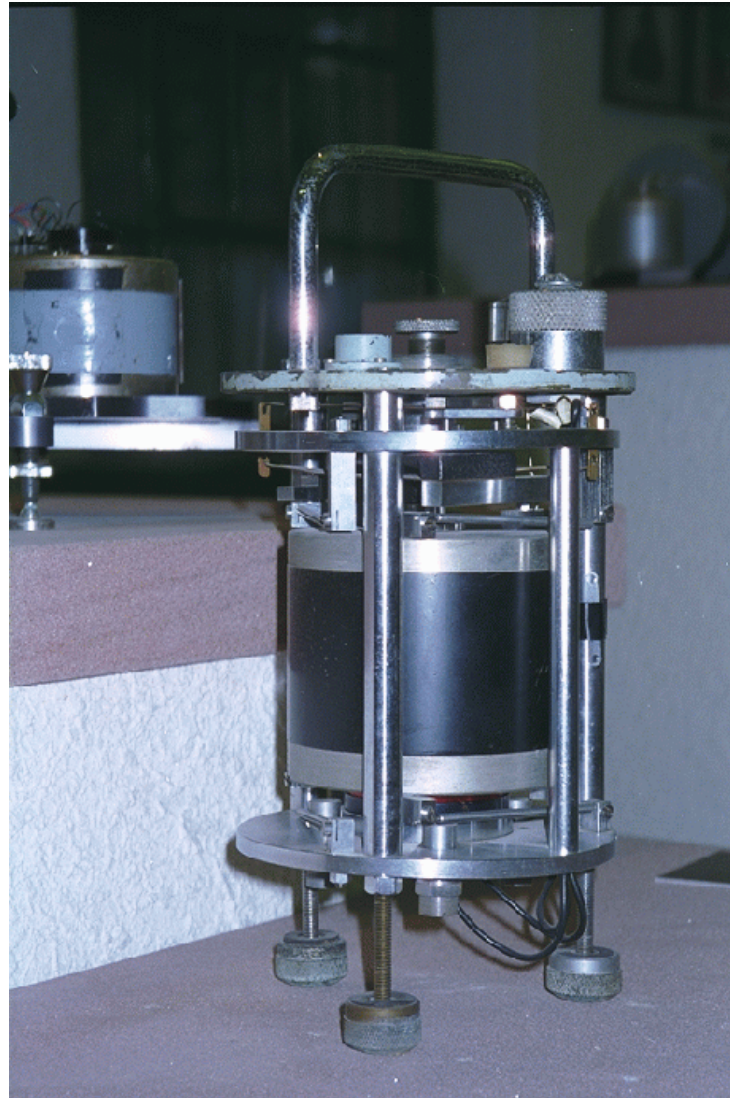


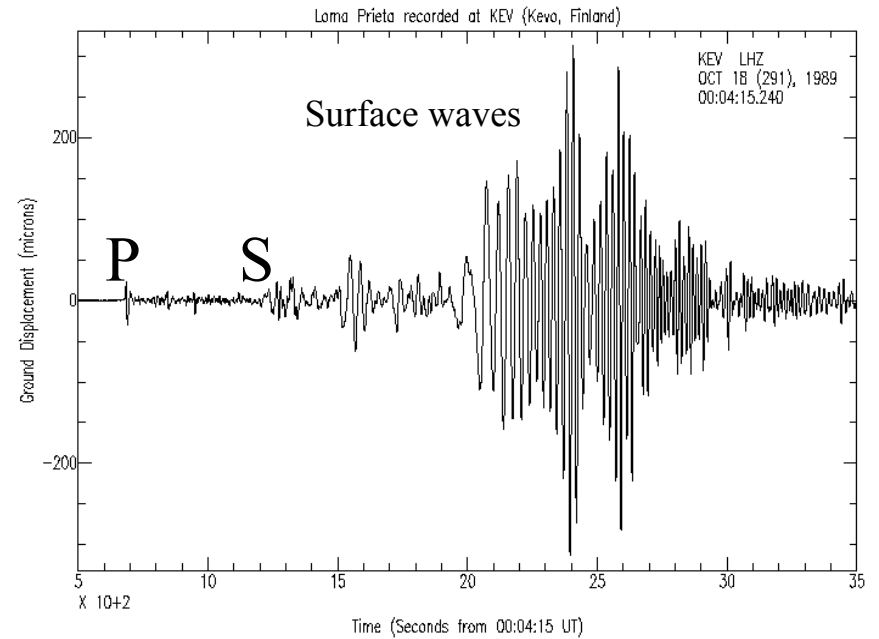
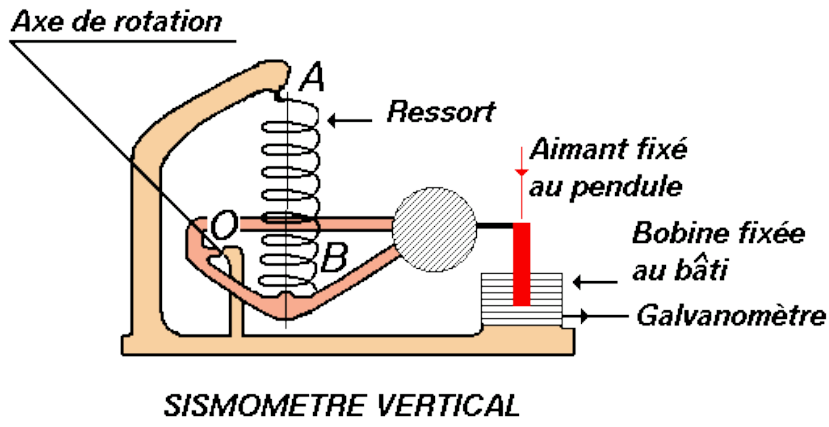
Vertical :

- masse 1200 kg
- période 5 s

- amortissement par pistons à air
- amplification mécanique par bras de levier
- enregistrement sur papier recouvert de noir de fumée

Ce sont deux beaux exemples de conception entièrement mécanique. Les frottements inhérents à cette conception obligent à utiliser une grande masse pour le pendule.



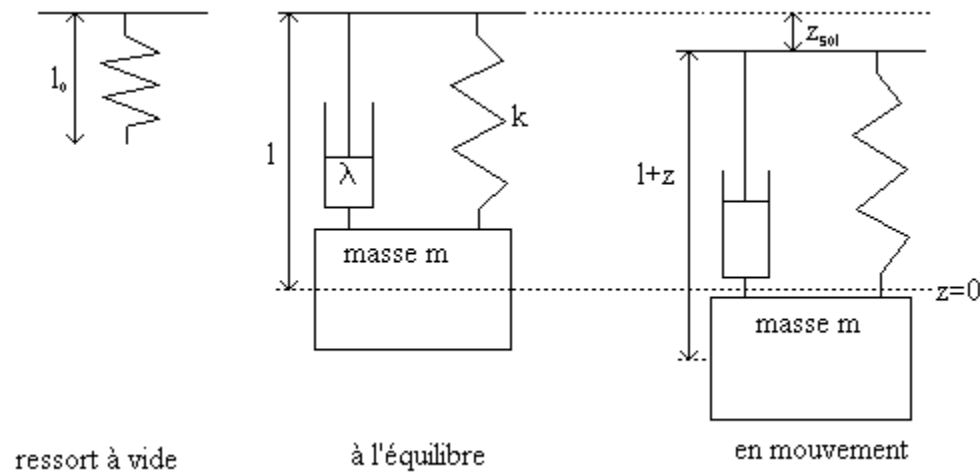


Period band: 500 s à 0,01s

sensitivity: best than the level of seismic ambient noise

Accelerations up to 2 g (4g last month in Japan!!)

a mass m ,
a spring of stiffness k and length at rest l_0
Damping λ



Equation de l'oscillateur libre amorti

Bilan des forces s'exerçant sur la masse:

- le poids $P=mg$

- la force d'amortissement

$$F = -\lambda v = -\lambda \dot{z}$$

- la tension du ressort

$$T = -k(l + z - l_0)$$

On se place dans un référentiel lié au sol. L'accélération de la masse est donc composée de deux termes: $m\ddot{z}$, qui correspond à l'accélération de la masse par rapport au bâti et $m\ddot{z}_{sol}$ qui correspond à l'accélération du bâti par rapport au sol. En appliquant le principe fondamental de la dynamique, on obtient l'équation suivante:

$$m(\ddot{z} + \ddot{z}_{sol}) = mg - \lambda \dot{z} - k(l + z - l_0)$$

$$\text{À l'équilibre: } z = z_{sol} = \dot{z} = \ddot{z} = \ddot{z}_{sol} = 0 \rightarrow mg = k(l - l_0)$$

$$m(\ddot{z} + \ddot{z}_{sol}) = -\lambda \dot{z} - kz$$

$$\ddot{z} + \frac{\lambda}{m}\dot{z} + \frac{k}{m}z = -\ddot{z}_{sol}$$

On pose généralement:

$$\omega_0^2 = \frac{k}{m}$$

$$\alpha = \frac{\lambda}{2} \sqrt{\frac{1}{km}}$$

$$M = -1$$

Alors l'équation s'écrit finalement:

$$\ddot{z} + 2\alpha\omega_0\dot{z} + \omega_0^2 z = M\ddot{z}_{sol}$$

où ω_0 représente la pulsation propre, α est la constante d'amortissement du système et M l'amplification. Cette équation est classiquement celle d'un oscillateur amorti.

$M=-1 \rightarrow$ pas d'amplification dans notre système.

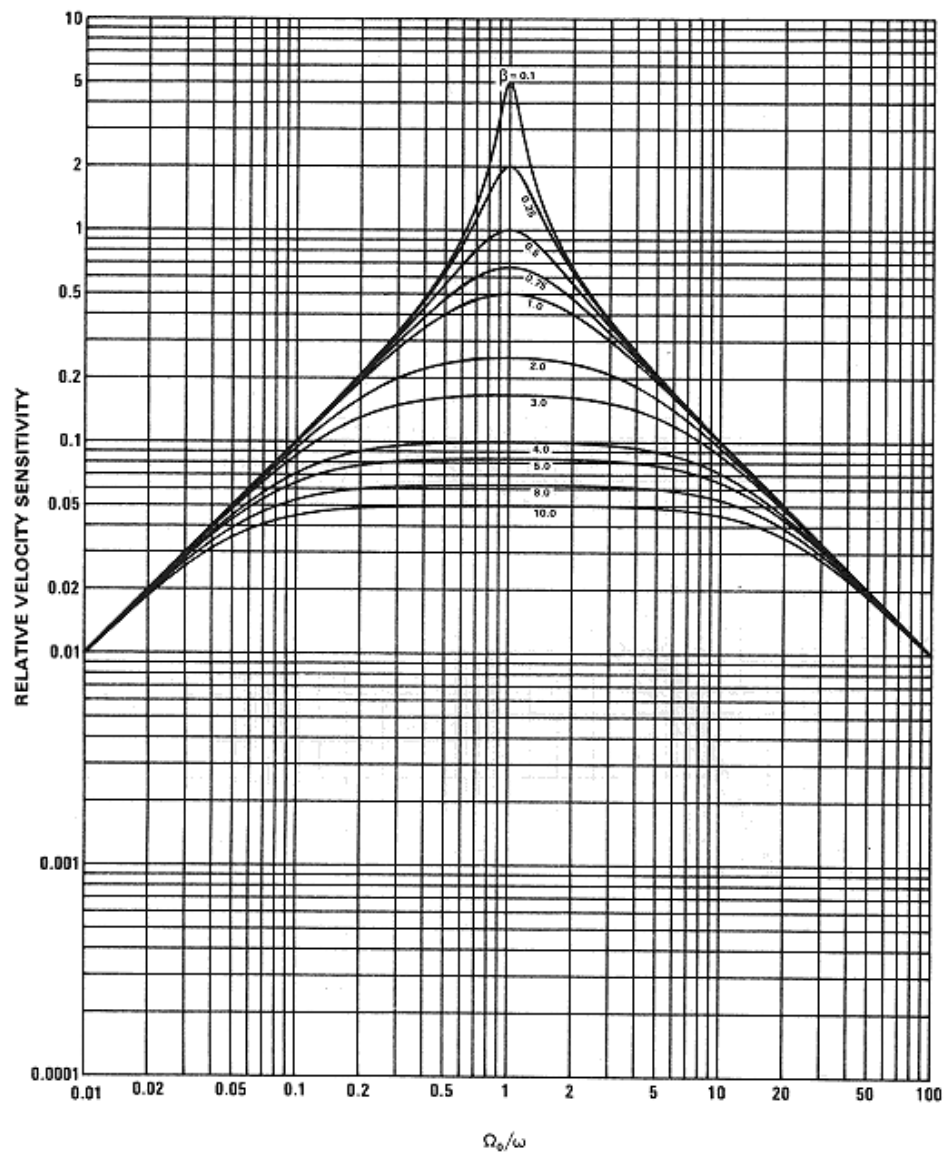
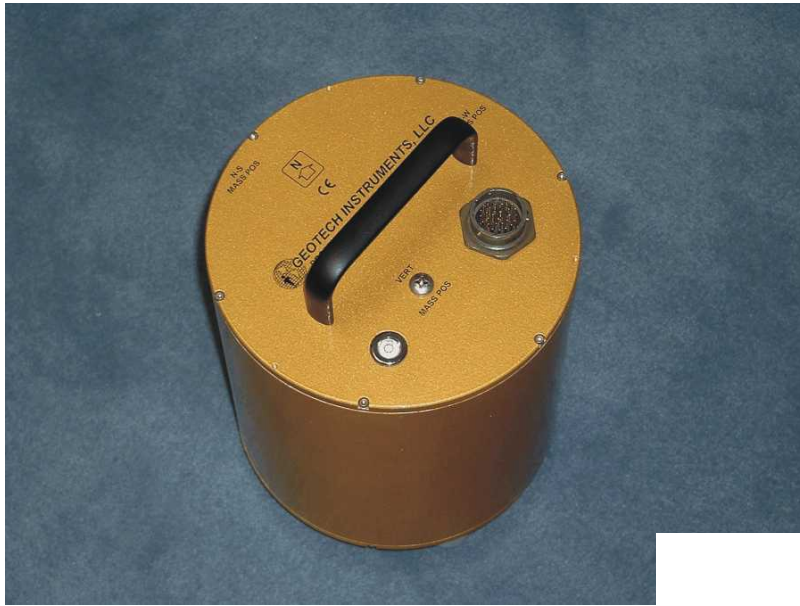
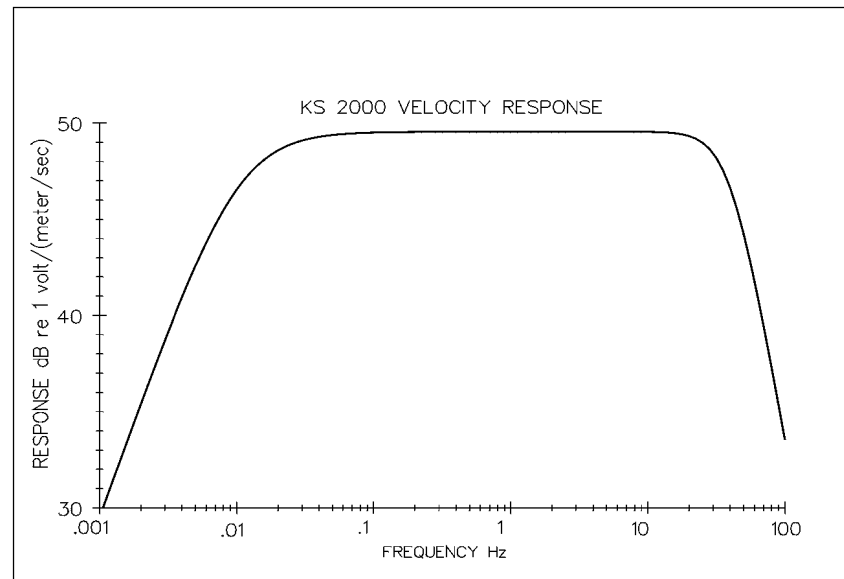
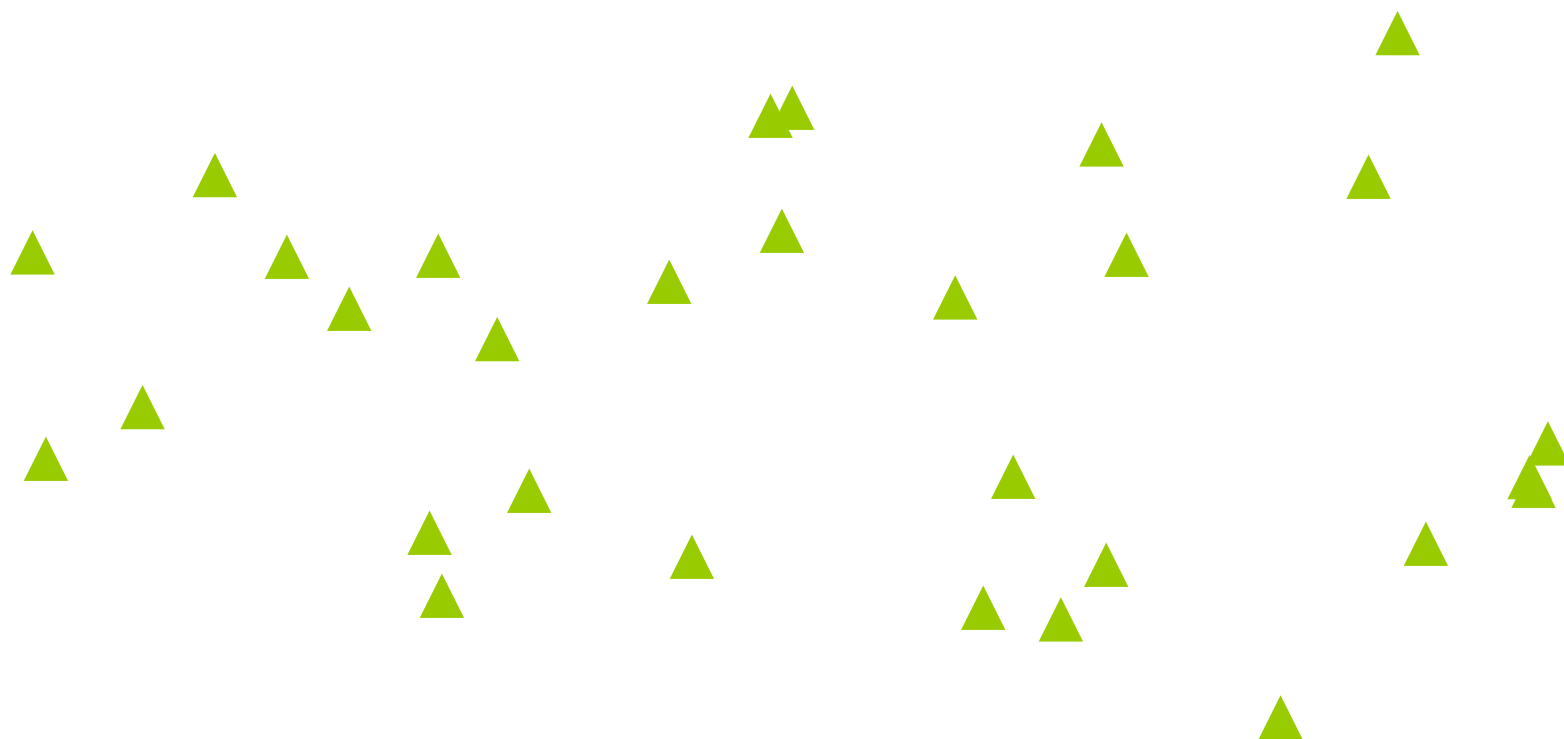


