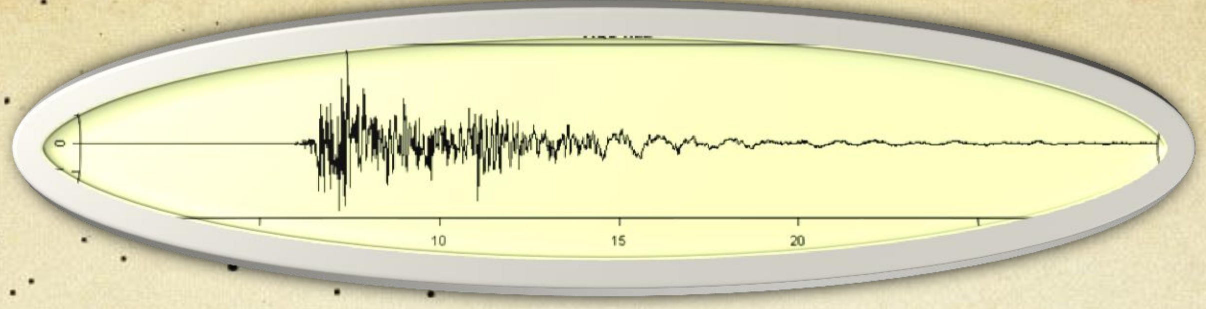

INGV

Understanding the Earthquake generation process: key results and present grand challenges

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Outline

1. **The Earthquake Generation Process**
   - Tectonic Processes (***why?***)
   - Observing and detecting (***where?***)
   - Faults and seismic waves (***how? - how big?***)
2. **Prevention and Forecasting**
   - Hazard and Risk
   - Earthquake probabilities of occurrence
3. **Impact on society**
   - Preparedness and Awareness
   - Communicating scientific results to the public
4. **Lessons learned and Conclusive Remarks**

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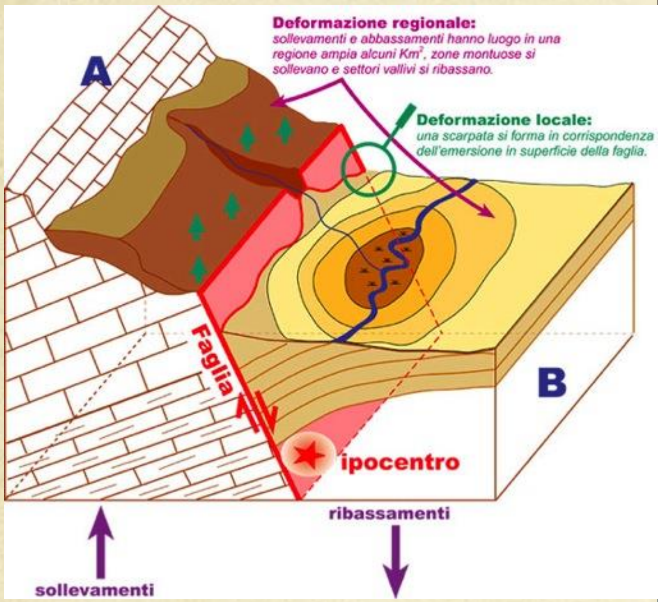
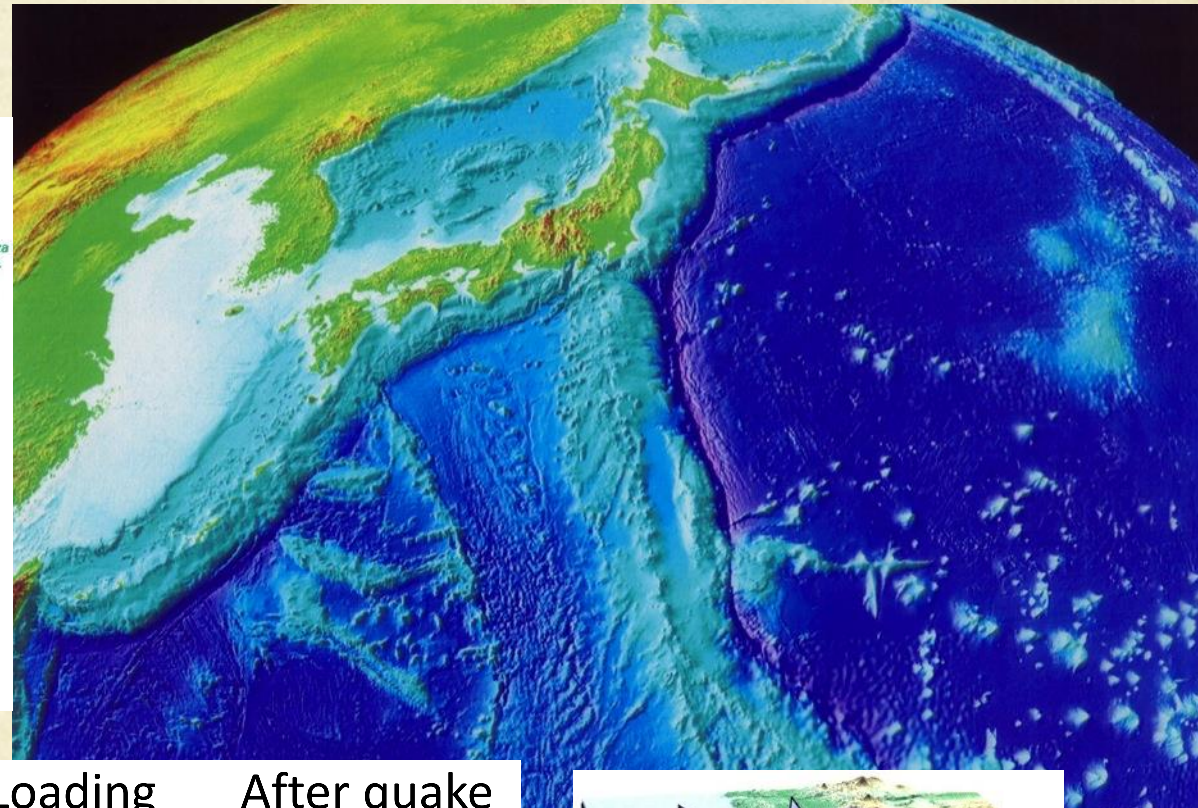
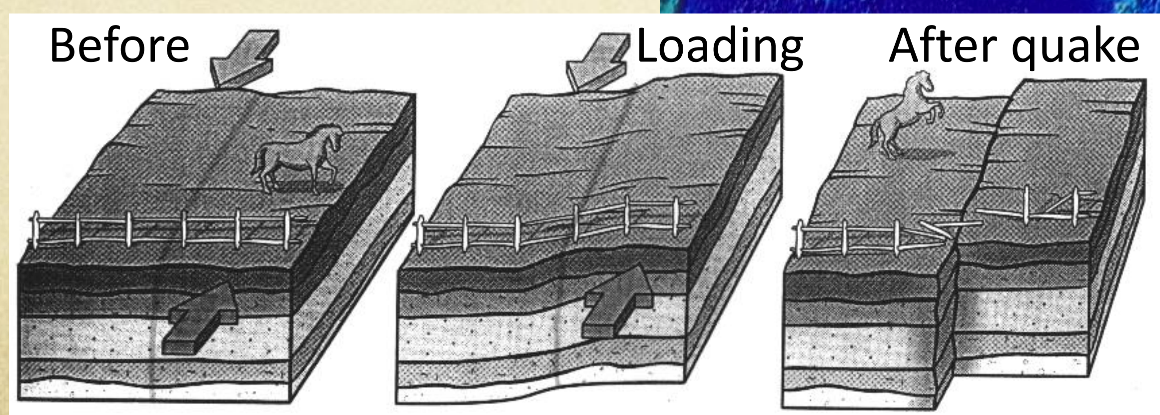
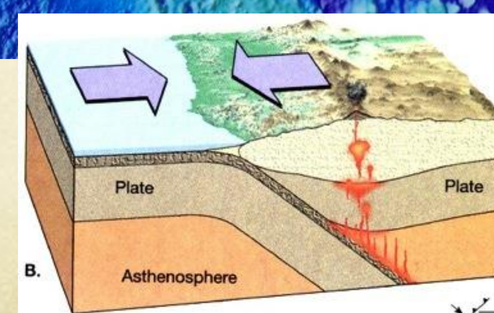
Tectonic Processes

