The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2142-18

Advanced Conference on Seismic Risk Mitigation and Sustainable Development

10 - 14 May 2010

Probabilistic Seismic Hazard Assessment at National and Regional Scale

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NATIONAL AND REGIONAL SEISMIC HAZARD

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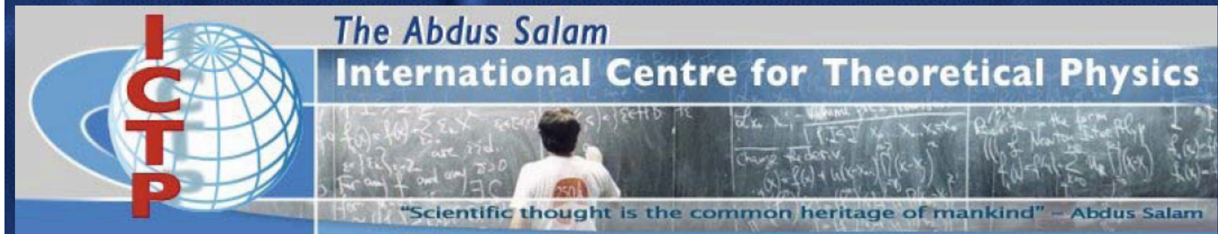


Advanced Conference on
Seismic Risk Mitigation and Sustainable Development

smr 2142, May 10-14, 2010, Trieste

Let’s start with a “strong statement”

“Earthquakes don't kill people … buildings do.

Earthquake resistant construction costs only 10% more than nonresistant construction.”

(Bilham, 1998)

RISK = HAZARD * VULNERABILITY * EXPOSED VALUE

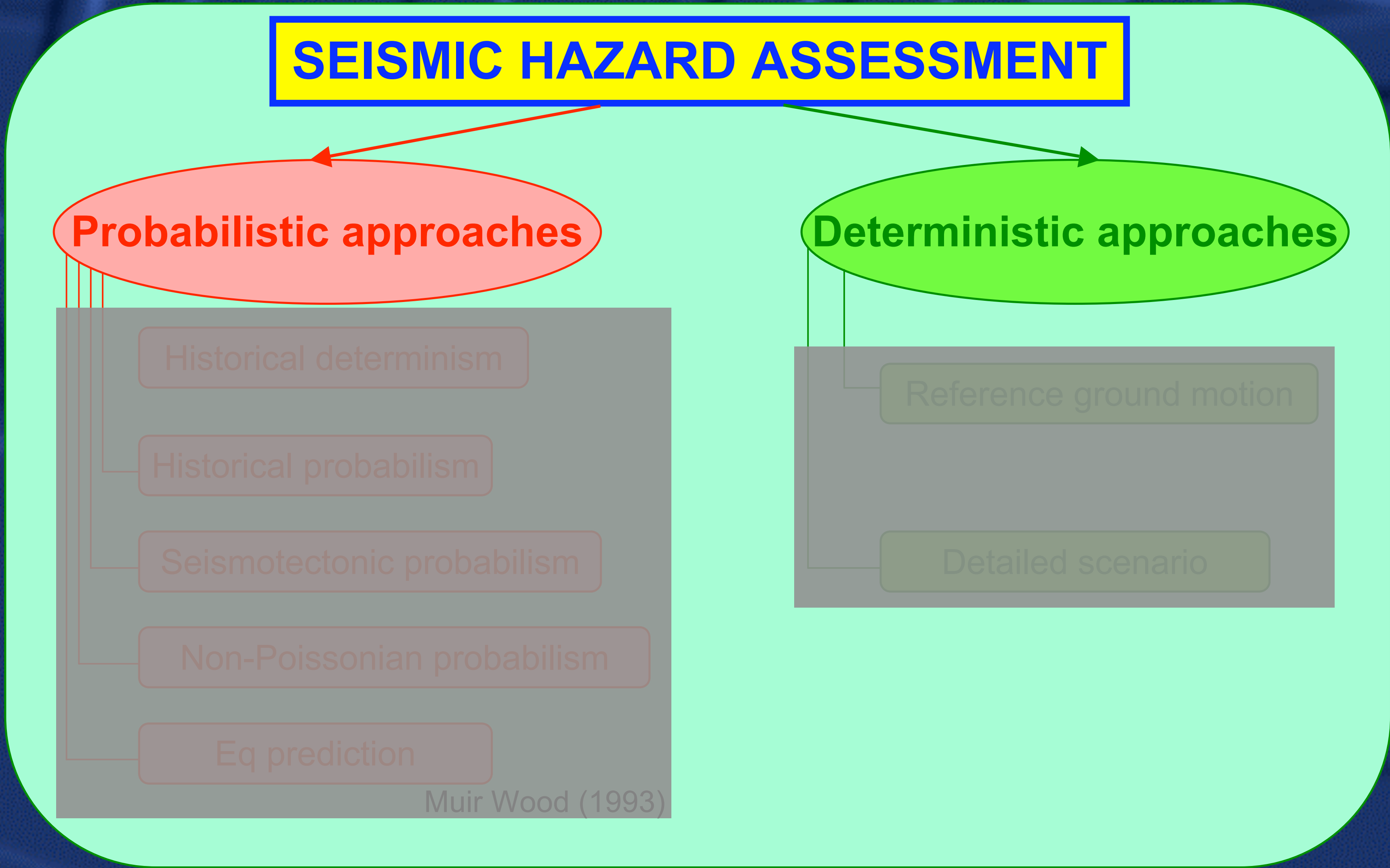
RISK = probability to observe a certain damage or loss of operativity

HAZARD = probability to observe a certain ground shaking (acceleration, intensity, etc.) in a fixed time period

VULNERABILITY = tendency of the study item (building, complex system, etc.) to suffer damage or modifications

EXPOSED VALUE = (economic, social, etc.) quantification of the study item

Approaches for SHA



Deterministic Approach (1)

- Select a small number of individual earthquake scenarios: M, R (Location) pairs
- Compute the ground motion for each scenario (typically use ground motion with 50% or 16% chance of being exceeded if the selected scenario earthquake occurs
- Select the largest ground motion from any of the scenarios

Deterministic approach (2)

(Abrahamson, 2006)

• Select a specific magnitude and distance (Maximum Credible Earthquake)

• Design for ground motion, not earthquakes
– Ground motion has large variability for a given magnitude, distance, and site condition
– Key issue: What ground motion level do we select?
Worst-case ground motion is not selected in deterministic approach
Combing largest earthquake with the worst-case ground motion is too unlikely a case
– The occurrence of the maximum earthquake is rare, so it is not “reasonable” to use a worstcase ground motion for this earthquake
– Chose something smaller than the worst-case ground motion that is “reasonable” (by tradition, select median or 84th percentile, worst-case ground motion is much higher)

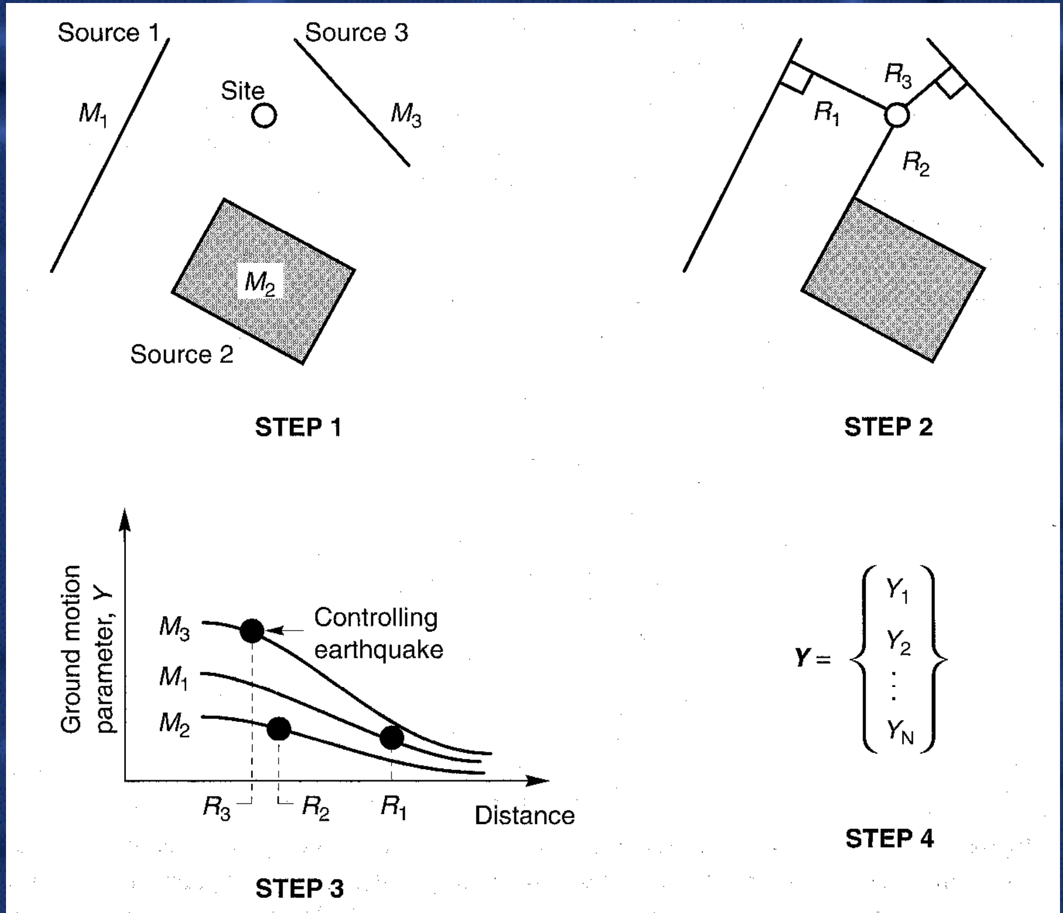
Steps of the deterministic approach

1. Identification and characterization of all earthquake sources capable of producing significant ground motion at the site.

2. Selection of a source-to-site distance parameter for each source zone. In most DSHAs, the shortest distance between the source zone and the site of interest is selected.

3. Selection of the controlling earthquake (i.e., the earthquake that is expected to produce the strongest level of shaking), generally expressed in terms of some ground motion parameter, at the site.

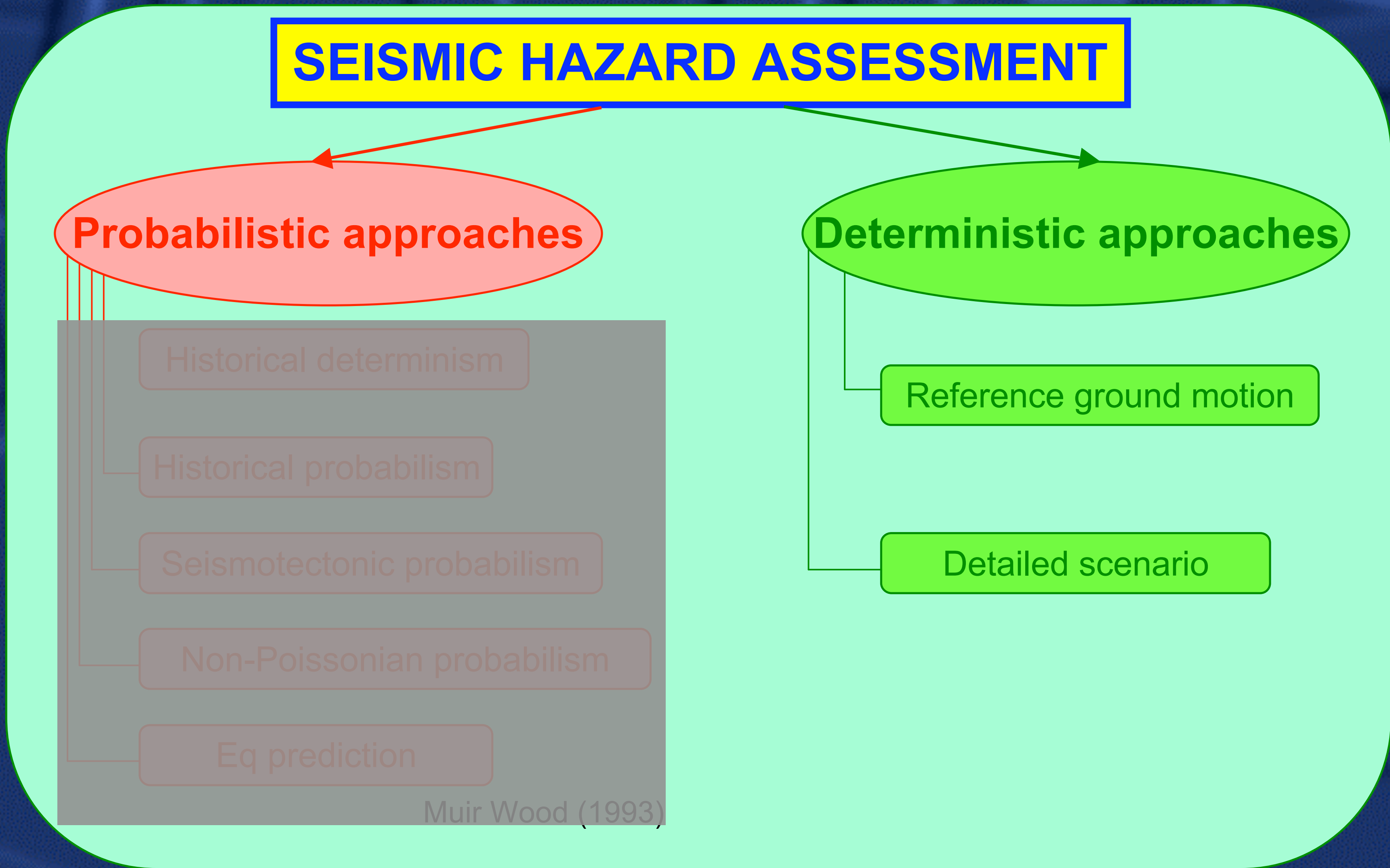
4. The hazard at the site is formally defined, usually in terms of the ground motions produced at the site by the controlling earthquake. Its characteristics are usually described by one or more ground motion parameters obtained from predictive relationships.



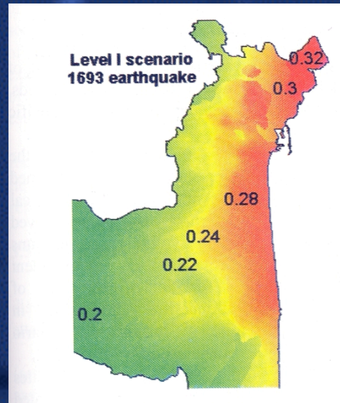
MCE, DBE, SSE, MPE, OBE

Over the years there have been many terms used to describe earthquake potential; among them the maximum credible earthquake (MCE), design basis earthquake (DBE), safe shutdown earthquake (SSE), maximum probable earthquake (MPE), operating basis earthquake (OBE), and seismic safety evaluation earthquake. The MCE, for example, is usually defined as the maximum earthquake that appears capable of occurring under the known tectonic framework. The DBE and SSE are usually defined in essentially the same way. The MPE has been defined as the maximum historical earthquake and also as the maximum earthquake likely to occur in a 100-year interval. Many DSHAs have used the two-pronged approach of evaluating hazards for both the MCE and MPE (or SSE and OBE). Disagreements over the definition and use of these terms have forced the delay, and even cancellation, of a number of large construction projects. The Committee on Seismic Risk of the Earthquake Engineering Research Institute (EERI) has stated that **terms such as MCE and MPE "are misleading** ... and their use is discouraged" (EERI Committee on Seismic Risk, 1984).

Deterministic approaches



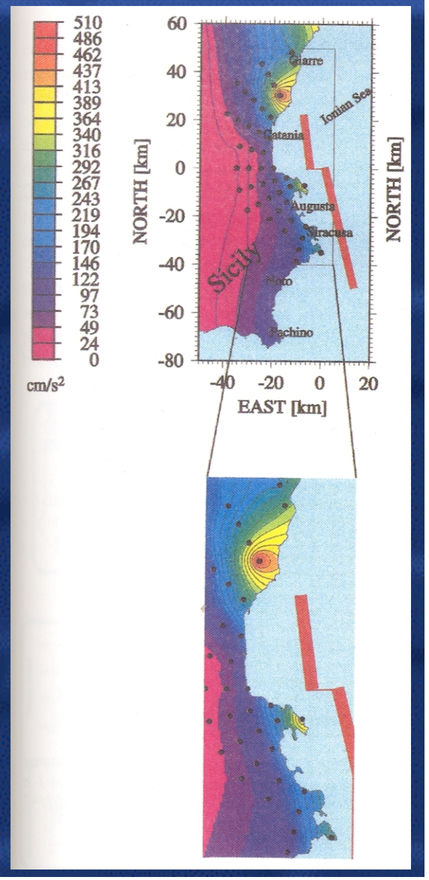
DETERMINISTIC APPROACH



(Pessina, 1999)

SOURCE CHARACTERISATION
Focus = historical & instrumental seismicity
Mechanism = geology, instrumental seismicity
Magnitude = geology, instrumental seismicity

Reference ground motion
-
Empirical attenuation relations



PATH DESCRIPTION
Intensity attenuation = historical seismicity
acceleration attenuation = instrumental seismicity

Detailed scenario
-
Modeling

SITE EFFECTS
Stratigraphy = geology, instrumental seismicity
Morphology = geology

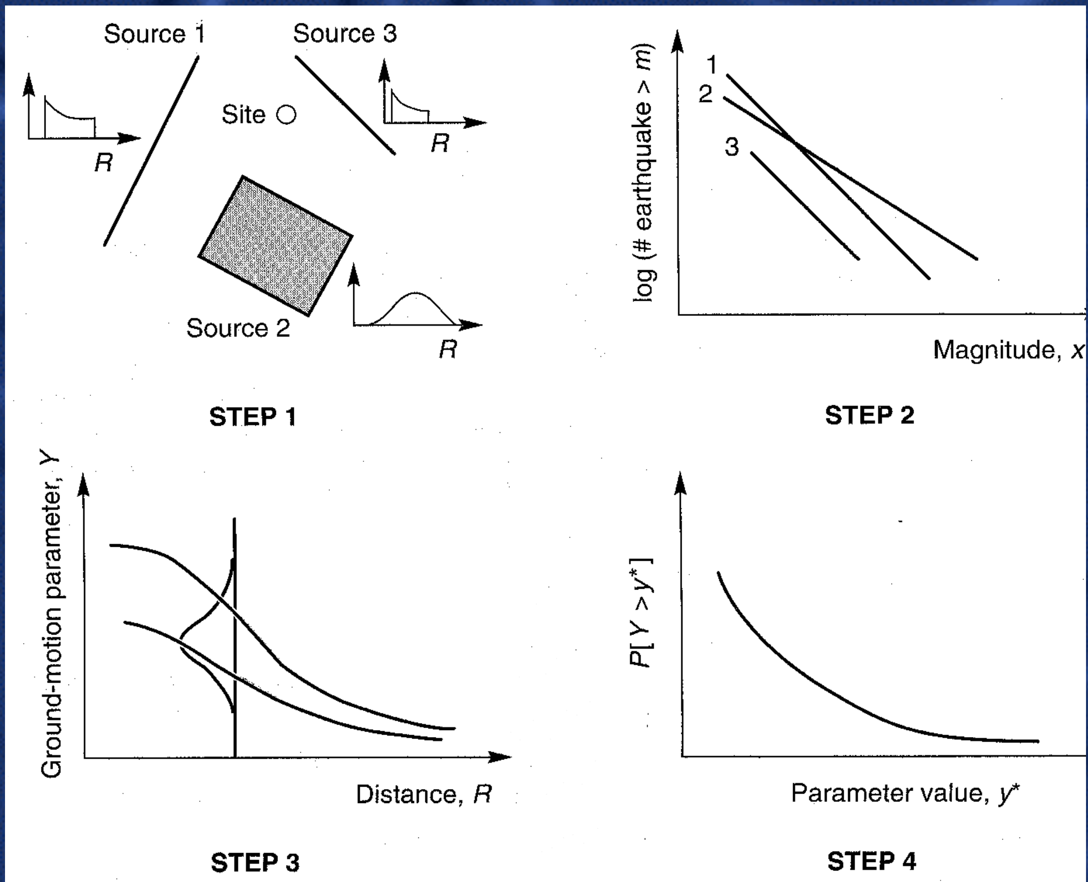
(Zollo & Emolo, 1999)

Probabilistic Approach (1)

- Source Characterization
  - Develop a comprehensive set of possible scenario earthquakes: M, R (location)
  - Specify the rate at which each scenario earthquake (M, R) occurs
- Ground Motion Characterization
  - Develop a full range of possible ground motions for each earthquake scenario (ε=number of std dev above or below the median)
  - Specify the probability of each ground motion for each scenario
- Hazard Calculation
  - Rank scenarios (M,R, e) in order of decreasing severity of shaking
  - Table of scenarios with ground motions and rates
  - Sum up rates of scenarios (hazard curve)
- Select a ground motion for the design hazard level
  - Back off from worst case ground motion until the sum of the rates of scenarios exceeding the ground motion is large enough to warrant consideration (e.g. the design hazard level)

PSHA according to the seismotectonic probabilism

- The 4 steps of PSHA



$$\gamma_j(C \text{ exceeds } c) = \gamma_j(C > c)$$
$$= \nu_j \iint P_j[C > c \mid \bar{s} \text{ at } l]\, P[\bar{s} \text{ at } l]\, d\bar{s}\, dl \quad (4)$$

where

γ_j = the frequency with which c is exceeded from earthquakes at source j

$\bar{s}$ = a vector of source properties

ν_j = the rate of occurrence of earthquakes of interest at source j

$P_j[C > c|\bar{s} \text{ at } l]$ = the probability that c is exceeded at the site, conditional on an earthquake at source j, with properties $\bar{s}$ at location l (the vertical line means "given that")

$P[\bar{s} \text{ at } l]$ = the probability that an earthquake with source properties $\bar{s}$ occurs at location l

The SSHAC methodology

• The methodology proposed by the Senior Seismic Hazard Analysis Committee (SSHAC) represents an up-to-date procedure for obtaining reproducible results from the application of PSHA

• The SSHAC methodology for PSHA is an example of aggregating expert opinion on a scientific issue

A properly executed PSHA project should consider:

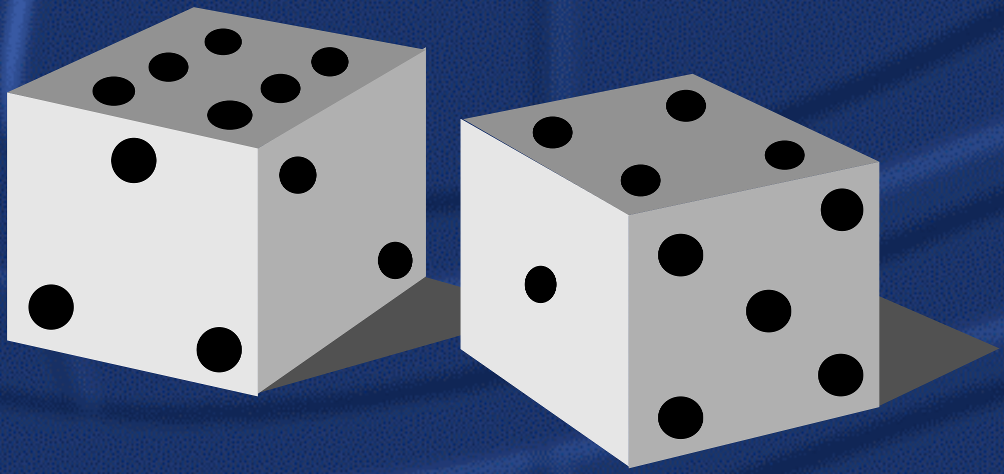
a) a representation of the legitimate range of technically supportable interpretations among the **entire** informed technical community,

b) the relative importance or credibility (weight) that should be assigned to the various hypotheses across that range.

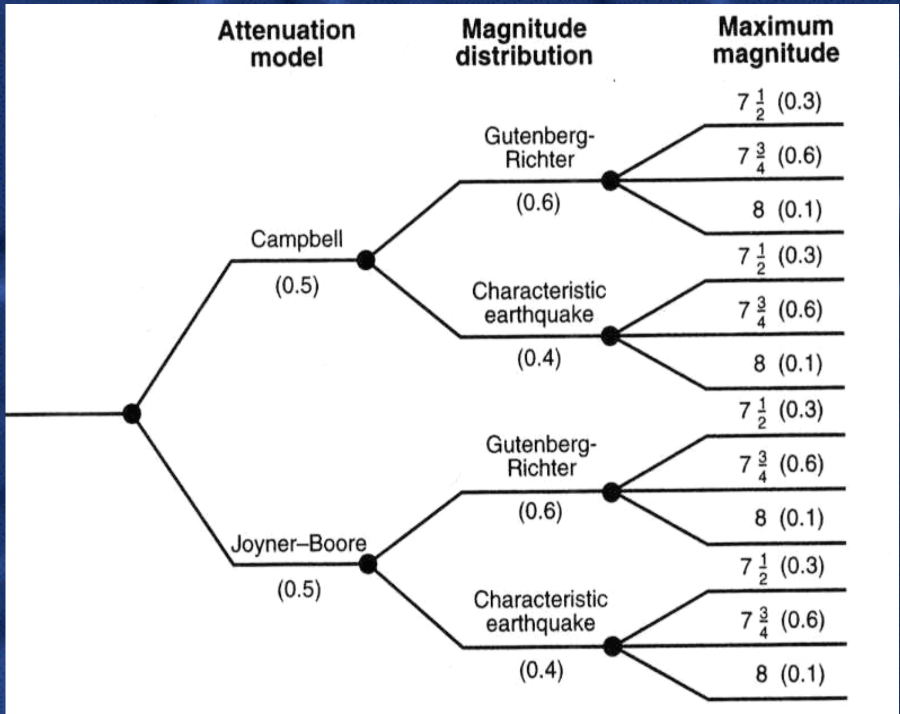
Aleatory and epistemic uncertainties

Stocastic or aleatory variability: displays the variability of different results in the same experiment. It is treated with the probability theory, e.g.: considering the standard deviation.