Figure 3.1b Normalised velocity sensitivity of direct-coupled seismometer.



Sismomètre large-bande (à retro-action)
Feed back broad band seismometer

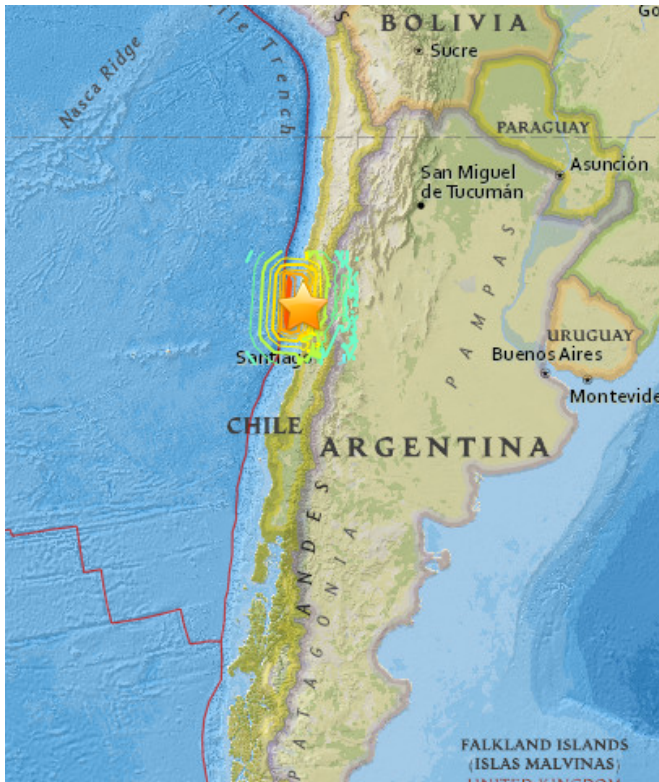




▲ GEOSCOPE

★ FDSN

NEWS!!!



2015-09-16 22:54:33 (UTC)

2015-09-17 00:54:33 (UTC+02:00) in your timezone

[Times in other timezones](#)

Nearby Cities

46km (29mi) W of Illapel, Chile

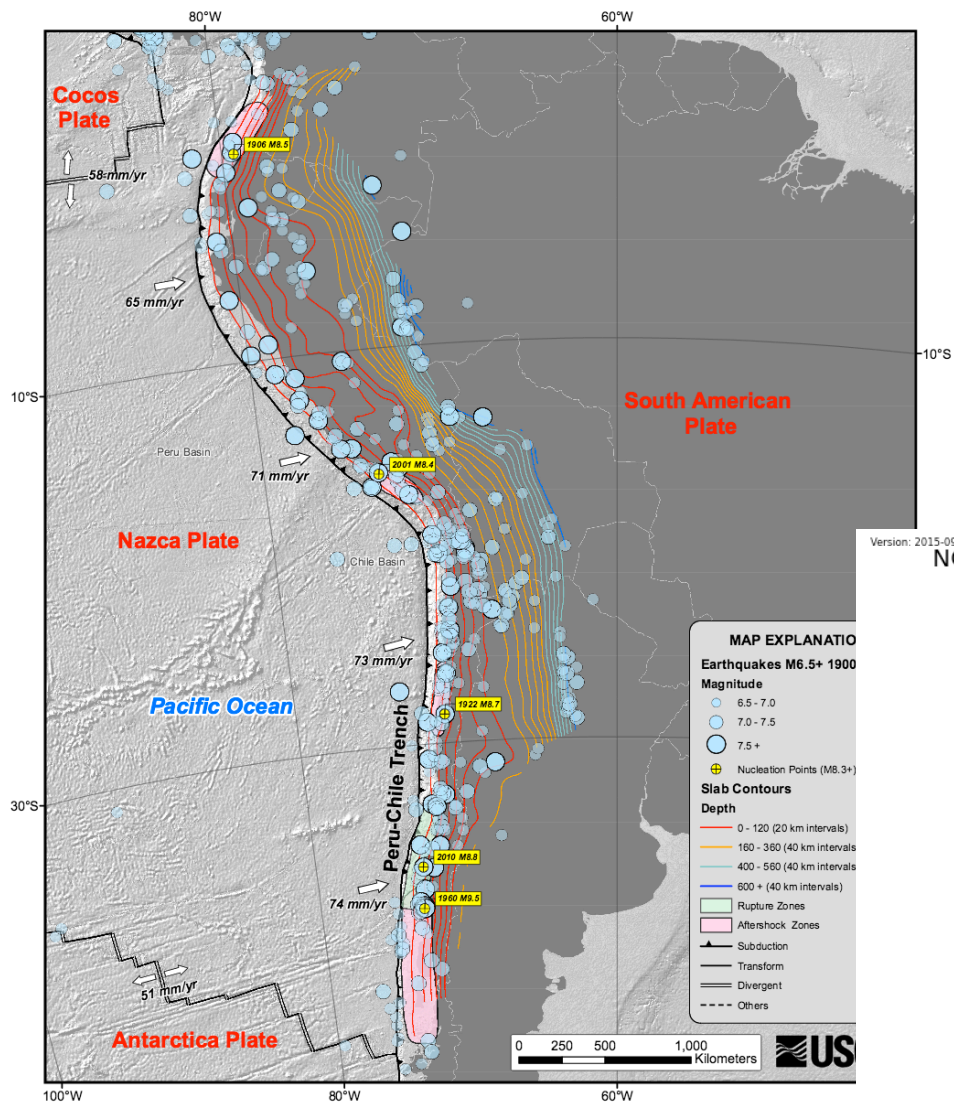
68km (42mi) WNW of Salamanca, Chile

105km (65mi) NNW of La Ligua, Chile

116km (72mi) SSW of Ovalle, Chile

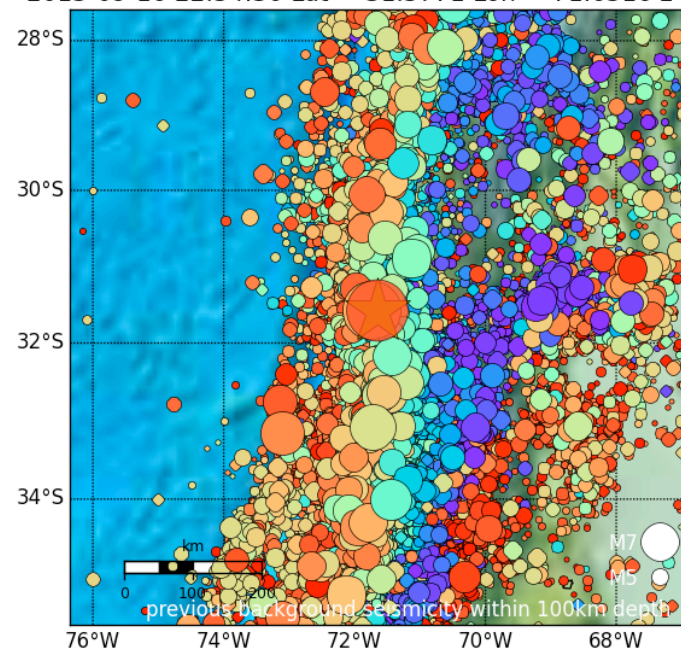
229km (142mi) NNW of Santiago, Chile

Sources: <http://ds.iris.edu/spud/event/5159022>
<http://earthquake.usgs.gov/earthquakes/>



Version: 2015-09-17 00:07

NO focal mechanism M8.3 NEAR COAST OF CENTRAL CHILE
2015-09-16 22:54:30 Lat= -31.5771 Lon= -71.6516 z=8.3

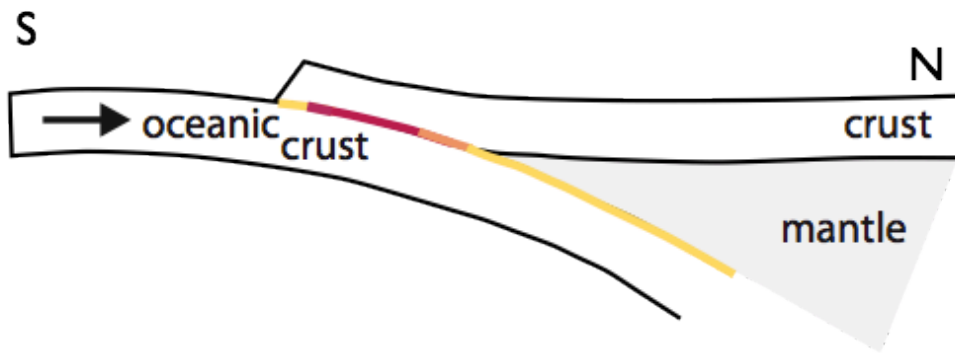


GCMT ref.

depth (km)
100
75
50
25
0

IRIS
www.iris.edu/spud

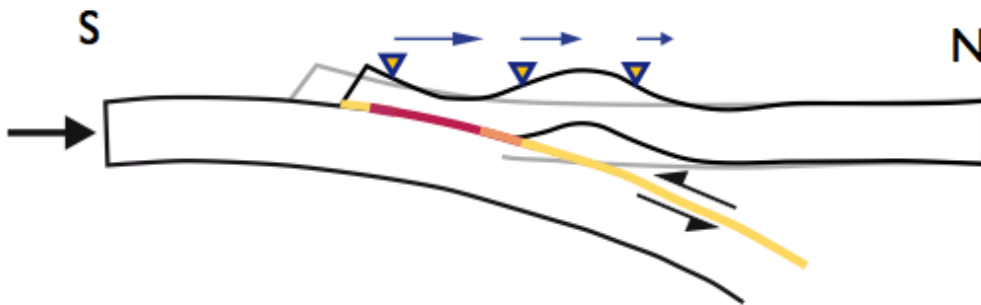
Initial state



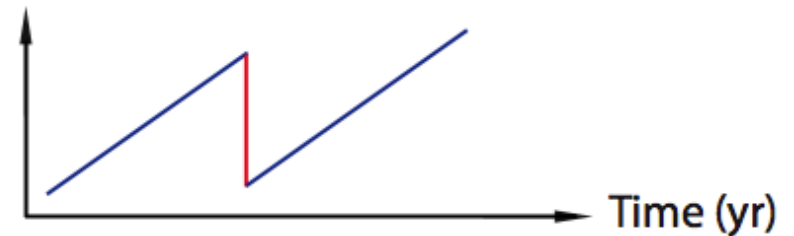
Seismic cycle (subduction)



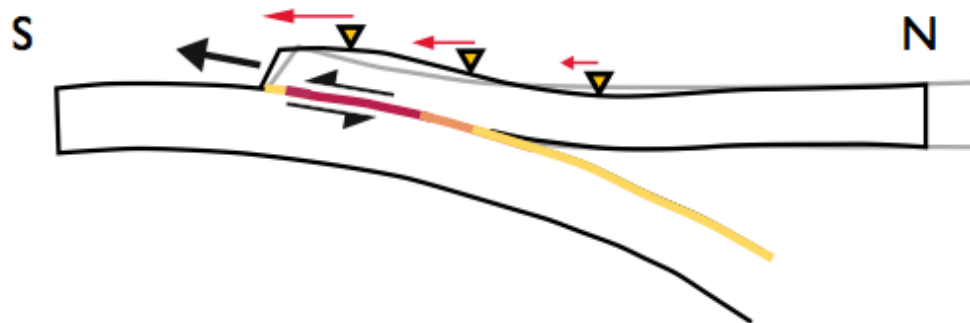
Interseismic period (~ 100 years)