Driving forces









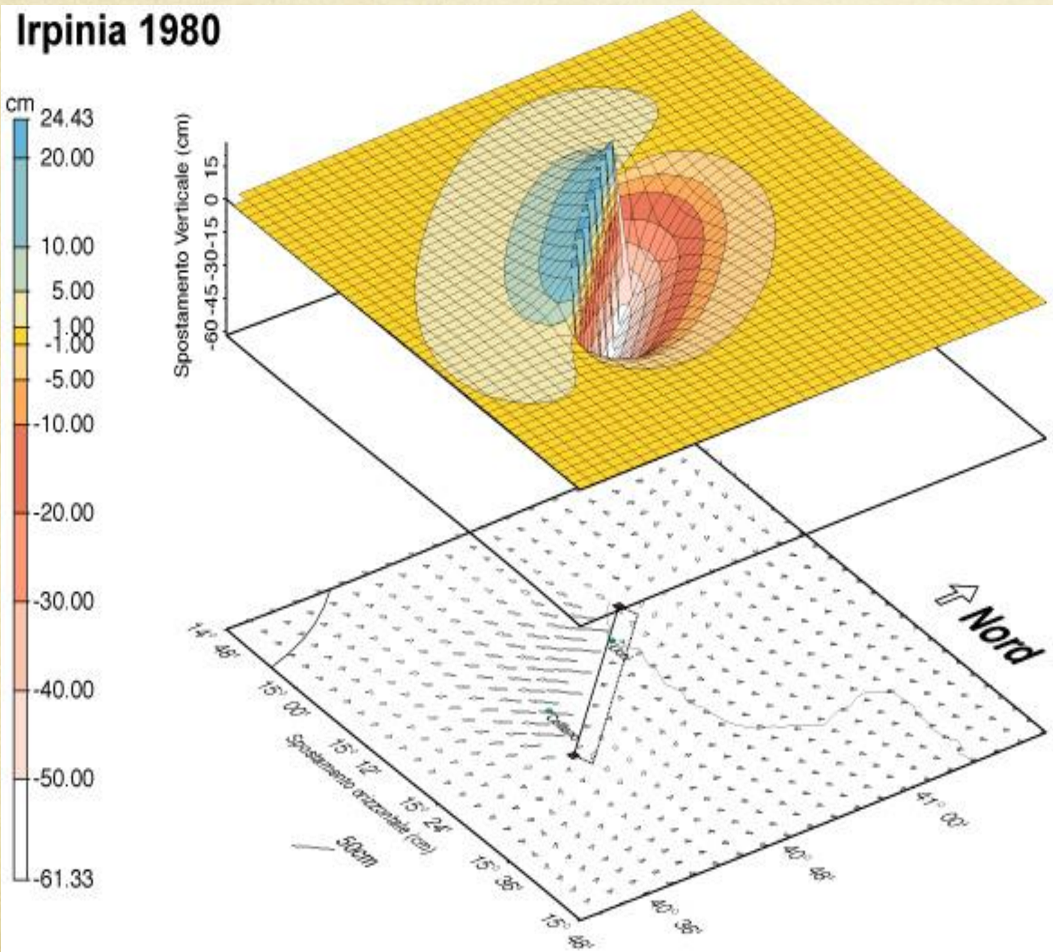
EGU 2013

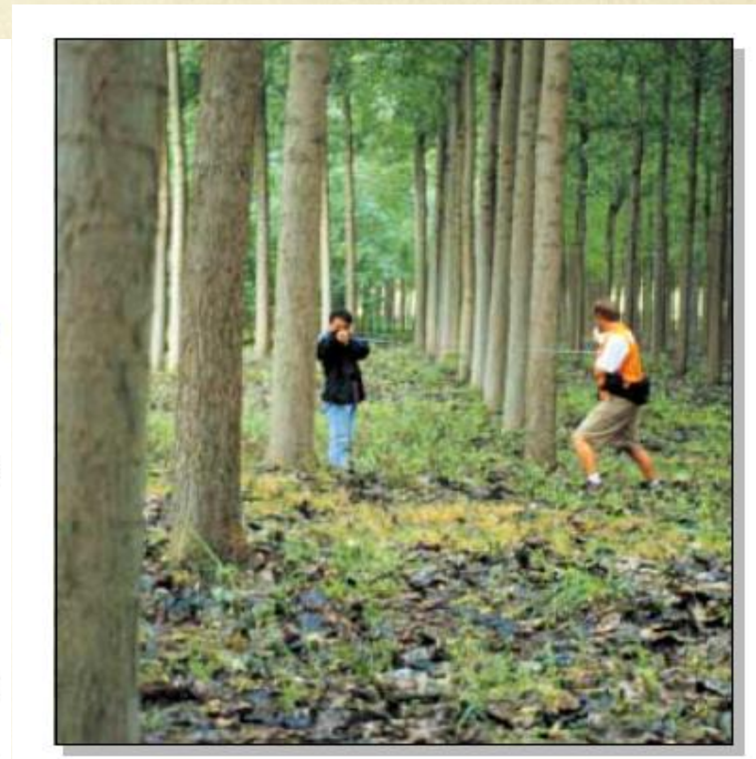
Tectonic Processes

- Plate tectonics sustains stress accumulation on plate boundaries and faults*
- The mechanical state of these faults controls the energy release, the size and frequency of earthquakes
- Earthquakes ruptures perturb the state of stress in areas surrounding the causative sources, which implies that faults interact and "*speak each other*"
- All the previous processes affect earthquake occurrence

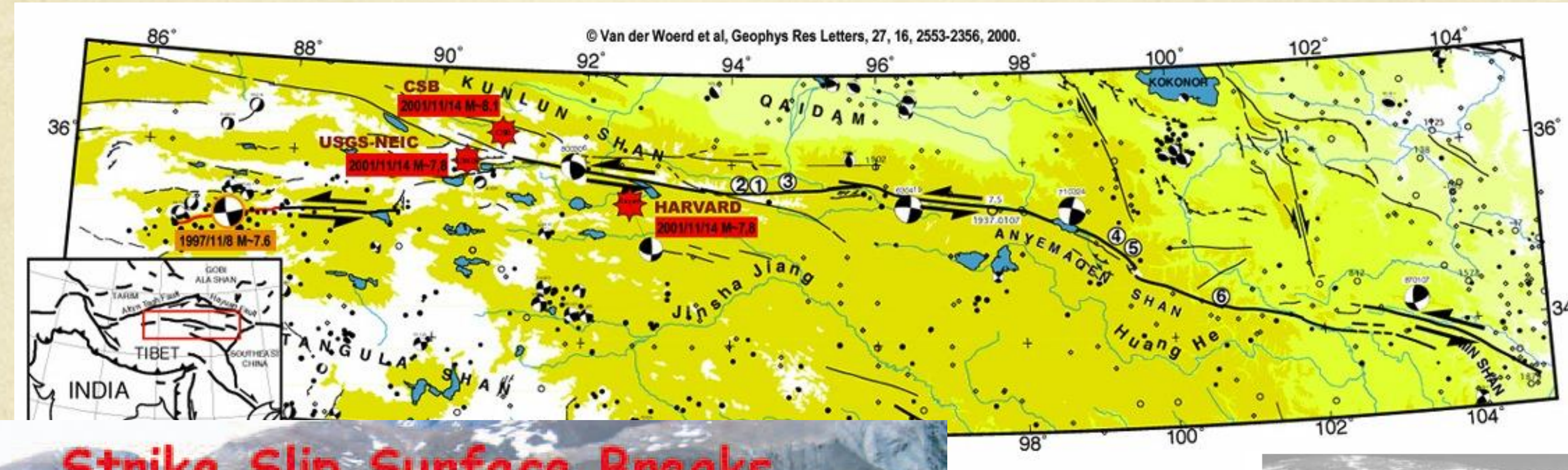
* A fracture in a rock formation along which there has been movement of the blocks of rock on either side of the plane of fracture. It is a discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of plate tectonics. Faults are caused by plate-tectonic forces.