Scientific or epistemic uncertainty: derives from the poor knowledge of the phenomenon or from lack of data. It is treated by the use of different options.



The logic tree



Example of a logic tree for incorporating epistemic uncertainty (after Kramer, 1996).

This logic tree terminates with a total of 2x2x3=12 branches.

For example, the relative likelihood of the combination of the Campbell attenuation, Gutenberg-Richter magnitude distribution, and maximum magnitude of 7.5, is 0.5x0.6x0.3=0.09.

In this way it is possible to assign to each hazard curve, derived from the choice of particular models and parameters, the likelihood coming from the logic tree analysis, and determine the mean or median hazard curve together with confidence bands.

As we have seen, most of the modeling uncertainty in SHA is determined by expert judgment (generally reflecting the lack of data and/or of scientific knowledge). Unfortunately, scientific truth, in many aspects of SHA, may not be discernible even to the most carefully constructed polls of experts.

The purpose of SHA is to provide practical answers to practical questions. Society does not have the luxury to wait for the answers until the “truth” is discovered (Reiter,1990).

Deterministic vs. probabilistic

(Abrahamson, 2006)

- Deterministic

– Consider of small number of scenarios: Mag, dist, number of standard deviation of ground motion(ε)

– Choose the largest ground motion from cases considered

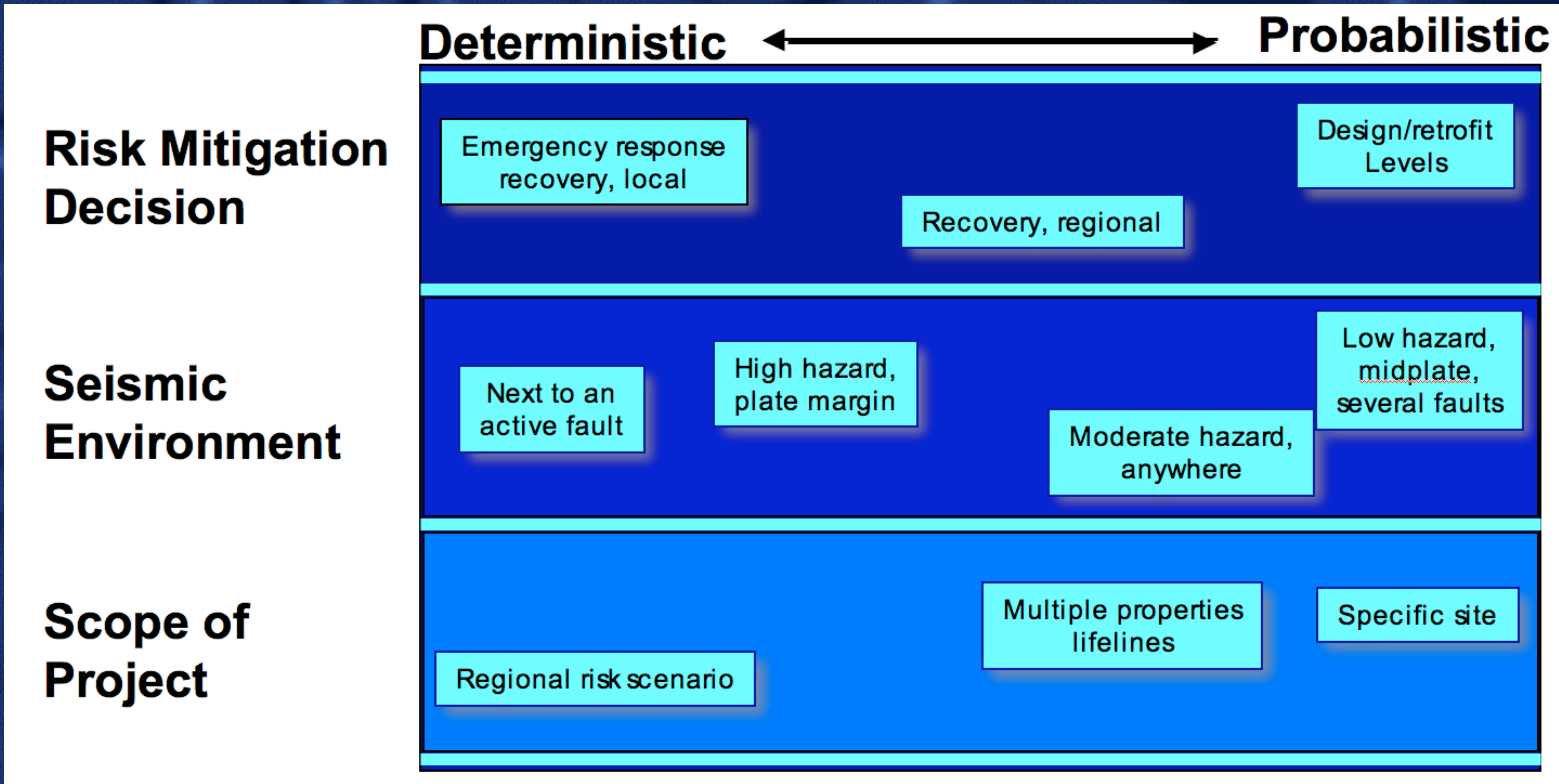
- Probabilistic

– Consider all possible scenarios: all mag, dist, and number of std dev

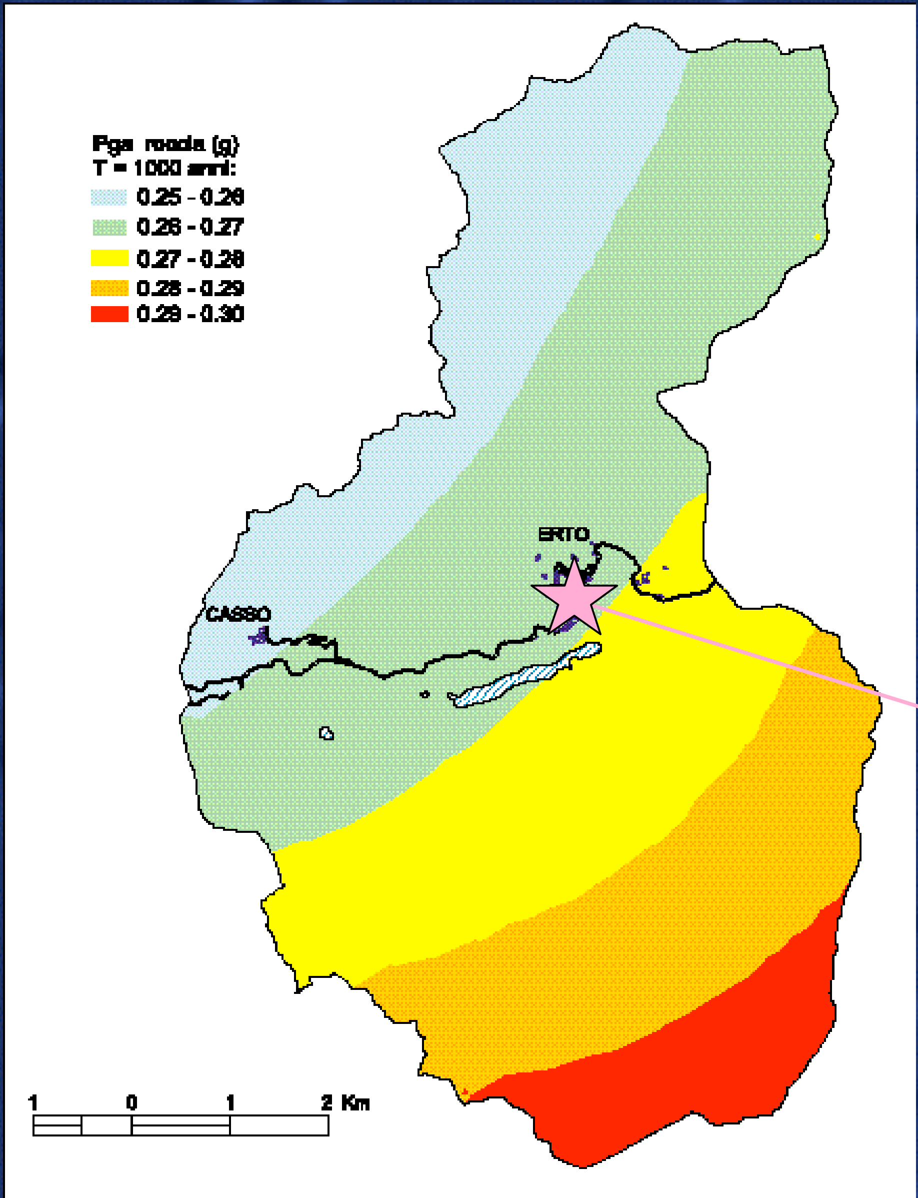
– Compute the rate of each scenario

– Combine the rates of scenarios with ground motion above a threshold to determine probability of "exceedance"

Seismic risk application in the deterministic-probabilistic spectrum



McGuire (2001)



PSHA and deterministic scenario for a site

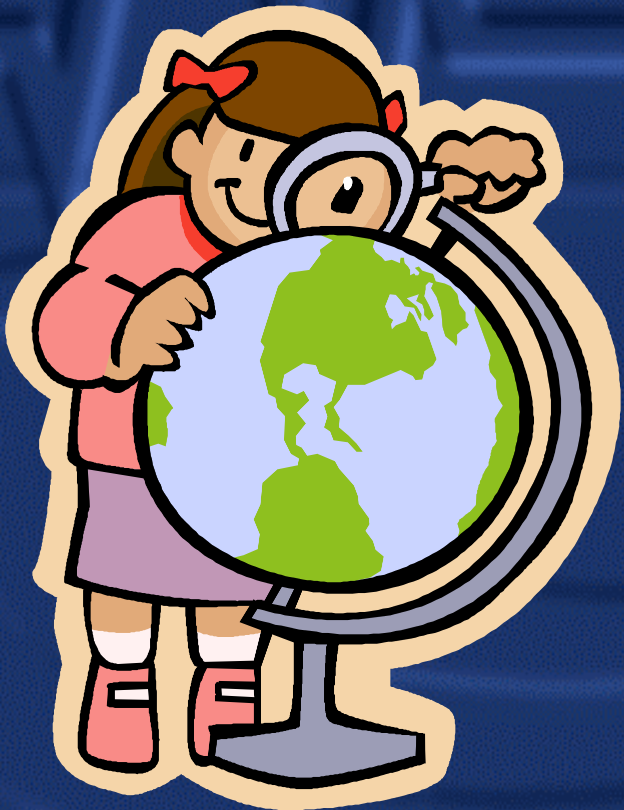
Deterministic Scenario

Regional max mag = 6.4
(Kijko and Graham 1999 method)

PGA	attenuation relation for rock
0.23	Ambraseys et al. 1996
0.30	Sabetta & Pugliese 1987
0.30	Chiaruttini & Siro 1981

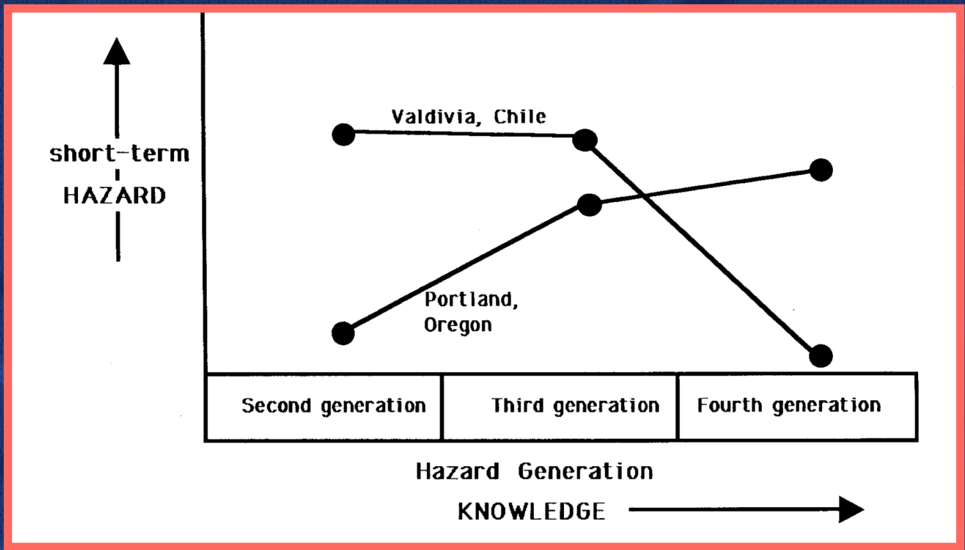
PSHA
1000-yr return period PGA on rock

Seismic hazard maps of Italy



Generations of SHA according to Muir-Wood (1993)

- Historical Determinism
- Historical Probabilism
- Seismotectonic Probabilism
- Non-Poissonian Probabilism
- Earthquake Prediction



General approach

The total probability theorem $P[E] = \int P[E \mid S] f_s(s) ds$

where $f_S(s) = \partial F_S(s) / \partial s$ is the PDF of S

and $F_S(s) = P[S < s]$ is the CDF of S

Application

Mean annual rate of exceedence

Attenuation model

$$\lambda_z = \sum_{i=1}^{N} \nu_i \int_{mo}^{mu} \int_{r=o}^{r=\infty} P(Z > z \mid m,r) f_M(m) f_R(r) dr dm$$

for all SZs

Mean annual rate of occurrence

M distribution

SZ geometry

In addition: define the earthquake occurrence model

3rd Generation Seismotectonic Probabilism (1)

The Cornell (1968) approach

3rd Generation Seismotectonic Probabilism (2)

The total probability theorem $P[E] = \int P[E \mid S] f_s(s) ds$

where $f_S(s) = \partial F_S(s) / \partial s$ is the PDF of S

and $F_S(s) = P[S < s]$ is the CDF of S

Application

$$\lambda_z = \sum_{i=1}^{N} \nu_i \int_{mo}^{mu} \int_{r=o}^{r=\infty} P(Z > z \mid m, r) f_M(m) f_R(r) drdm$$

- λ_z: Mean annual rate of exceedence
- $\sum_{i=1}^{N}$: for all SZs
- ν_i: Mean annual rate of occurrence
- $P(Z > z \mid m, r)$: Attenuation model
- $f_M(m)$: GR distribution
- $f_R(r)$: uniform seismicity

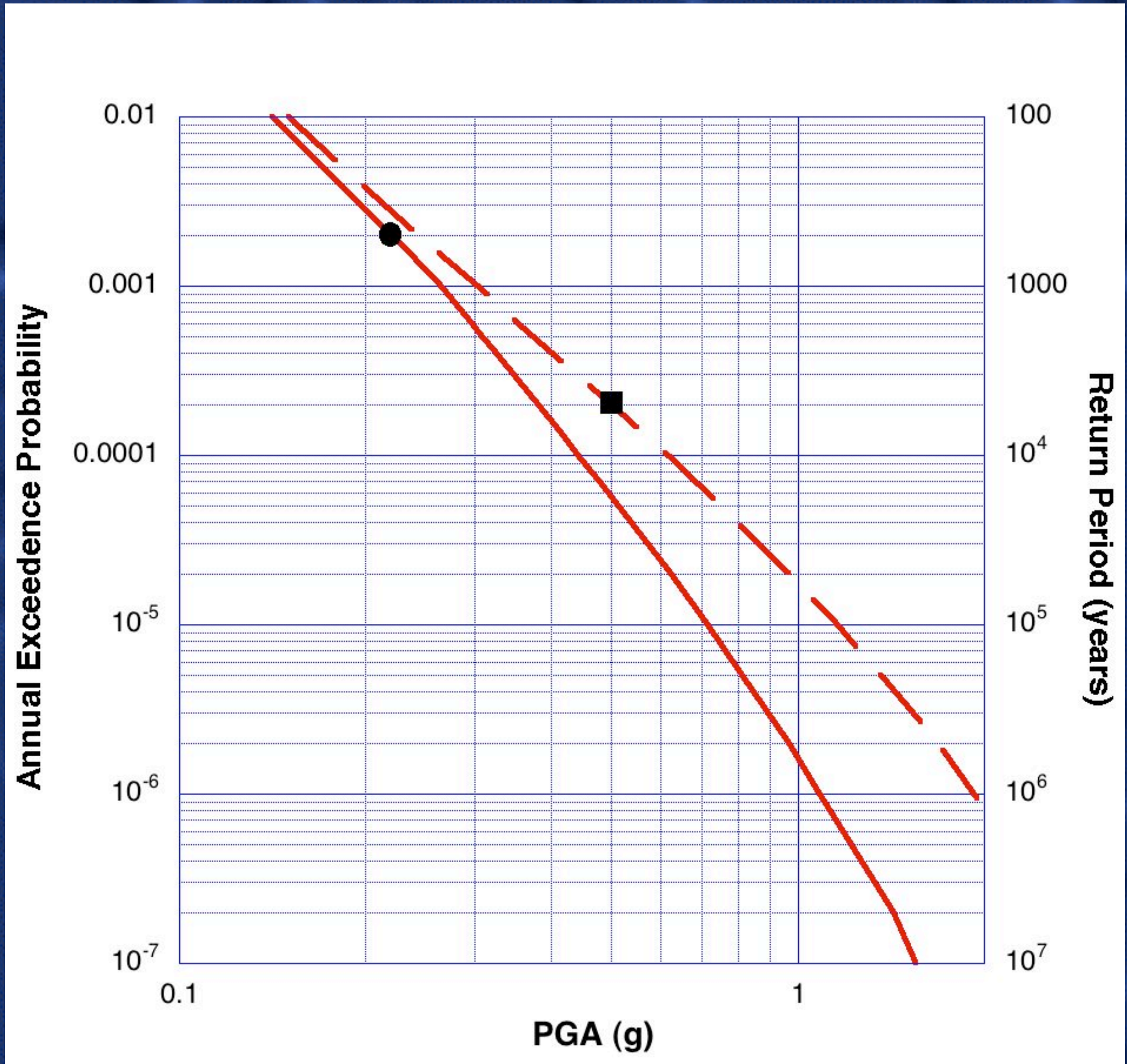
If it is a Poisson process (stationary, independent, non-multiple events)

$$P[Z_T > z] = 1 - e^{-\lambda_z T}$$

$$T = -t / \ln(1 - P(Z_T > z))$$

where: T=return period;
t=period of analysis

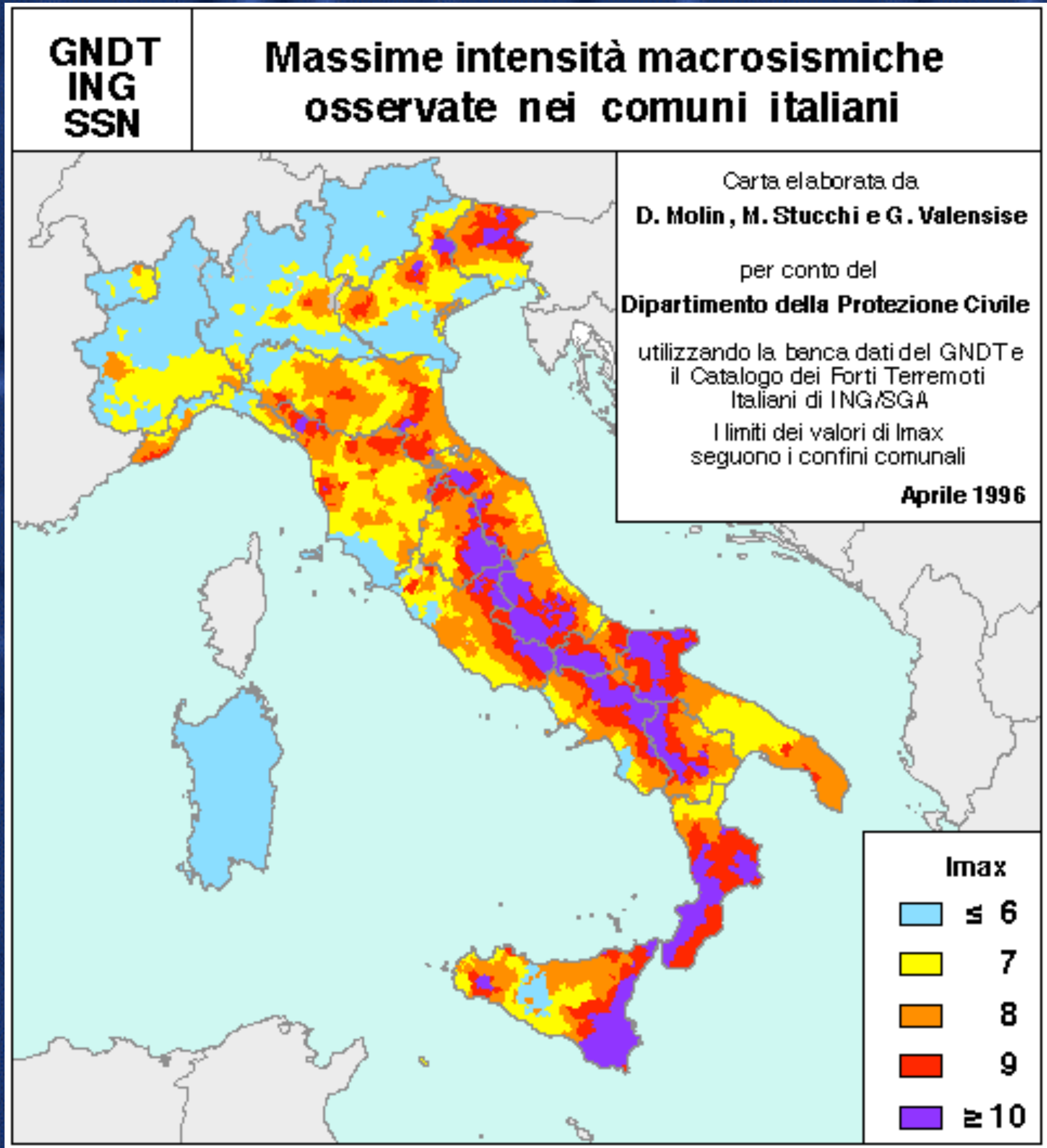
The hazard curve



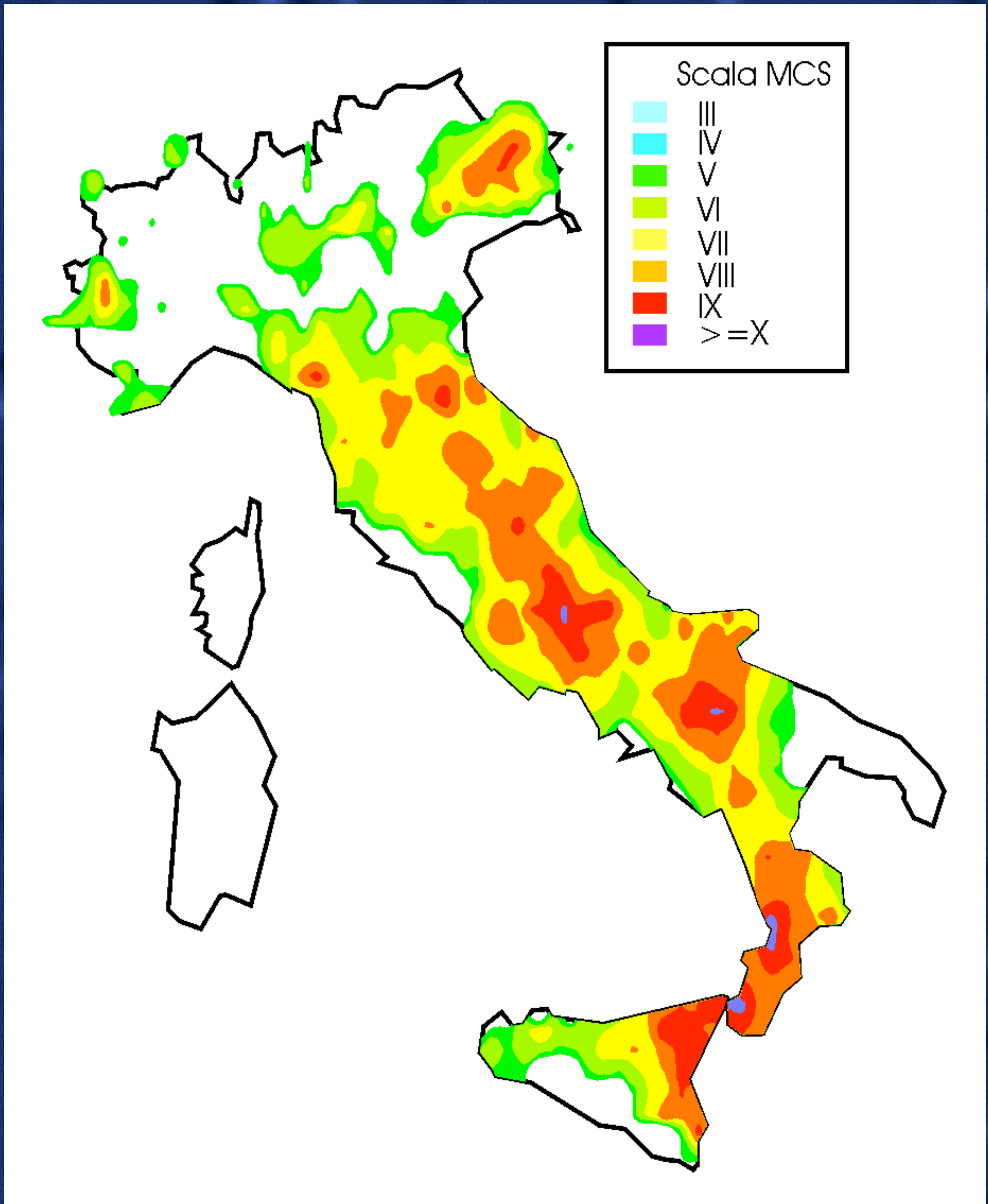
Hazard curves for a normal building (solid line) and a critical facility (dashed line) in the neighbourhood of Trieste.