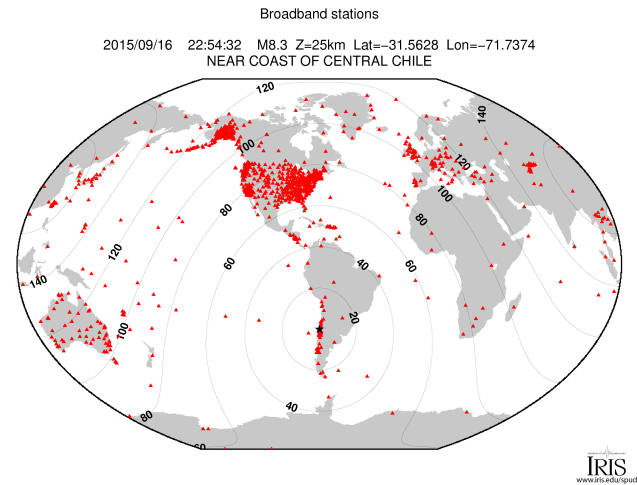
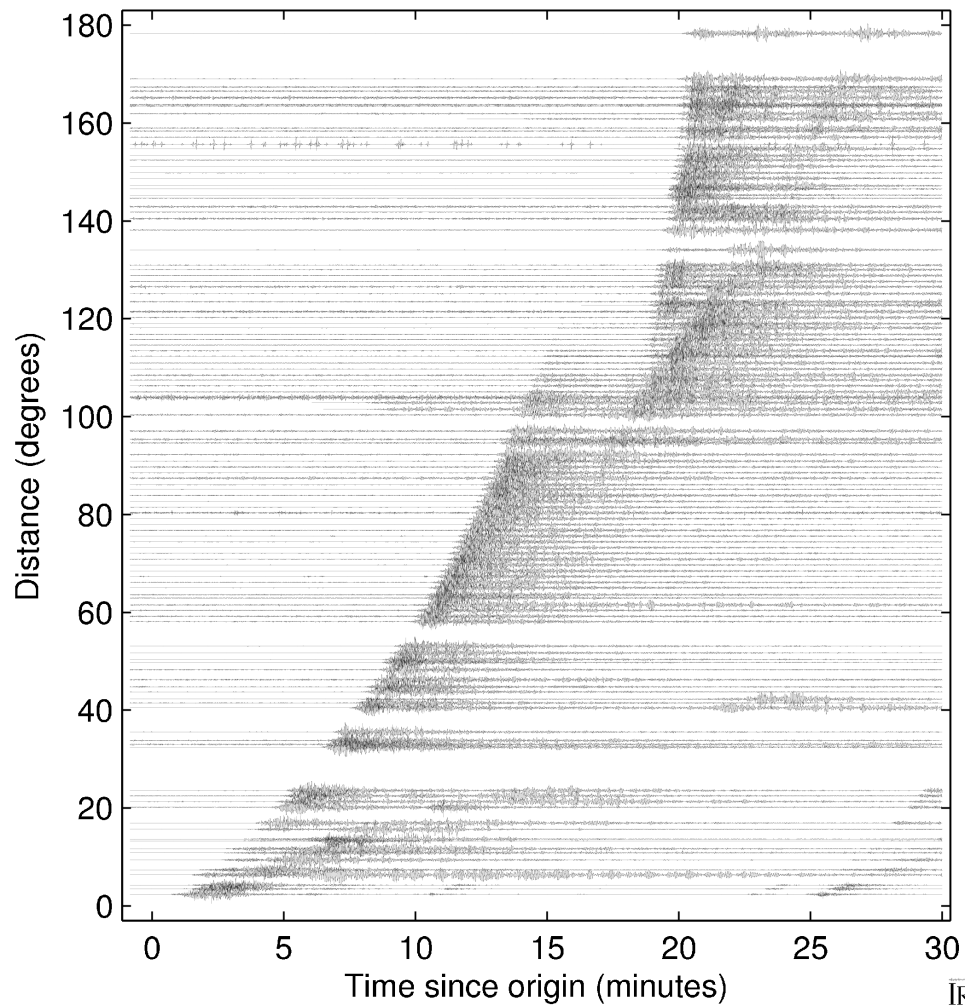
Horizontal displacement



Co-seismic period (~ seconds)



Combed and aligned on origin 0.3to1.0Hz BHZ
NEAR COAST OF CENTRAL CHILE
2015/09/16 22:54:32 M8.3 Z=25km Lat=-31.5628 Lon=-71.7374



Scientific - Moment Tensor

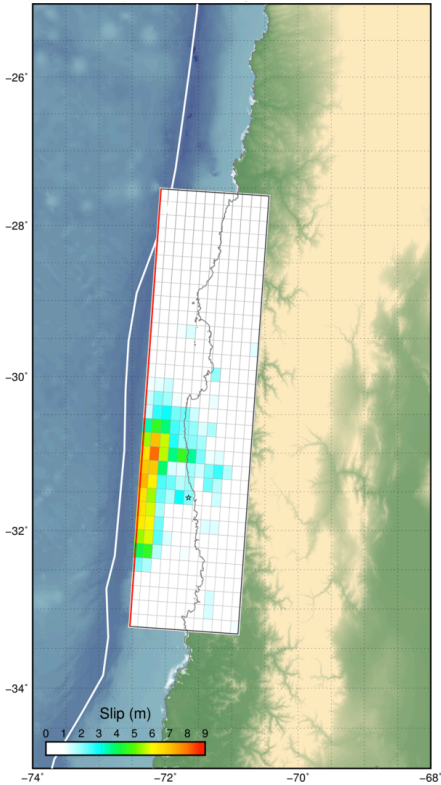
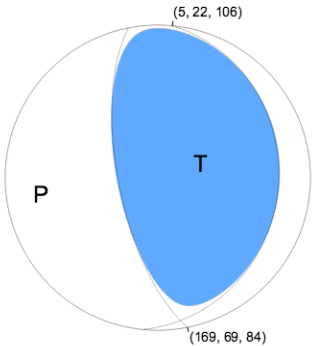
Data Source [GCMT¹](#)

Centroid Moment Tensor (Mwc)

Moment	2.856e+21 N-m
Magnitude	8.24
Depth	17.8 km
Percent DC	94%
Half Duration	–
Catalog	GCMT (gcm20150916225433)
Data Source	GCMT¹
Contributor	US⁴

Nodal Planes

Plane	Strike	Dip	Rake
NP1	5°	22°	106°
NP2	169°	69°	84°



NOAA's National Weather Service

Pacific Tsunami Warning Center

weather.gov

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No Current Warning, Watch, or Advisory in Effect

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Click on the map or table below for more information.

Image last created on Thu, 17 Sep 2015 07:46:48 UTC.

Time (UTC)	Region	Type	To: Details
1 17 Sep 2015 07:26		Ptww Threat Message	Pac html text
2 17 Sep 2015 06:55	Near the Coast of Central Chile	Advisory Supplement	Haw html text
3 17 Sep 2015 06:26		Ptww Threat Message	Pac html text
4 17 Sep 2015 05:55	Near the Coast of Central Chile	Advisory Supplement	Haw html text
5 17 Sep 2015 05:36		Ptww Threat Message	Pac html text
6 17 Sep 2015 04:53	Near the Coast of Central Chile	Advisory Supplement	Haw html text
7 17 Sep 2015 04:27		Ptww Threat Message	Pac html text
8 17 Sep 2015 03:50	Near the Coast of Central Chile	Advisory Supplement	Haw html text
9 17 Sep 2015 03:26		Ptww Threat Message	Pac html text
10 17 Sep 2015 02:51	Near the Coast of Central Chile	Advisory Supplement	Haw html text
11 17 Sep 2015 02:25		Ptww Threat Message	Pac html text
12 17 Sep 2015 01:24	Near the Coast of Central Chile	Advisory	Haw html text
13 17 Sep 2015 01:22		Ptww Threat Message	Pac html text
14 17 Sep 2015 00:25	Near the Coast of Central Chile	Watch Supplement	Haw html text
15 17 Sep 2015 00:24		Ptww Threat Message	Pac html text
16 16 Sep 2015 23:47		Ptww Threat Message	Pac html text
17 16 Sep 2015 23:26	Near the Coast of Central Chile	Watch Supplement	Haw html text
18 16 Sep 2015 23:23		Ptww Threat Message	Pac html text
19 16 Sep 2015 23:09	Off the Coast of Northern Chile	Watch	Haw html text
20 16 Sep 2015 23:05	Off the Coast of Northern Chile	Watch	Haw html text
21 16 Sep 2015 23:01		Ptww Threat Message	Pac html text
22 13 Sep 2015 08:20	Gulf of California	Information Statement	Haw html text
23 13 Sep 2015 08:20		Ptww Information Statement	Pac html text

UTC = Coordinated Universal Time (aka: GMT or Zulu).
To: = recipient of messages.

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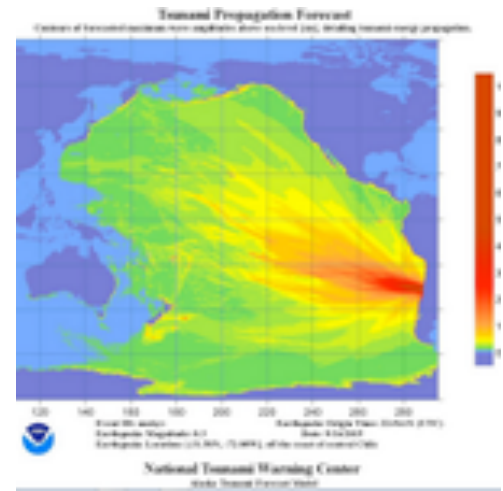
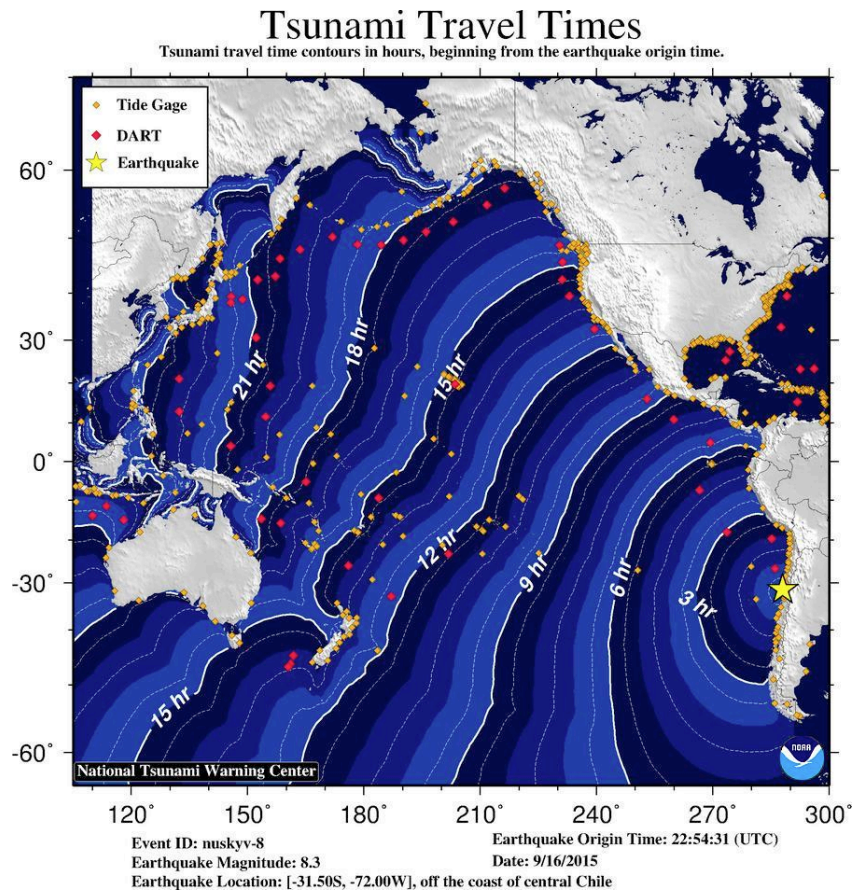
Responsibilities

History

Media & Visitor Info

Staff

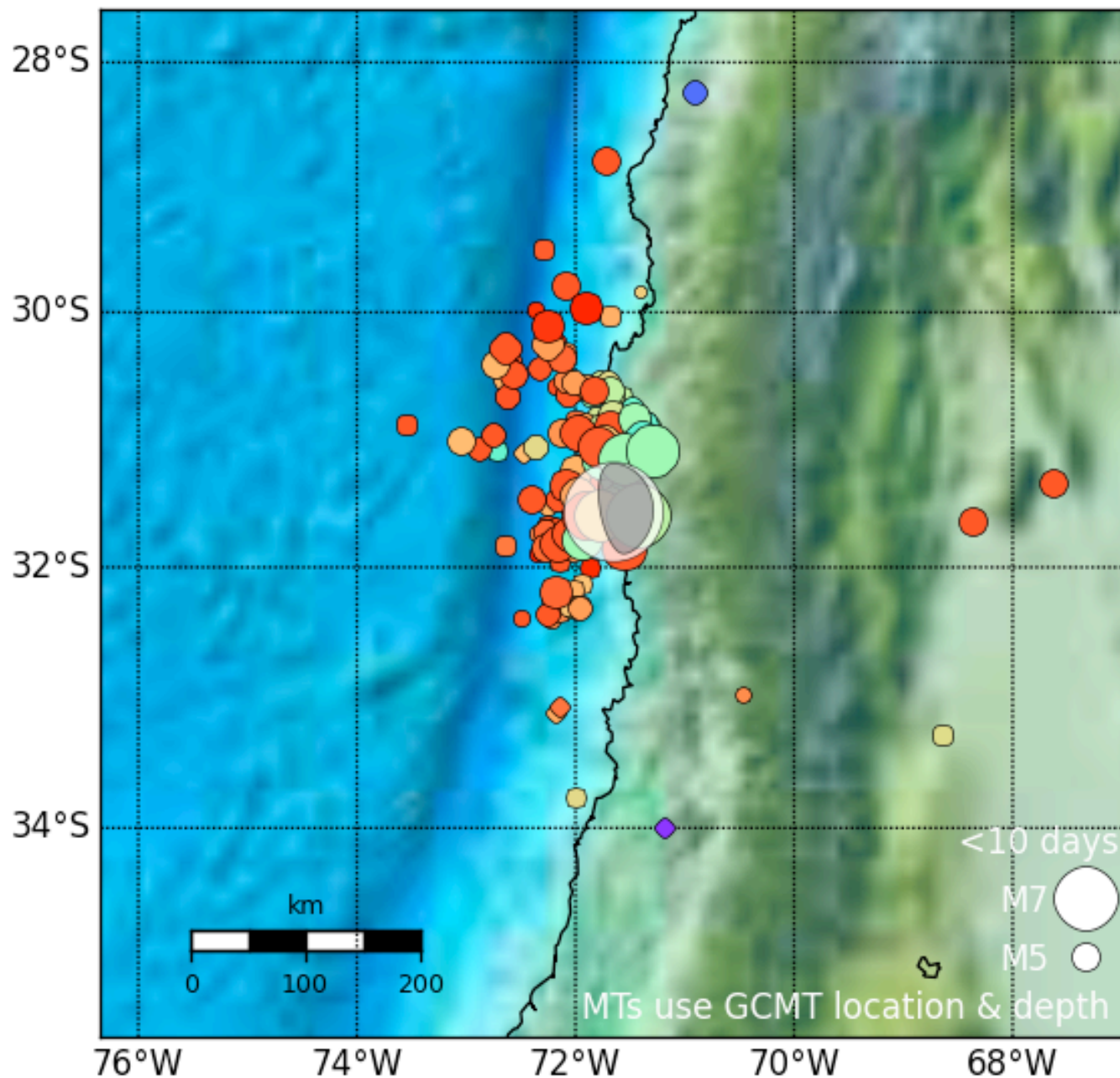
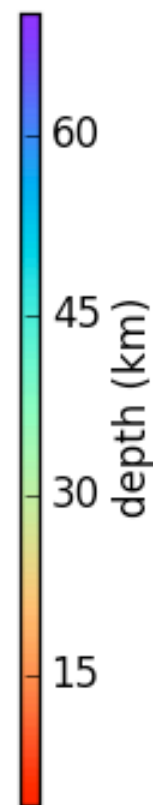
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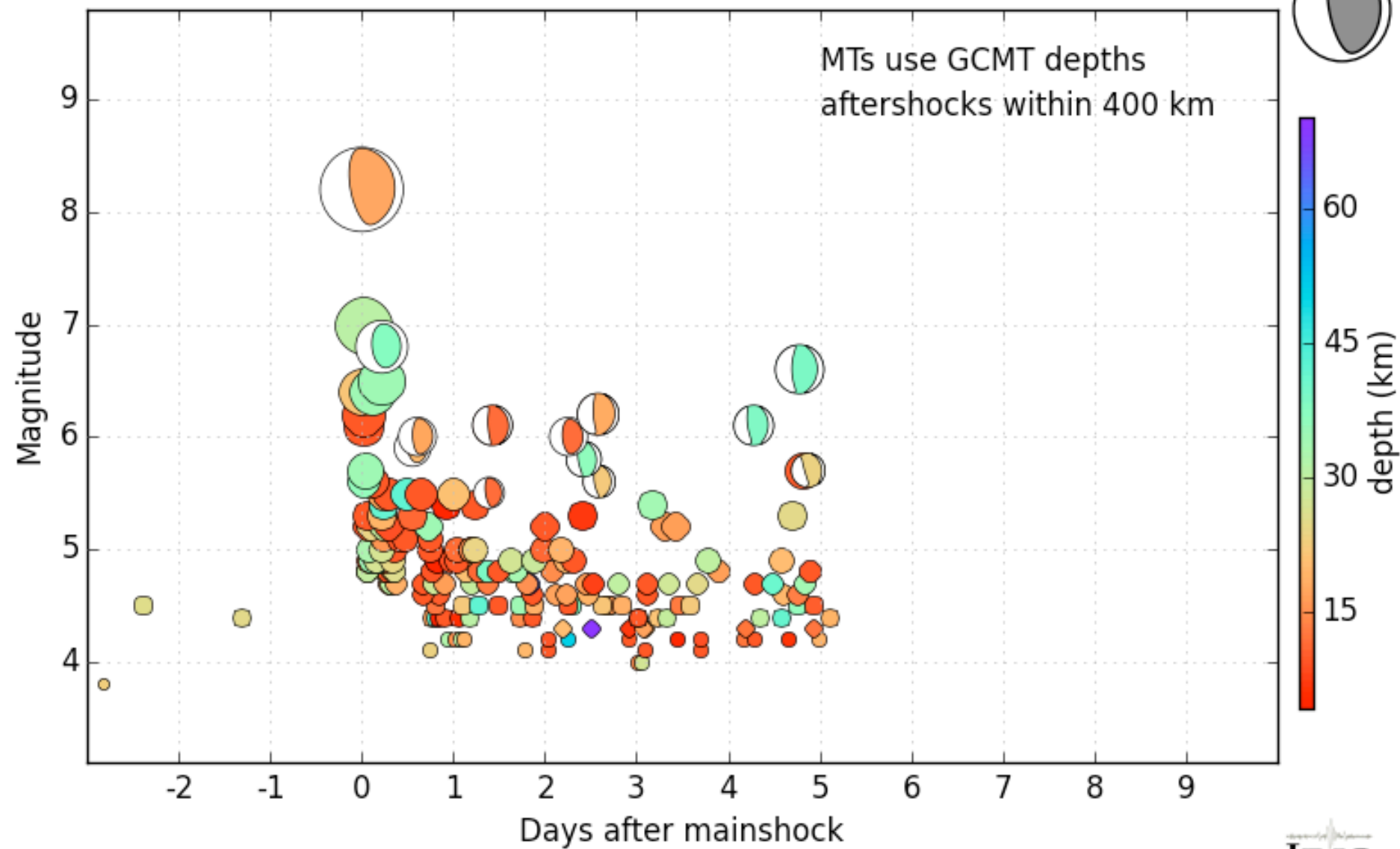
M8.2 NEAR COAST OF CENTRAL CHILE

