Seismic activity and hazard in Northwestern Europe

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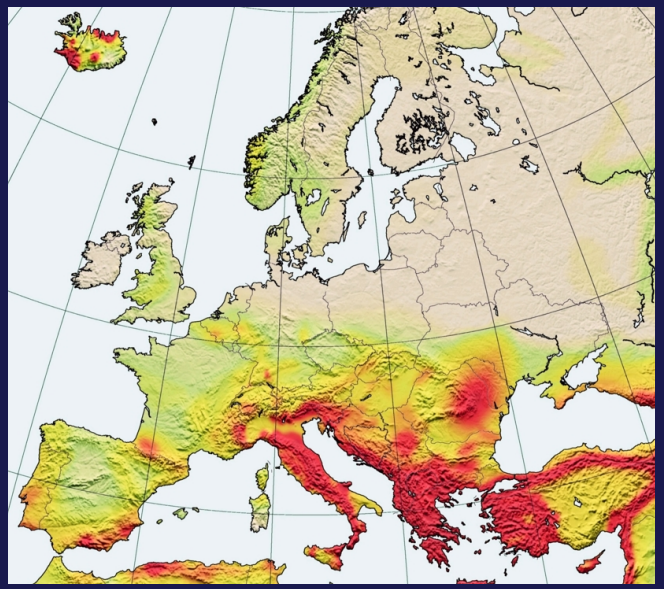
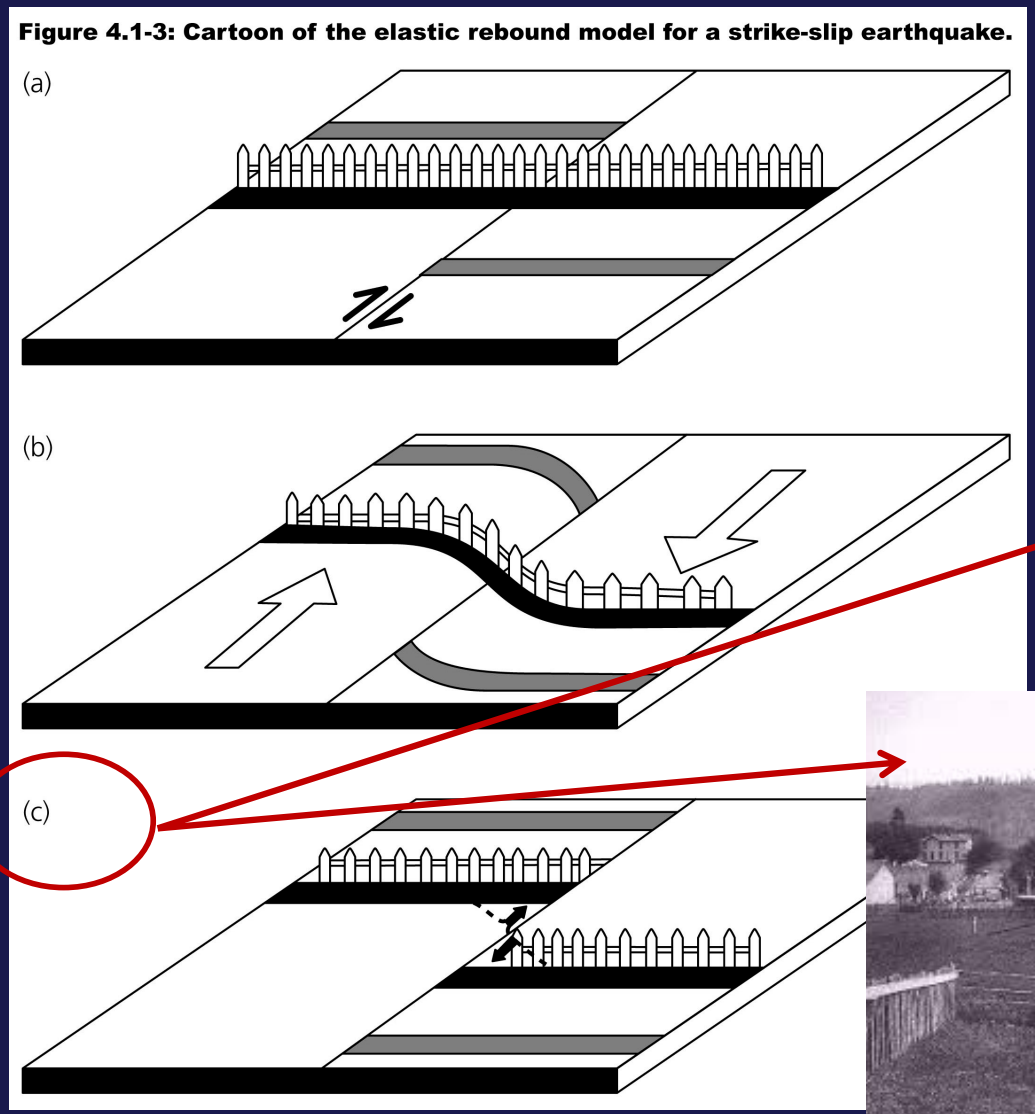


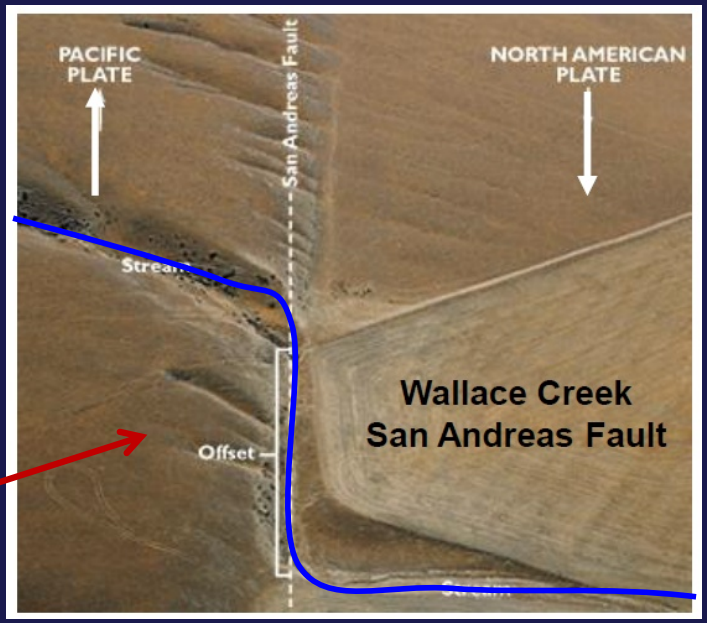
What is a tectonic earthquake?

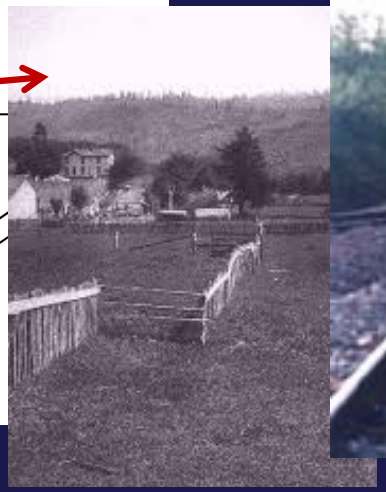
An earthquake is the result of a sudden release of energy in the Earth's crust

Tectonic earthquakes occur anywhere in the earth where there is sufficient stored elastic strain energy to drive fracture propagation along a fault plane

Deformation and earthquake
Elastic rebound model of previously stored elastic stress (Reid, 1906)