For the critical facility,also the possible activity of “silent” faults has been taken into account in the logic tree approach.

1st Generation Historical Determinism

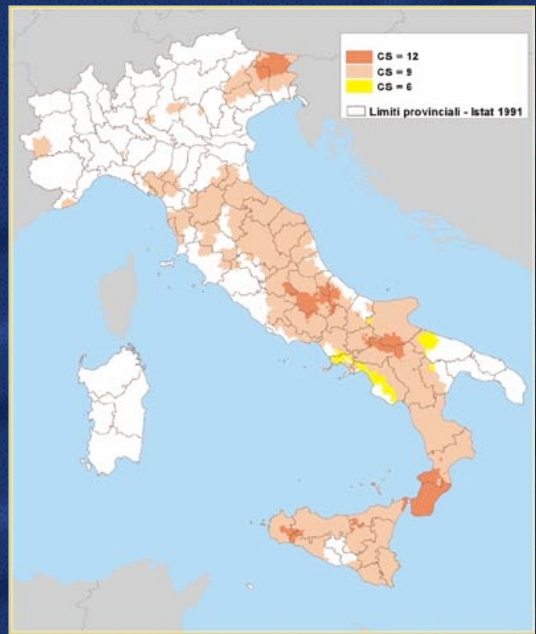


Seismic zonation in 1975



2nd Generation
Historical
Probabilism

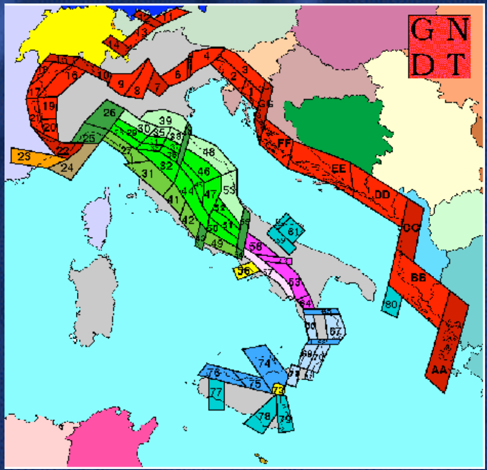
1979 CNR seismic hazard map
used as basis of the1980-1984
national seismic zonation
Gumbel statistics
on the PFG earthquake catalogue



3rd Generation: Seismotectonic Probabilism (1)

Seismic hazard map of Italy
GNDT 1990-1995

- Seismotectonic zonation
- Eq catalogue revision
- Ground motion estimation



WIDE SEISMOGENIC ZONES

NT4.1, un catalogo parametrico
di terremoti di area italiana al di sopra della soglia del danno

a parametric catalogue
of damaging earthquakes in the Italian area

per i giochi di hazard

a cura di
Romano Camassi e Massimiliano Stucchi

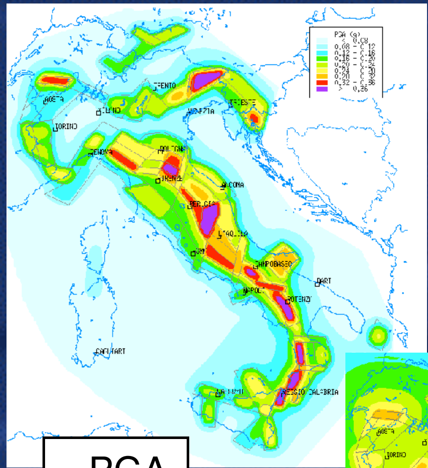
aggiornamento marzo 1998

DOM4.1, un database di osservazioni macrosismiche
di terremoti di area italiana al di sopra della soglia del danno
an intensity database
of damaging earthquakes in the Italian area

il dato è tratto

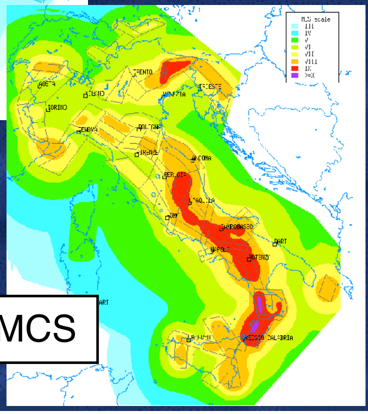
a cura di
Giancarlo Monachesi e Massimiliano Stucchi

CATALOGUE & DATABASE

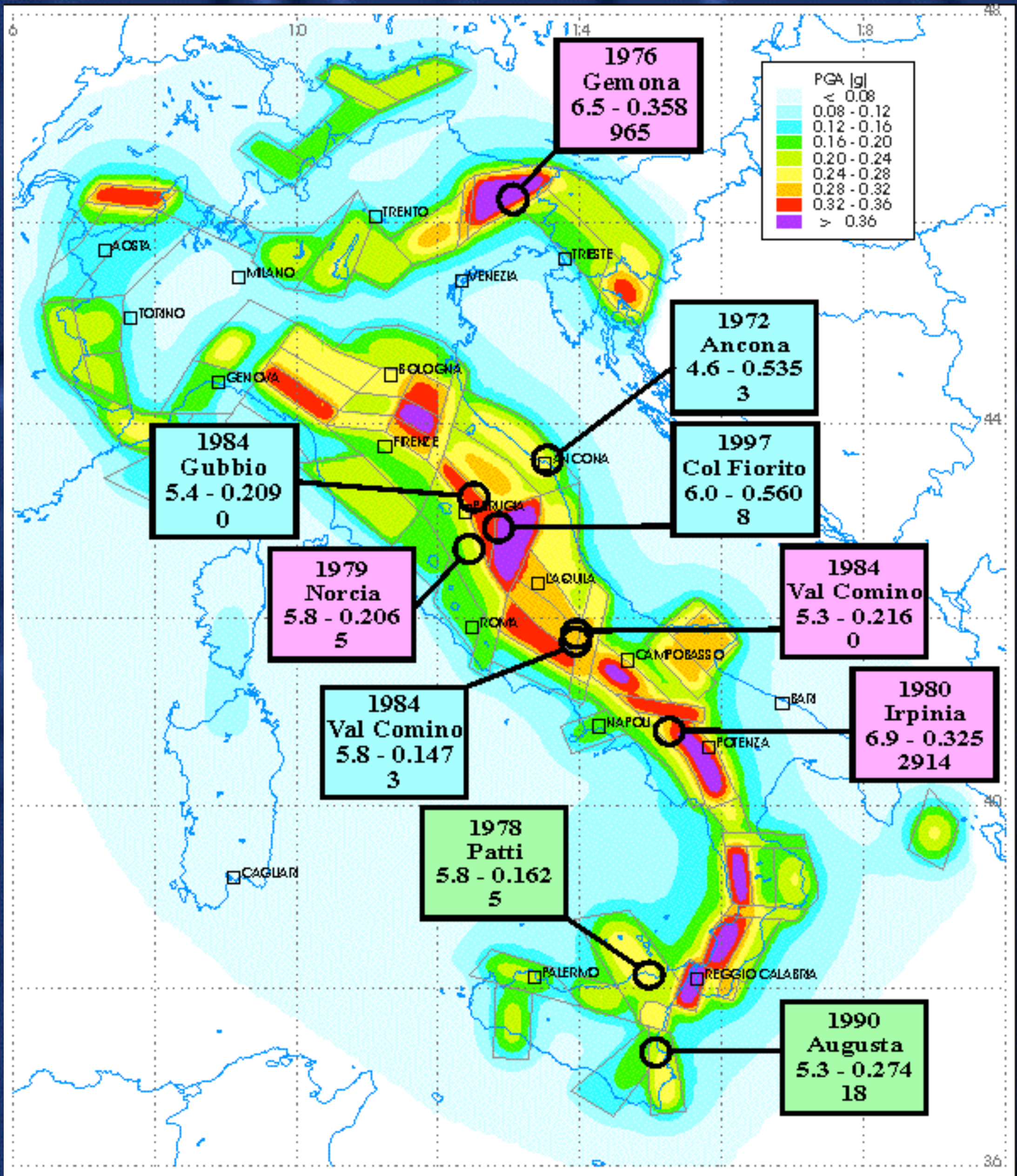


PGA

1996



MCS



3rd Generation: Seismotectonic Probabilism (2)

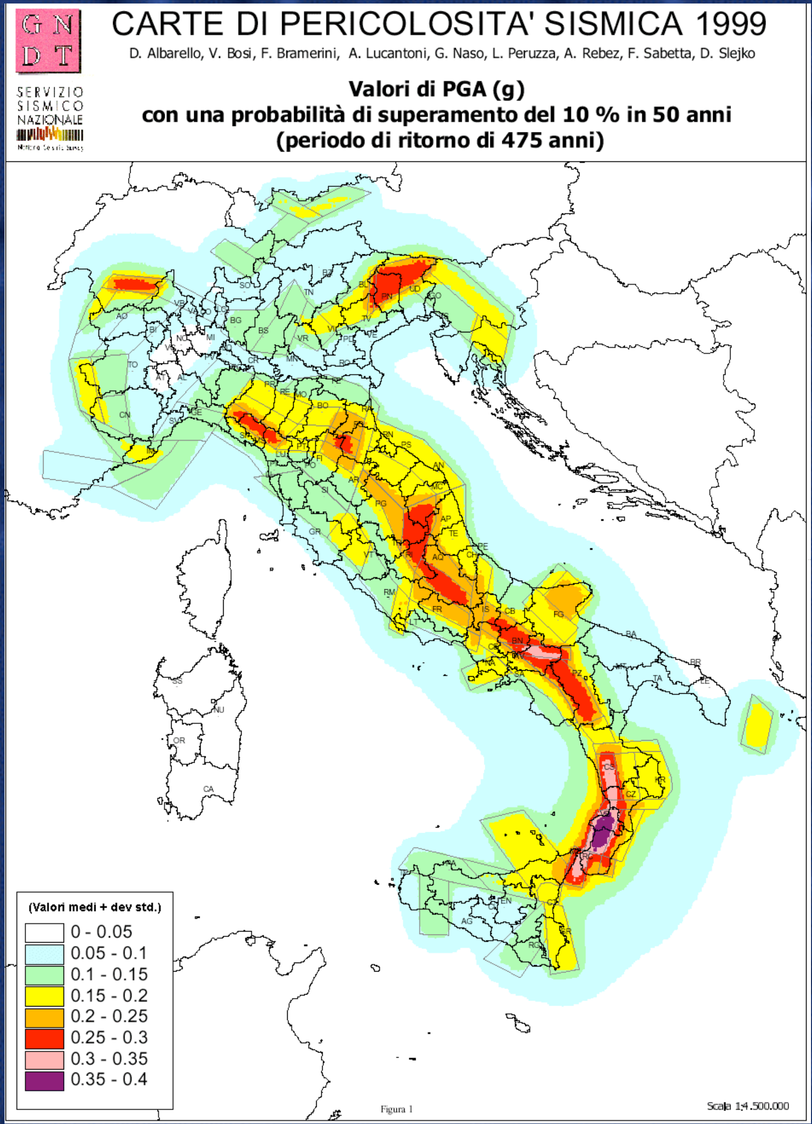
Gruppo Nazionale per la Difesa dai Terremoti

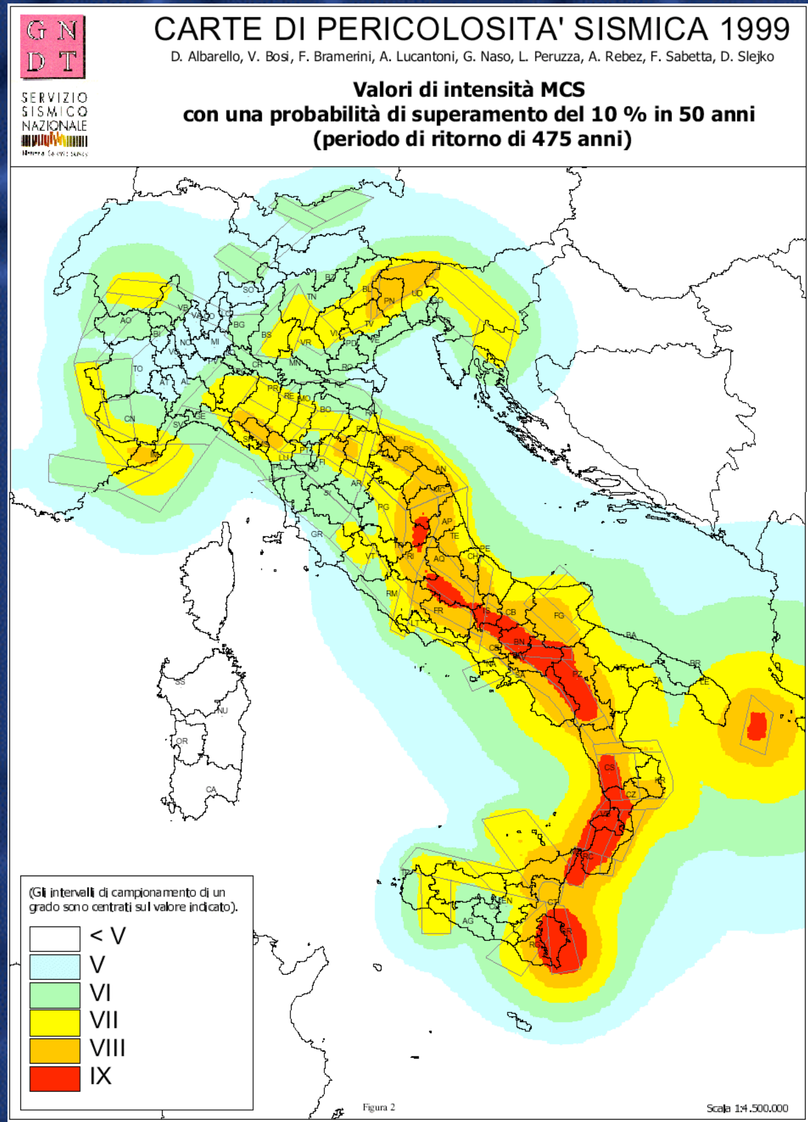
Seismic Hazard Map of Italy

475-yr return period PGA
on an average soil

In color boxes
(red=rock, blue=stiff soil, green=soft soil):
year, place, magnitude, max recorded PGA,
and number of deaths for recent eqs

"Consensus" seismic hazard maps (1): basic products for the 2003 national seismic zonation





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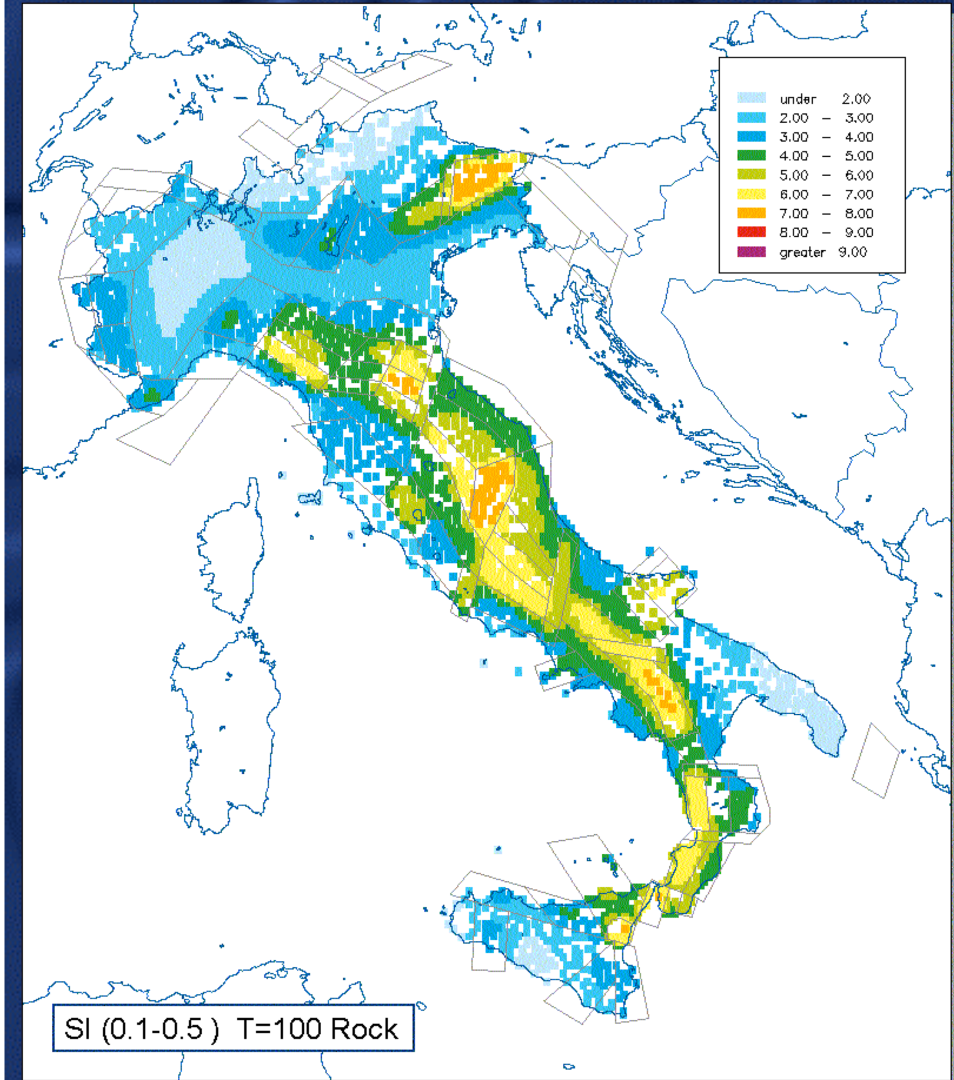
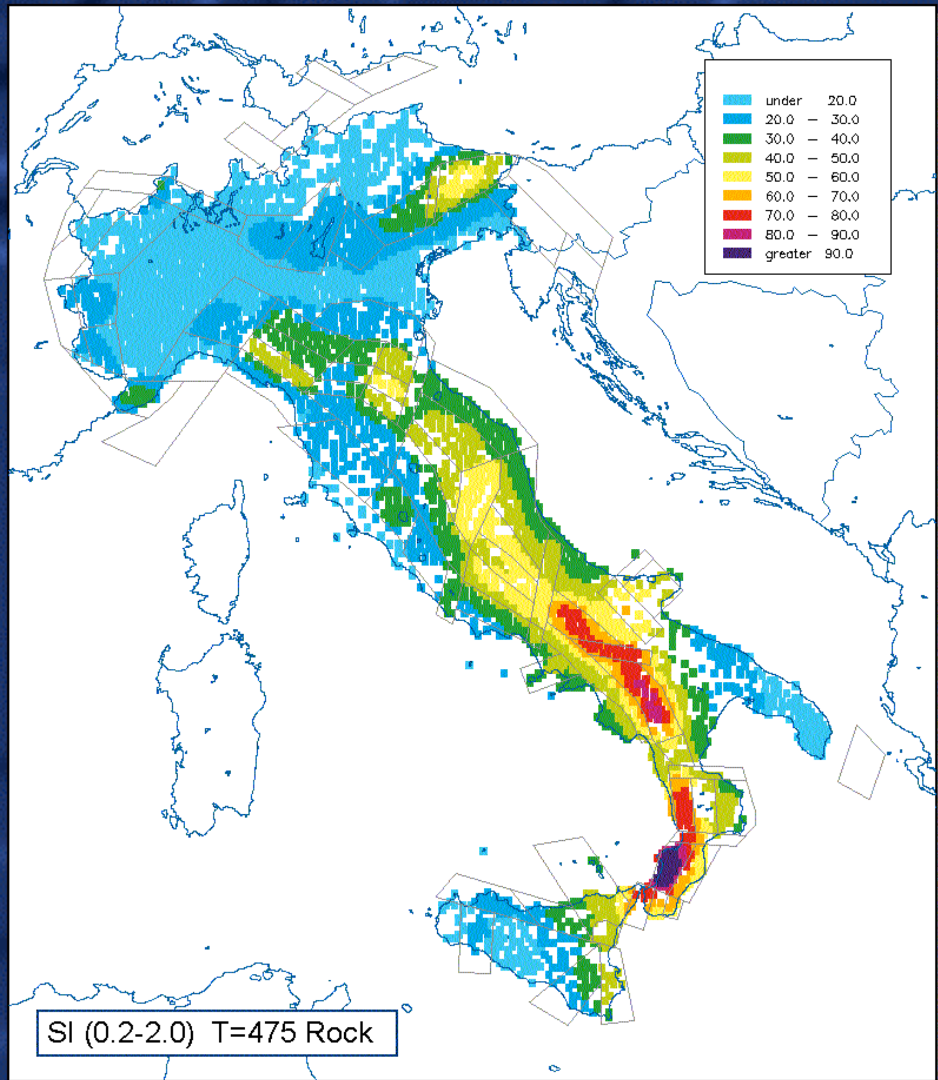
"Consensus" seismic hazard maps (2): basic products for the 2003 national seismic zonation





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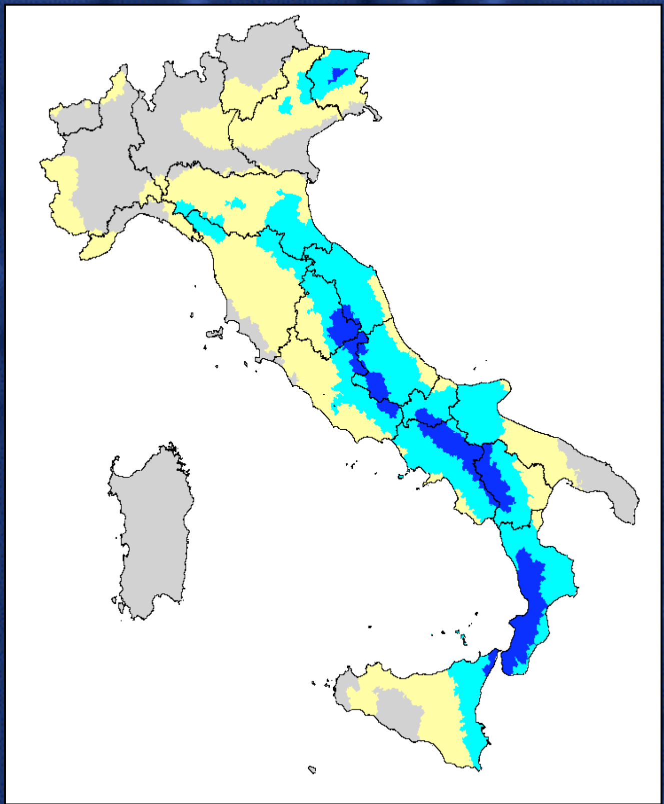
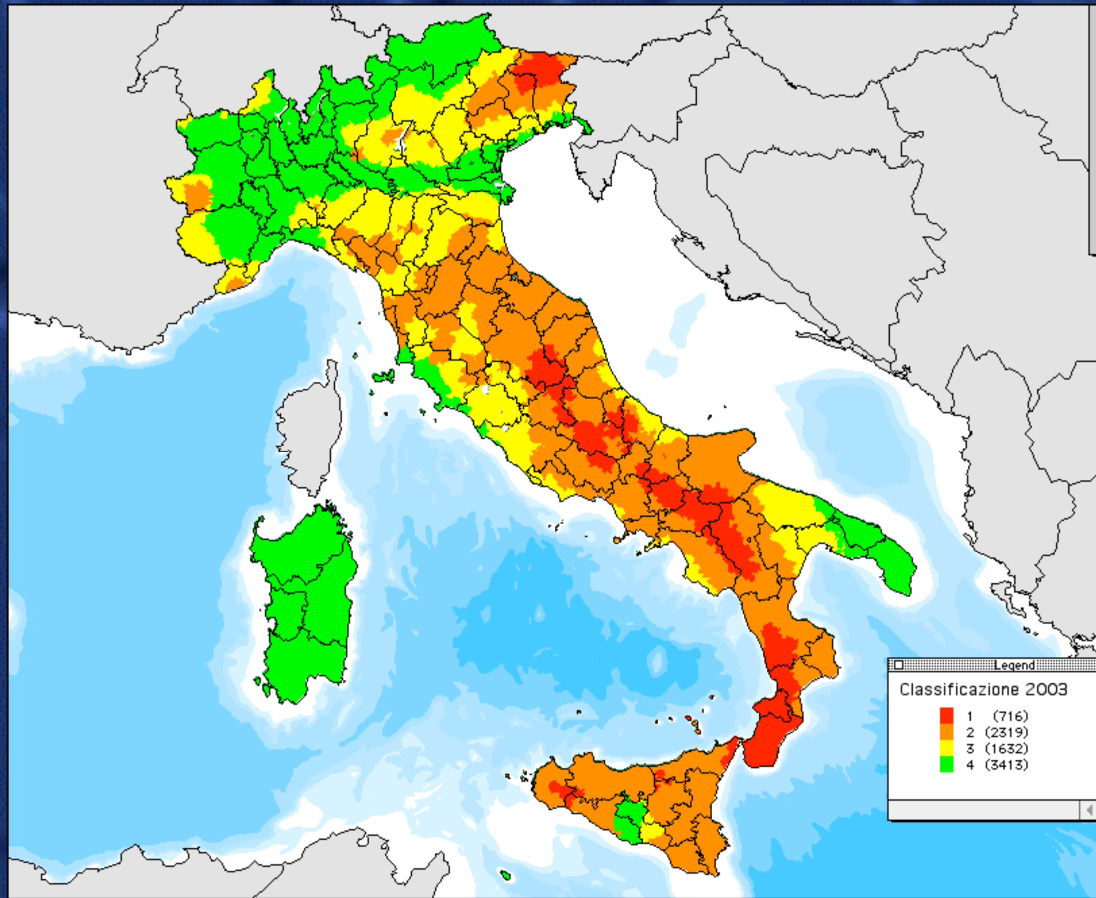
The Italian seismic zonation 2003