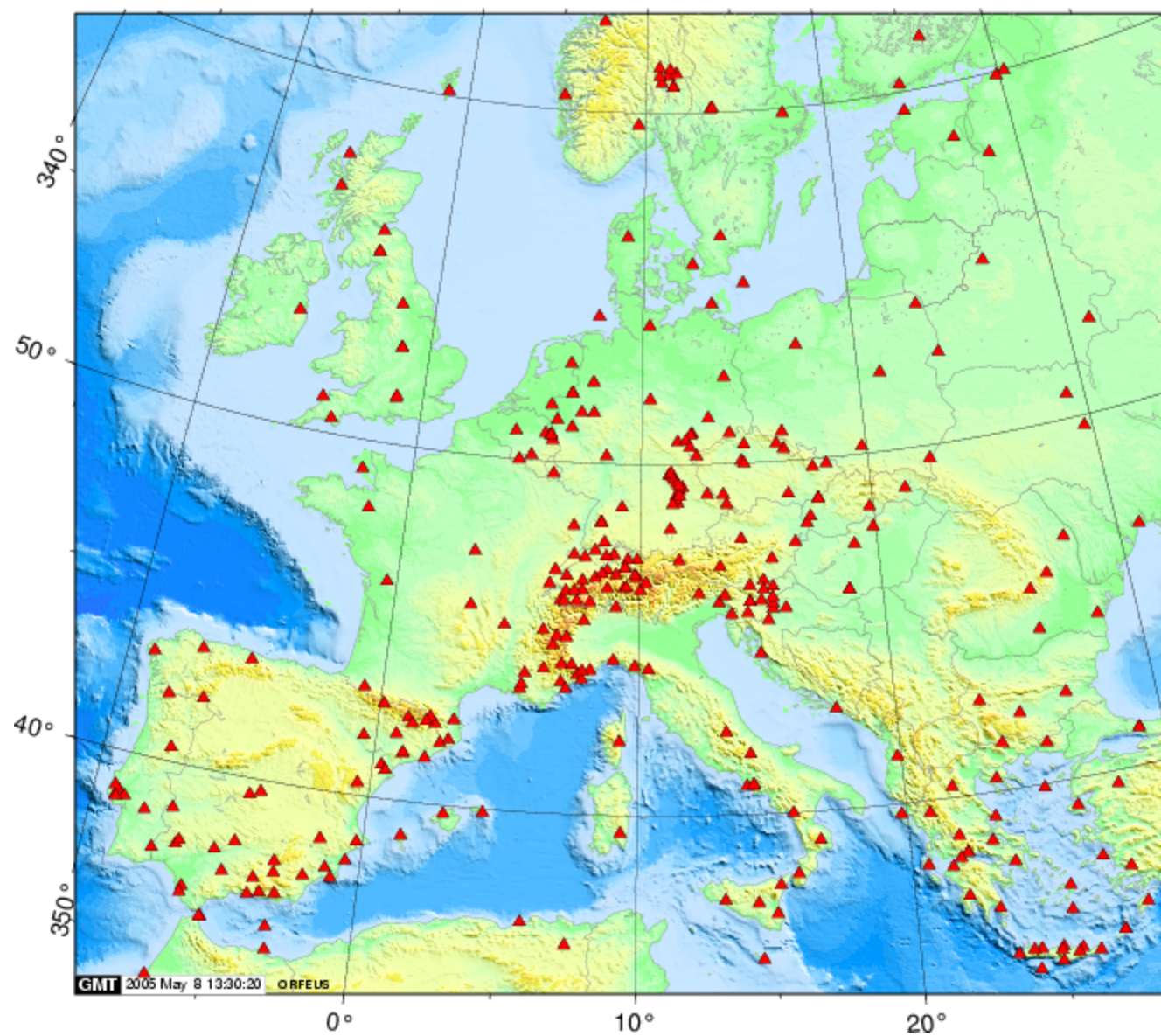
2015-09-16 22:54:32 Lat= -31.57 Lon= 288.35 z=25.0km

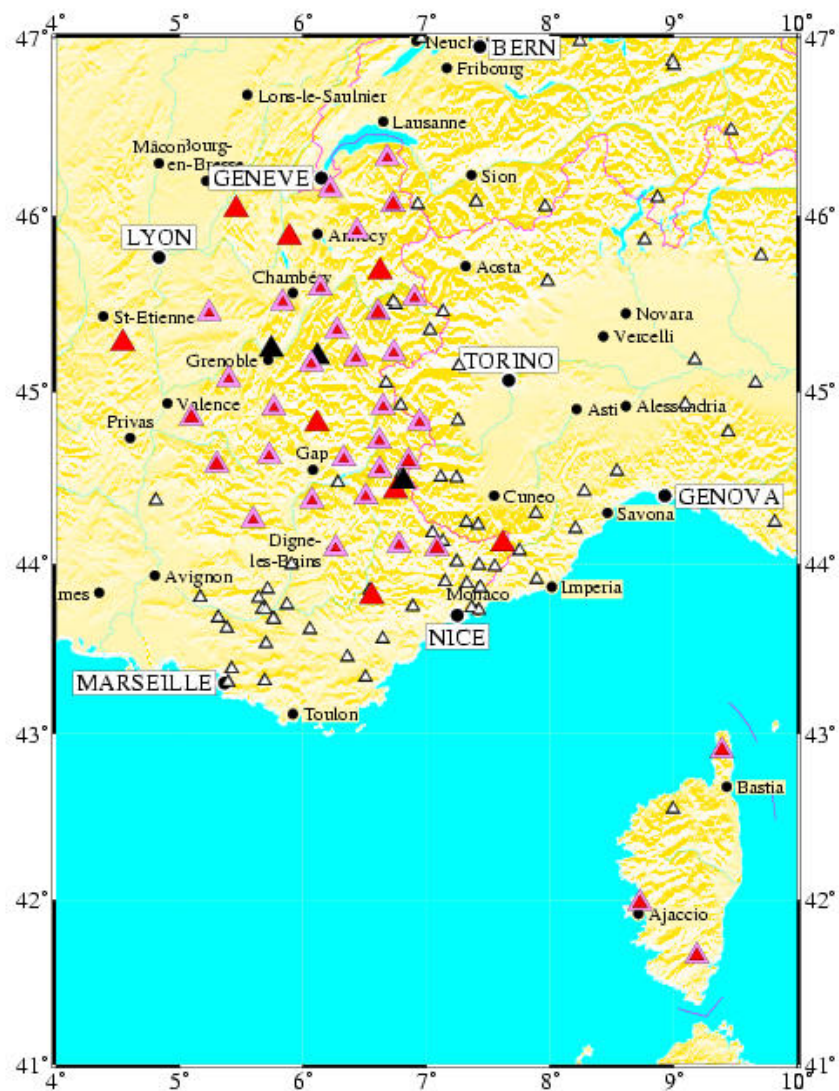


M8.2 NEAR COAST OF CENTRAL CHILE

2015-09-16 22:54:32 Lat= -31.57 Lon= 288.35 z=25.0km

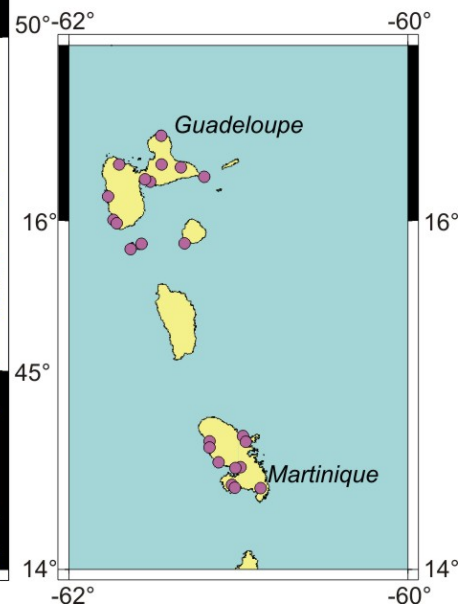
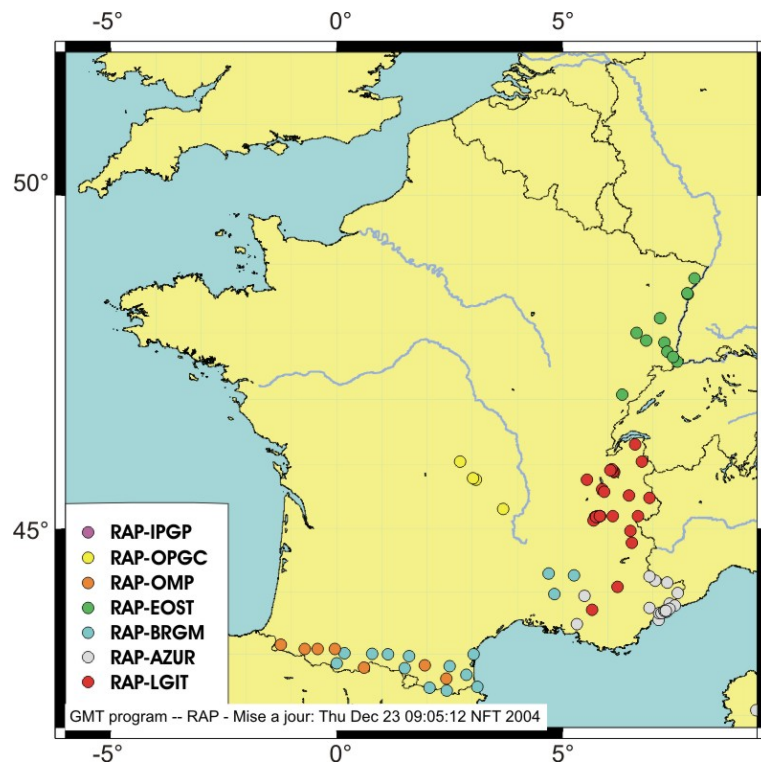




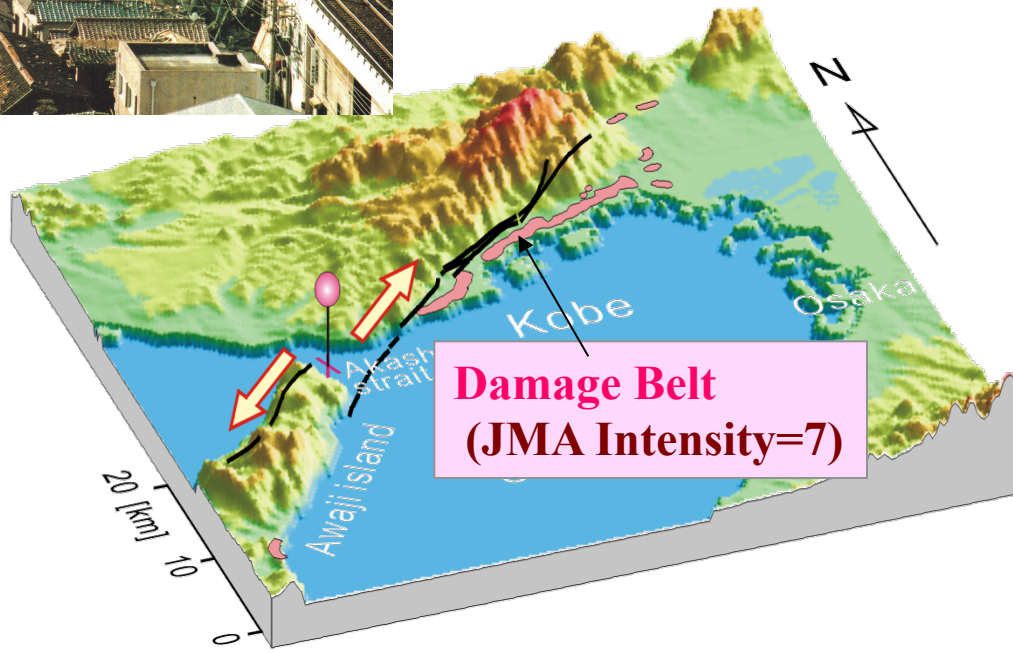


Surveillance de la sismicité des Alpes et de la Corse

- ▲ Station CP télémetrée (1C)
- ▲ Station CP Sismalp1 (1C)
- ▲ Station CP Sismalp3 (1C)
- ▲ Station CP Sismalp3 (3C)
- △ Autre station CP