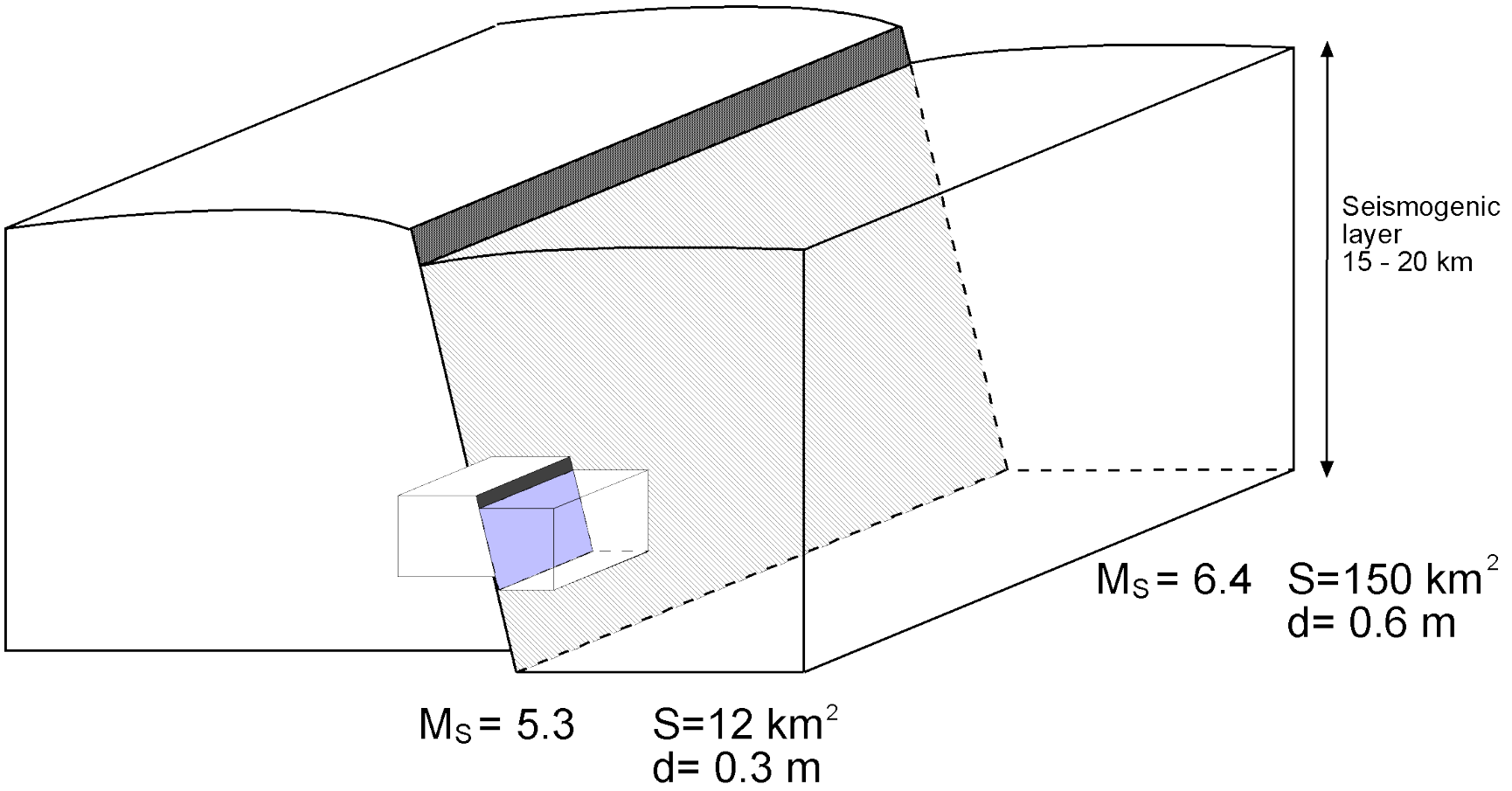






Izmit, Aug. 1999, M = 7.3

Size: Small and large earthquakes

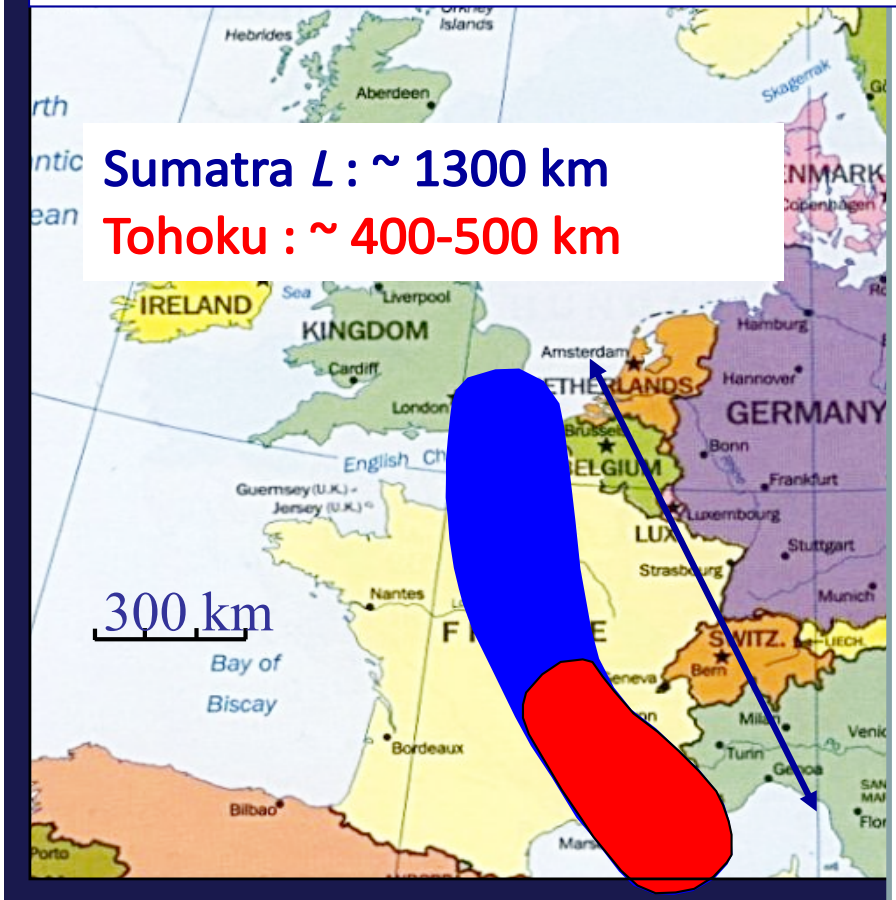


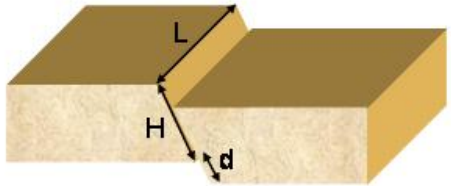
Today: moment magnitude Mw, directly related to the source:

$M_w = 2/3 \log M_o - 6.07$ where $\mathbf{M_o = \mu S d}$ [Nm], μ = shear modulus

Small and large earthquakes

(a) Roermond 1992 : M= 5.4, d ~30 cm
(b) Izmit 1999 : M= 7.4, d ~2 m
(c) San Francisco 1906 : M= 7.9, d ~4 m
(d) Sumatra-Andaman 2004 : M= 9.2, d ~10 m
(e) Tohoku 2011 : M= 9.0, d ~12 m, > 50 m