Earthquakes deform the landscape and shake the Earth surface





Strong Earthquakes break the Earth surface due to slip at depth



Kokoxili earthquake Mw 7.9 (Qinghai Province, China)

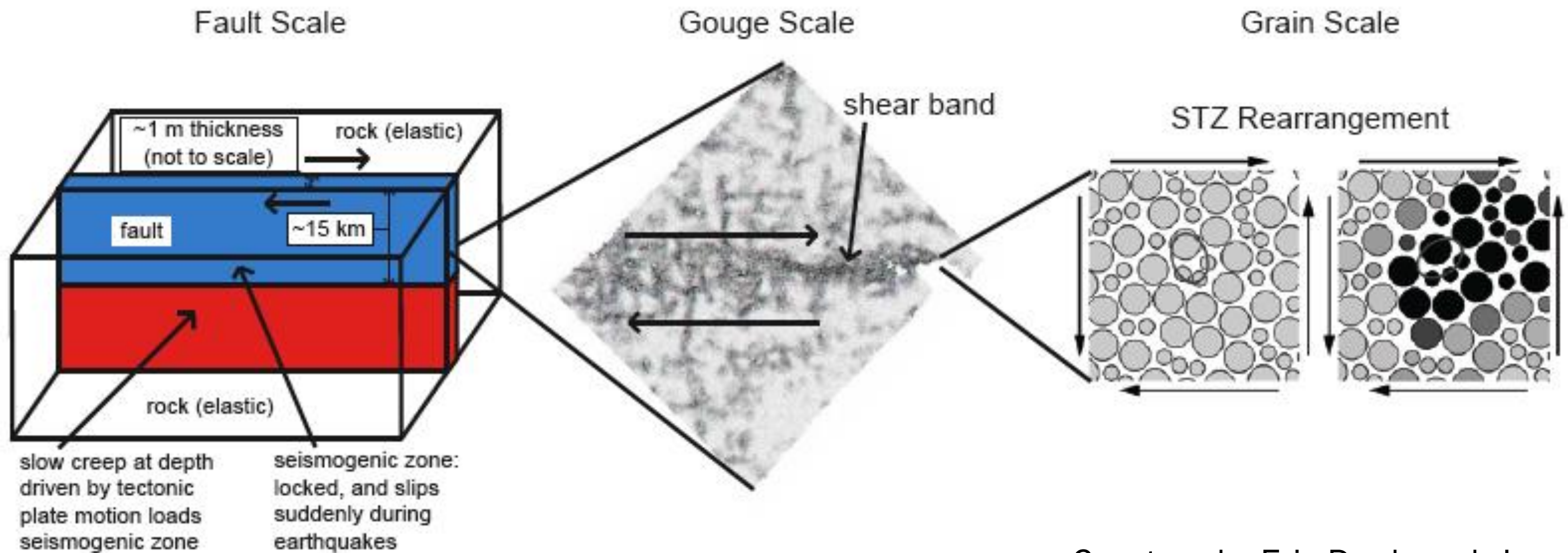
Novel observations and interpretations from simulations

The challenge is to reconcile geological observations of natural faults and seismological and geodetic measurements with laboratory tests on experimental faults

Geology

Seismology

Laboratory



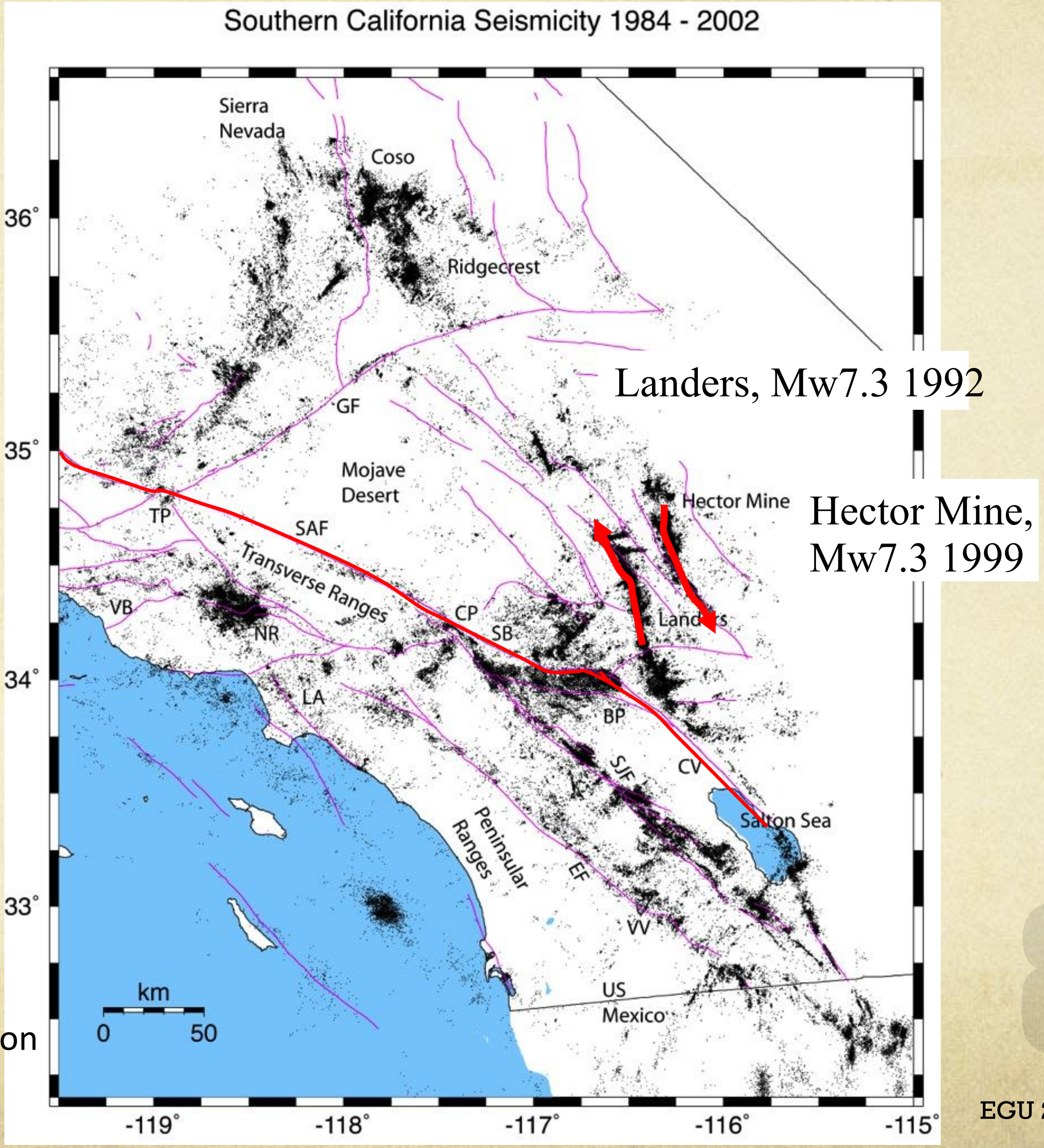
Courtesy by Eric Daub and Jean Carlson

Daub, E. G., and J. M. Carlson, Friction, Fracture, and Earthquakes, Ann. Rev. Cond. Matter Phys. 1, 397-418 (2010).