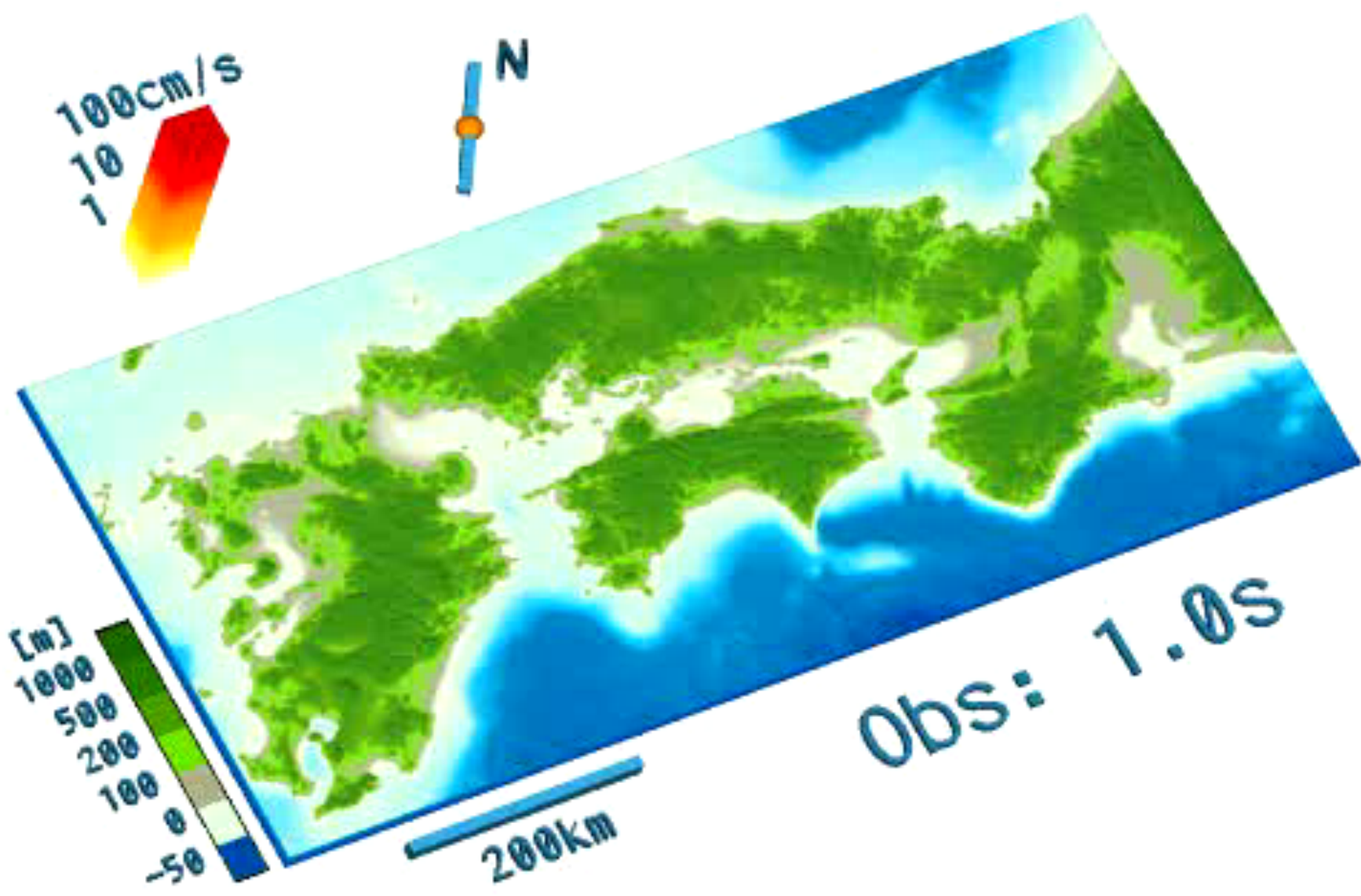
Séisme de Kobé (M7.3 15 janvier 1995



10 ans après le séisme de Kobé

Strong Motion Network:
K-NET, KiK-net, 1800 Stations, NIED





MAGNITUDE D'UN SÉISME

* Introduite en 1935 par Charles RICHTER (1900-1985) pour comparer les séismes entre eux: M_L .

•Quantité mesurable et calculée à partir:

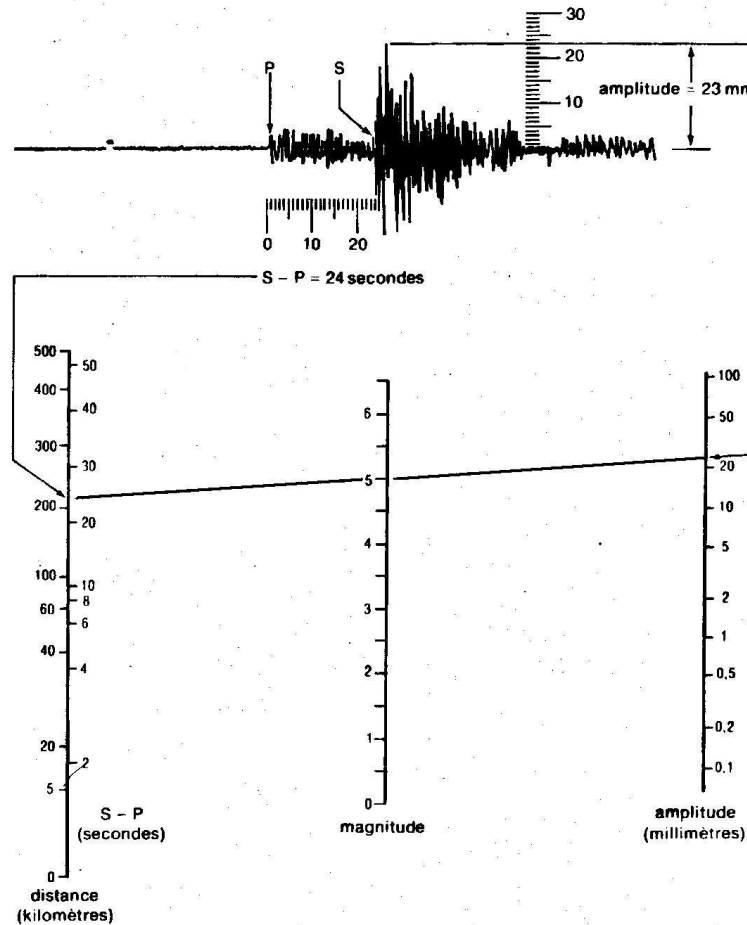
de l'amplitude A et de la période T du déplacement du sol pour une onde sismique donnée

$$M_L \text{ ou } M_S \text{ ou } m_b \propto \log (A/T)$$

de la durée du signal τ enregistrée (faibles distances)

$$M_D \propto \log \tau$$

**EXEMPLE DE CALCUL
DE LA MAGNITUDE RICHTER (M_L)
D'UN TREMBLEMENT DE TERRE LOCAL**



Méthode de calcul de la magnitude locale M_L :

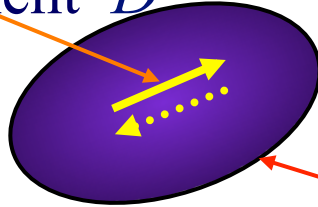
1. Mesurer la distance au foyer en employant l'intervalle entre les ondes P et S, $(S-P) = 24 \text{ secondes}$.
2. Mesurer la hauteur de l'élongation maximale sur le sismogramme (23 millimètres).
3. Tirer une droite entre les points correspondants sur les échelles de distance (à gauche) et d'amplitude (à droite) pour obtenir la magnitude $M_L = 5,0$ sur l'échelle du milieu.

(d'après Bruce BOLT, les tremblements de terre, Bibliothèque "Pour la Science", 1982)

Figure 11

Définition du Moment sismique

Glissement D



$$M_o = \mu D S$$

Surface de la
faille S

μ est la rigidité du milieu, S , la surface de la faille qui a joué, D , le déplacement moyen sur la faille.

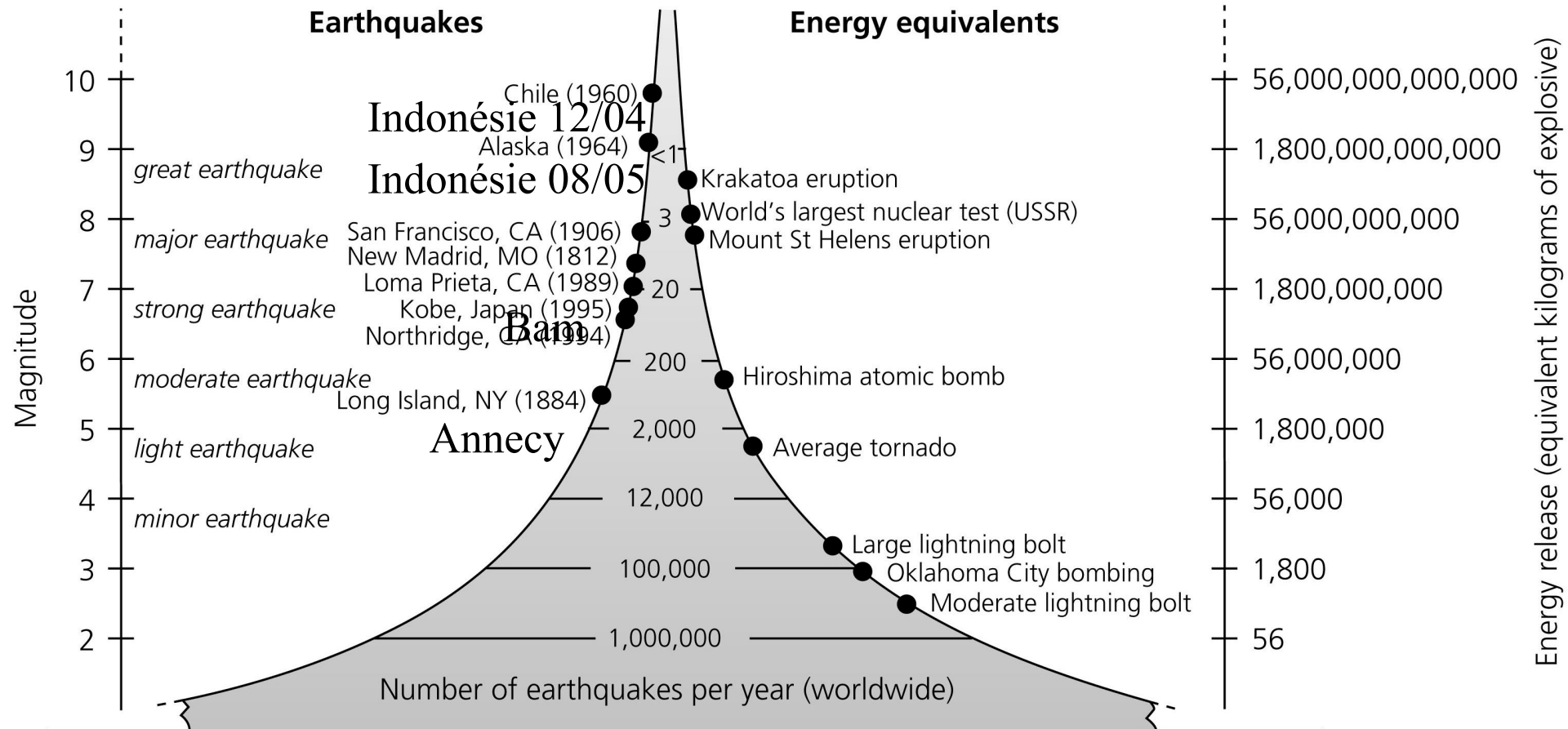
Magnitude de moment : $M_w = (2/3) \log M_o - 6,0$ (M_o en N.m)

• La Magnitude est donc une quantité logarithmique : elle sert à estimer l'énergie E d'un séisme ☒

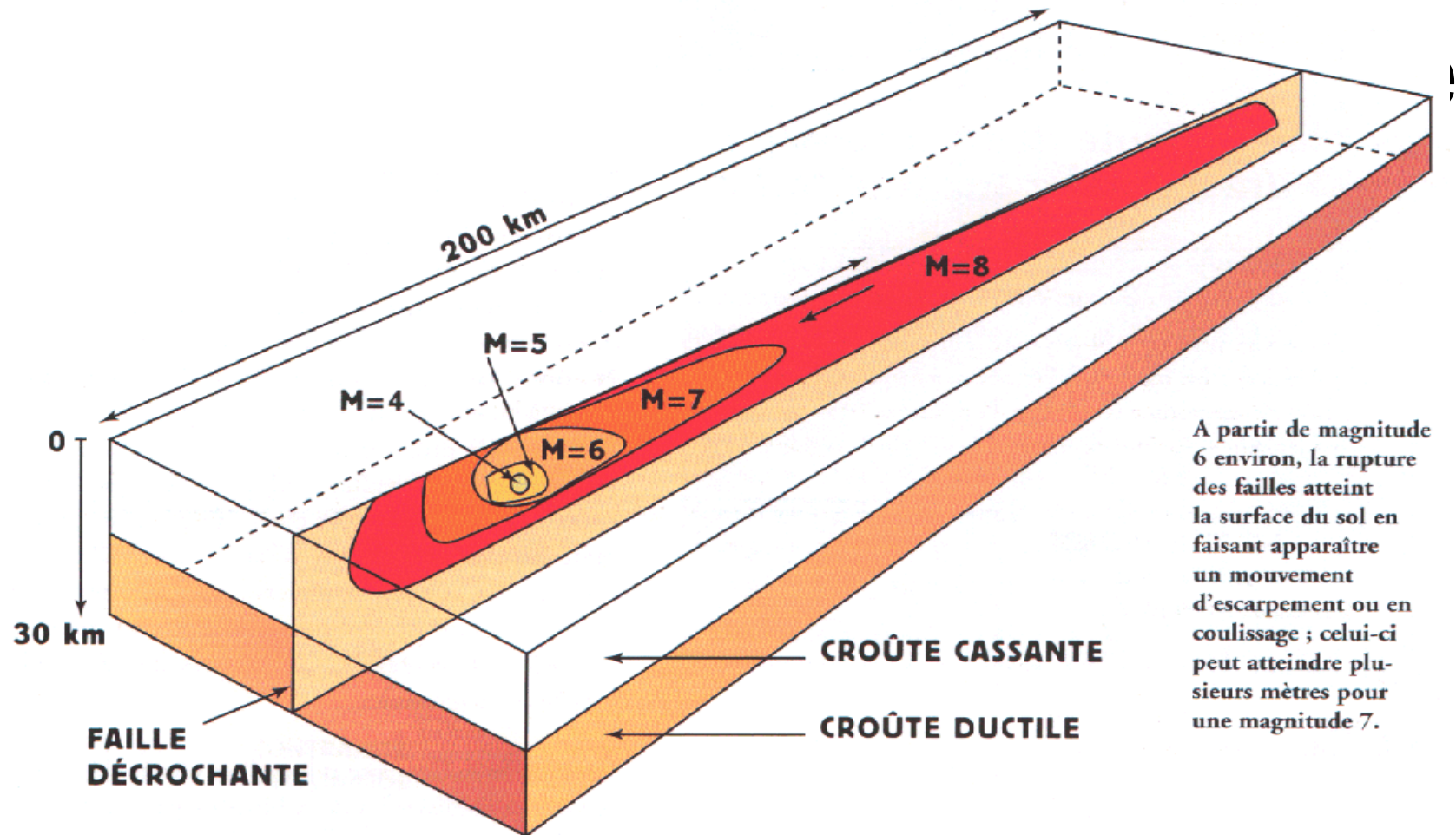
• $\log E \text{ (J)} = 1,5 M_w + 4,8$ si $M \text{ ☒ } M + 1$ $E \text{ ☒ } 32 E$

☒ un séisme de magnitude 6 libère 1000 fois plus d'énergie qu'un séisme de magnitude 4.

Figure 1.2-2: Comparison of frequency, magnitude, and energy release.