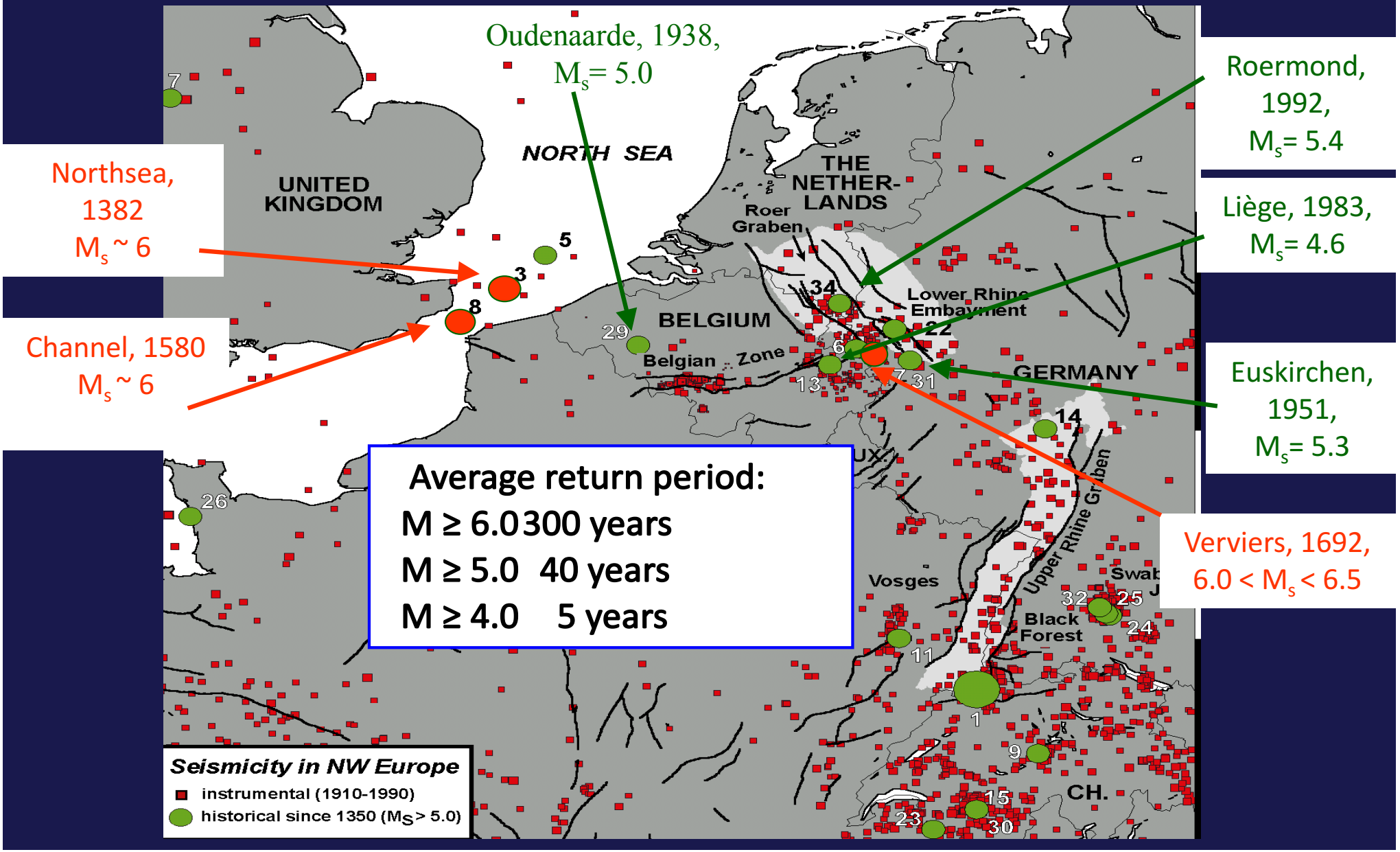


San Francisco
L: 470 km

Izmit L: 70 km

Roermond
L: 3 km

Historical (>1350) and instrumental (>1910) seismicity around Belgium:
14 M ≥ 5.0 earthquakes since 1350 (3 M > 6)



Intraplate Earthquakes ???
➔ Crust is close to rupture

☞ Continental crust in plate interior is virtually everywhere in a state close to seismic failure

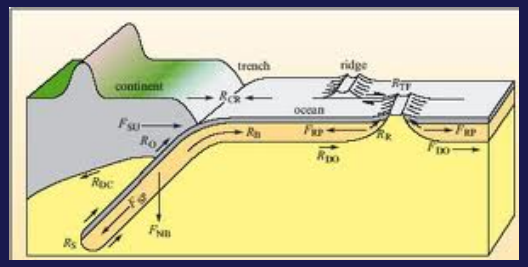
(1) Induced seismicity from reservoirs filling or fluid injections

(2) Earthquakes triggered by the small change in stresses associated with other earthquakes

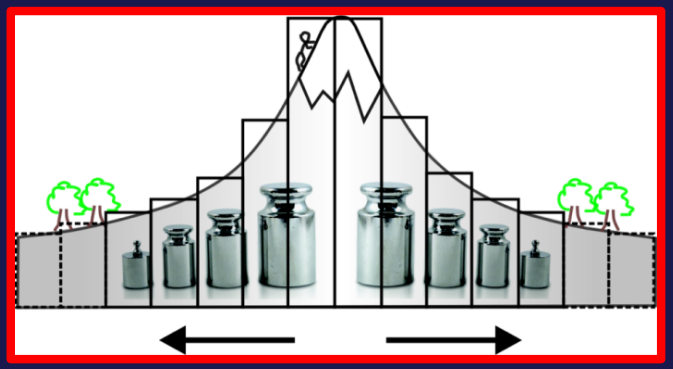
(3) Stresses inferred from boreholes similar to Coulomb's failure criterion

Source of stresses inside the plate

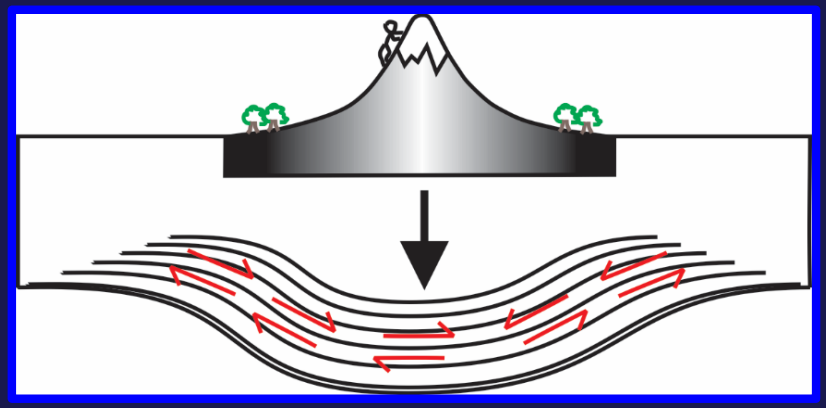
(1)Forces participating in or withstanding the plate motion (e.g. ridge push, slab pull)



(2) Density heterogeneities



(3) Loading and associated flexure of the lithosphere



How often does it shake?

How to address that problem?

→ Looking for Earthquakes in the past

Instrumental:
1938 Oudenaerde earthquake (Ms = 5.0)

- 2 deaths, numerous injured
- Panic
- > 17500 damages on chimneys
- In Ghent:
  - 500 kg stone block felt down from St.-Jozefskerk
  - A watchtower of the belford felt down on the street

Instrumental: 1983 Liège (Ms = 4.7)

1000 homeless

16000 building damaged

St Nicolas:

FACADES

356 shored up

NON-HABITABILITY

93 houses

DEMOLITION

15 houses

→ Total estimated cost: 250 10^6 EUR

→ Disaster Fund: 100 10^6 EUR (current val.)

Historical:
Example of historical text (1580)

"1580. Den VI Aprilis, sgoensdaeghs naer Paesschen XV LXXX, tusschen vyf ende ses hueren naer middagh, wesende claer ende stille weder, is binnen deser stede van Audenaerde ghebuert een eertbevinghe, duer welcke diveersche steenen van caven ende tichelen van de huysen ghevallen zyn, daer duere eeneghe lieden doot, ende eeneghe tot op der doot ghequetst zyn gheweest. Welcke voorscrevene eertbevinghe duerde wel twee zoo drie pater-nosters, eerst beghinnende al bevende ghelick of daer eenen grooten vaerwaeghen up straete voor by ghepasseert hadde, waer by alle ghelaes

Waardoor verscheidene stenen van schoorstenen (caven) en pannen van de huizen gevallen zijn, waardoor enkele mensen gedood en enkele zwaar gekwetst werden.