PROPOSAL 1999
OF SEISMIC ZONATION





ZONE 1
716 Munic. 9%

ZONE 3
1632 Munic. 20%

ZONE 2
2319 Munic. 29%

ZONE 4
3413 Munic. 42%

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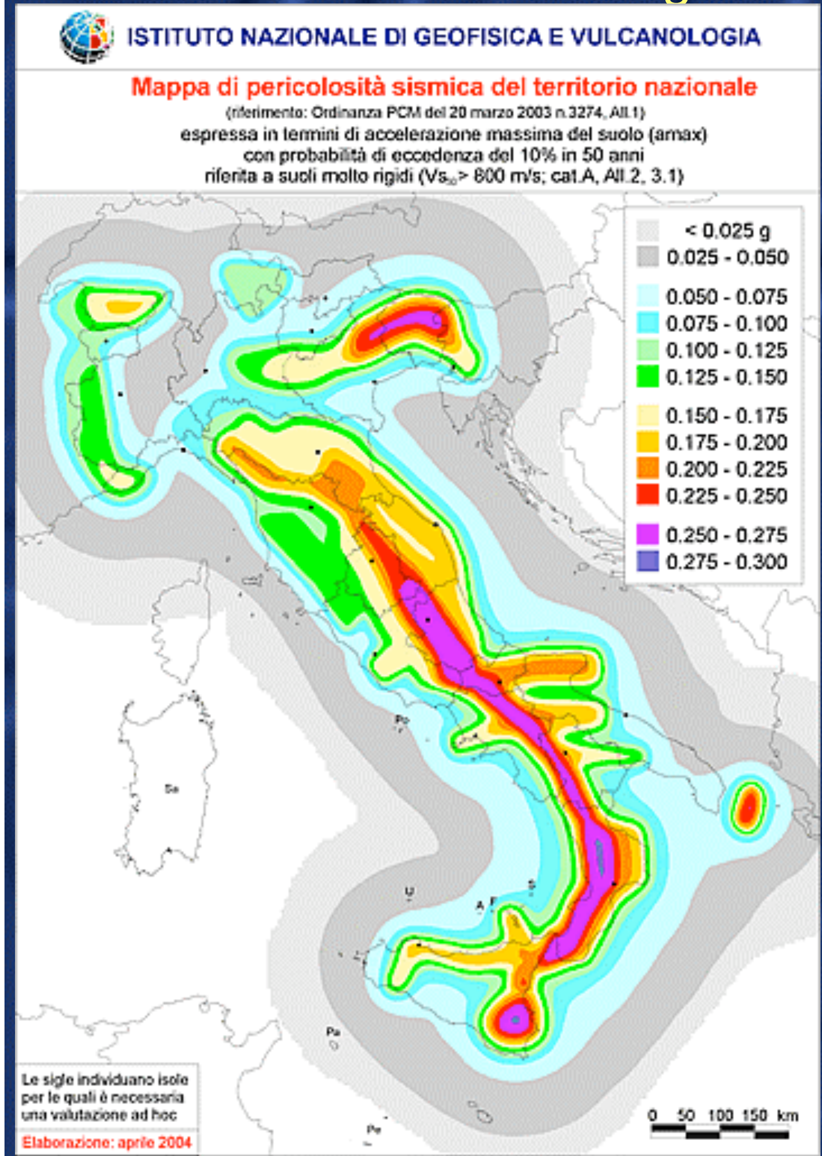
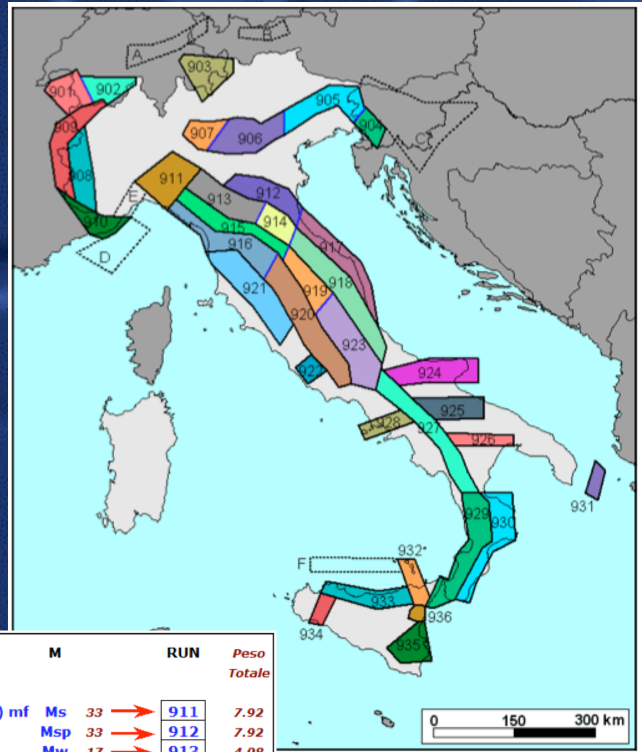
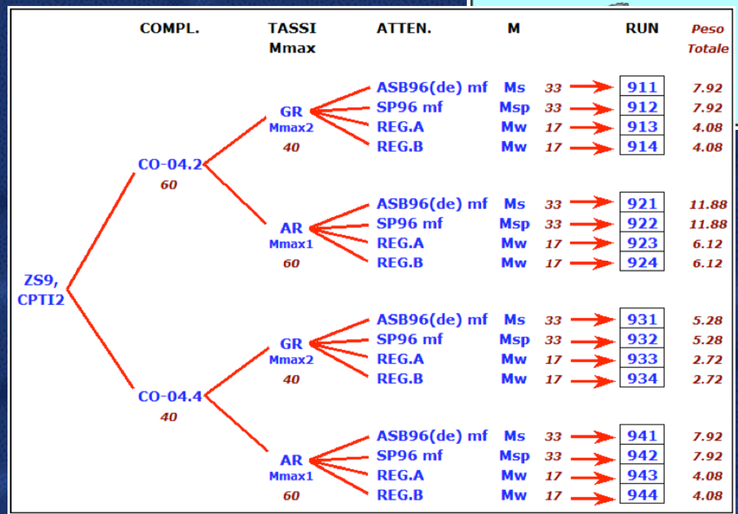
The most recent seismic hazard map of Italy in agreement with Ord. 3274



Seismic hazard map (Gruppo di Lavoro, 2004) used as basis of the present Italian seismic zonation



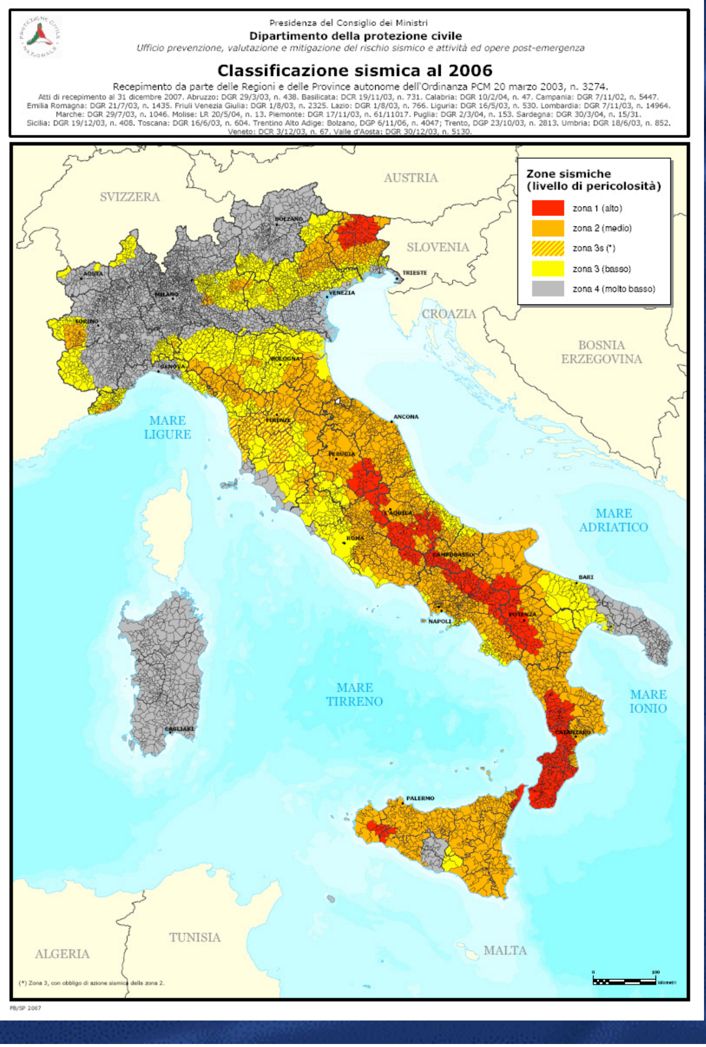


The Italian seismic code

SEISMIC CODE = SEISMIC ZONATION + BUILDING CODE

SEISMIC ZONATION = list of municipalities with similar seismic hazard used for design checking decisions (regional law based on the INGV map)

BUILDING CODE = technical rules for designing new buildings and retrofitting old ones based on the uniform hazard response spectrum of the site (see the INGV web site)



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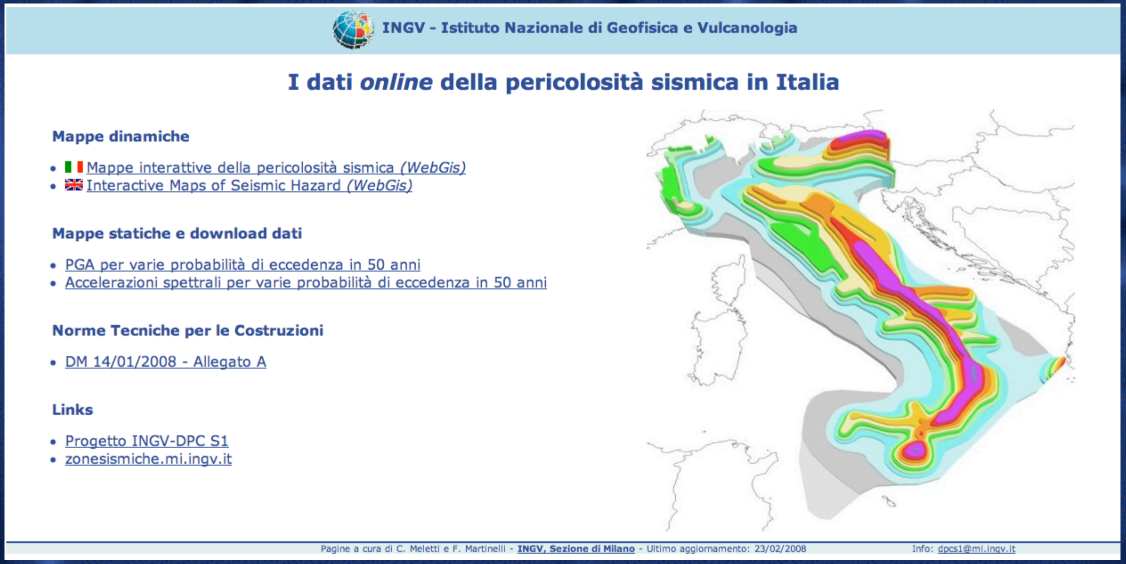
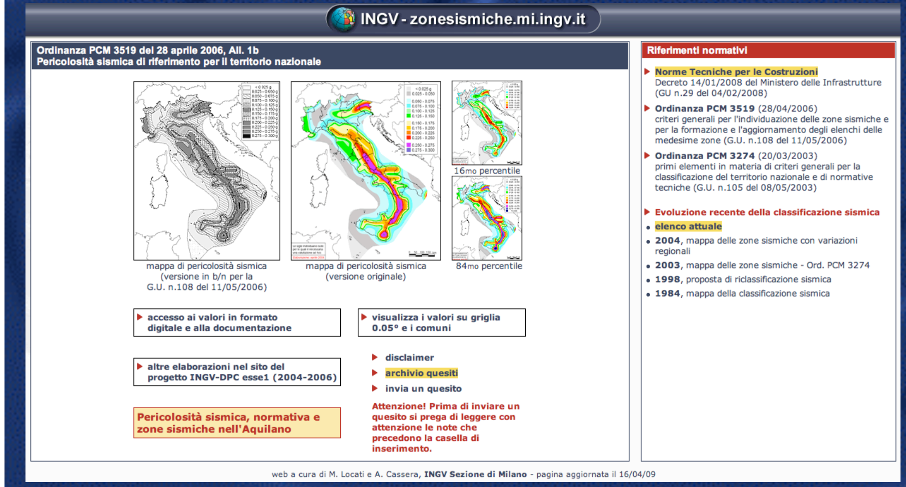
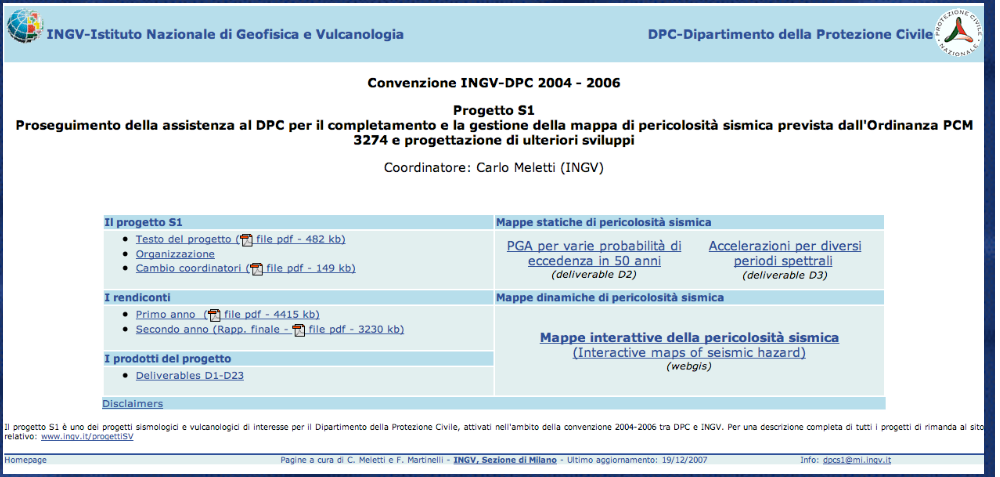
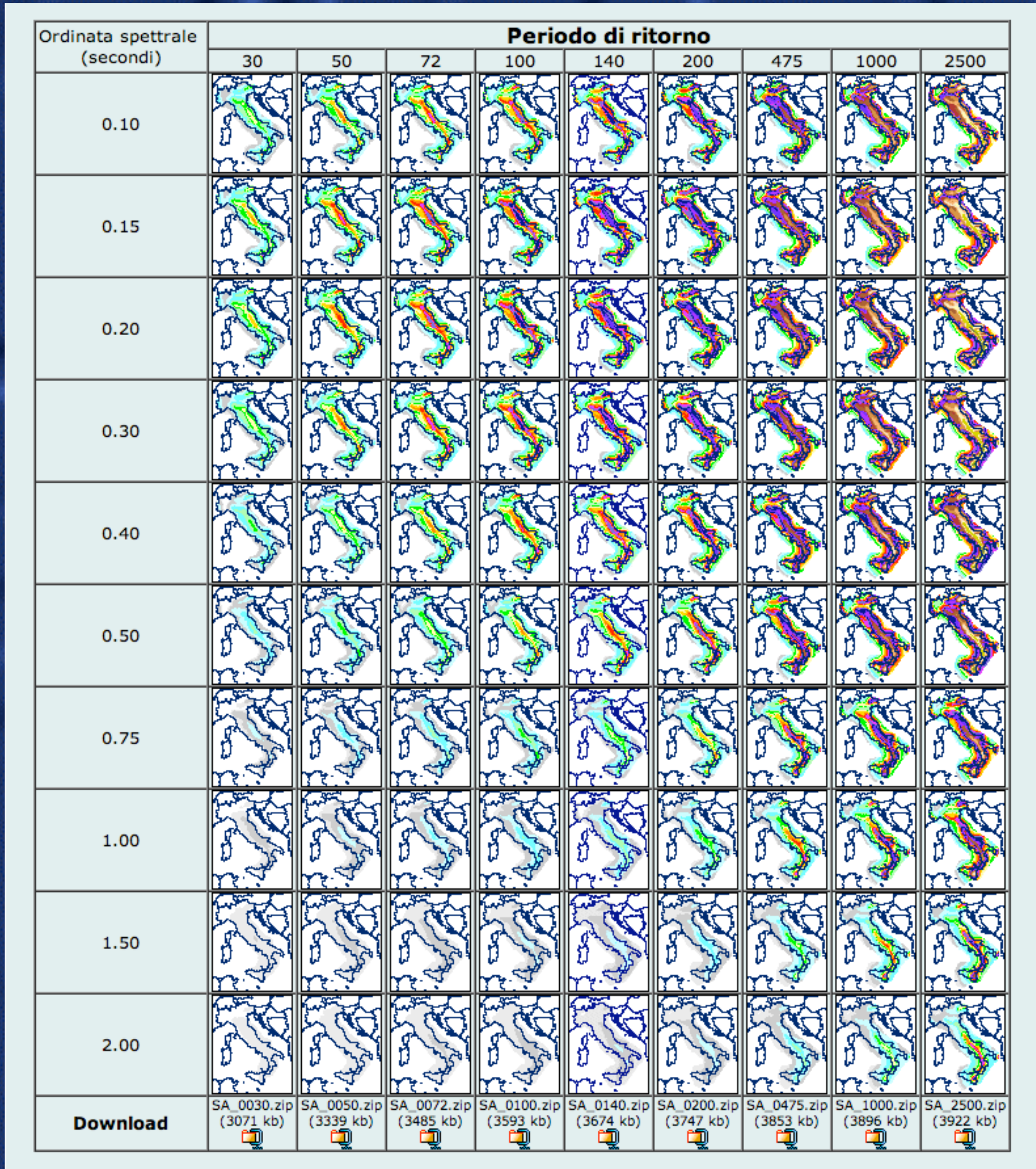
The Italian seismic hazard web site





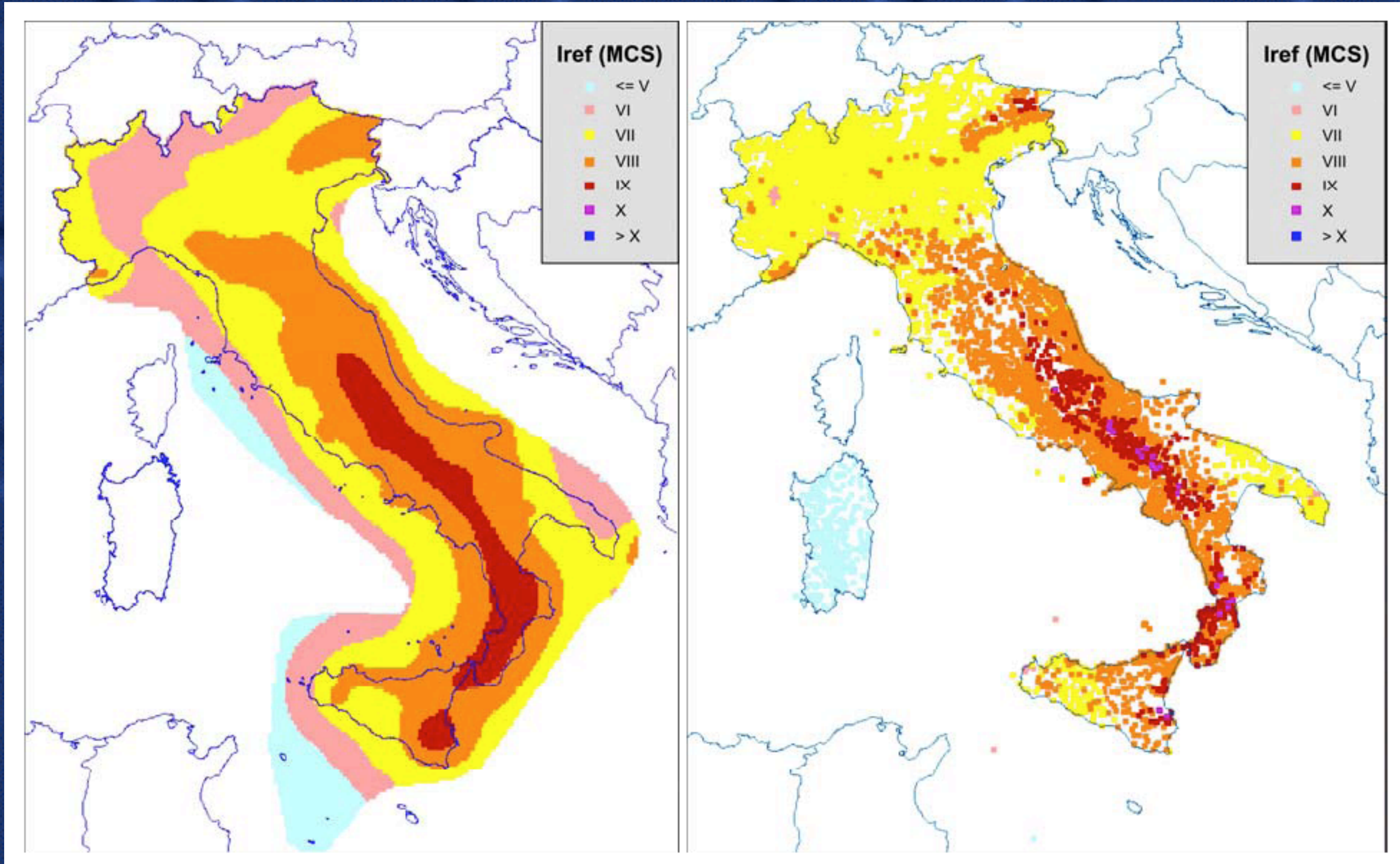


The Italian seismic hazard web site (2)

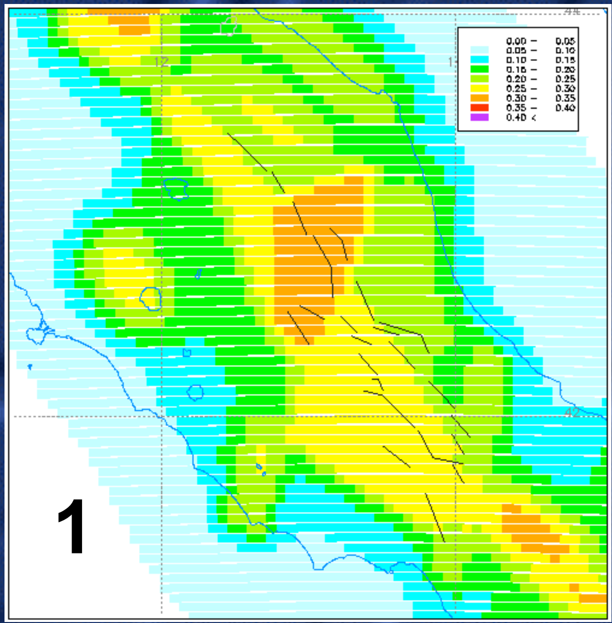


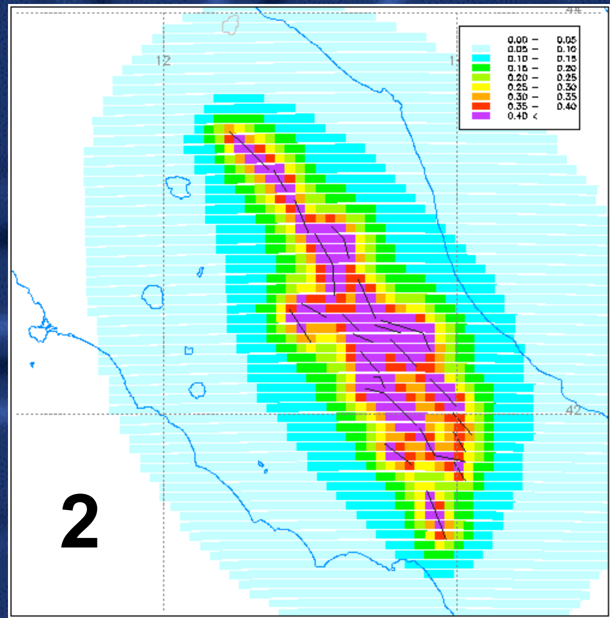
Ordinata spettrale (secondi)	Periodo di ritorno								
	30	50	72	100	140	200	475	1000	2500
0.10									
0.15									
0.20									
0.30									
0.40									
0.50									
0.75									
1.00									
1.50									
2.00									
Download	SA_0030.zip (3071 kb)	SA_0050.zip (3339 kb)	SA_0072.zip (3485 kb)	SA_0100.zip (3593 kb)	SA_0140.zip (3674 kb)	SA_0200.zip (3747 kb)	SA_0475.zip (3853 kb)	SA_1000.zip (3896 kb)	SA_2500.zip (3922 kb)