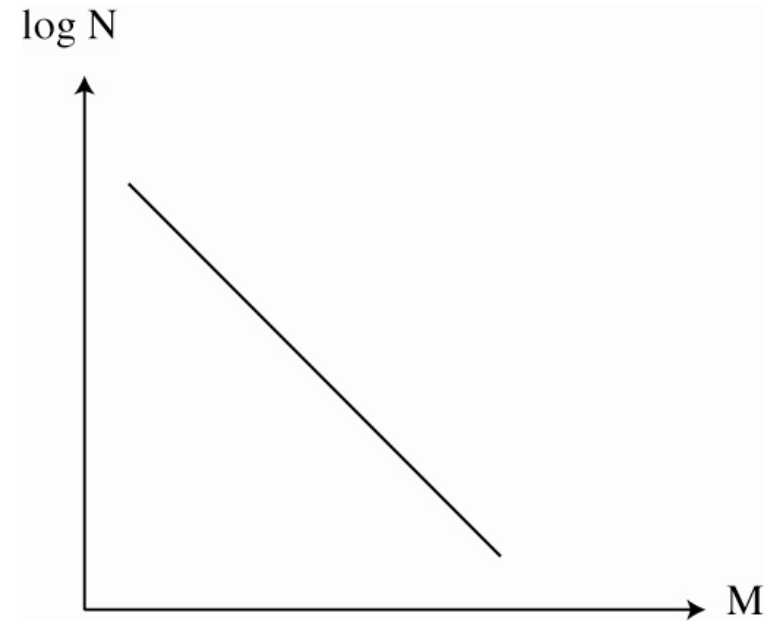
MAGNITUDE ET SURFACE DE RUPTURE



Explorer le mouvement des failles en profondeur

Loi de Gutenberg-Richter:

Prévision statistique?



$$\log N = -bM + \log a$$

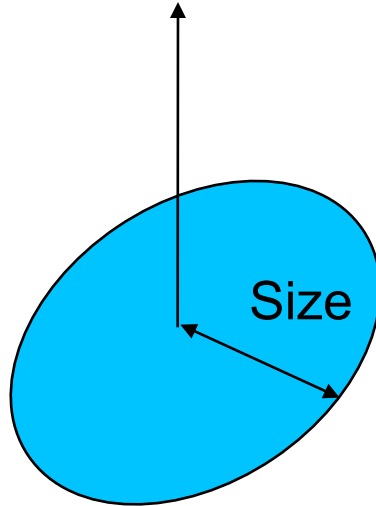
a : constante et b : constante

N : nombre de séismes par unités de temps de magnitude supérieure M .

On observe suivant les régions : $0.8 < b < 1.2$ (attention à la validité statistique!)

Pour la sismicité globale, $b \simeq 1$.

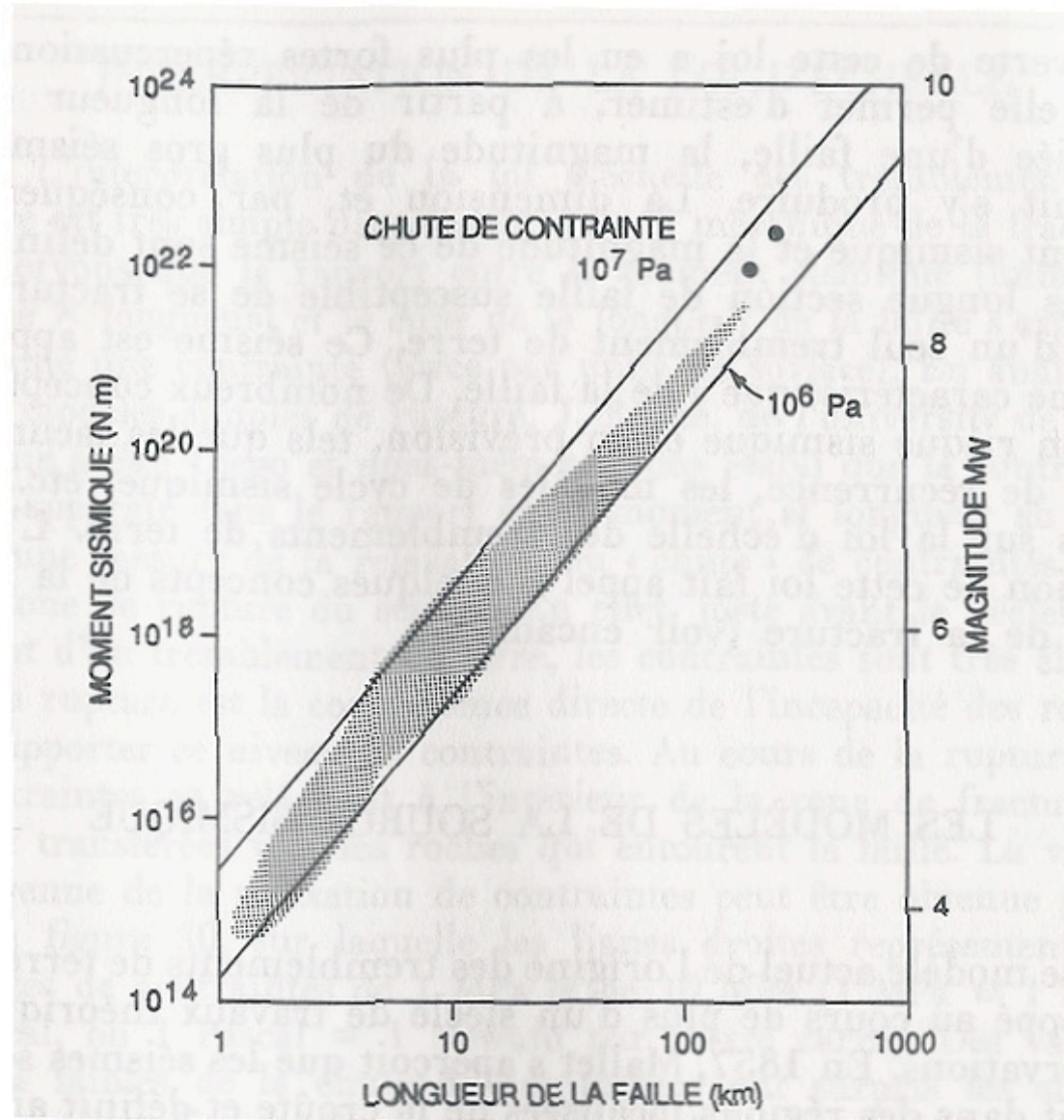
Earthquake scaling law



There is a single scale:

Earthquake size L

$$M_0 \simeq \Delta\sigma L^3$$



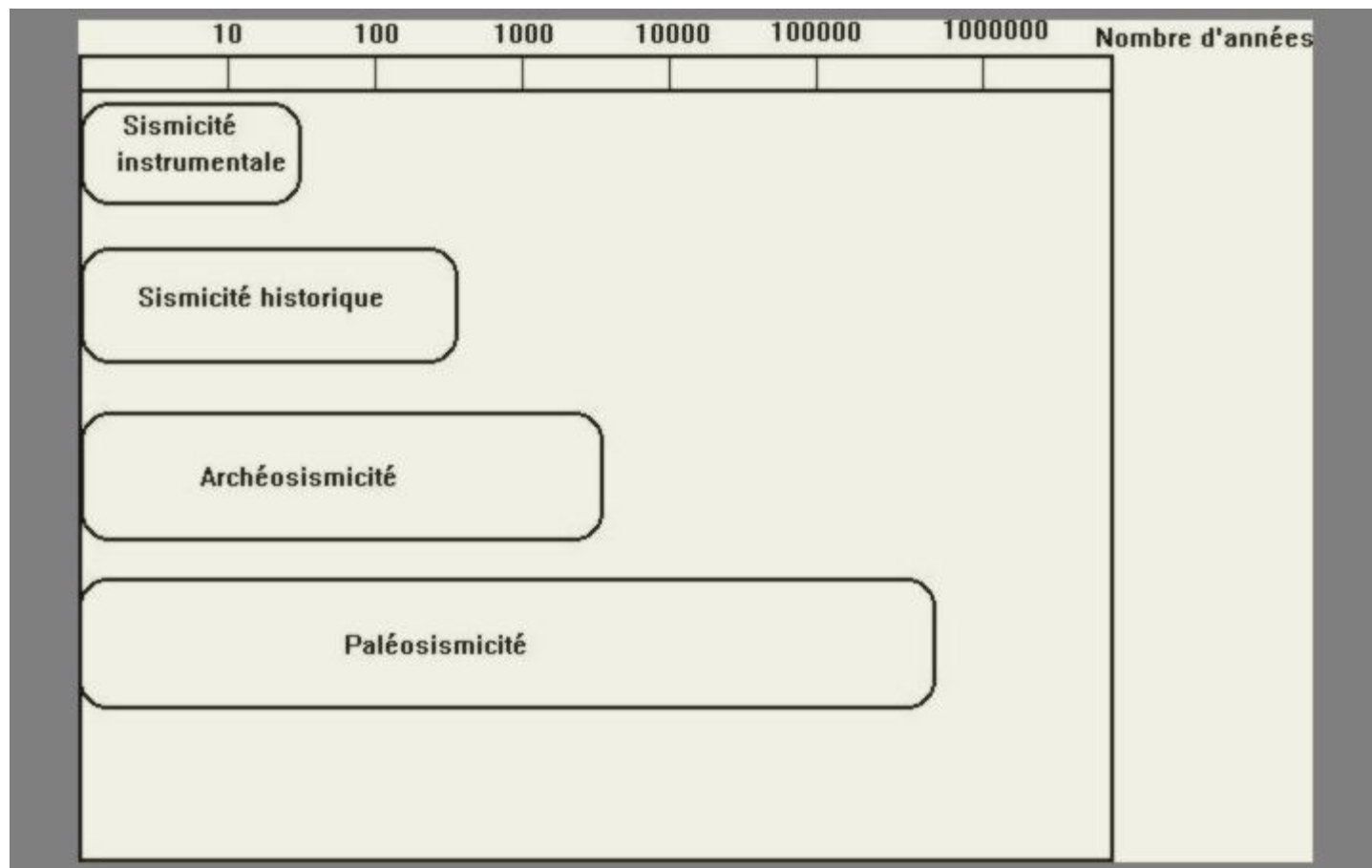


Table 1.2-4 Modified Mercalli intensity scale.

Intensity	Effects
I	Shaking not felt, no damage: not felt except by a very few under especially favorable circumstances.
II	Shaking weak, no damage: felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.
IV	Shaking light, no damage: during the day felt indoors by many, outdoors by very few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably (0.015–0.02 g)
V	Shaking moderate, very light damage: felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees and poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (0.03–0.04 g)
VI	Shaking strong, light damage: felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (0.06–0.07 g)
VII	Shaking very strong, moderate damage: everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (0.10–0.15 g)
VIII	Shaking severe, moderate to heavy damage: damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (0.25–0.30 g)
IX	Shaking violent, heavy damage: damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (0.50–0.55 g)
X	Shaking extreme, very heavy damage: some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (More than 0.60 g)
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level destroyed. Objects thrown into the air.

Note: Parentheses show the average peak acceleration in terms of g (9.8 m/s), taken from Bolt (1999).

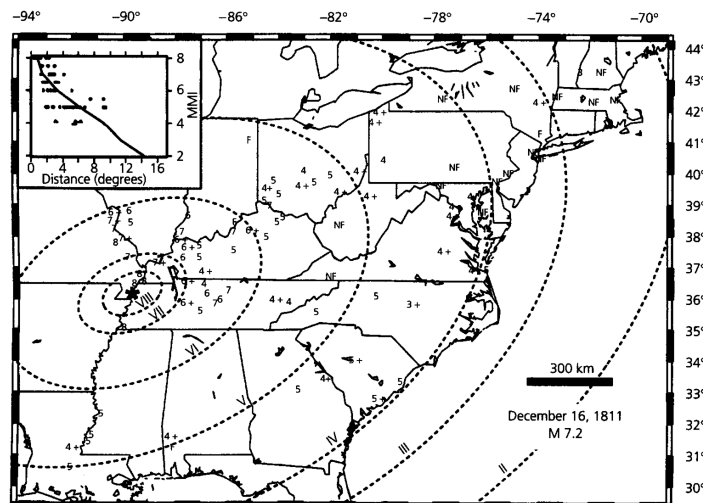


Fig. 1.2-4 Isoseismals for the first of the three largest earthquakes of the 1811–12 New Madrid earthquake sequence. Such plots, though based on sparse data, often provide the best assessment of historical earthquakes and of the effects of future ones. (After Hough *et al.*, 2000. *J. Geophys. Res.*, 105, 23,839–64, Copyright by the American Geophysical Union.)

TYPE DE STRUCTURE	SEISME / SITE	DEGRÉ DES DÉGÂTS				
		1	2	3	4	5
Maçonnerie en briques crues	Est Kazakh stan 1990 / Saisan			X		



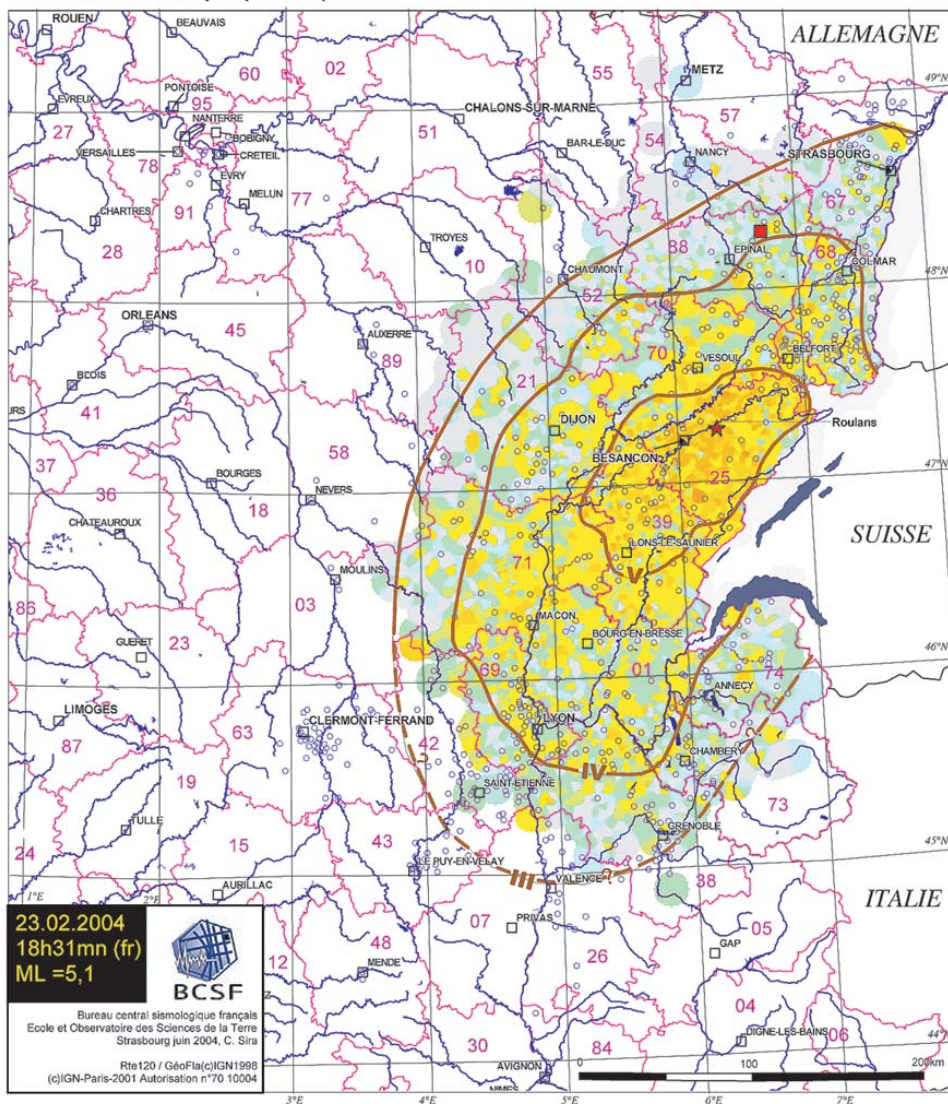
TYPE DE STRUCTURE	SEISME / SITE	DEGRÉ DES DÉGÂTS				
		1	2	3	4	5
Maçonnerie en moellons bruts	Nord Péloponèse, Grèce 1995 / Aegion				X	