Observing and detecting

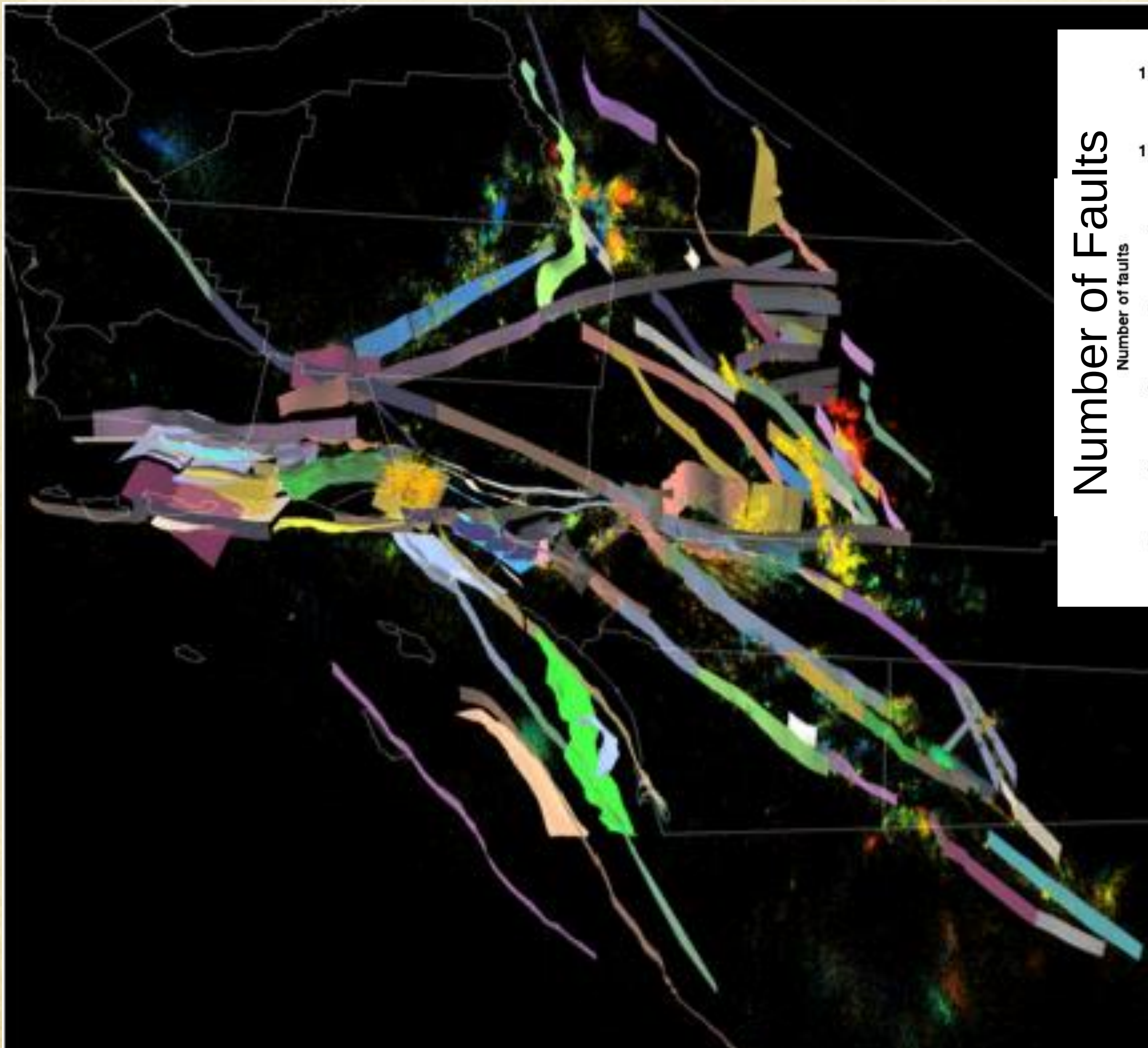
- Progress in monitoring systems (multidisciplinary networks) and in collecting high quality data
- Multidisciplinary high-precision observations in nature (real world) and laboratories
- Progress in modeling and simulating earthquake processes through high performance computing facilities
- Integrated approach to research infrastructures for promoting multidisciplinary and cross-disciplinary research

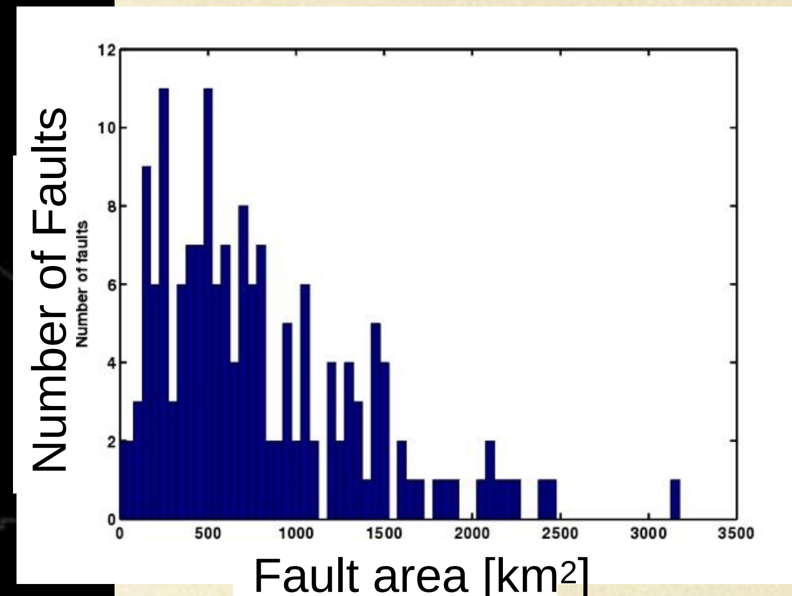
- Earthquakes do not occur everywhere, but on specific areas
- Major earthquakes break well known active faults
- Seismicity clusters around major faults, but also off fault
- Distributed and clustered seismicity are related to strain accumulation



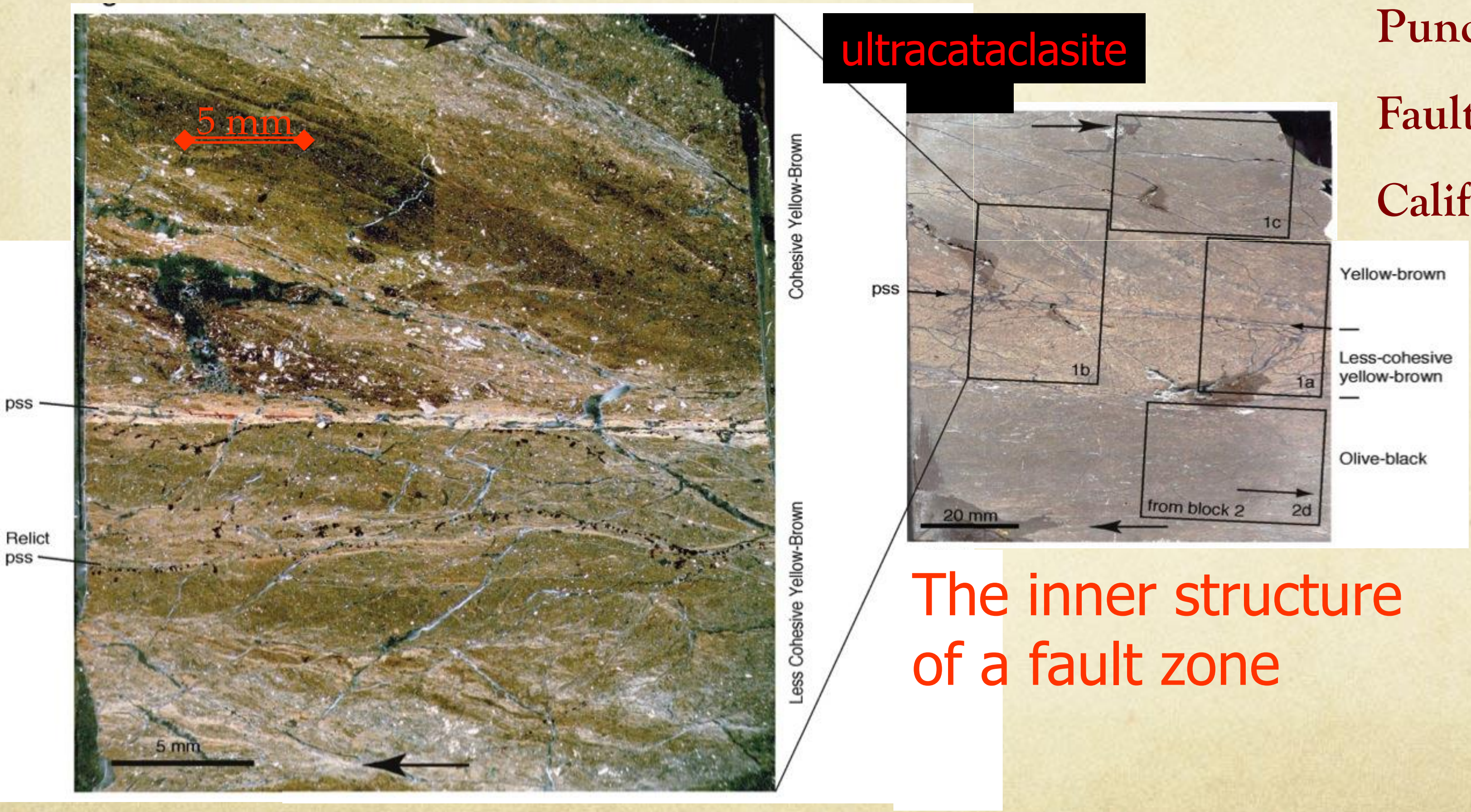
Relocations from Hauksson and Shearer (2005)