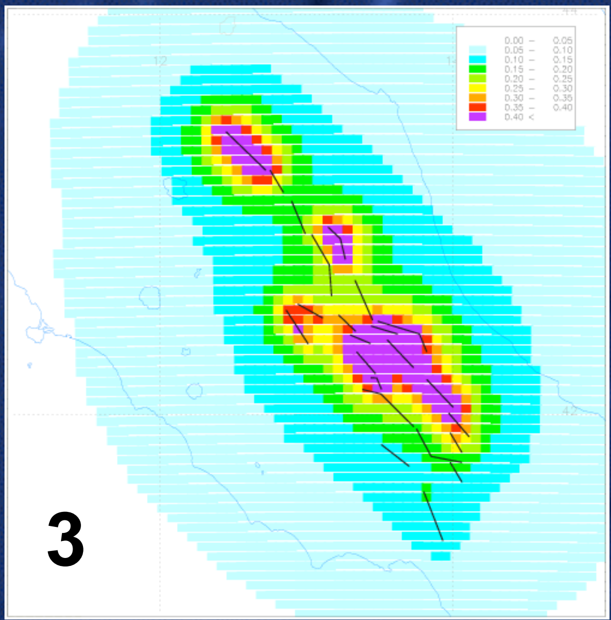
An alternative method: the site approach



Comparison between the intensity with an exceedence probability less than 10% in 50 yrs according to MPS4 and the site approach (from Albarello et al., 2007)







From the 3rd to the 4th generation PSHA

Seismic Hazard in Central Italy

475-yr return period PGA

1 - Cornell approach with SZ's
2 - Cornell approach with faults
3 - characteristic time-dependent eq on faults

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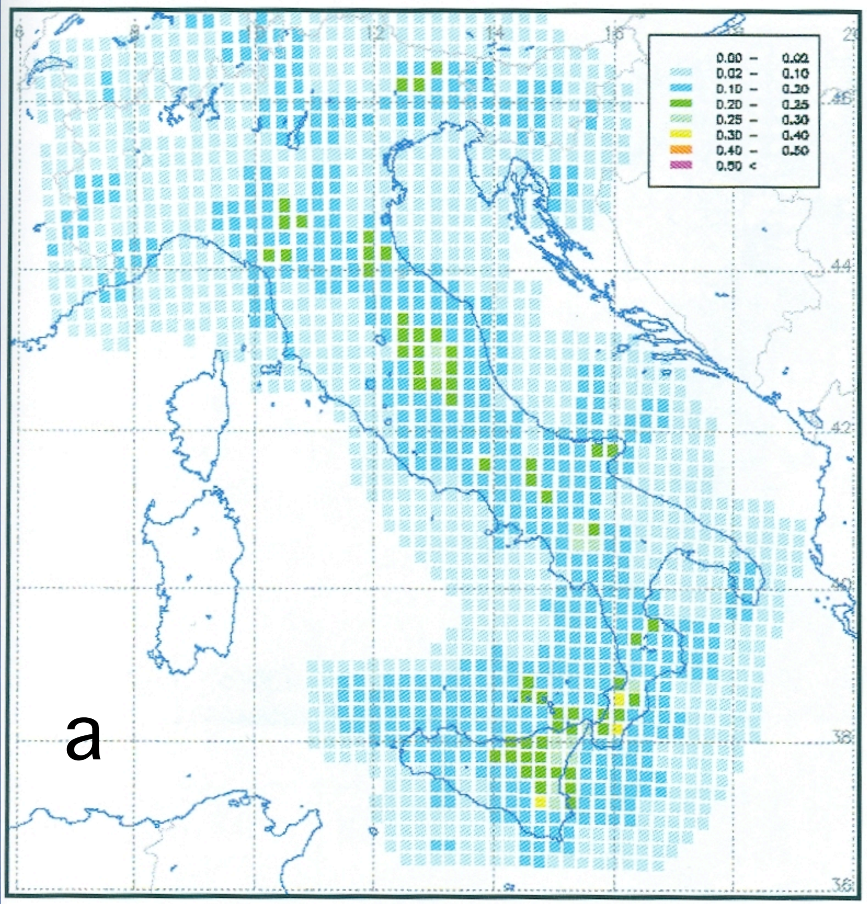
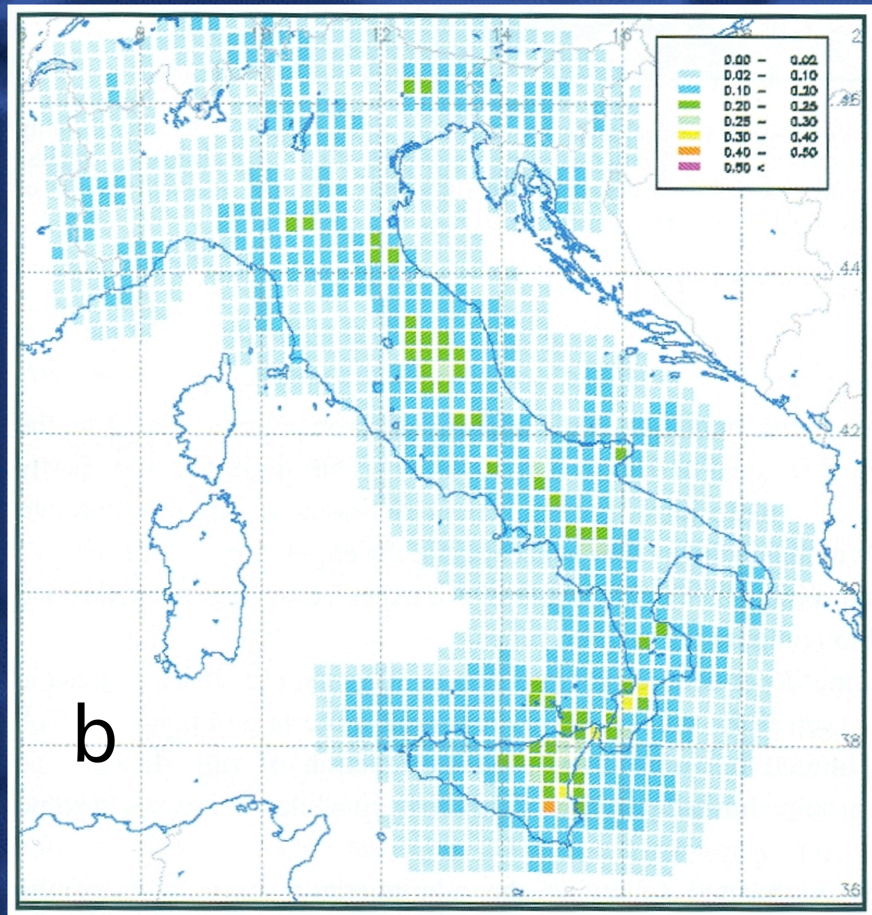
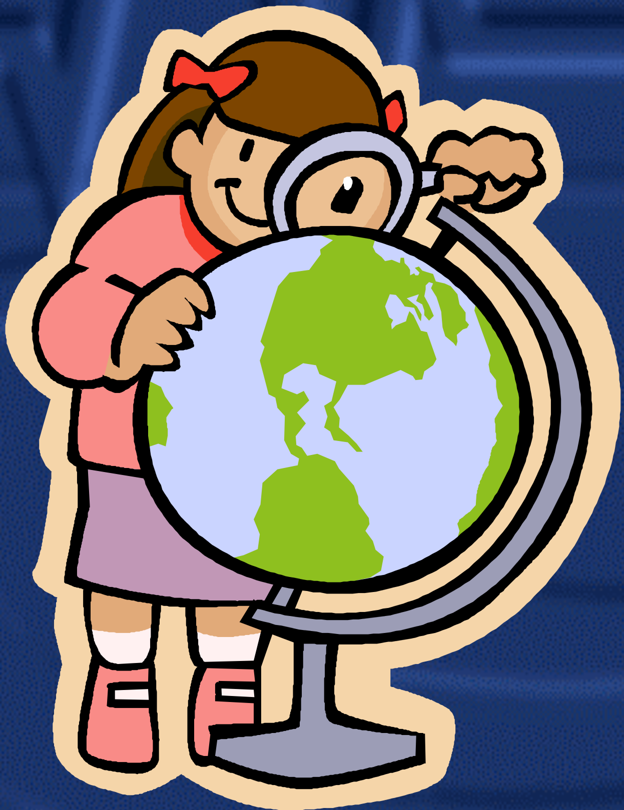
4th Generation: Non-Poissonian Probabilism



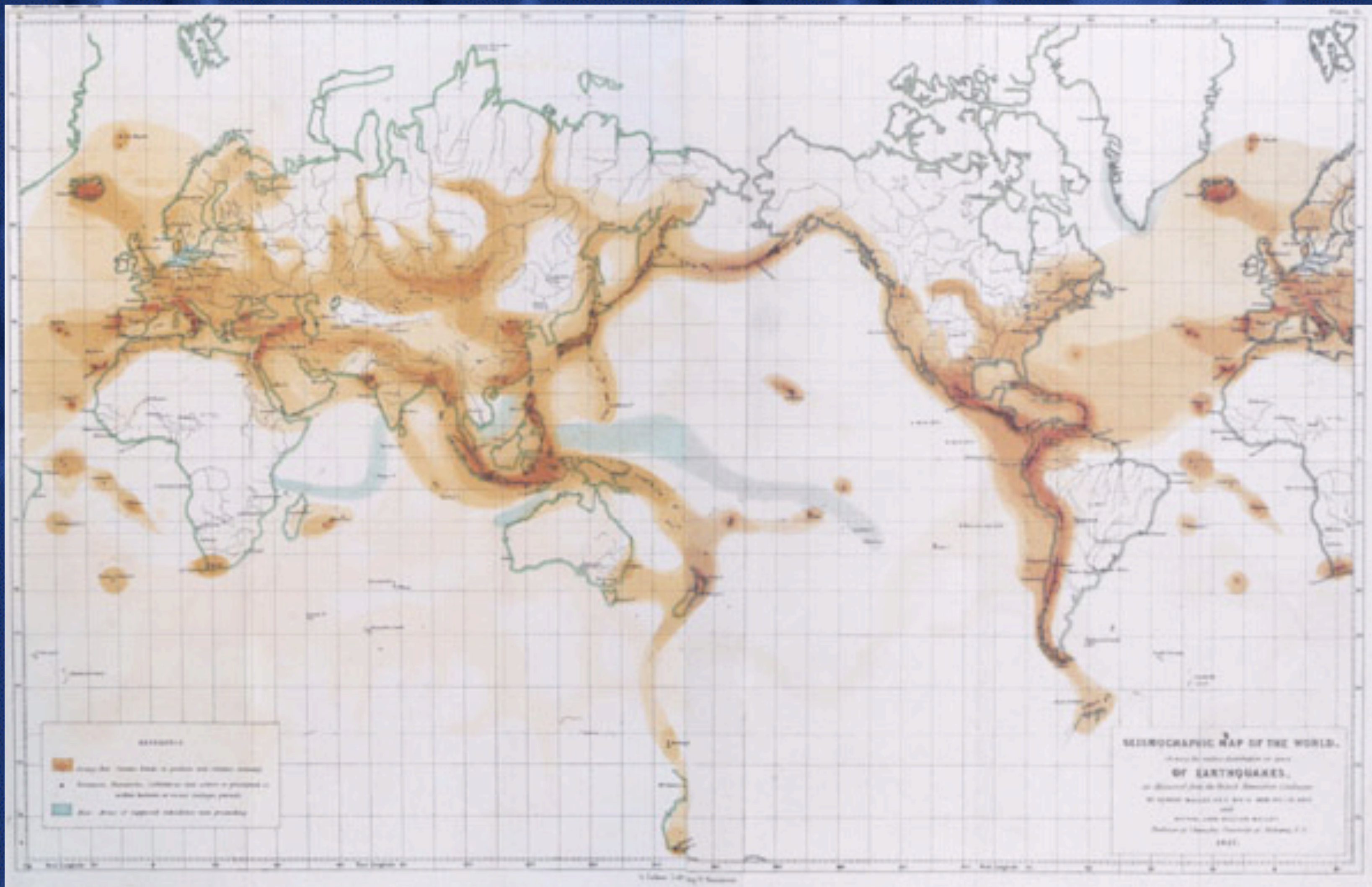


PGA with a 10% exceedence probability in 30 yrs
a - Poisson model
b - time-dependent model

Global seismic hazard maps



The first hazard map (?)



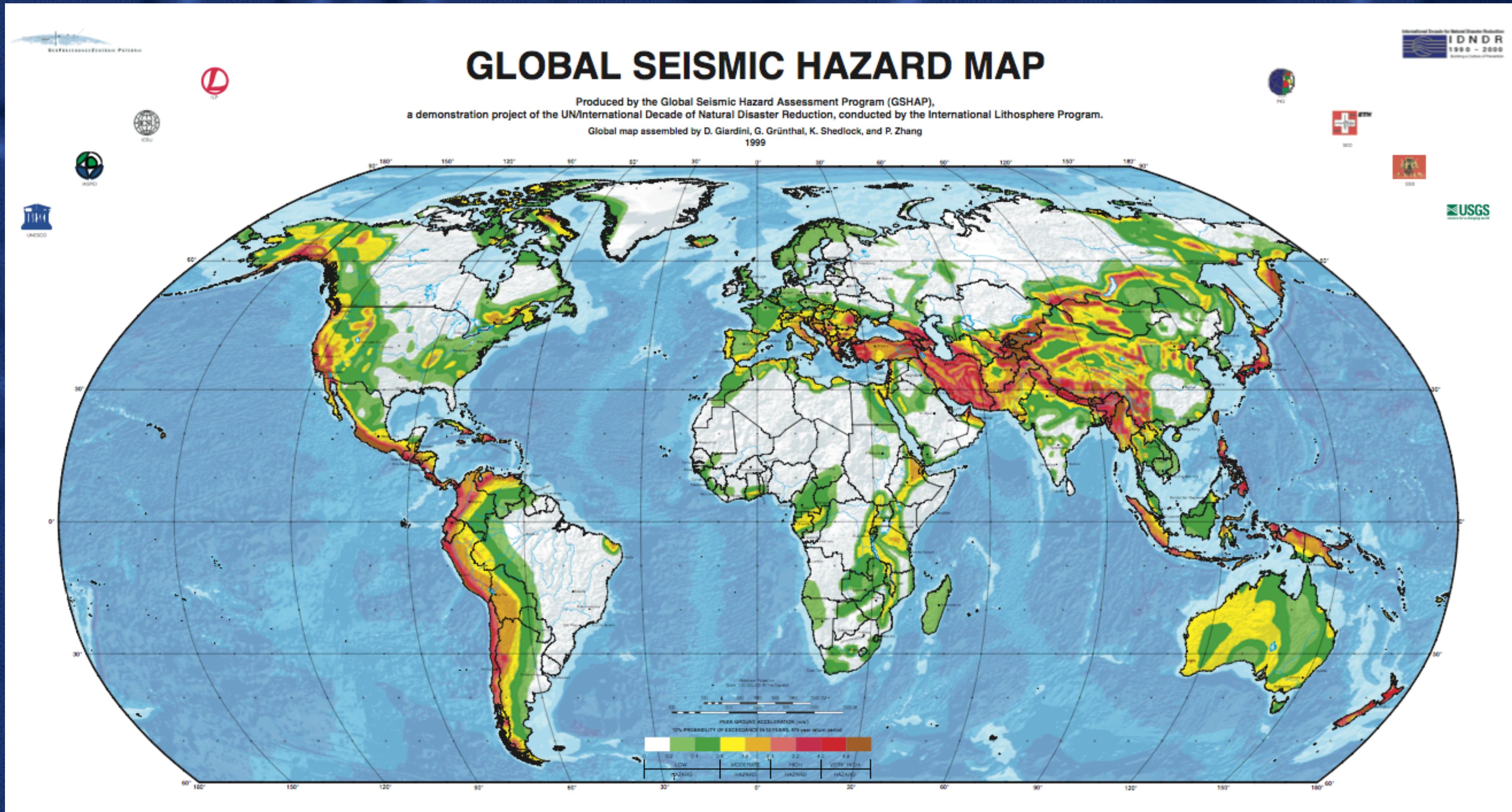
- Map of world earthquake occurrence by Robert Mallet in 1854

The GSHAP project (1)

- The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU), and endorsed as a demonstration program in the framework of the United Nations International Decade for Natural Disaster Reduction (UN/IDNDR). The primary goal of GSHAP was to create a global seismic hazard map in a harmonized and regionally coordinated fashion, based on advanced methods in probabilistic seismic hazard assessments (PSHA). The GSHAP strategy was to establish Regional Centres which were responsible for the coordination and realization of the four basic elements of modern PSHA:
- 1. Earthquake catalogue
- 2. Earthquake source characterization
- 3. Strong seismic ground motion
- 4. Computation of seismic hazard.

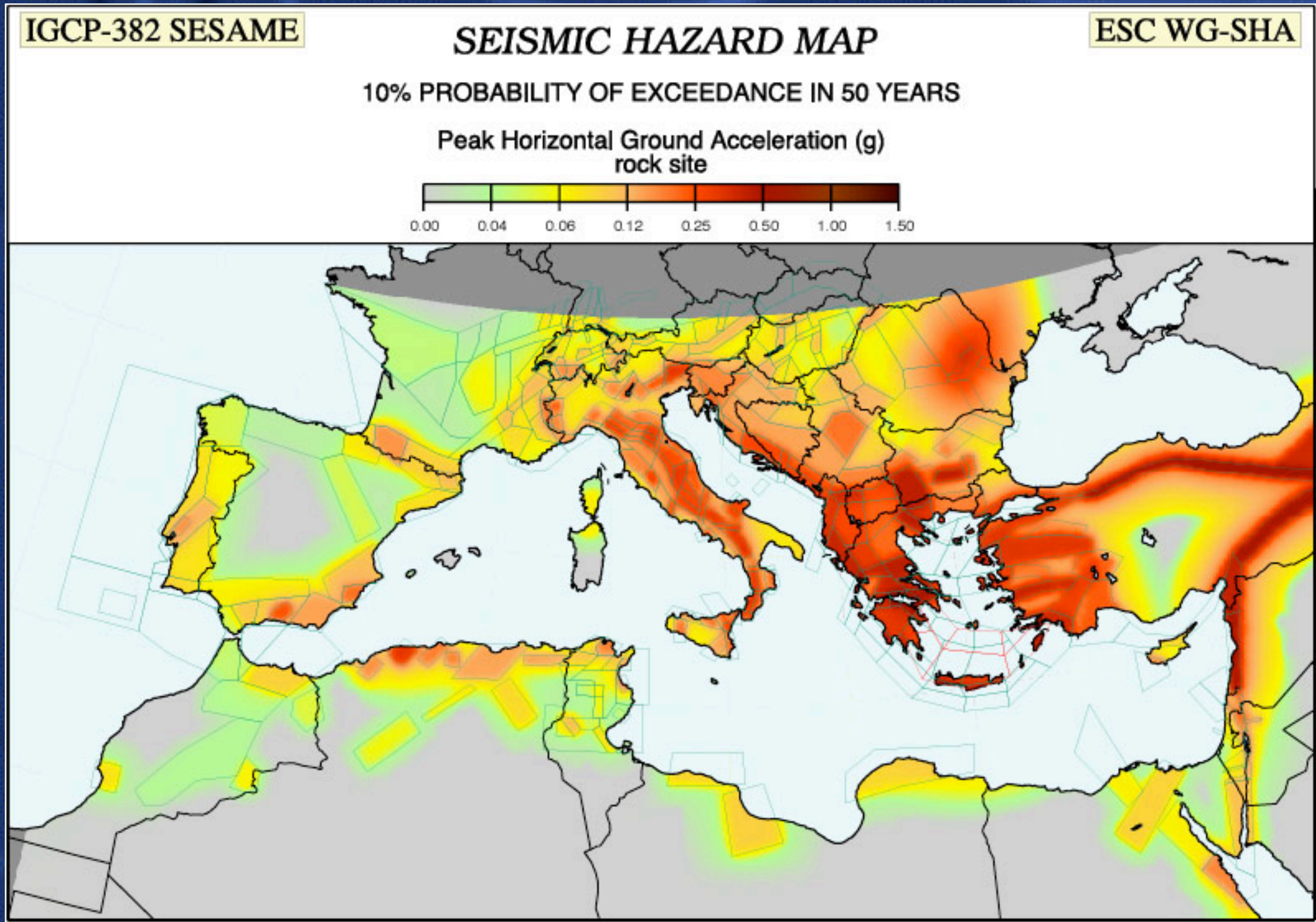
The GSHAP project (2)

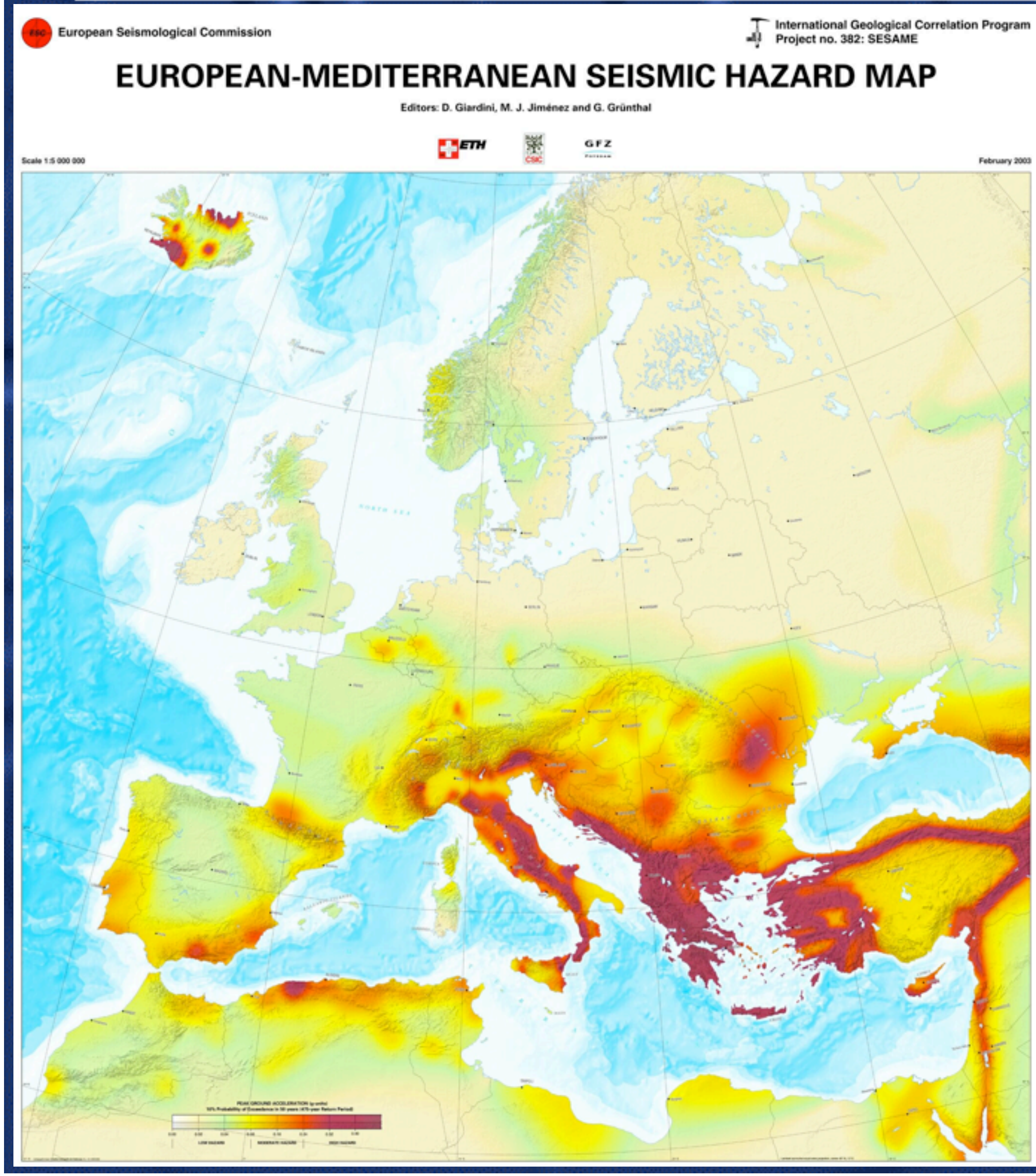
- Seismic hazard map produced by GSHAP (Giardini et al., 1999)
  http://www.seismo.ethz.ch/GSHAP/index.html



The ESC project (1)

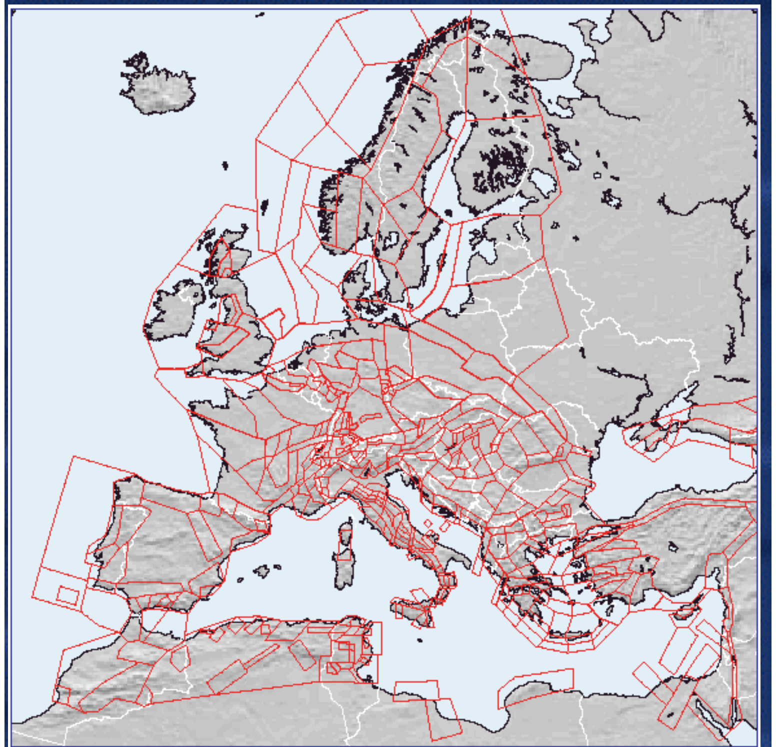
- The ESC-SESAME is the **first ever unified model for Probabilistic Seismic Hazard Assessment for Europe and the Mediterranean**. It was developed within the framework of several recent projects on global and regional seismic hazard assessment and allows for homogeneous hazard computation throughout the whole European-Mediterranean domain.