TYPE DE STRUCTURE	SEISME / SITE	DEGRÉ DES DÉGÂTS				
Ossature en béton armé	Nord Péloponnèse, Grèce 1995 / Aegion	1	2	3	4	5
						X



Séisme du 23 février 2004 de Roulans (dép.25)
Carte macrosismique (EMS98)



Intensités macrosismiques communales (EMS98)

- VI - dégâts légers
- V - fortement ressenti (seuil de dégâts)
- IV - largement ressenti
- III - faiblement ressenti
- II - rarement ressenti
- I - non ressenti
- commune ayant ressenti la secousse (sans estimation d'intensité)

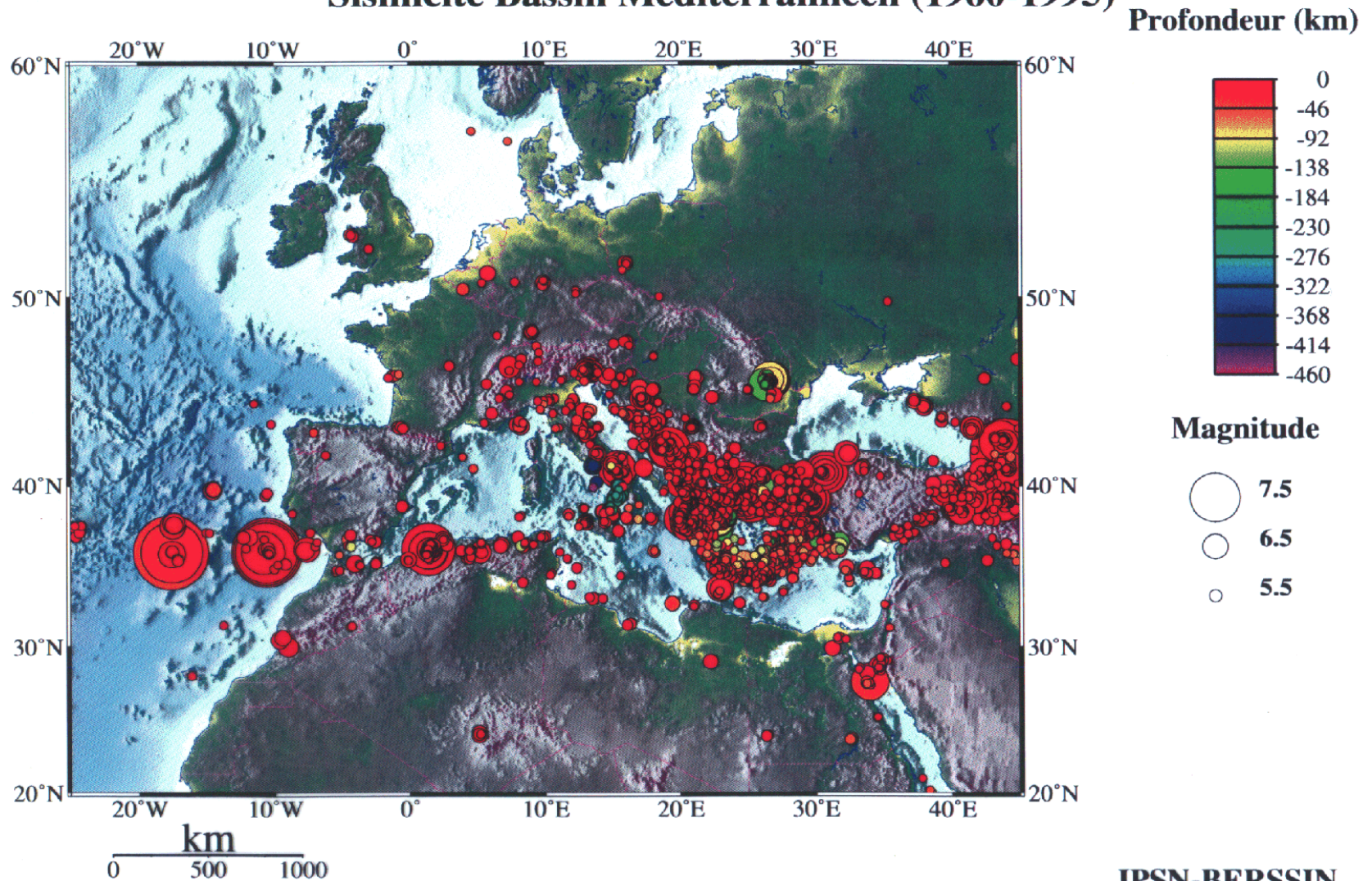
isoséiste

- ★ épicentre du séisme de Roulans (localisation Rénaass)
- épicentre du séisme de Rambervillers fév.2003 (localisation réseau local)

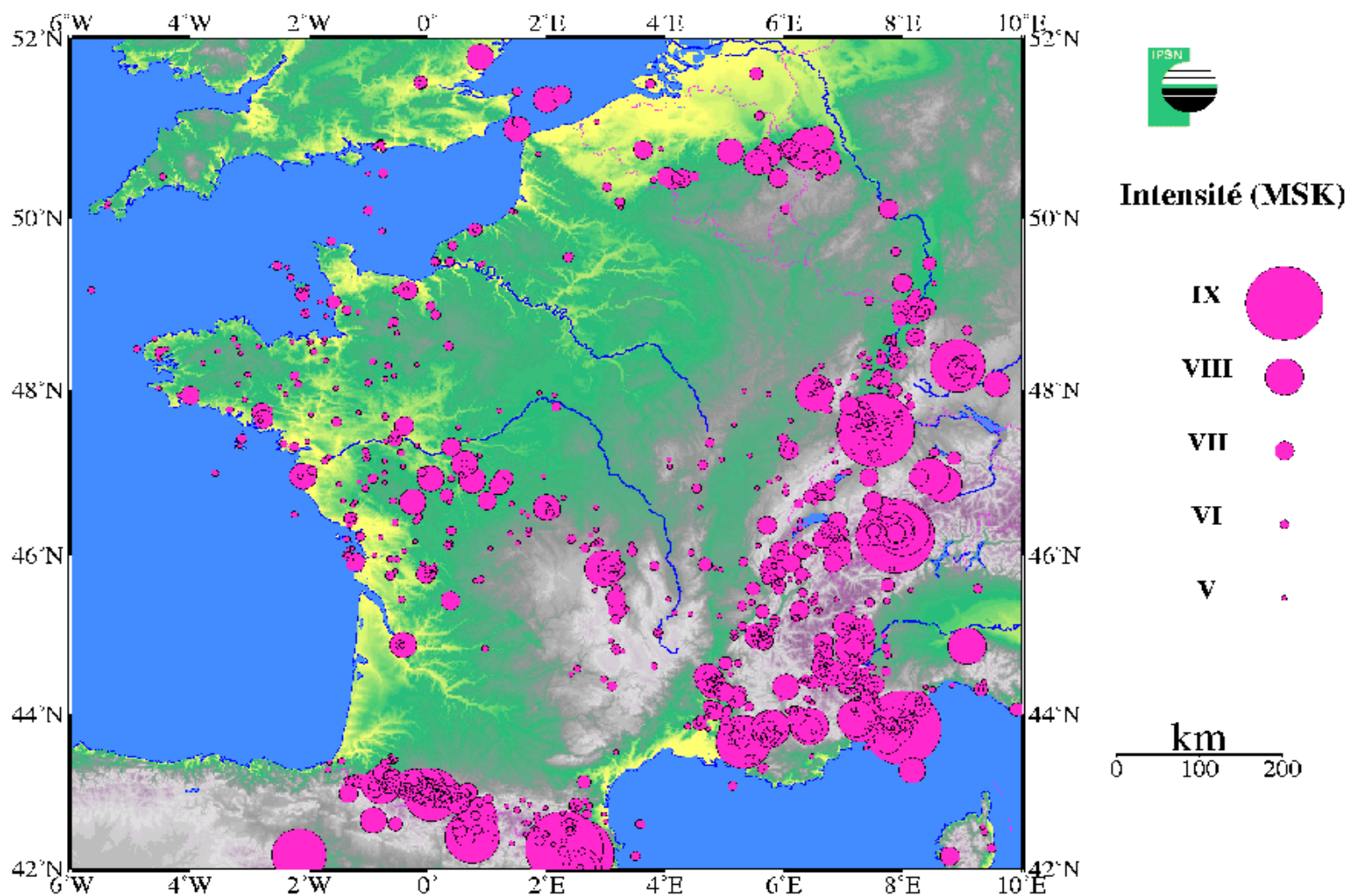
- limite départementale et n° du département
- hydrographie

Définir les failles actives

Sismicité Bassin Méditerranéen (1960-1995)



Sismicité historique (1000 ans environ)



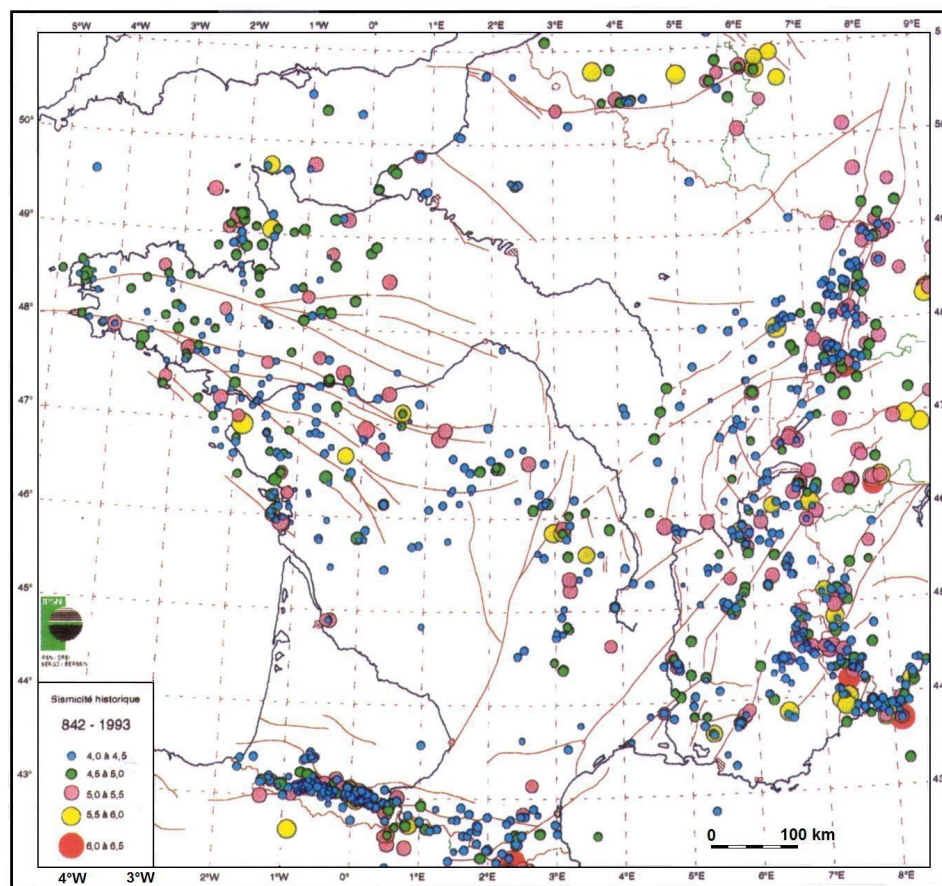
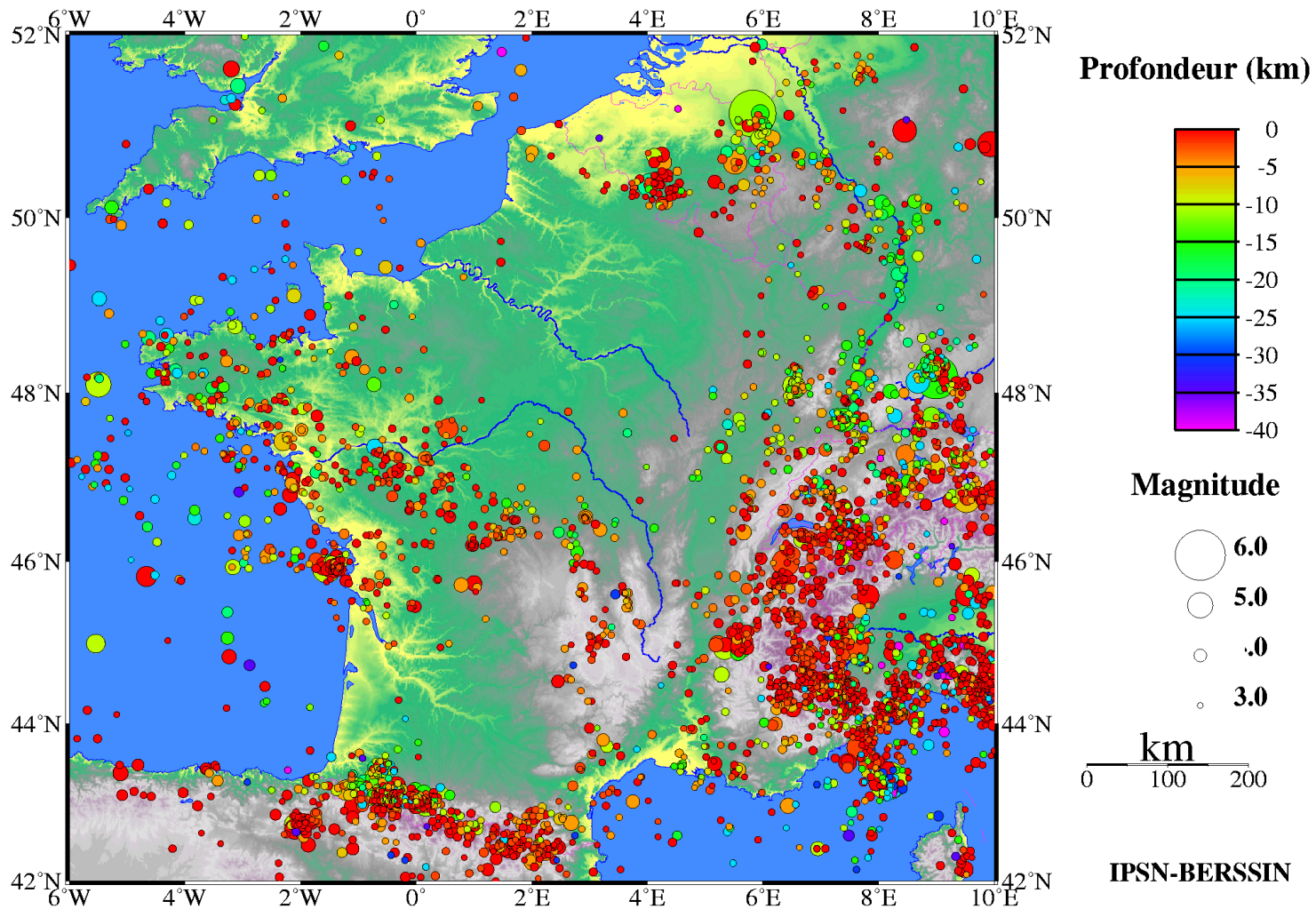
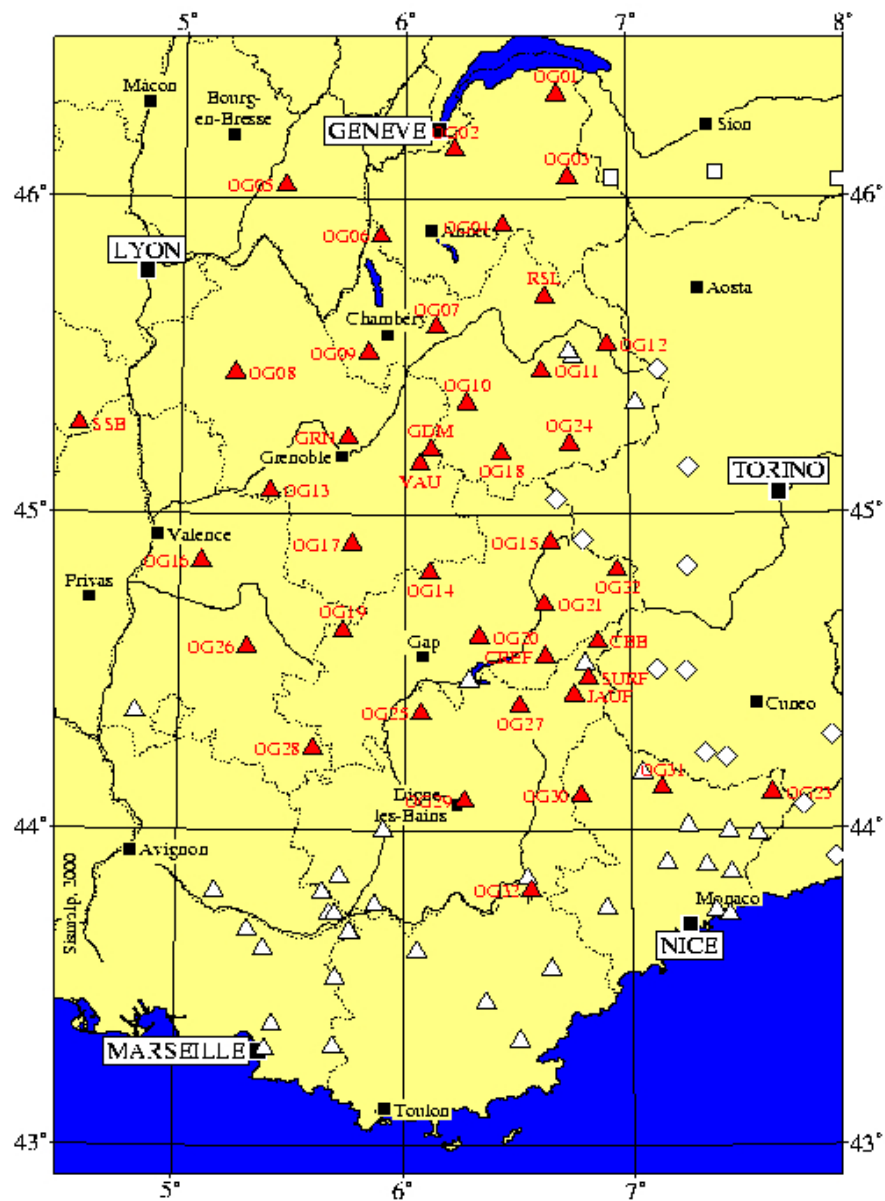