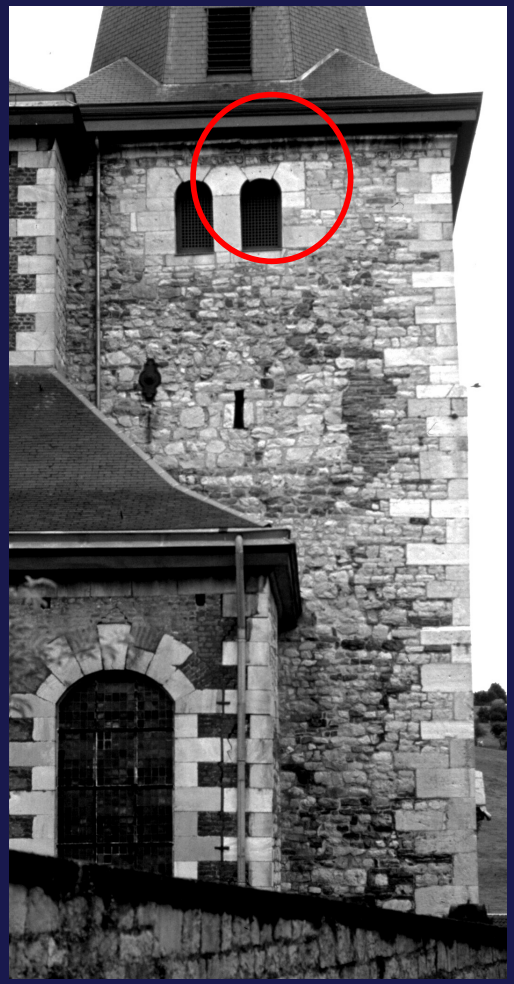
een gro
schuyff
boomen
ontrent sagh vertrecken ; zoo dat elck daer van beroert ende benaut was. Die in huysen waeren, meenden dat thuys inviel, zoo dat elck uuyt zynen huyse ende zyn huys verloochenende, up strate quaem gheloopen, niet wetende watter schuulde, ende den eenen ghebuer den anderen quaem zyn ghevaerte vertellen. Die te platte lande waeren, hoorden ende saghen tghedruyst, coemende van uuyt den westen, treckende naer dhooste, ende de eerde haer upheffen ghelick drie zoo vier baren in twatere, alzoo voorts loopende. Welcke voorscrevene eertbevinghe bevonden es niet alleendelijck hier gheschiet tzyne, maer allomme gheheel Vlaenderen duere, ende ander circumvoisine landen."

Bron: *Audenaerdsche Mengelingen*

Architectural heritage
Example: the 1692 Verviers M~6 1/4 earthquake

(*1692 destroyed by an Earthquake, rebuild 1698*), in Crapoel, near Eupen

1692 Earthquake (cont')



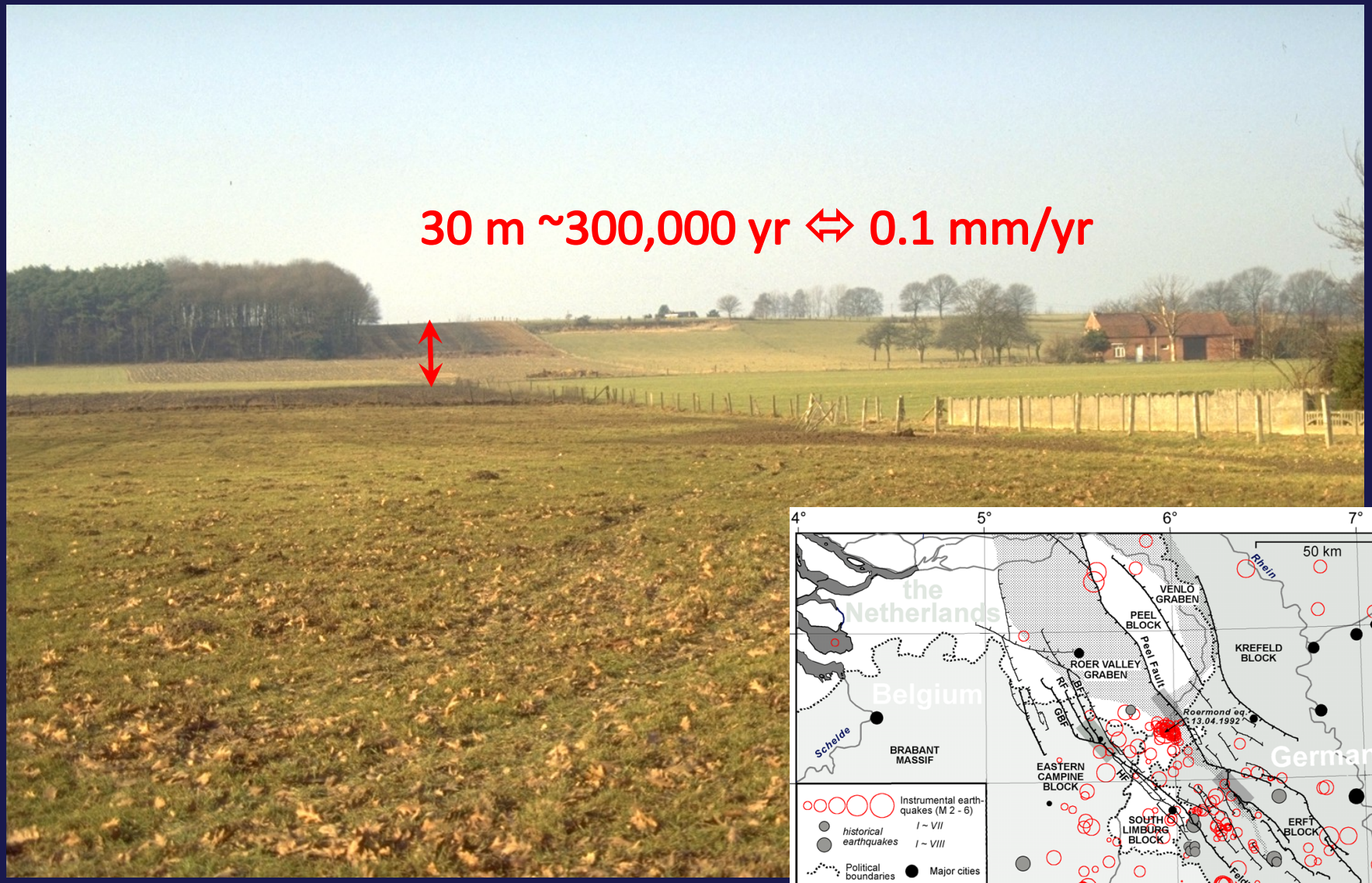
Remains of the EQ on the towers of the Soiron en Andrimont churches
Also in Hesbaye (1828 M= 5.0 Earthquake)

Geology (paleoseismology)

Bora peak EQ, Idaho, M=6.9, 1983

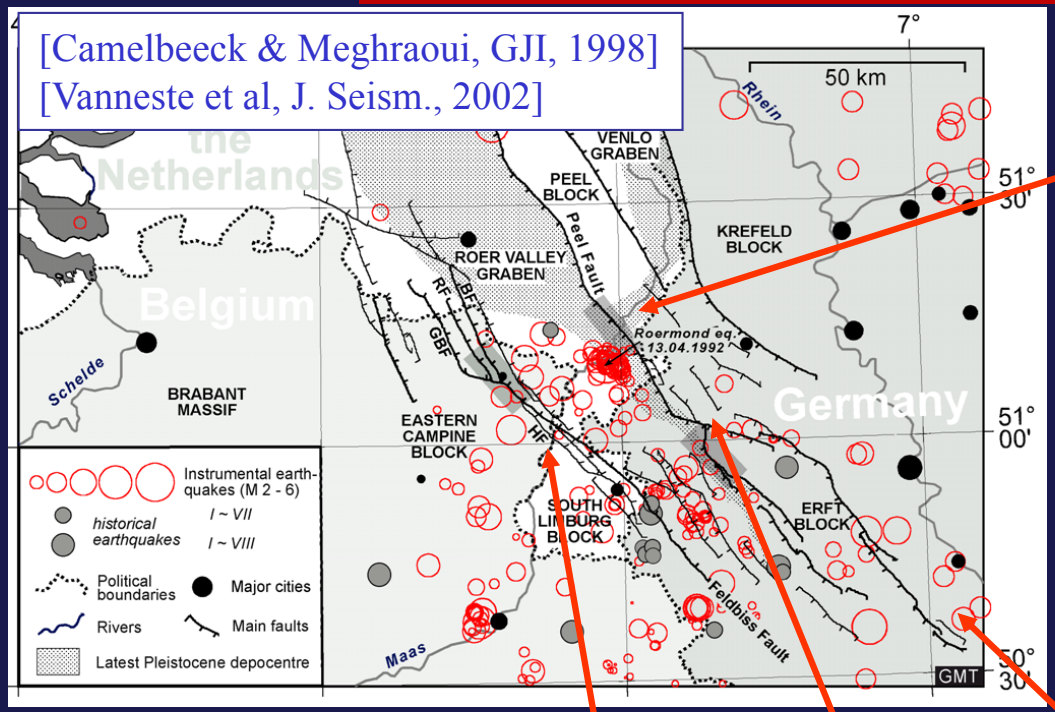
http://www.smate.wwu.edu/teched/geology/GeoHaz/eq-faults/eq-faults-14.JPG