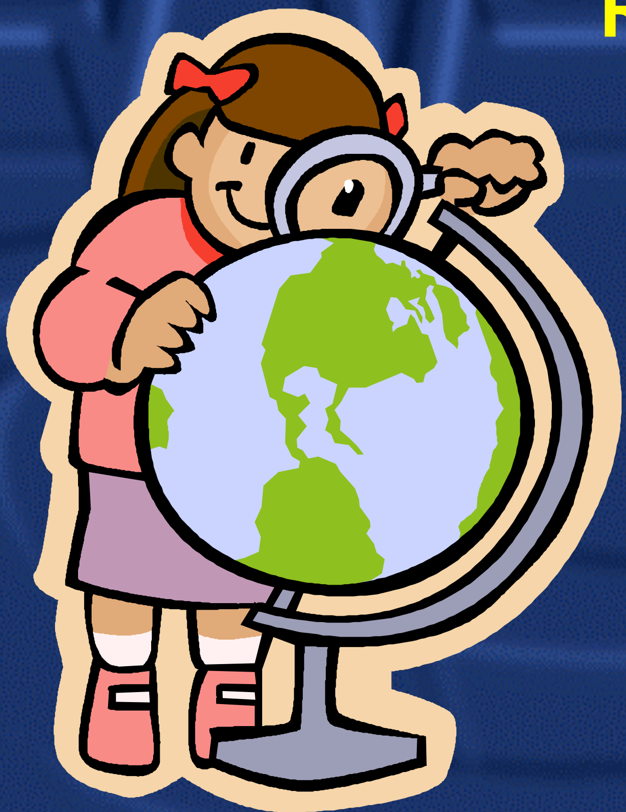


The ESC project (2)

- Seismic hazard map of the European – Mediterranean region (Jimenez et al., 2003) http://wija.ija.csic.es/gt/earthquakes/



Regional studies on seismic risk



OGS

PROTEZIONE CIVILE

Civil Defence of the Friuli Venezia Giulia Region

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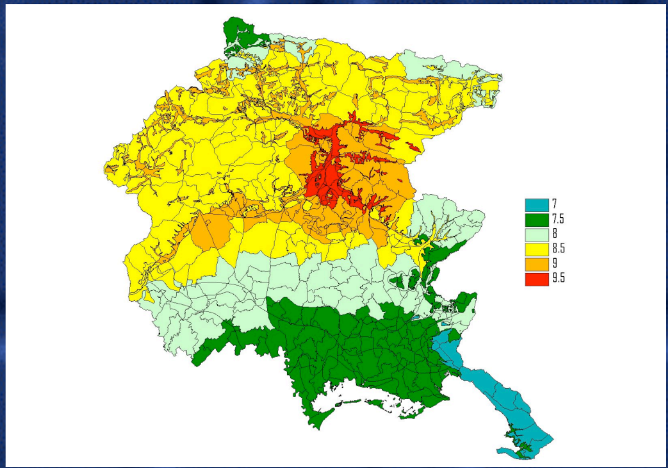
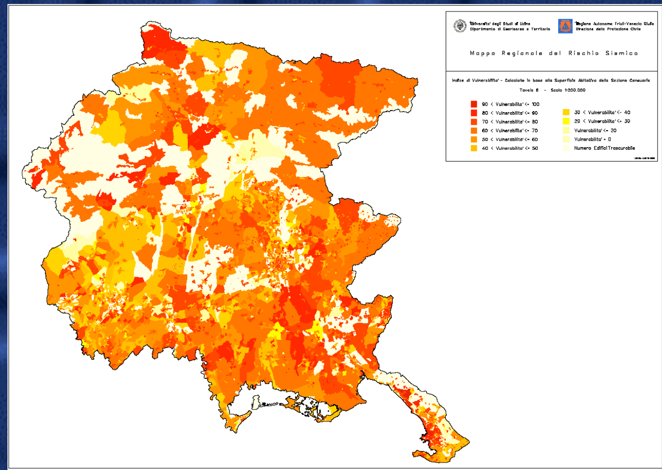
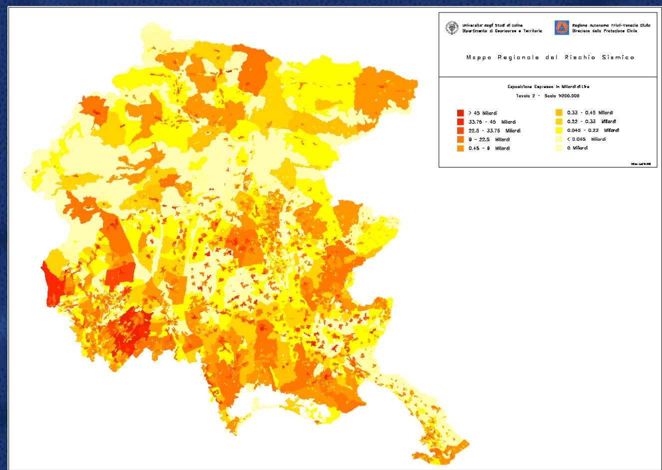
SEISMIC HAZARD



VULNERABILITY



X



EXPOSED VALUE

=

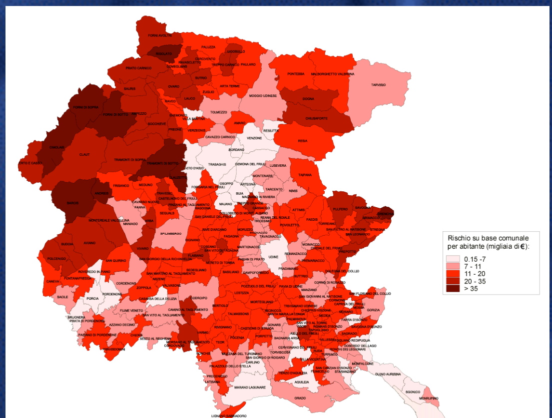
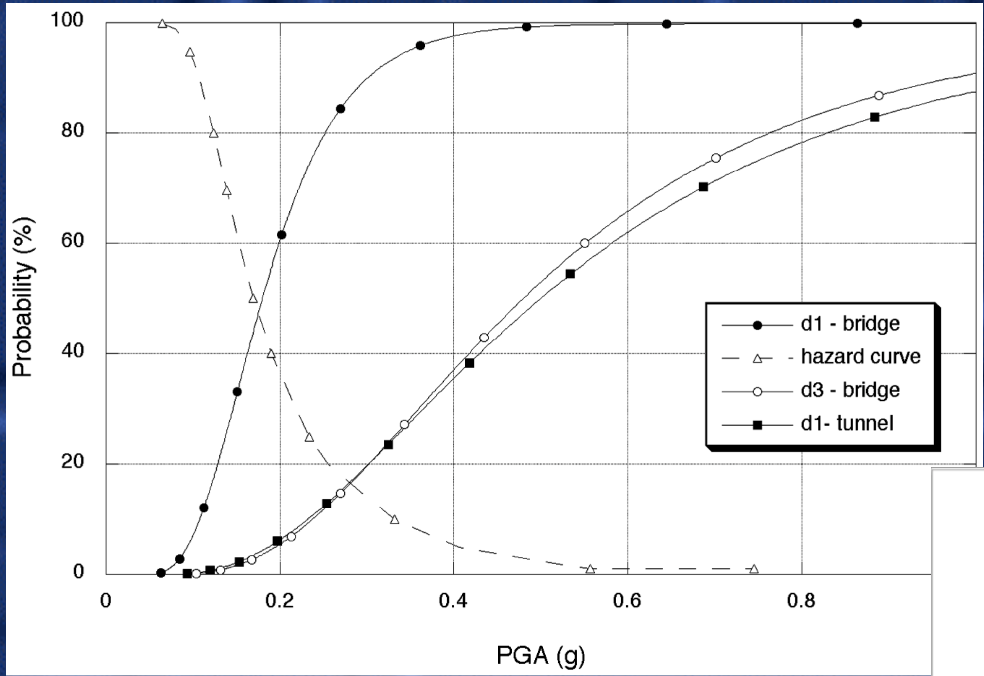


Fig. 14 - Rischio sismico per abitante riferito al comune.

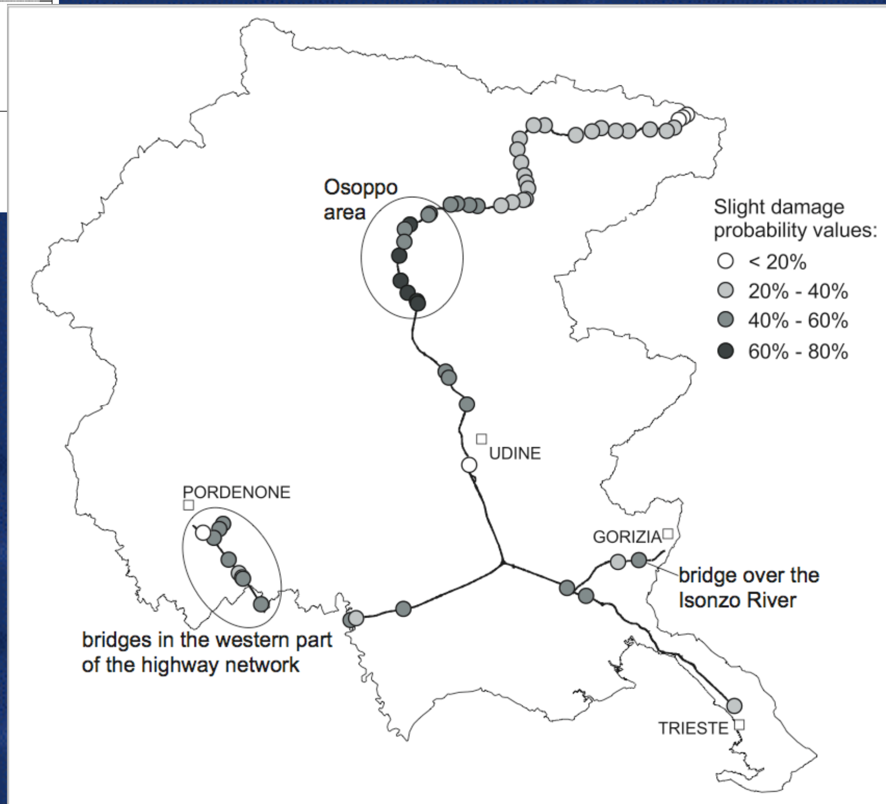
SEISMIC RISK

Bridges in Friuli - Venezia Giulia (NE Italy)



Fragility curves (non-exceedence probability) for a bridge of a specific vulnerability class according to two damage states; fragility curve for a tunnel according to one damage state; hazard curve, in terms of a 50-year exceedence probability, for one of the bridges considered in the study

A 50-year probability of observing a slight damage for the bridges of the regional highway network



Codermatz et al. (2003)

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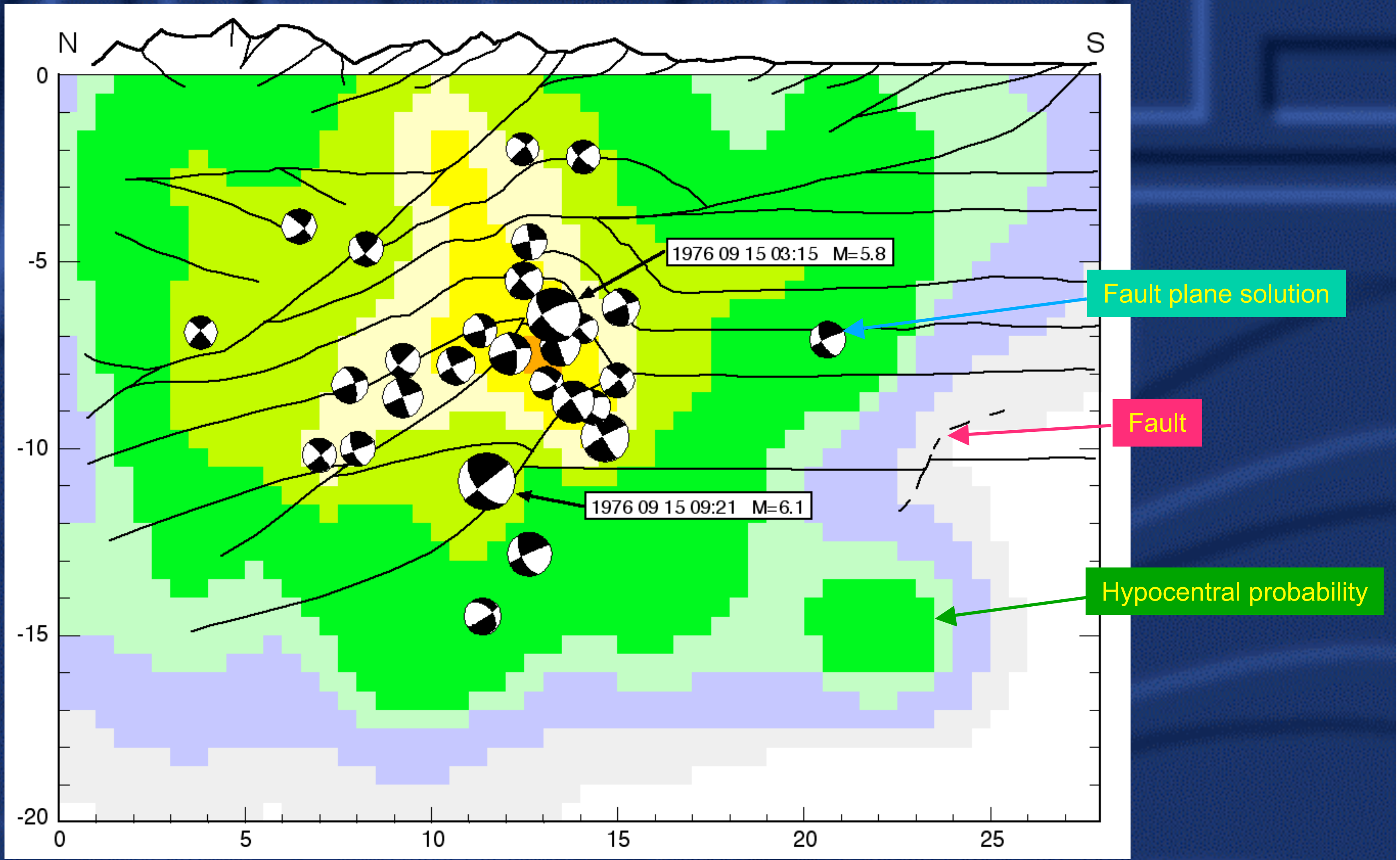
THE CONTRIBUTION OF THE INSTRUMENTAL SEISMOLOGY



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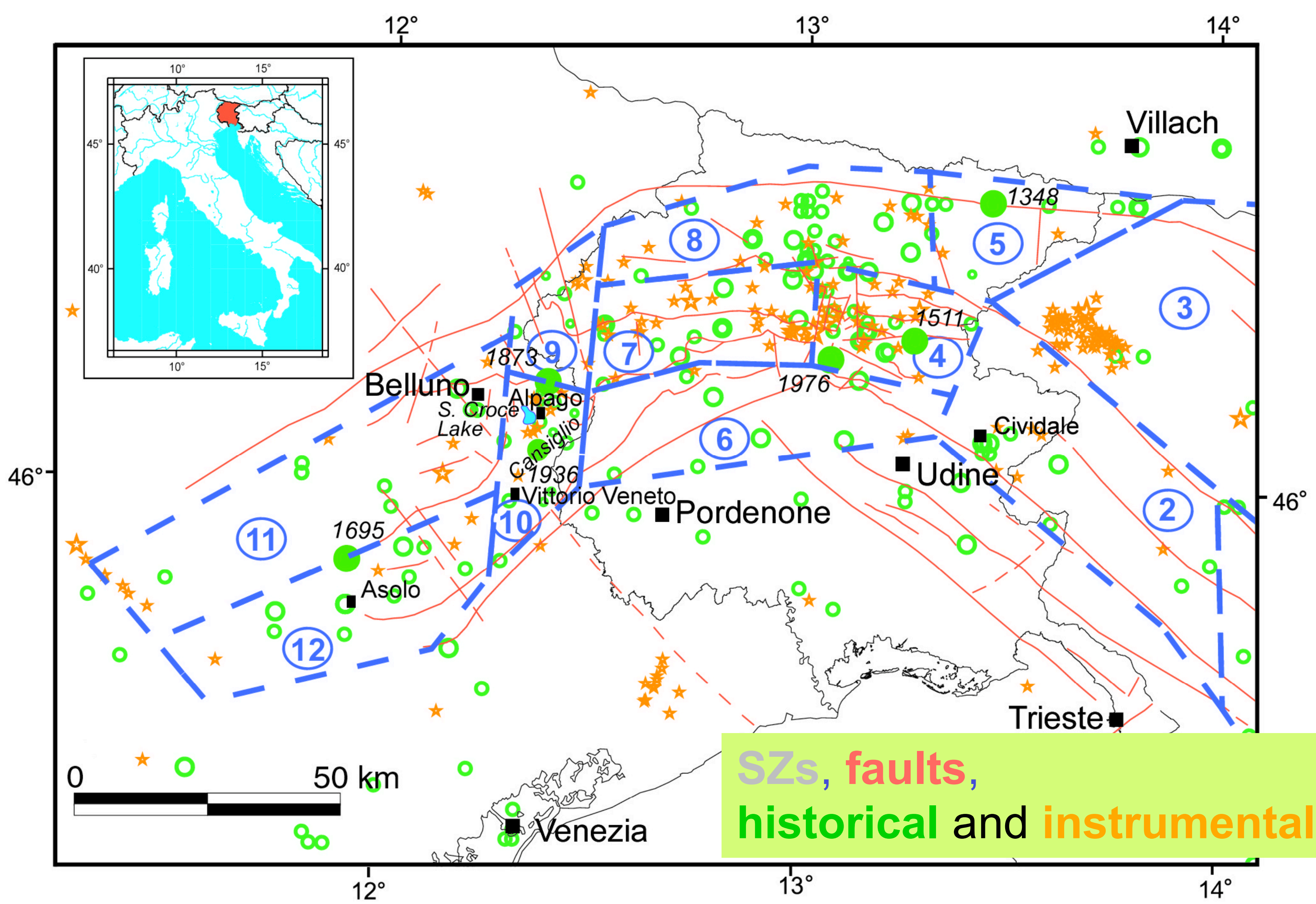
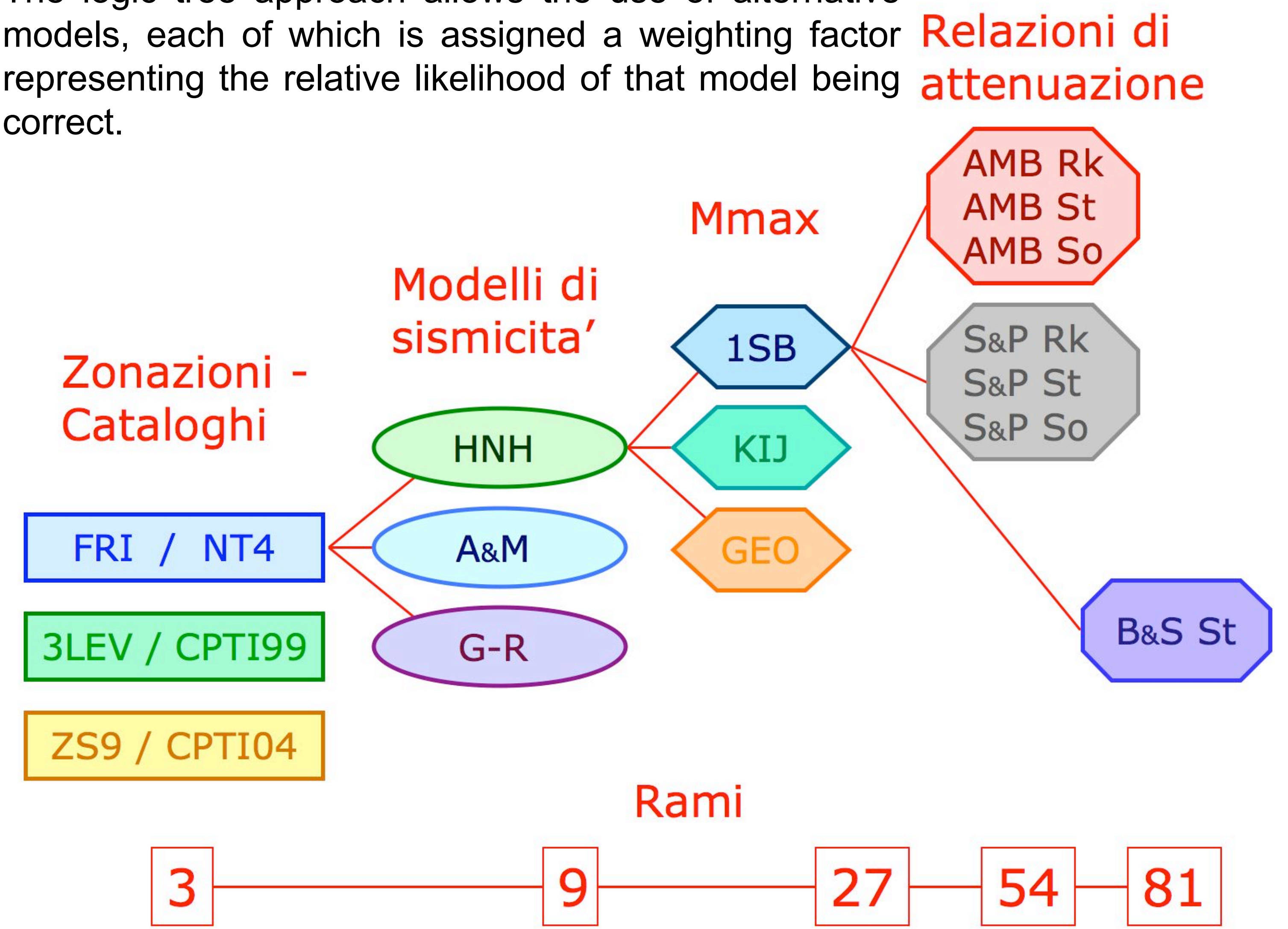
Seismogenic zonation for the Eastern Alps



SZs, faults,
historical and instrumental eqs

The logic tree scheme

The logic tree approach allows the use of alternative models, each of which is assigned a weighting factor representing the relative likelihood of that model being correct.