Southern California Earthquake Center: SCEC Community Fault Segment Model





The anatomy of a seismogenic fault investigated on the field



Punchbowl

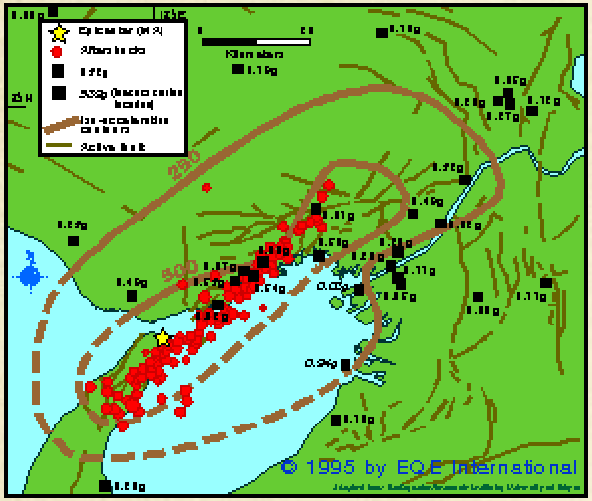
Fault

California

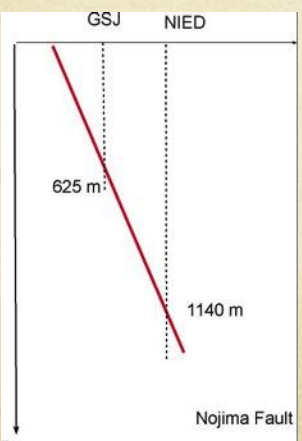
The inner structure of a fault zone

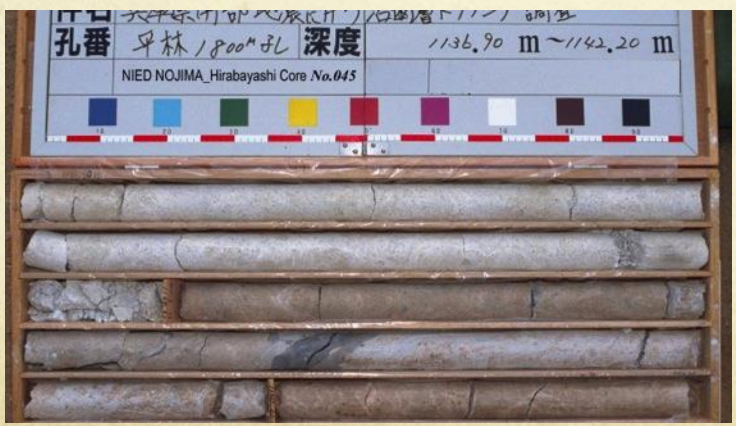
Chester et al. (2004, 2005)

Deep Scientific Drilling of active faults: an example from Japan

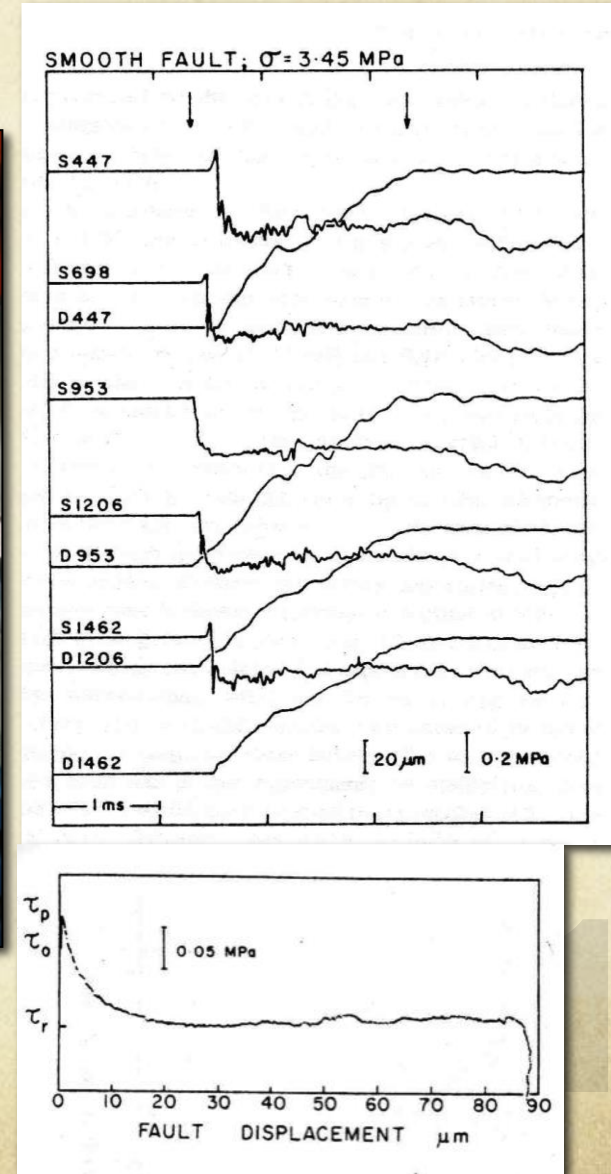


The 1995 Kobe earthquake (Japan)