Geology (paleoseismology) in belgium: Fault scarp in Bree



Geology (paleoseismology)

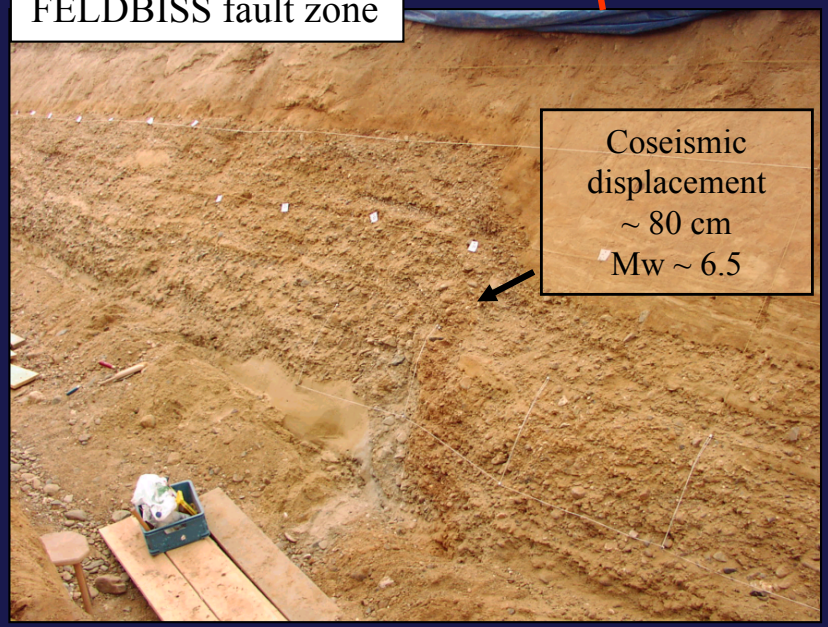
[Camelbeeck & Meghraoui, GJI, 1998]
[Vanneste et al, J. Seism., 2002]



PEEL fault

ERFT fault

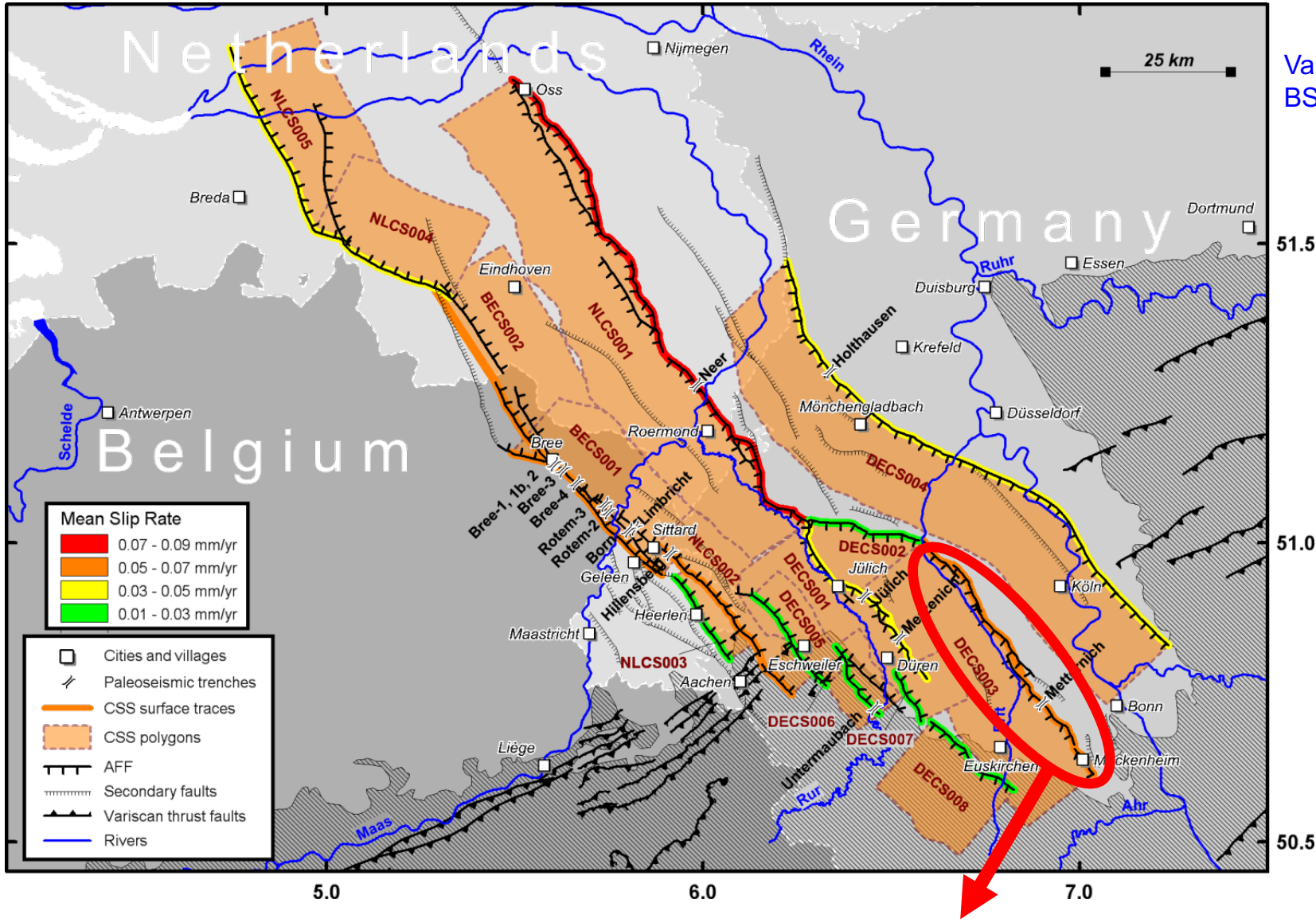
FELDBISS fault zone



Coseismic displacement ~ 80 cm Mw ~ 6.5

RURRAND

Seismotectonic zone in the Roer Graben



Vanneste et al., BSSA 2013

Erft / Swist fault longest possible rupture: 55 km ➔ $M_W = 7.1$

Seismicity in Belgium: Take home message

- Felt earthquake

  Recurrence: ~1 year

- A destructive earthquake (M≥6) likely to occur

  1382-1580-1692, impacts the whole territory

  Recurrence: ~300 years, **cost >10 billions € (Munich Re)**

- A small-moderate earthquake (M<6) locally destructive

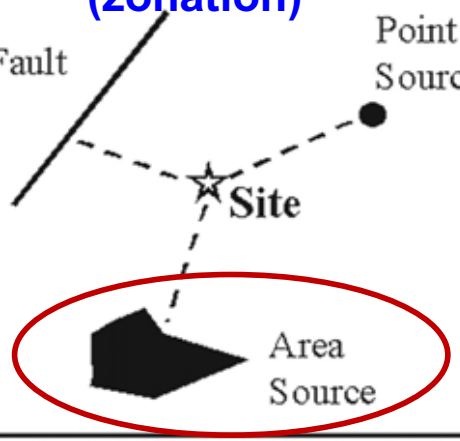
  Liège 1965 & 1983, Hainaut 1965-1966-1967-1968