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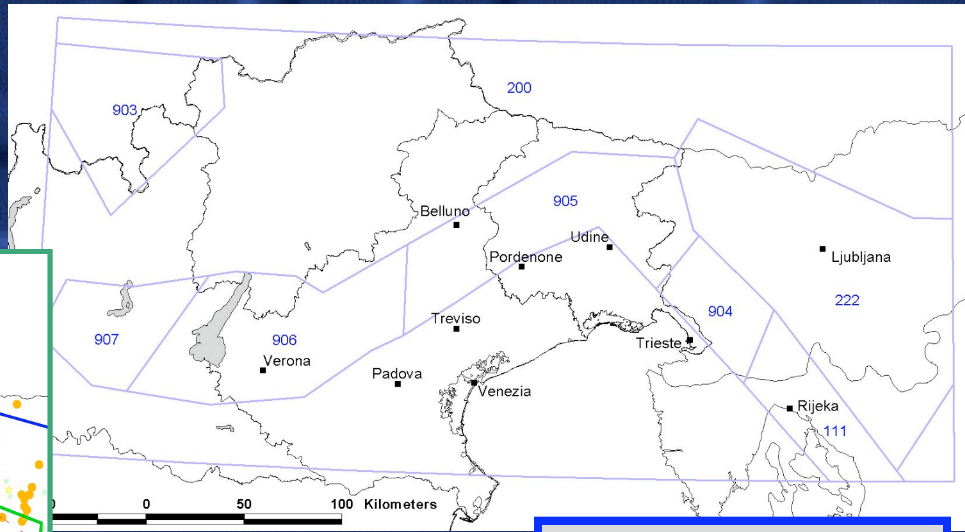
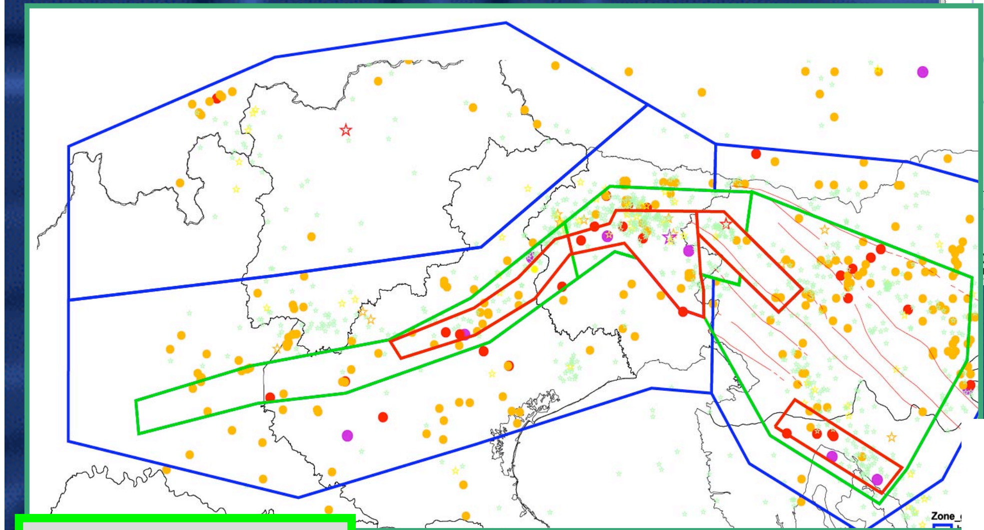
Seismogenic zonations for NE Italy



ZS9 zonation

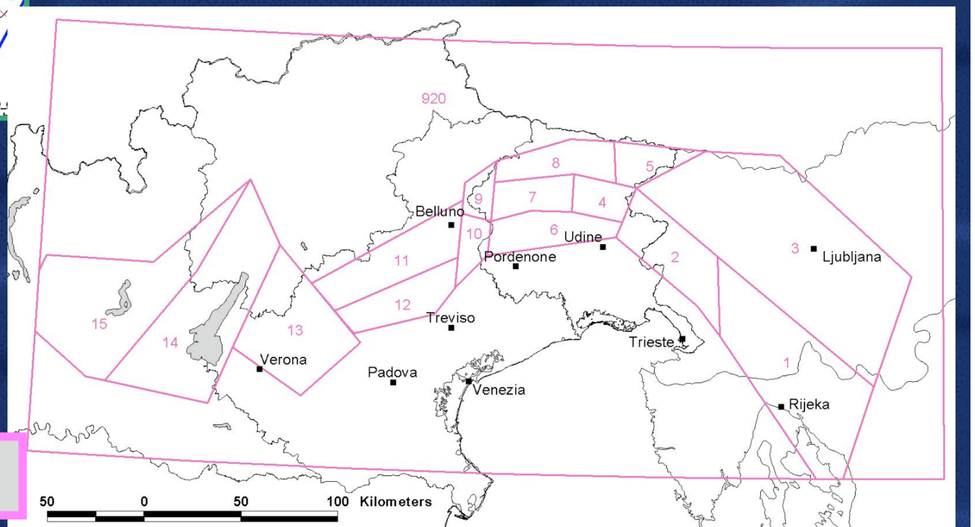


3LEV zonation

High Mag.

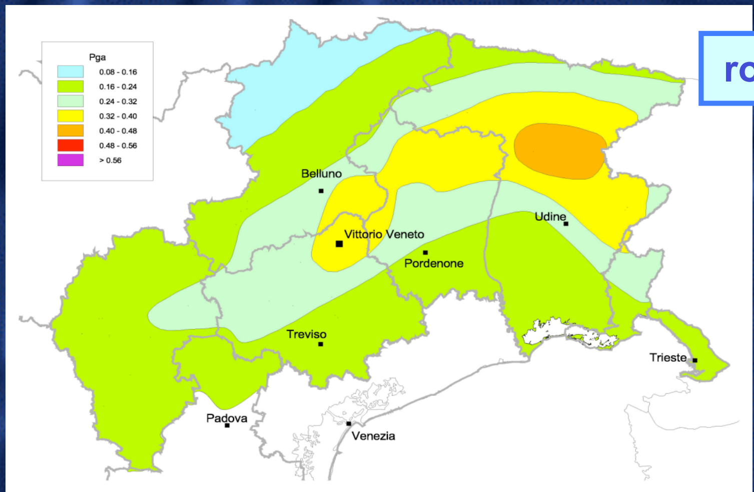
Medium Mag.

Low. Mag



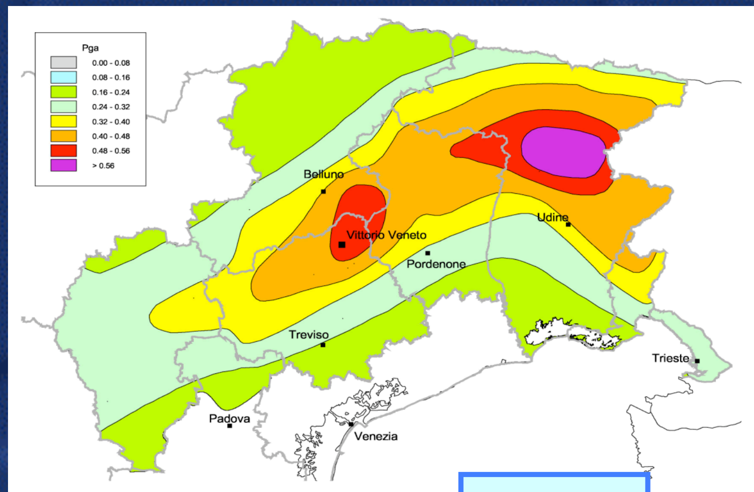
FRI zonation

Hazard maps for NE Italy

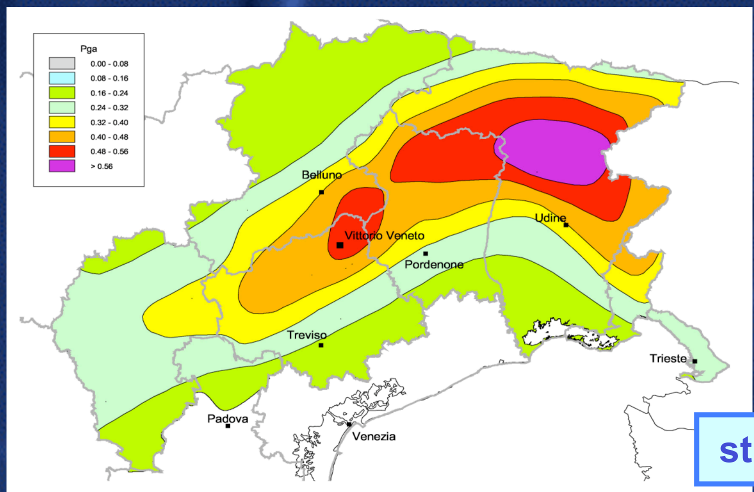


rock

PGA with a 475-yr return period



soft soil



stiff soil

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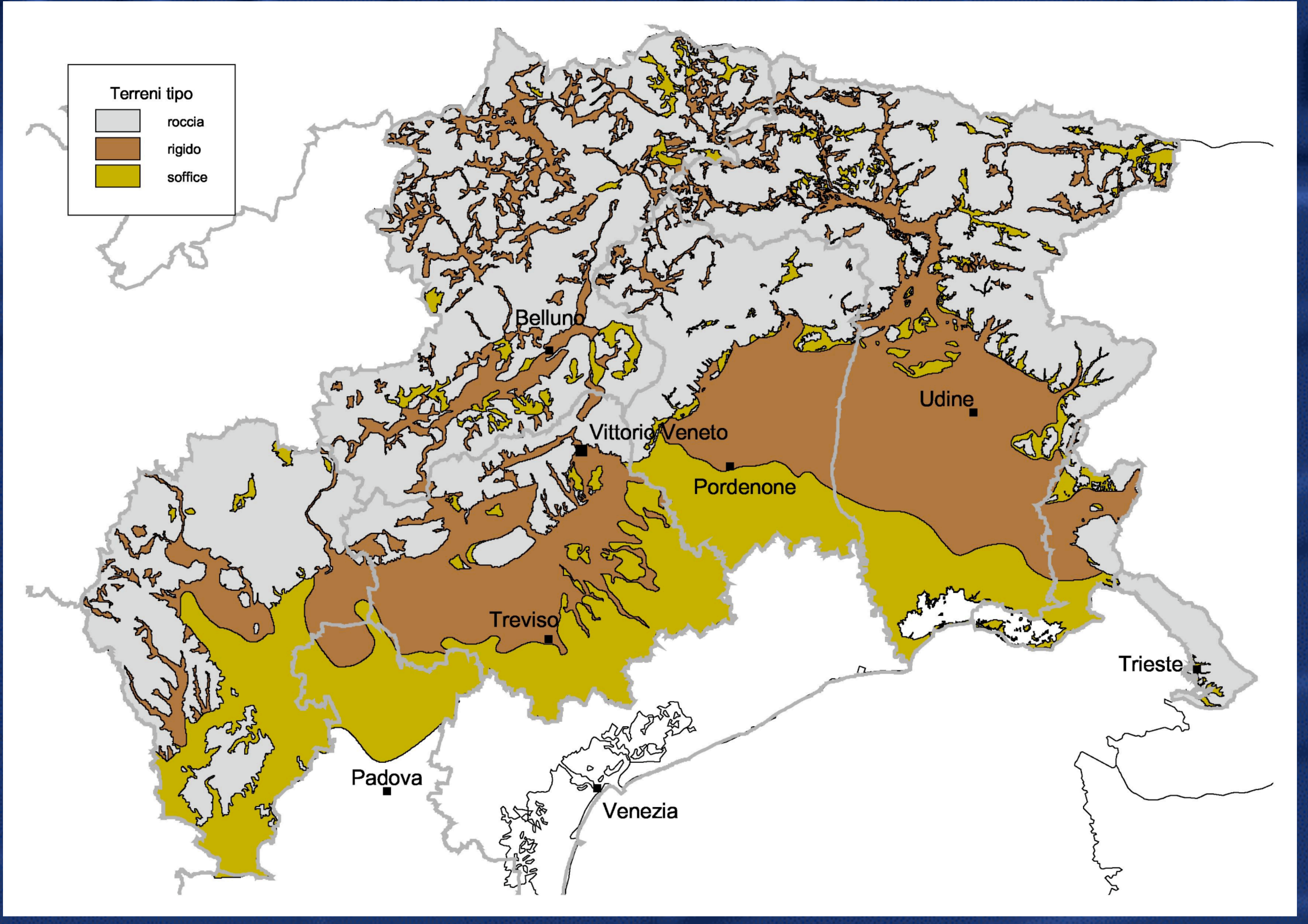
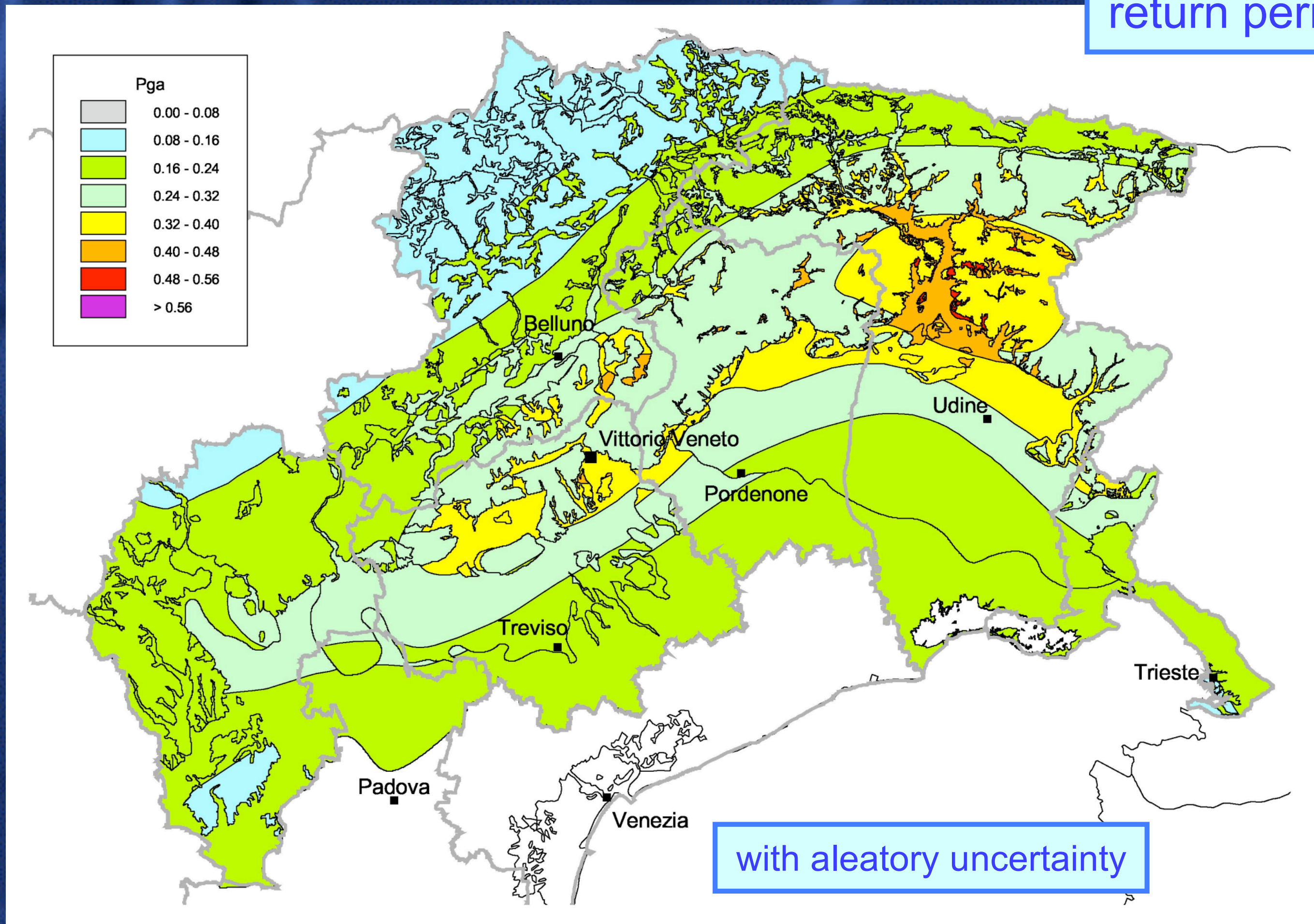
Soil types in NE Italy



Soil hazard map for NE Italy

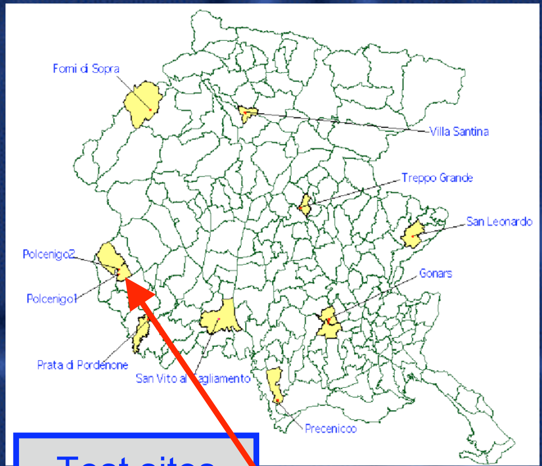
from attenuation relations

PGA with a 475-yr return period



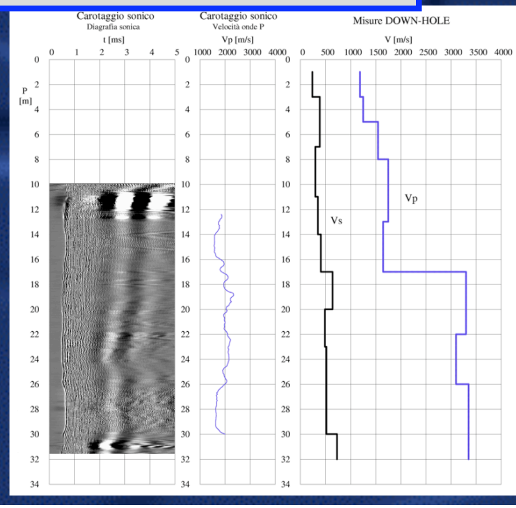
with aleatory uncertainty

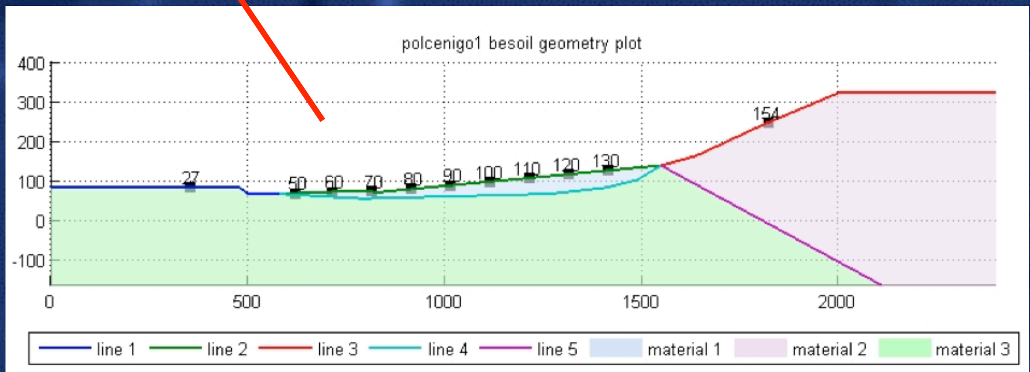
Amplification factors for the litho-types (1D and 2D modelling)

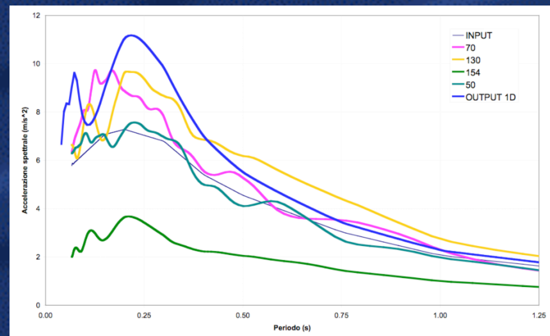


Test sites

Cross- and down-hole, sonic log, geoelectrics, reflection seismics





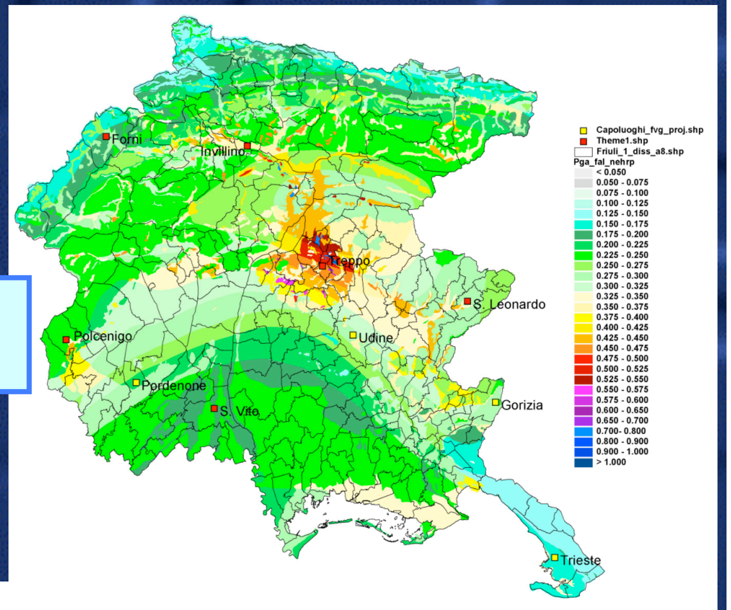


NEHRP Class	NEHRP Description	NEHRP V30 (m/s)	FaL NEHRP	FaL FVG	EC8 Class	EC8 V30 (m/s)
A	Hard rock	>1500	0.8	1		
B	Rock	760-1500	1.0	1	Rock	>800
C	Very dense soil and soft rock	360-760	1.2	1.2	Stiff	800-360
D	Stiff soil	180-360	1.5	1.7	Soft	360-180
E	Soft soil	<180	2.1	1.9	Very soft	<180

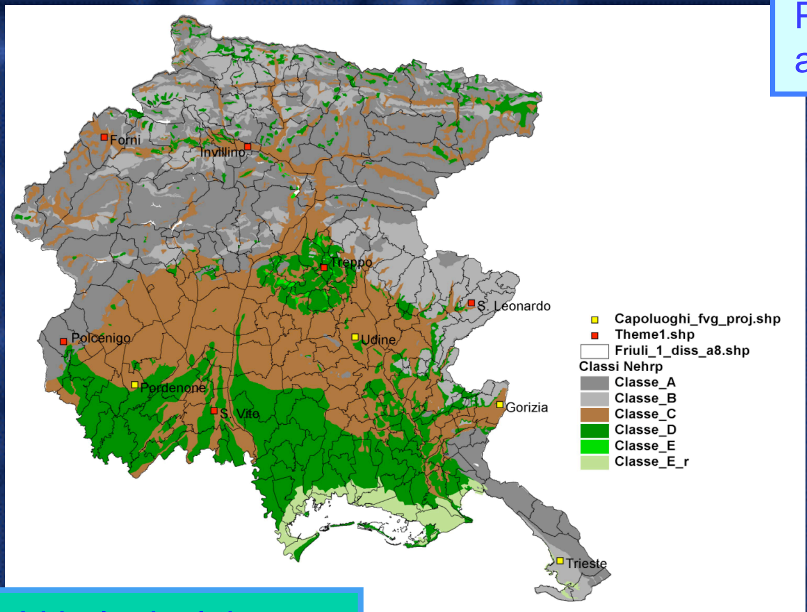
Amplification factors as ratio of the input and output areas of the response spectra between 0.1-0.5 s.