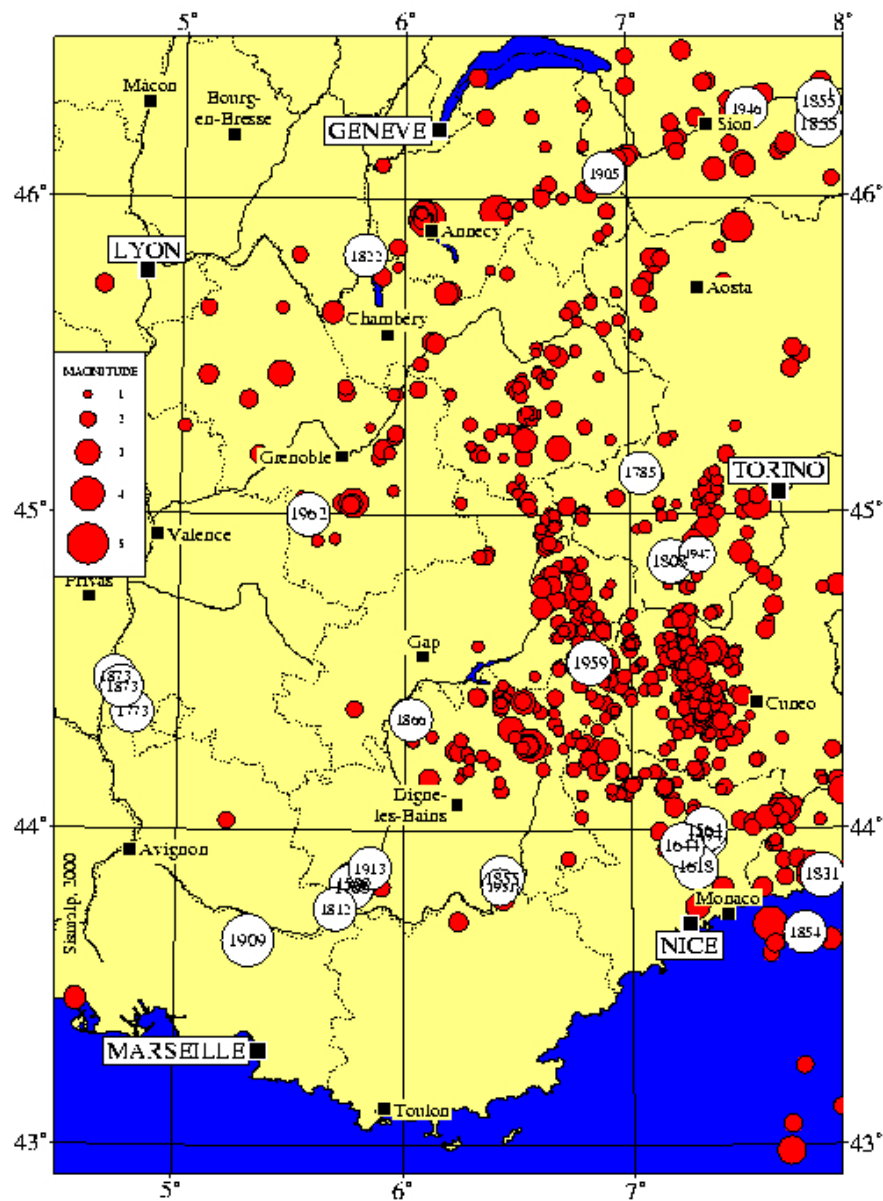
Figure 14 : Magnitudes calculées à partir des données macrosismiques de la base SIRENE (BRGM / EdF / IPSN)

Sismicité instrumentale (Fichier LDG 1962-1995)



Le cas des Alpes

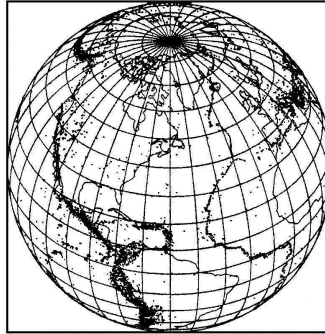




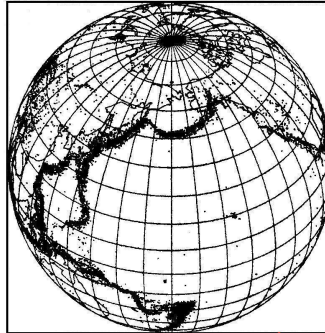
Importance des observatoires
pour définir les failles sismogènes

SISMICITE MONDIALE M > 4,5

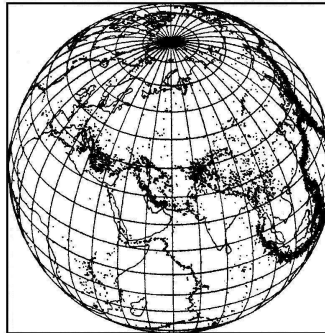
1968 - 1988



On remarque la sismicité superficielle de la dorsale médio-atlantique qui se trouve pratiquement à égale distance des continents Europe/Afrique et Amérique. Cette dorsale n'est cependant pas une ligne continue mais présente de nombreux décrochements (failles transformantes). On observe également l'importante sismicité des Andes et de l'Amérique centrale, caractéristique des zones de subduction. Au Nord, au niveau du golfe du Mexique, ces zones se transforment en faille transformante (faille de San Andreas en Californie). A l'Est du Pacifique, on observe également bien les contours des plaques Caraïbe, Cocos et Nazca.



La sismicité (mis à part le point chaud des Iles Hawaï) se trouve concentrée autour de l'océan Pacifique. Elle est caractéristique des zones de subduction (qu'elles soient de type "arc insulaire" à l'ouest, ou de type "andin" à l'est) sauf au niveau de la faille de San Andreas. On remarque les contours nets de la plaque Philippines.



La sismicité du continent eurasién est beaucoup plus dispersée que celle des dorsales (ici, on voit la dorsale indienne) et des zones de subduction (ici, les îles de la Sonde). Ceci est dû à la collision de plaques continentales (Afrique/Eurasie et Inde/Eurasie). On remarque les contours nets de la plaque Arabie.

En Afrique, une sismicité dispersée est observée dans le sud-est du continent : c'est la région des grands lacs appelée aussi rift africain.

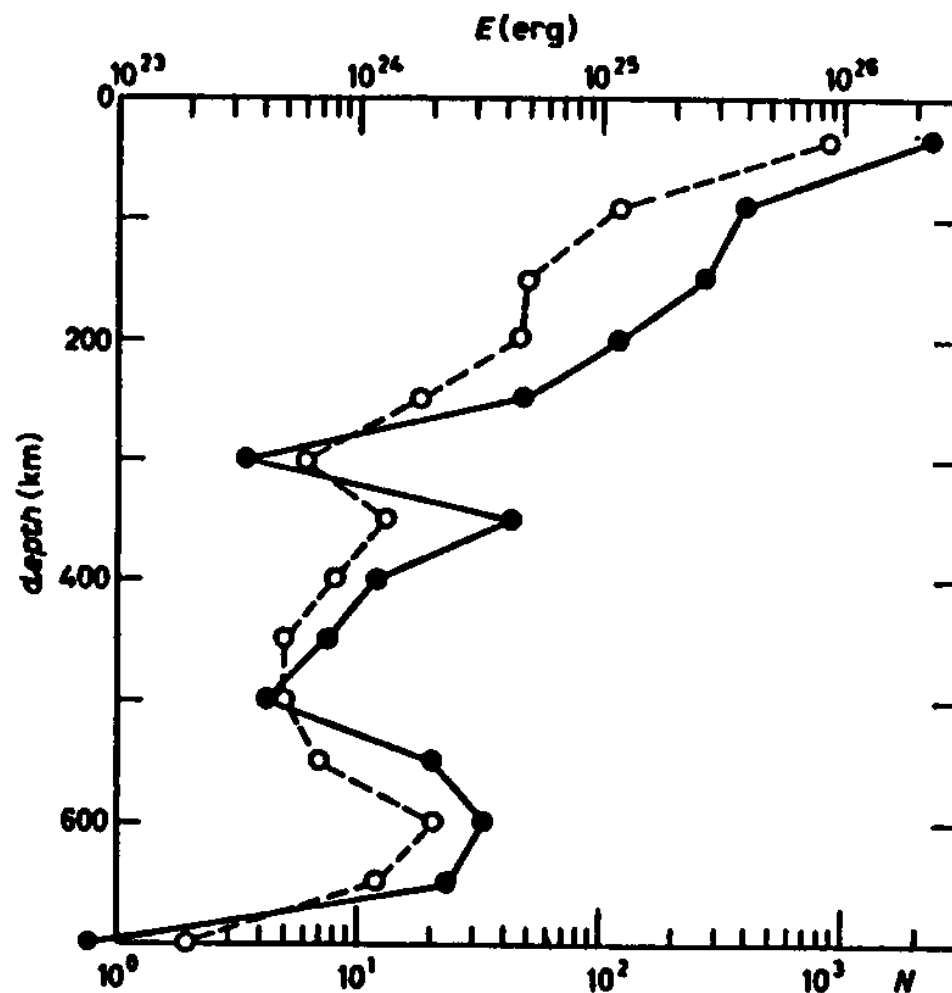


Fig. 3. - The variation of seismic activity as a function of depth. The solid curve shows the energy and the dashed curve the number of events with $m_b > 7$. The scale at the top indicates the energy (E) and that at the bottom the number (N). Each data point represents the value for a depth range of 50 km centered at the depth of each data point and for the time period of 75 years from 1904 to 1974 [10].

Figure 1.2-1: Global seismicity, 1963-1995.

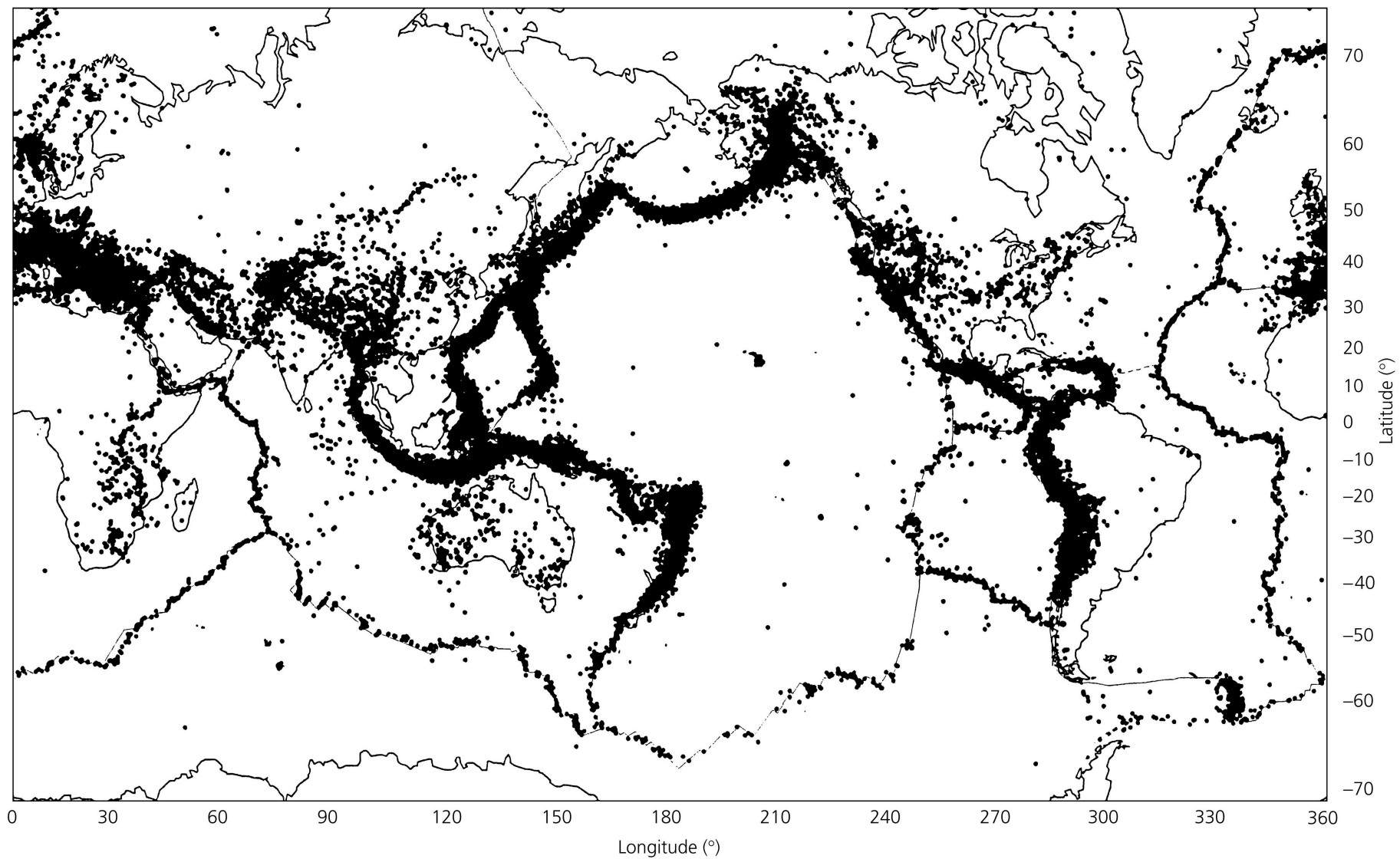


Figure 5.4-24: Locations of the largest earthquakes during 1904-1976.