  Oudenaarde 1938, Roermond 1992

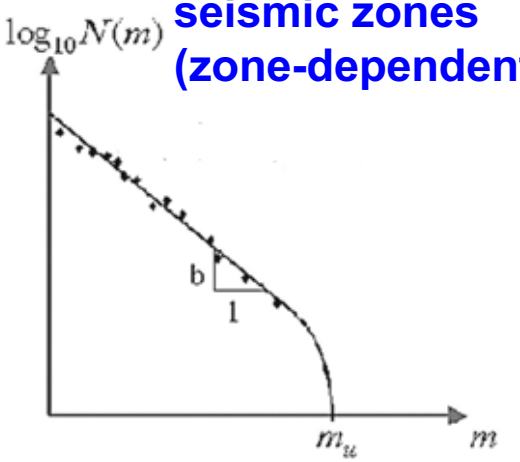
  Recurrence : ~10-30 years, **cost ~250 10^6 €**

Hazard? ➔ Probabilistic analyze

Step 1: **Seismic source (zonation)**

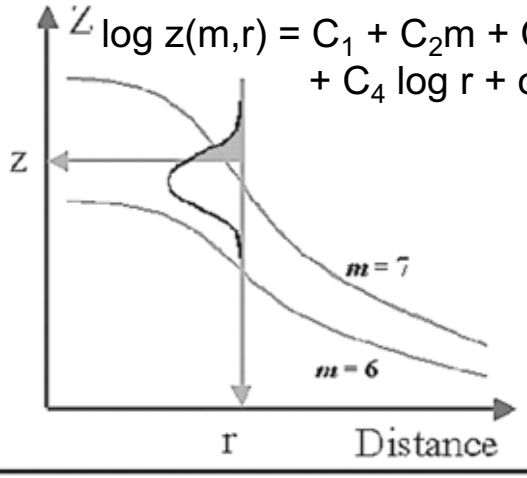


Step 2: **activity in the seismic zones (zone-dependent)**

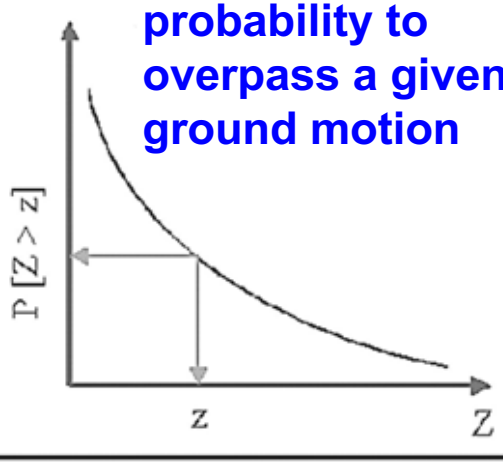


Step 3: **Attenuation laws**

$$\log z(m,r) = C_1 + C_2 m + C_3 r + C_4 \log r + \sigma$$



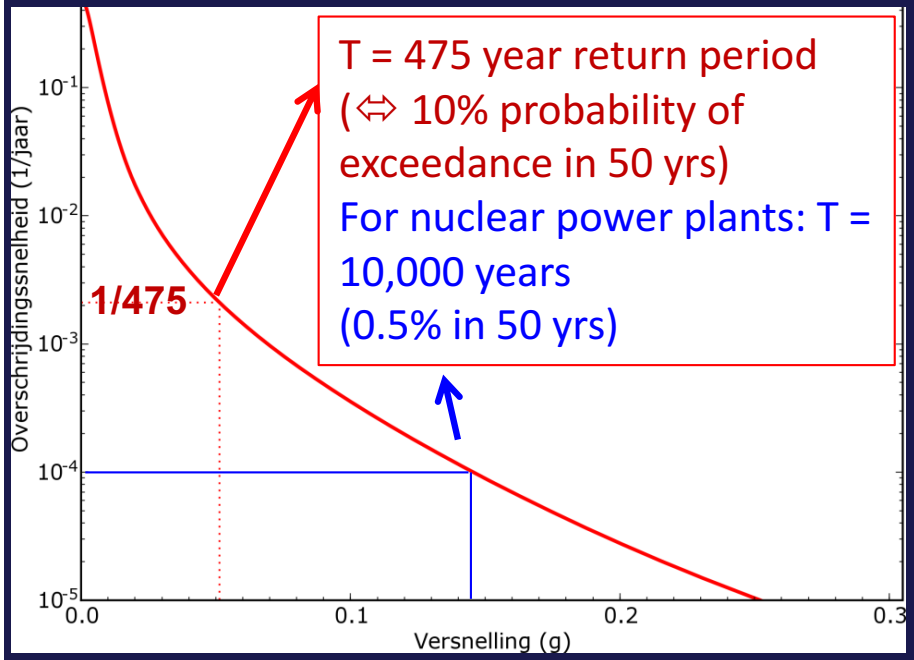
Result: **Calculation of the probability to overpass a given ground motion**



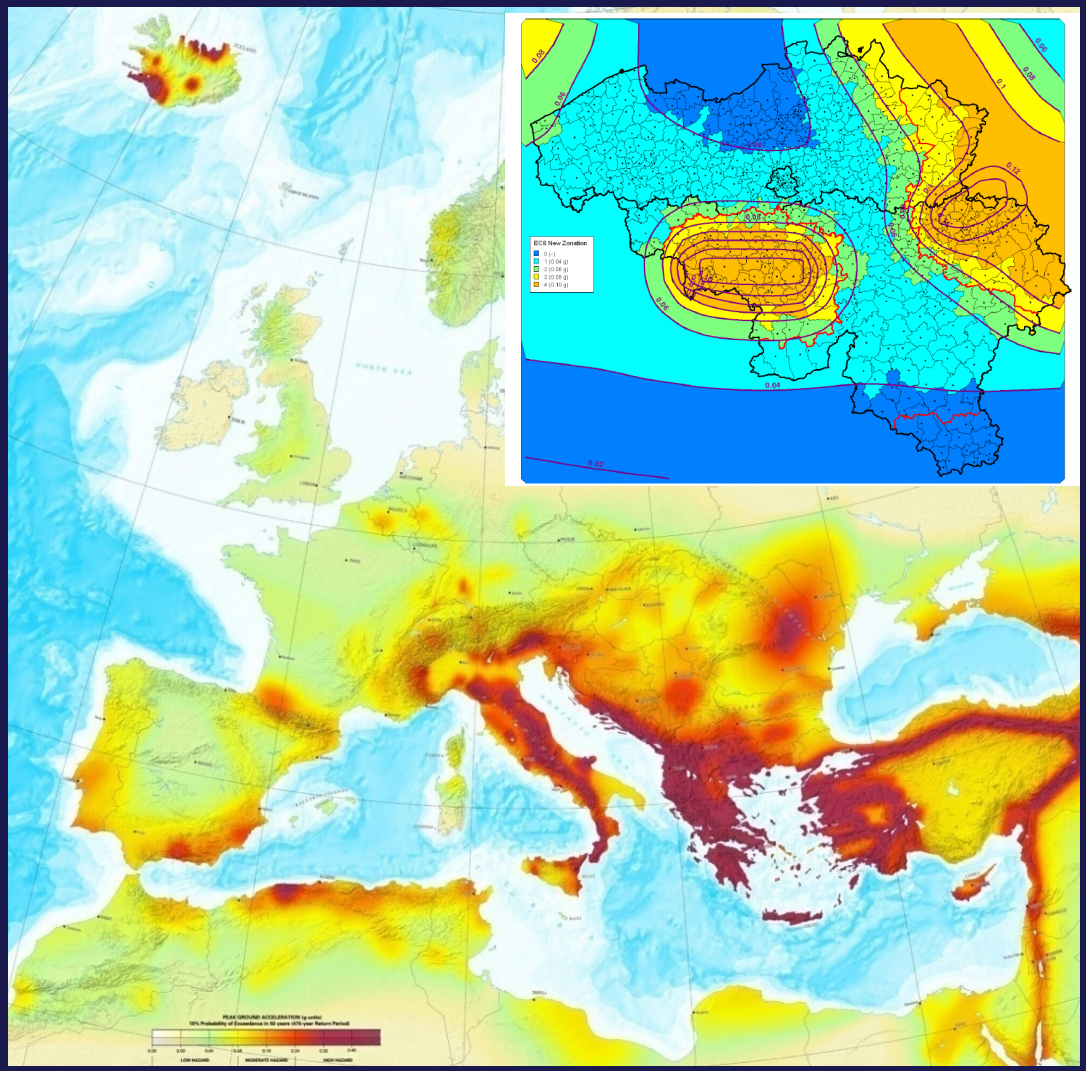
(Reiter, 1990)