Soil hazard map from lithological amplification factors

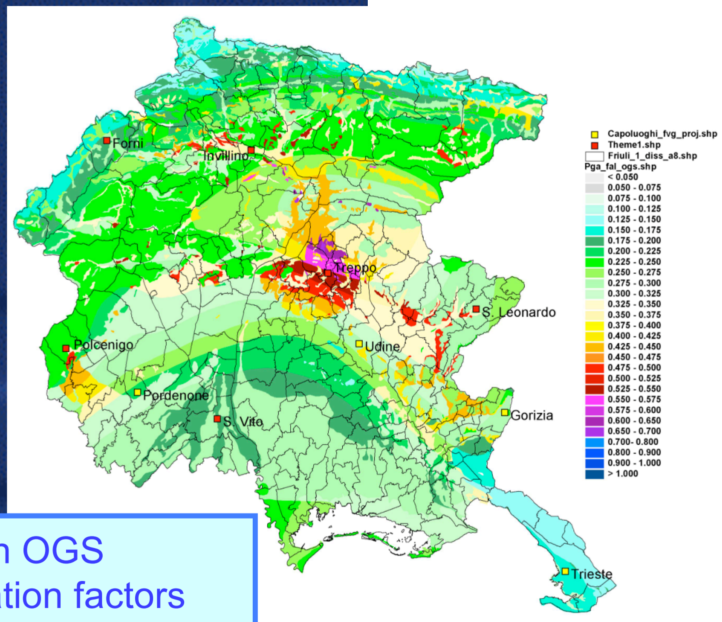
in terms of PGA with a 475-year return period



PGA with NEHRP amplification factors



Lithological themes



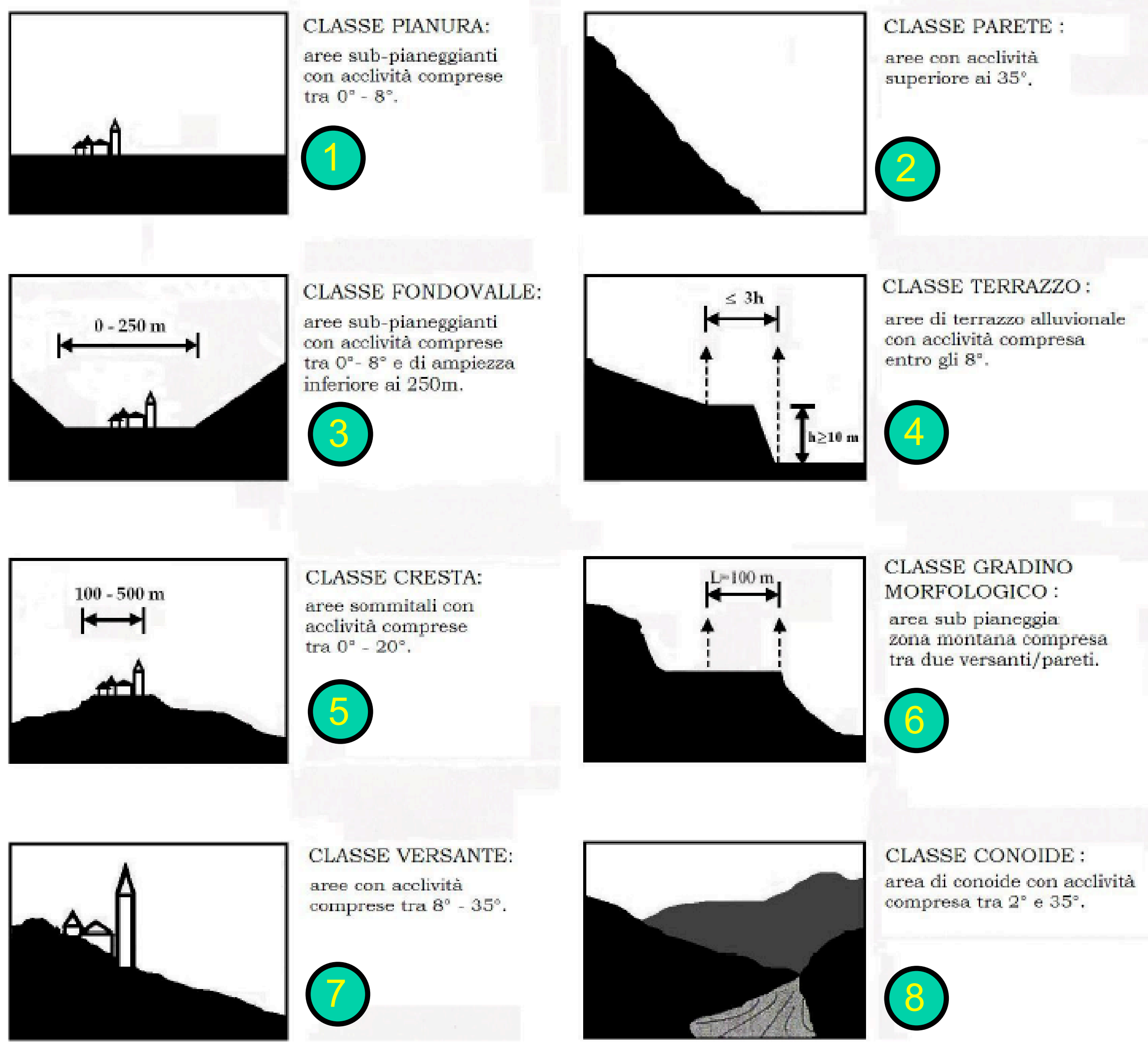
PGA with OGS amplification factors

Amplification factors for the morpho-types

Amplification factors:

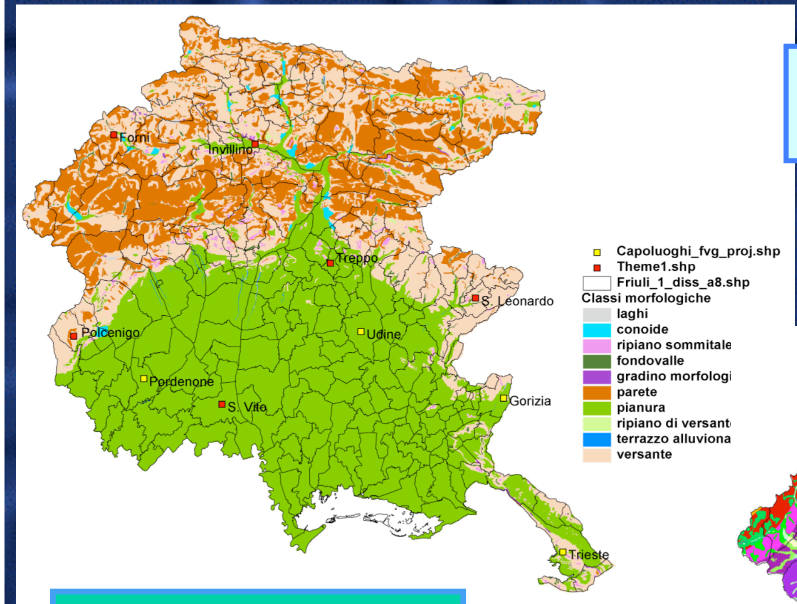
1 = 1.0
2 = 4.0
3 = 1.8
4 = 4.0
5 = 4.0
6 = 3.5
7 = 1.0
8 = 1.6

from the analysis of the damage observed during the ML6.4 1976 earthquake (Grimaz, 2006)



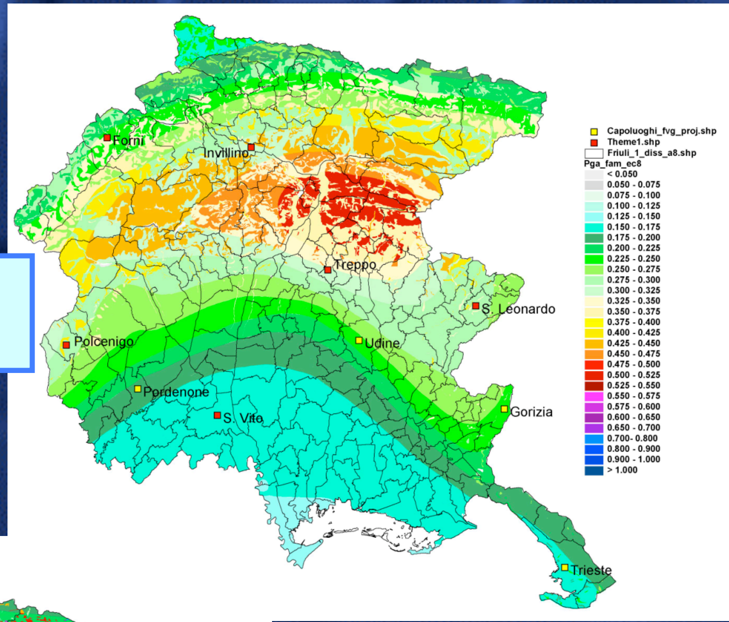
Soil hazard map from morphological amplification factors

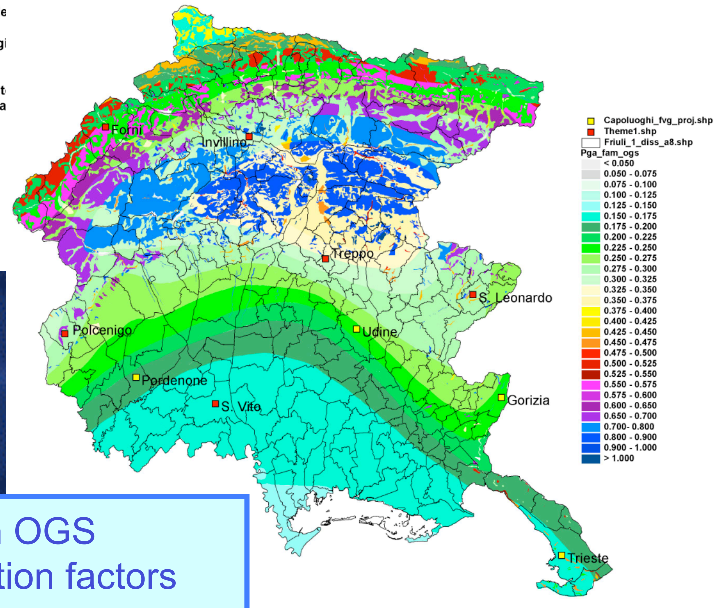
in terms of PGA with a 475-year return period



Morphological themes

PGA with EC8
amplification factors

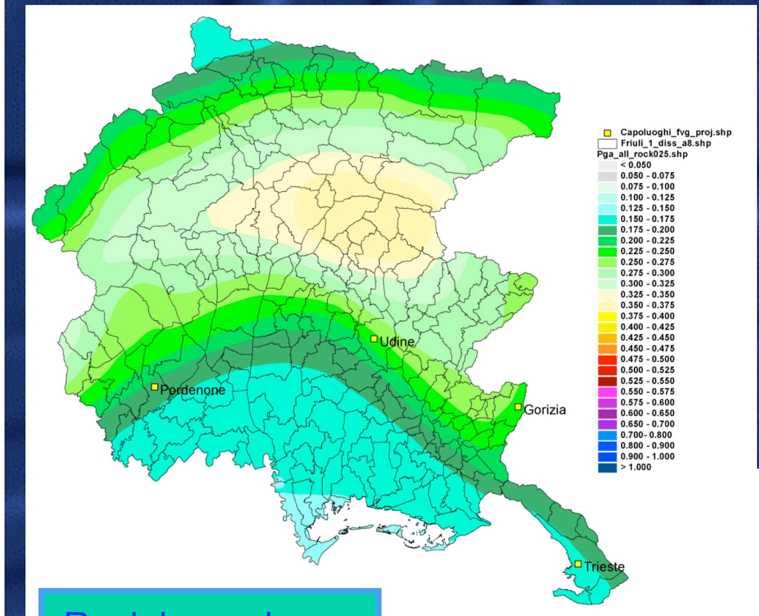




PGA with OGS
amplification factors

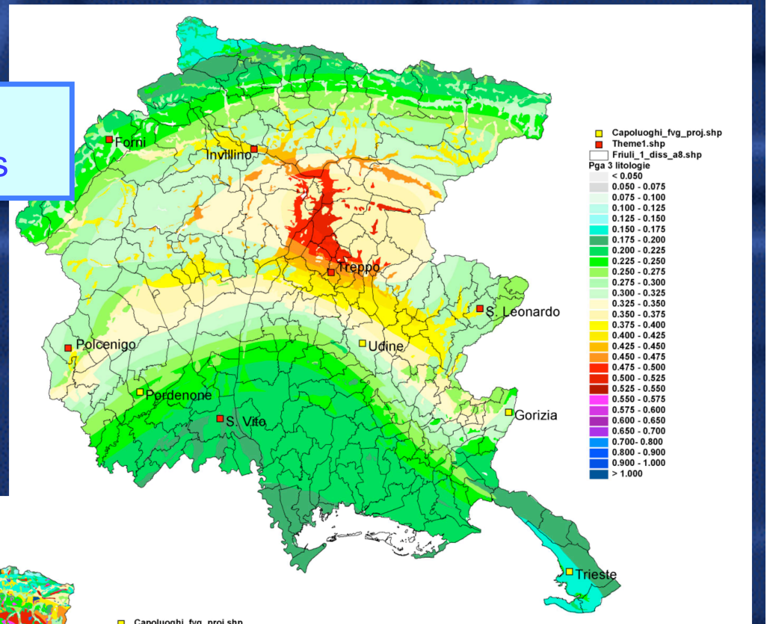
Soil hazard map from lithological and morphological amplification factors

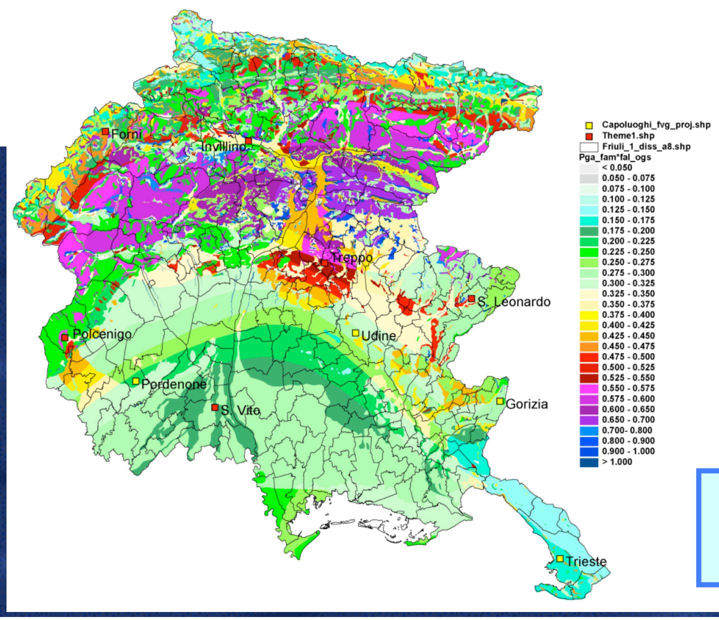
in terms of PGA with a 475-year return period



Rock hazard map

PGA with different attenuation relations





PGA with OGS amplification factors

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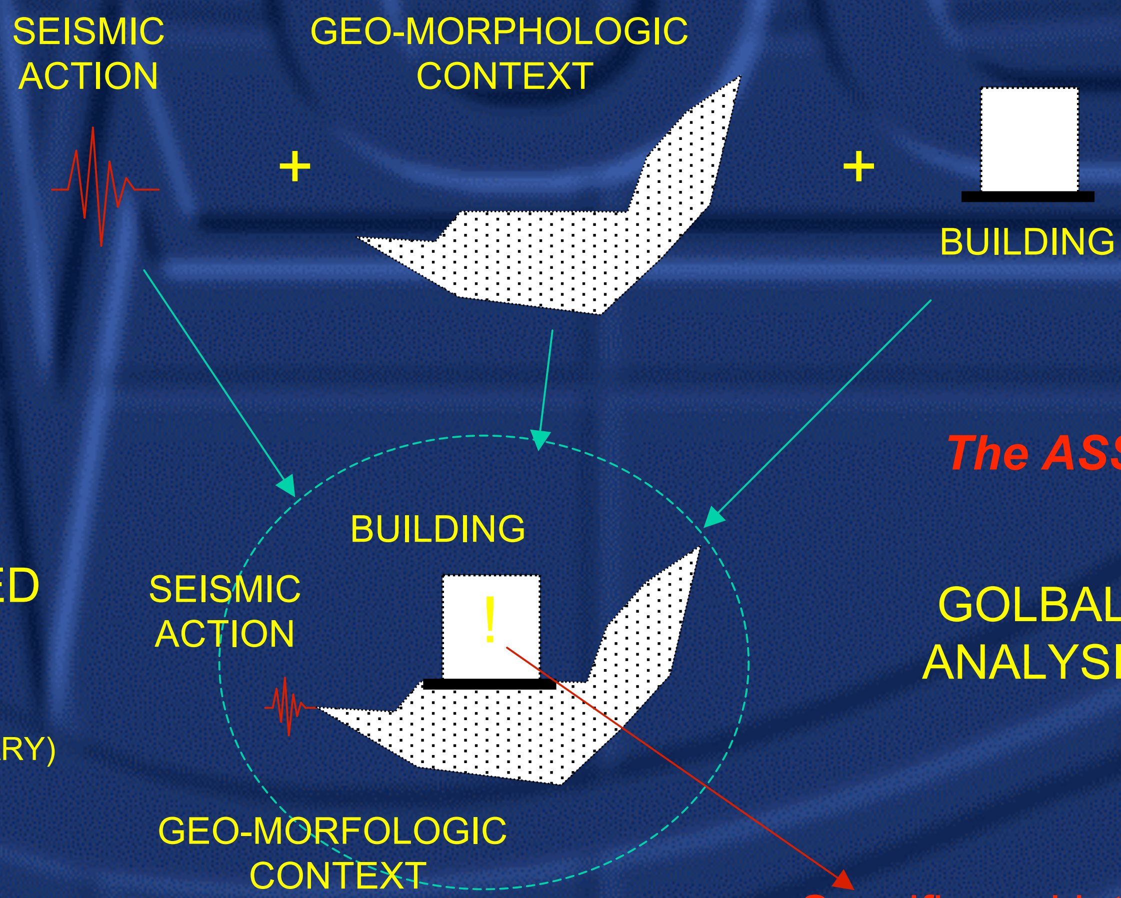
RESULTS FROM PREVIOUS STUDIES



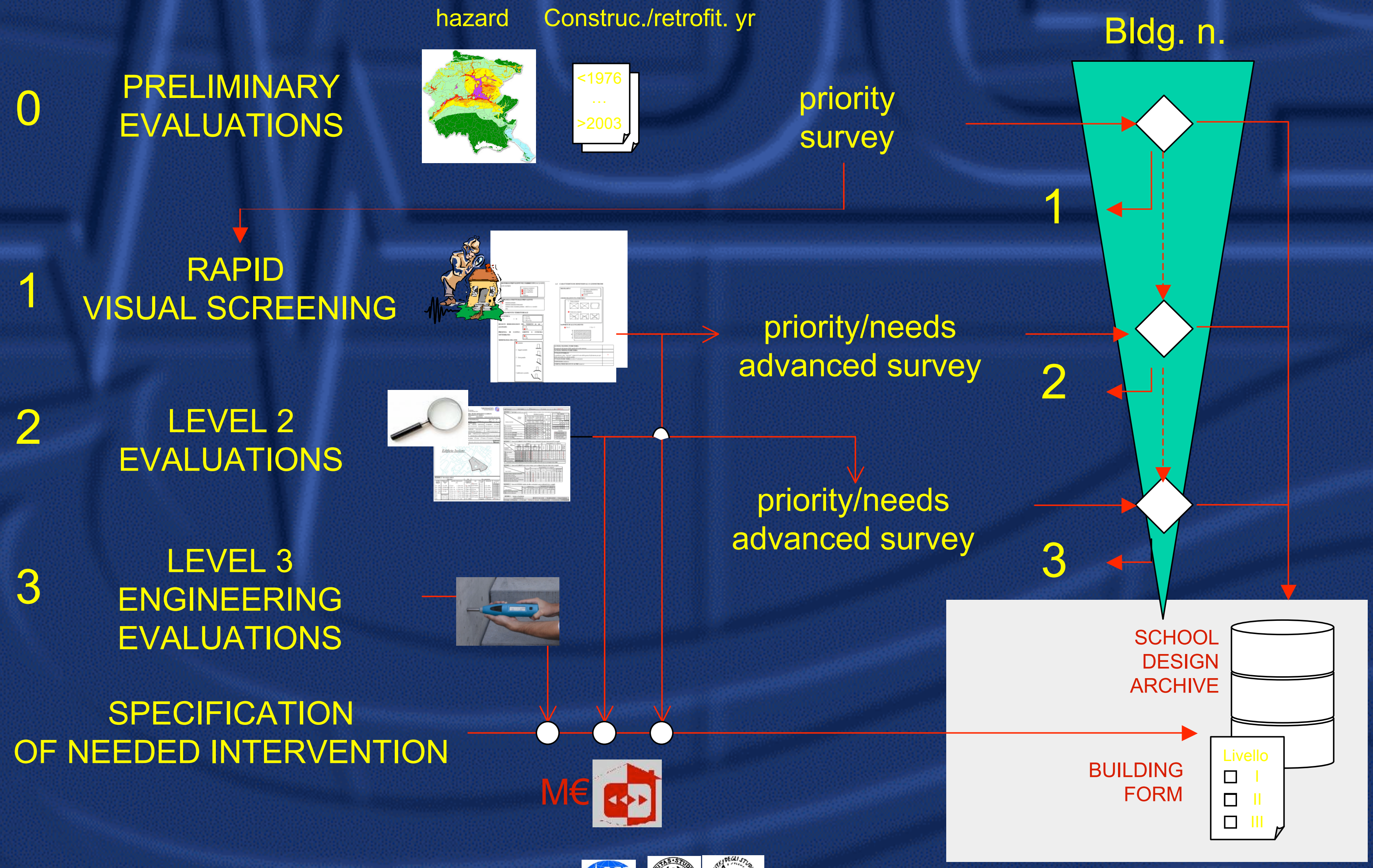
The ASSESS project

INTEGRATED
HOLISTIC
PROJECT
(MULTIDISCIPLINARY)

GOLBAL
ANALYSIS

Specific and integrated
JUDGEMENT

ASSESS: the progressive approach



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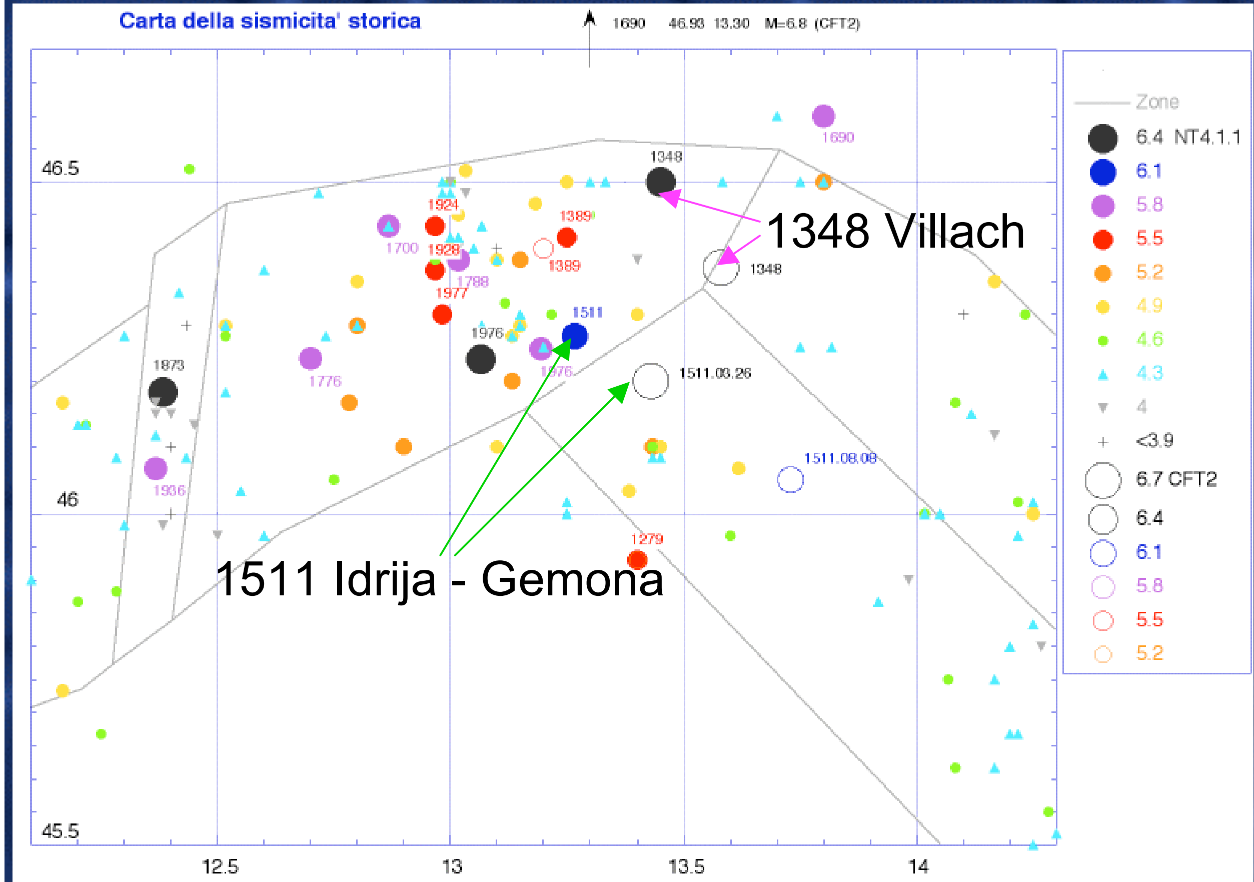
The HAREIA project



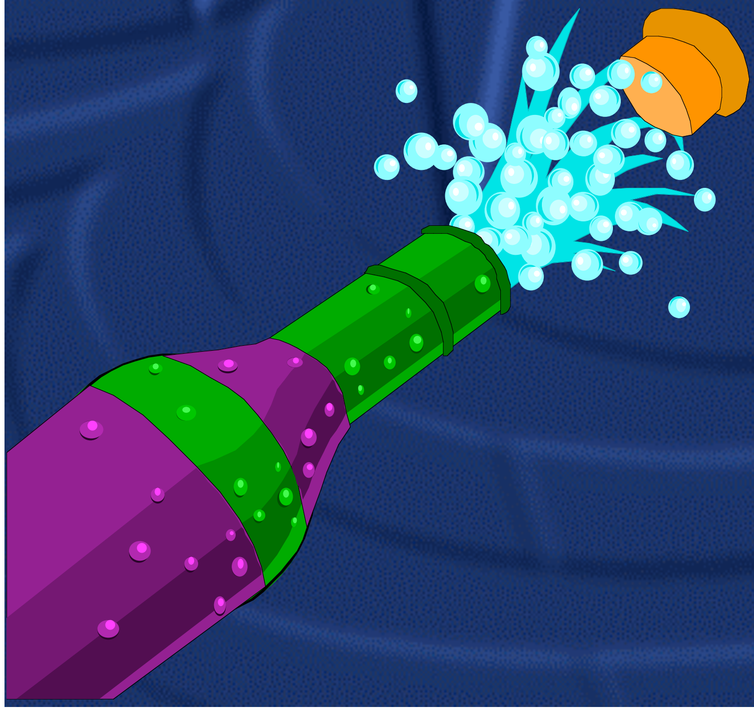
Doubts remain on the epicenters of the two strogest events in the Eastern Alps

Image from: http://nisee.berkeley.edu/kozak/
Images of Historical Earthquakes
The Jan T. Kozak Collection
Fresco of 1361 in St. Mary chapel (Karlstein Castle, Prague) illustrating the damage caused to the Arnoldstein castle by the Villach (Austria) earthquake of January 25, 1348

National and regional seismic hazard
Dario Slejko
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

"Building a culture of prevention is not easy…
the benefits are not tangible;
they are the disasters that did not happen”

Kofi Annan after the Bam earthquake



This is

The end

(That’s all Folks !)