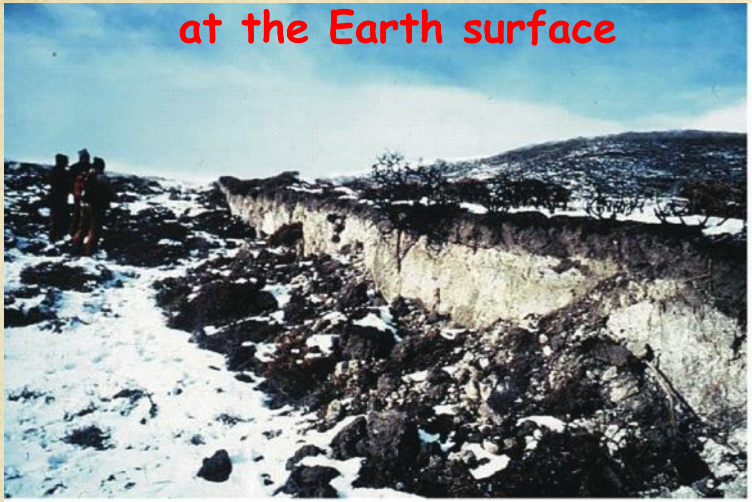




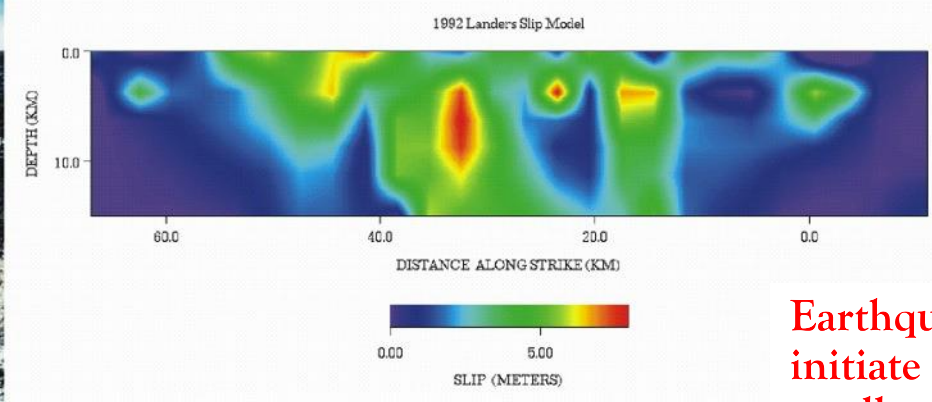
Laboratory Experiments on rock friction



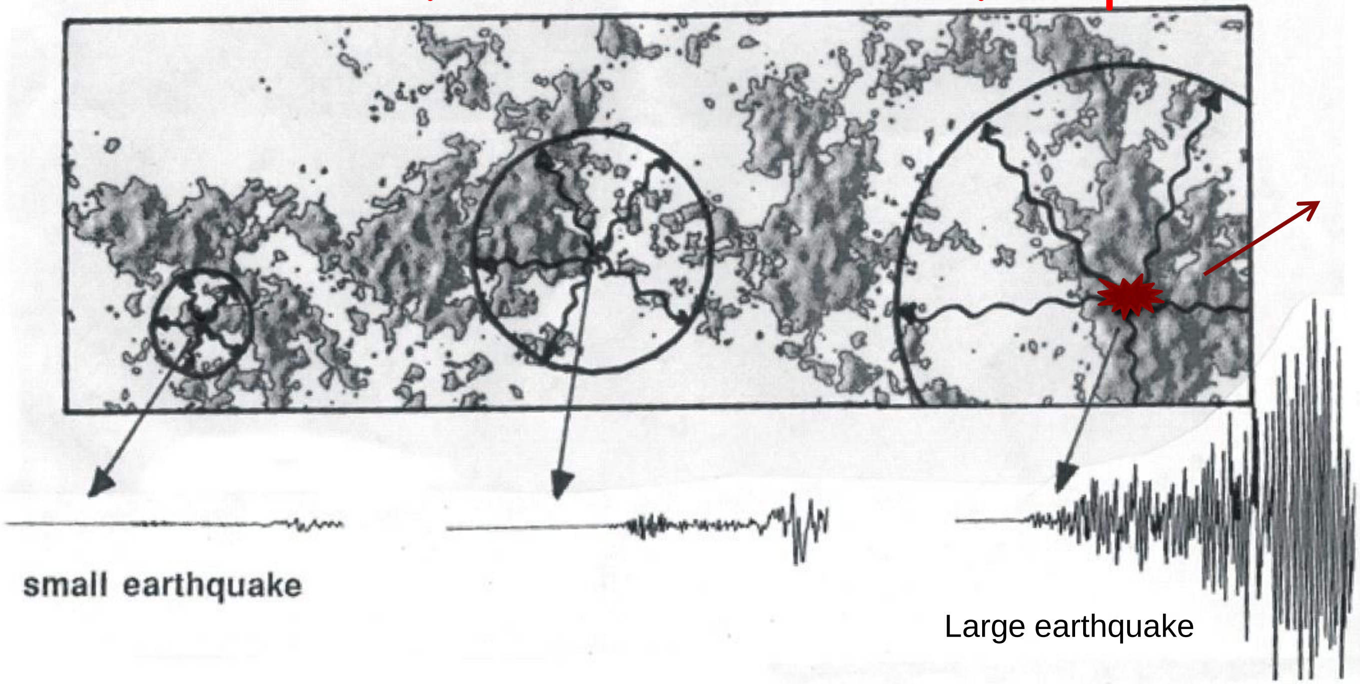
(Okubo and Dieterich, 1984)



at depth

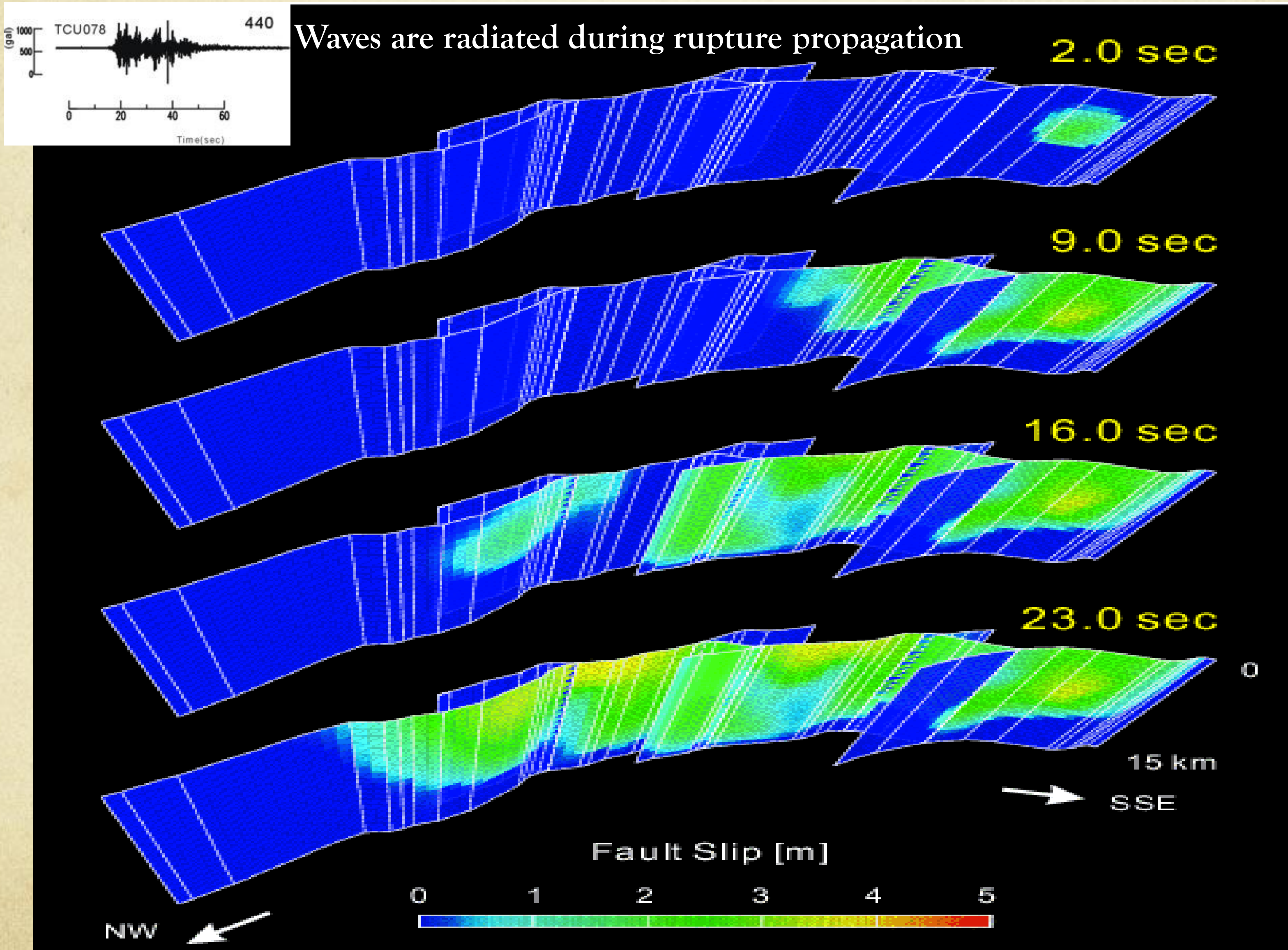


Generation of seismic waves on the fault plane



Earthquakes initiate on a small volume. Processes associated with nucleation are not well known We don't have direct observations of earthquake nucleation

Rupture Propagation during the 1992 Landers (California) earthquake



Earthquake Ruptures:

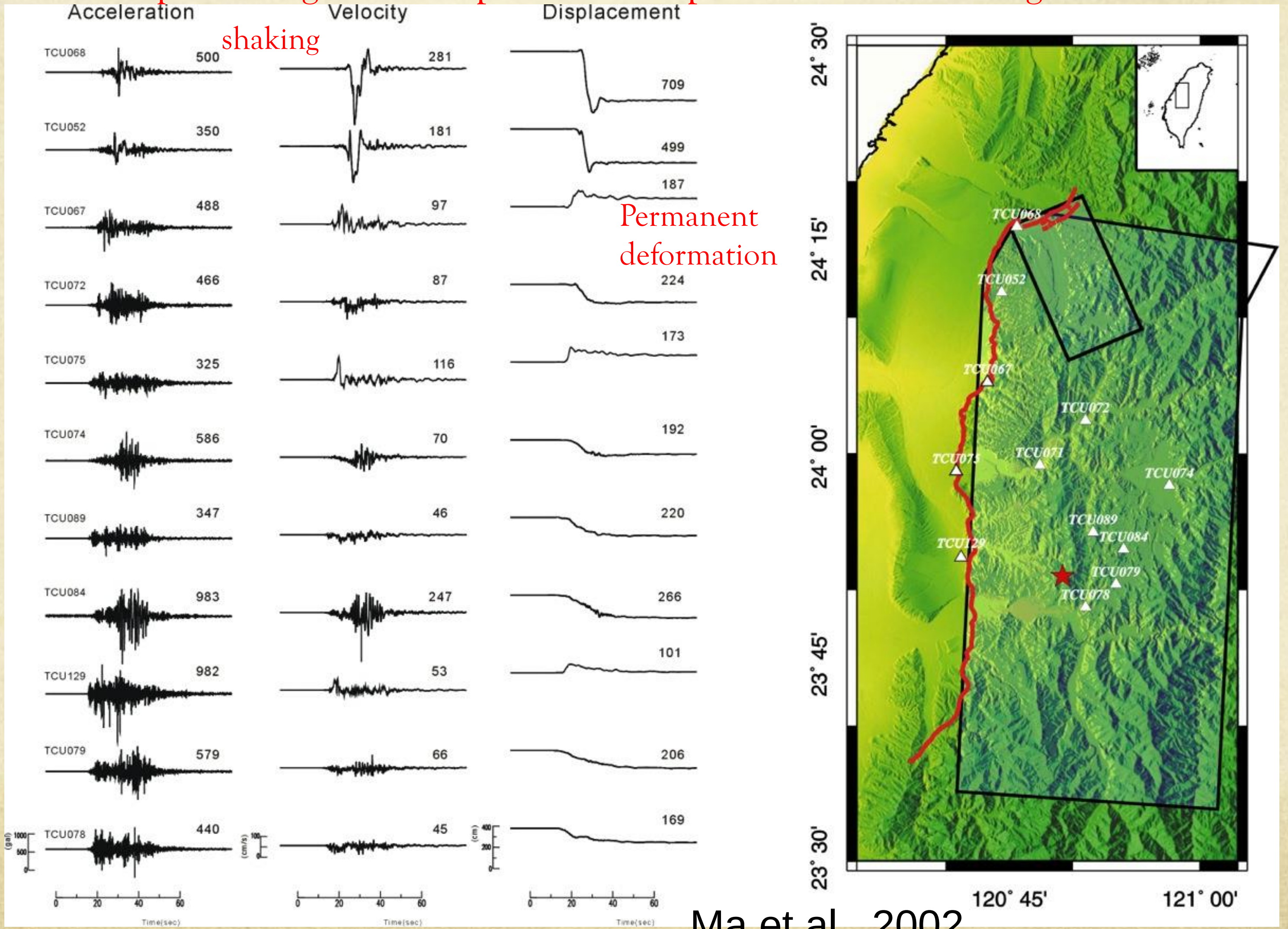
- Initiate
- Propagate
- Arrest

on complex fault surface

Numerical model by Aochi and Madariaga

Observed Ground Motions during the M 7.7, Taiwan, 1999 earthquake

The earthquake magnitude depends on amplitudes of observed ground motion

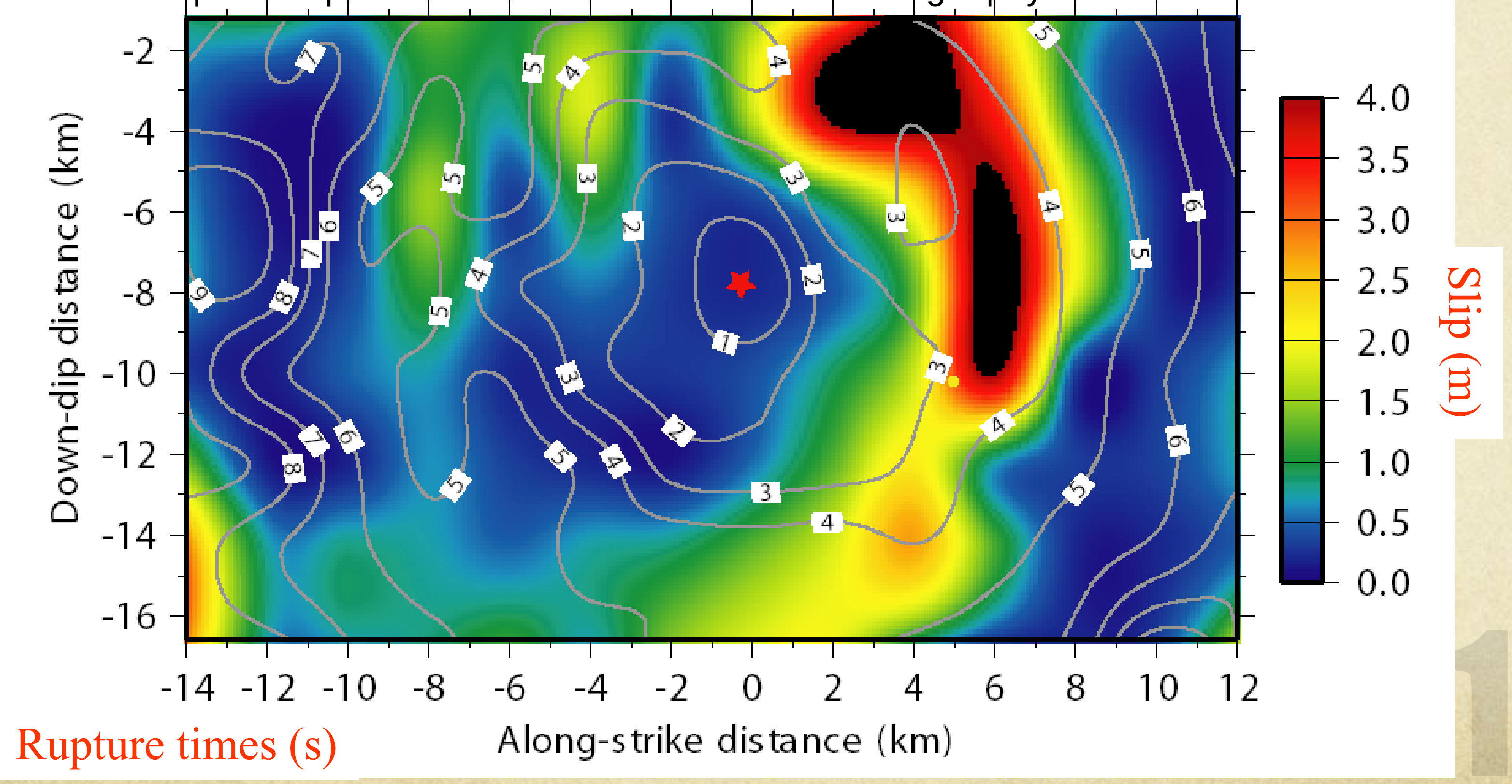


Ma et al., 2002

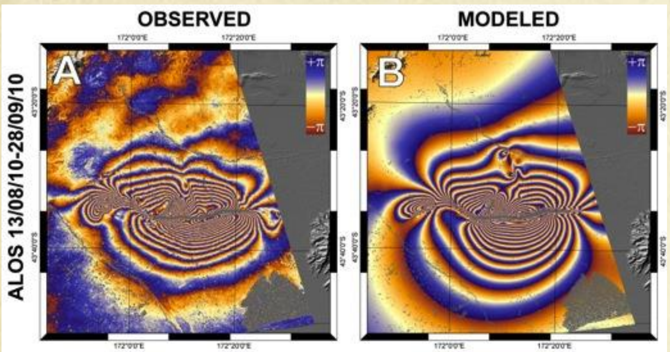
Seismological observations: Rupture History
Earthquake ruptures propagate within the Earth crust