And then, calculating ground motion prediction equations…

Result from the probabilistic analyze

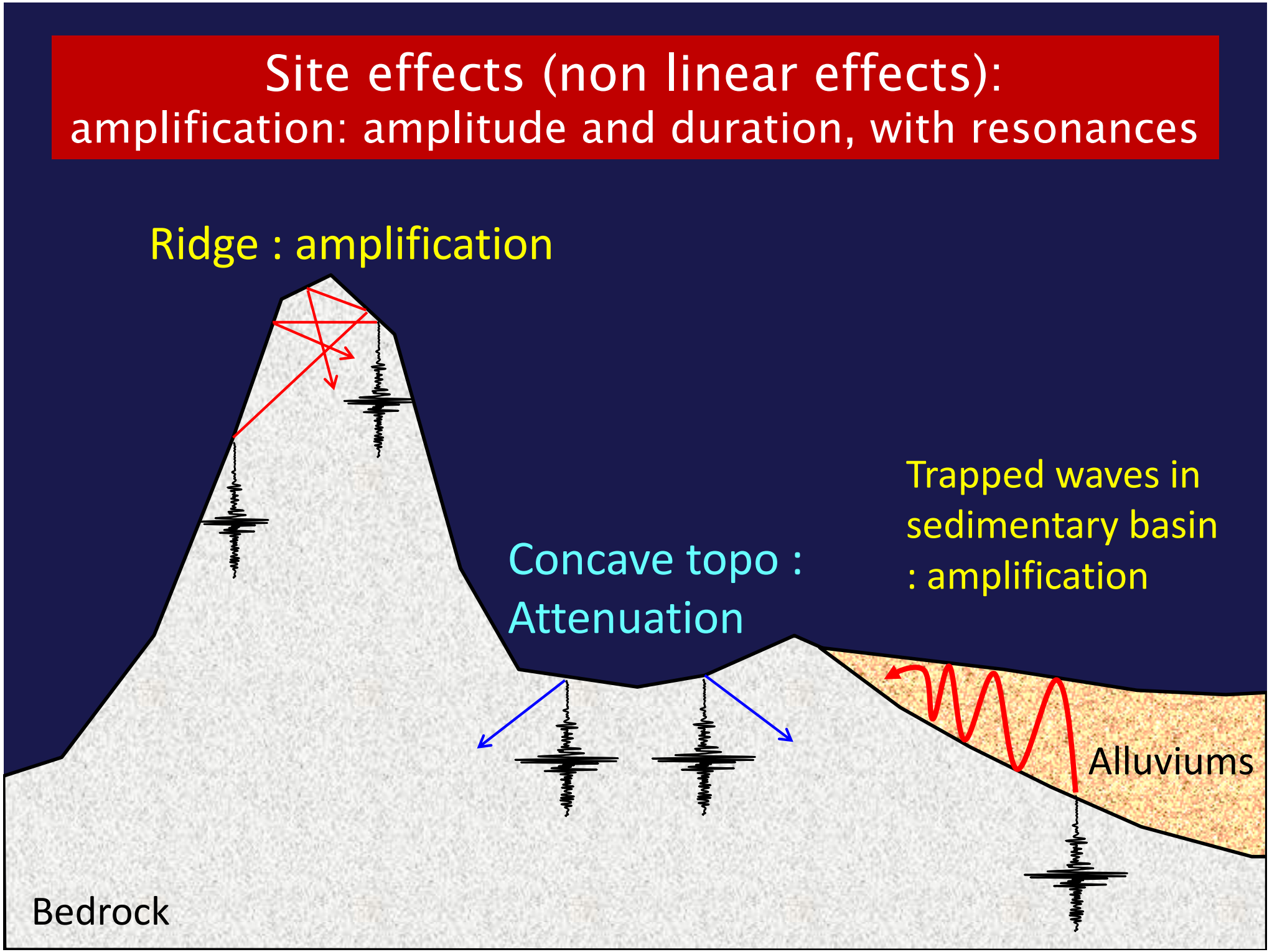


Probability of exceedance
(= 1 / return period)
at a given location
Here:
exceed 0.05 g after 475 yr,
0.15 g after 10000 yr



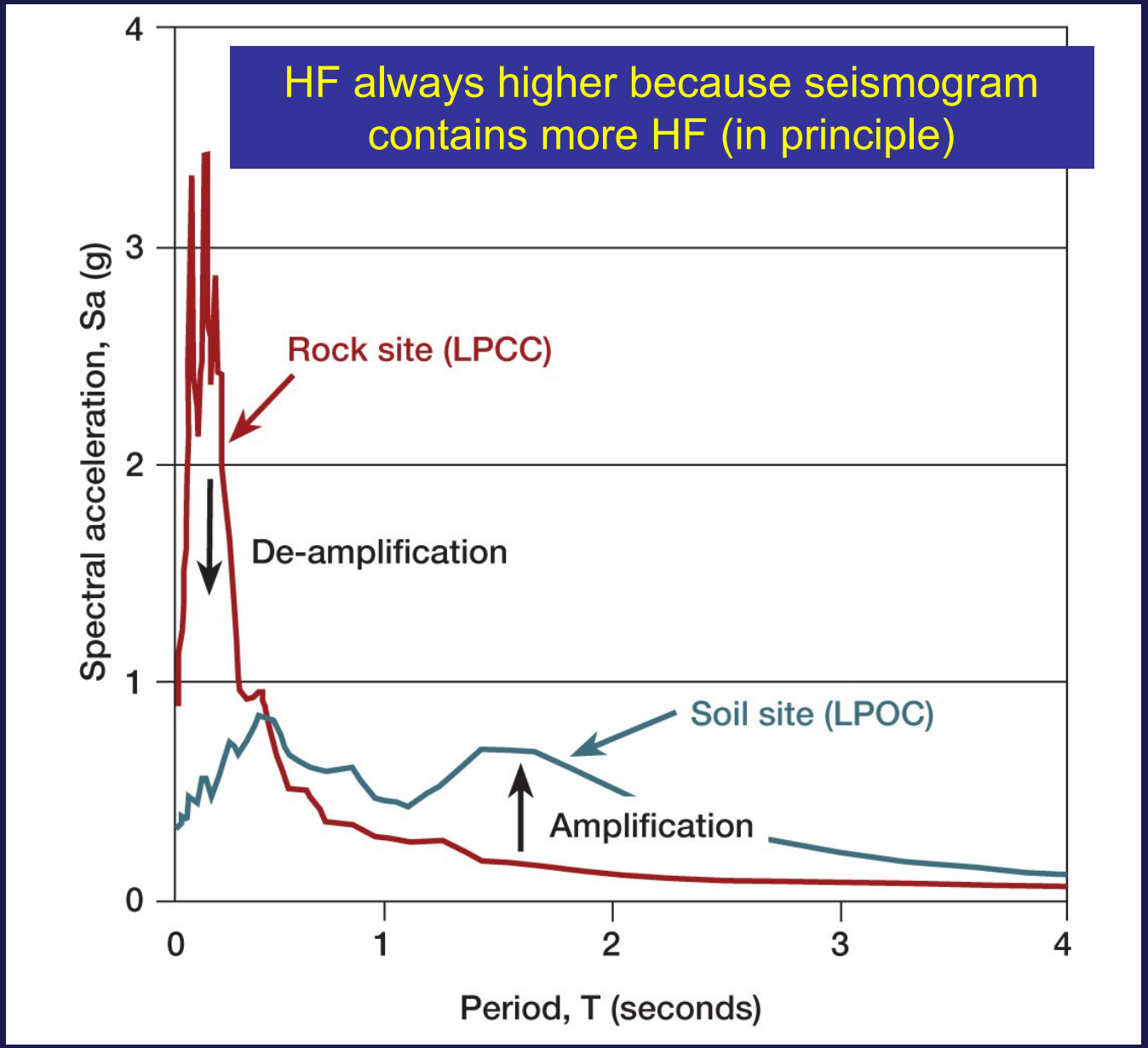
PGA European SESAME-project
Return period of 475 yr of a given acceleration
(Giardini et al., 2003)

Site effects (non linear effects):
amplification: amplitude and duration, with resonances



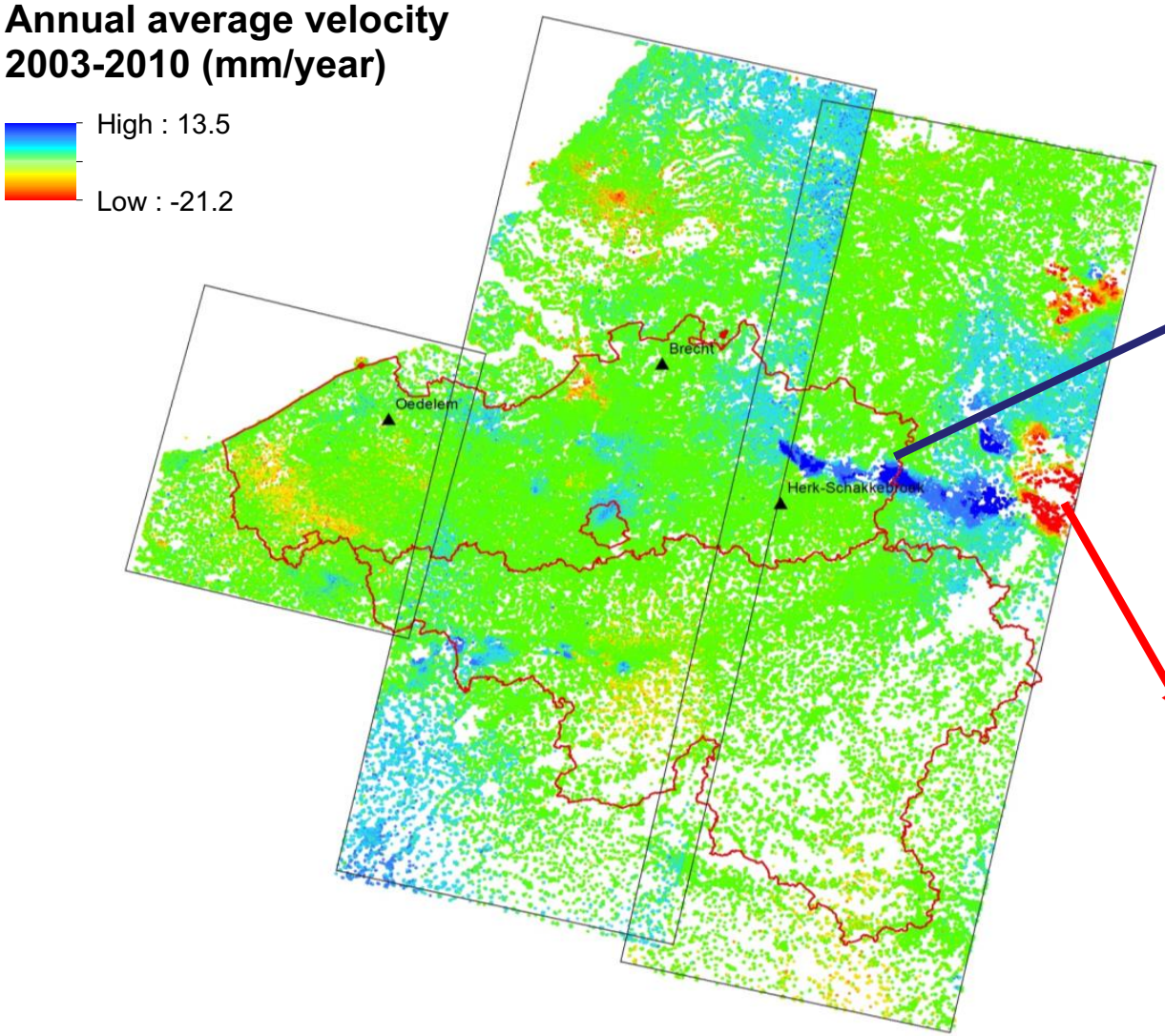
Site effects & response spectra: Effect of sediments

Highly dependent on local geology (shear strength & thickness of sediments)



http://canterbury.royalcommission.govt.nz/Interim-Report-Section-3.2

Ground movements highlighted by radar interferometry (PSInSAR)

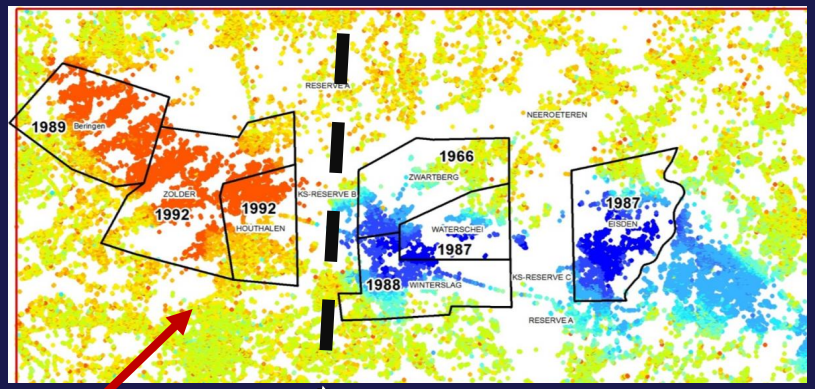


Limburg coal mines
Uplift > 1 cm/year since the closure the mines.

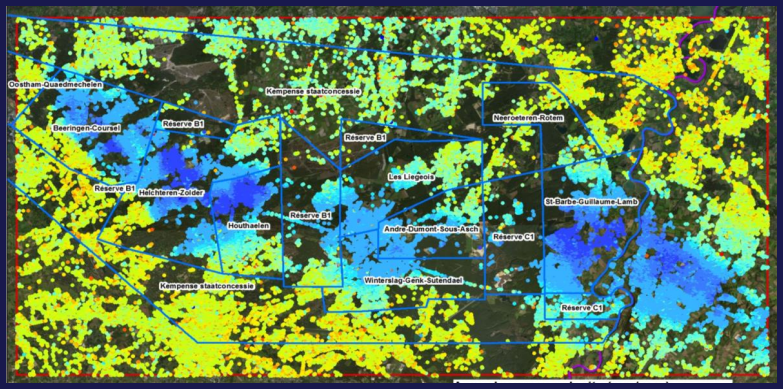
Brown coal mines
near Julich
Subsidence ~ cm/year

Difference East-West, evolution through time

1992-2001



2003-2010



Last closed: 1992

Fault as a barrier

Velocities ranging -3/+3 cm/yr

The Einstein telescope & geophysics

1. Seismic hazard analysis, given the expected life time of the infrastructure:

→ expected ground motion

2. Slow land movements: natural, anthropogenic

3. There are earthquakes, but is not an issue (as far as I understand)

Newtonian noise

The Einstein telescope & geophysics

How this infrastructure may be useful to geoscientists?

1. Strainmeters,: unique opportunity to determine strain rates ($<10^{-9}$ /yr) in continental stable zone, close to active faults

2. Seismic array to monitor nuclear explosion, deep Earth studies, seismic noise…

3. Newtonian noise: what could be gained from study of environmental effects (hydrogeology, atmosphere) on geophysical measurements? And conversely…

4. Measuring coseismic displacements (as in Japan?)