Fault dimensions scale with Earthquake Magnitude:
A M 9 event can break ≈1000 km

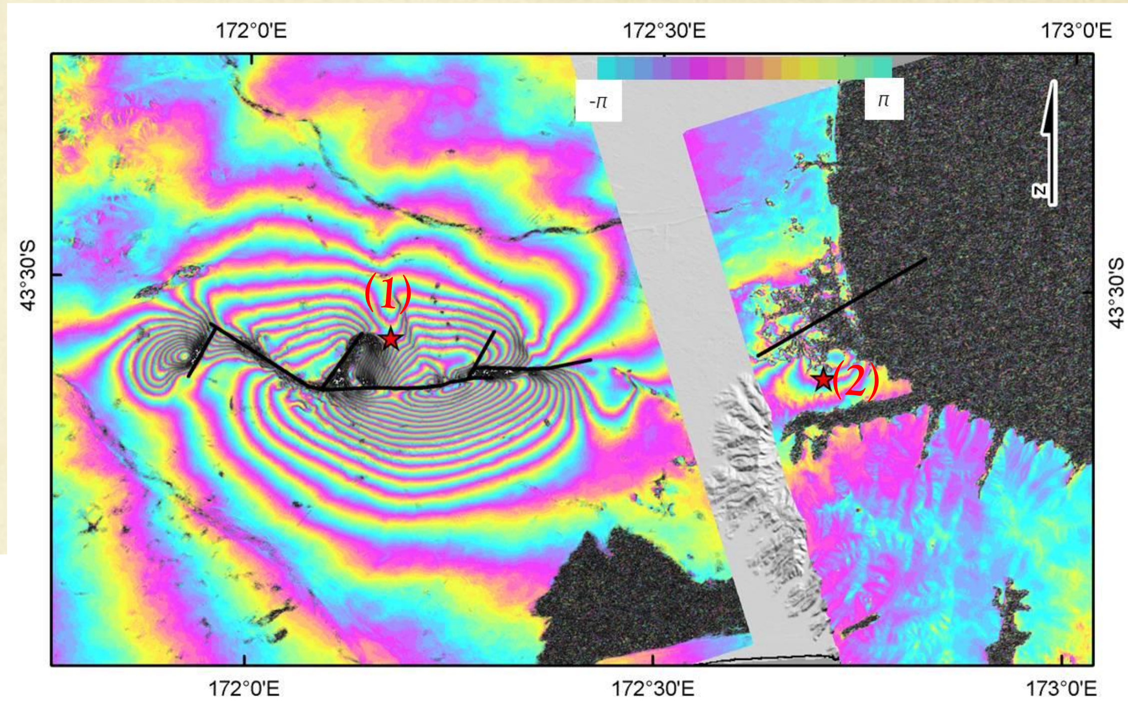
Slip and rupture time distributions obtained from geophysical data inversion

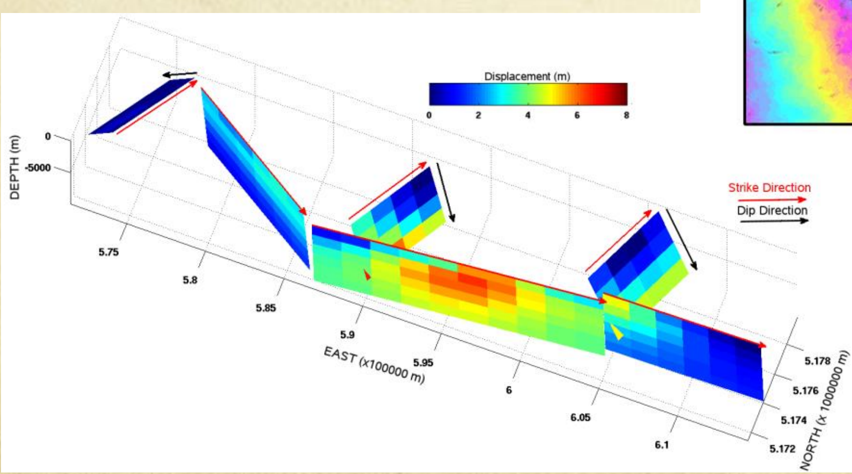


The New Zealand earthquake doublet:
(1) 2010 Darfield (September 3rd) M 7.1
(2) 2011 Christchurch (February 21st) M 6.3



Observations from Space





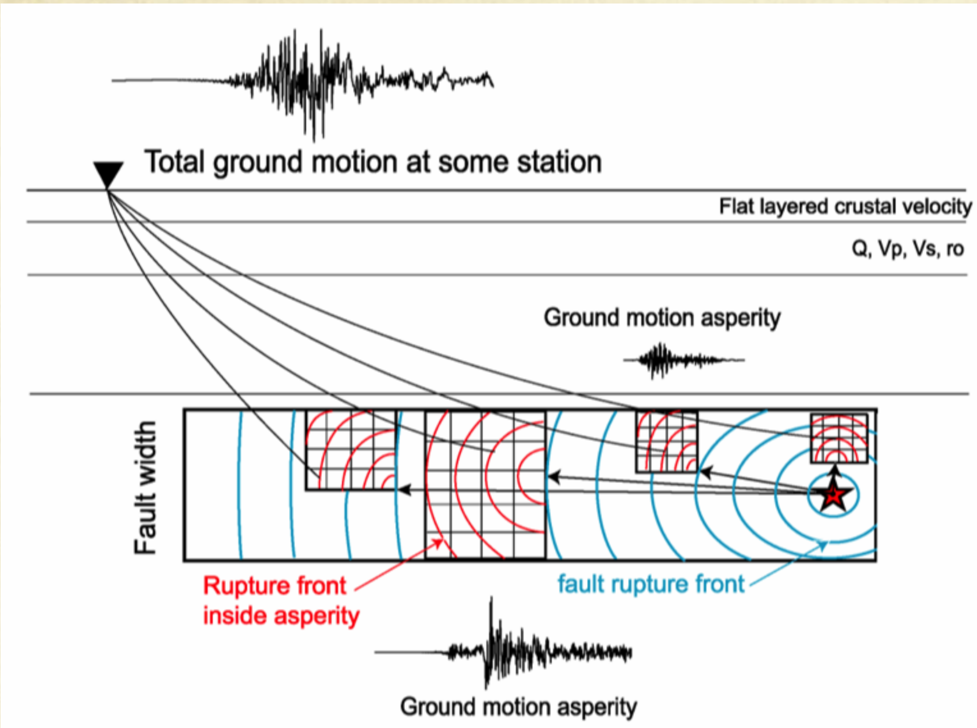
Measuring coseismic deformation from satellite Earth observations

Courtesy of Salvatore Stramondo

Preliminary conclusions I

- Scientists have reached substantial progress in understanding the physical processes causing earthquakes
- We still have a limited knowledge of how earthquake rupture initiates (earthquake nucleation)
- We have a better comprehension on why, where and how earthquakes occur
- **How can we use this scientific progress for prevention and forecasting ?**

Contributions to seismic prevention: predicting ground shaking during earthquakes

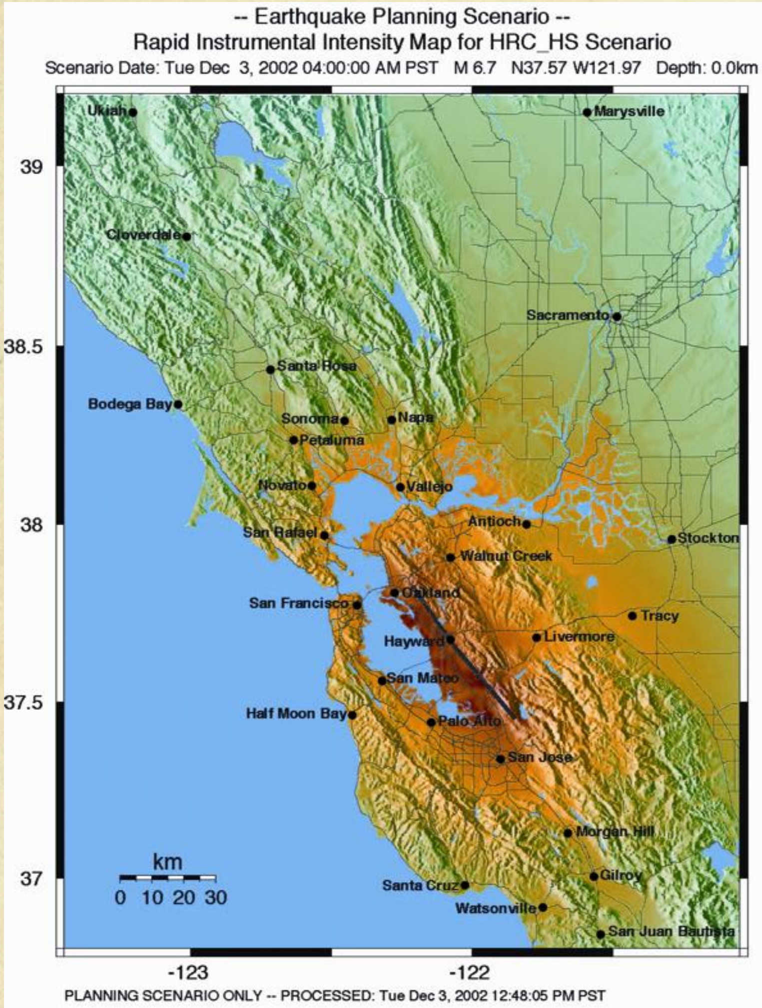


A mosque stood with a few other structures amid the rubble of collapsed buildings in the town of Golcuk, 60 miles east of Istanbul.

Associated Press Photo by Enric Marti
Taken from New York Times, August 20, 1999

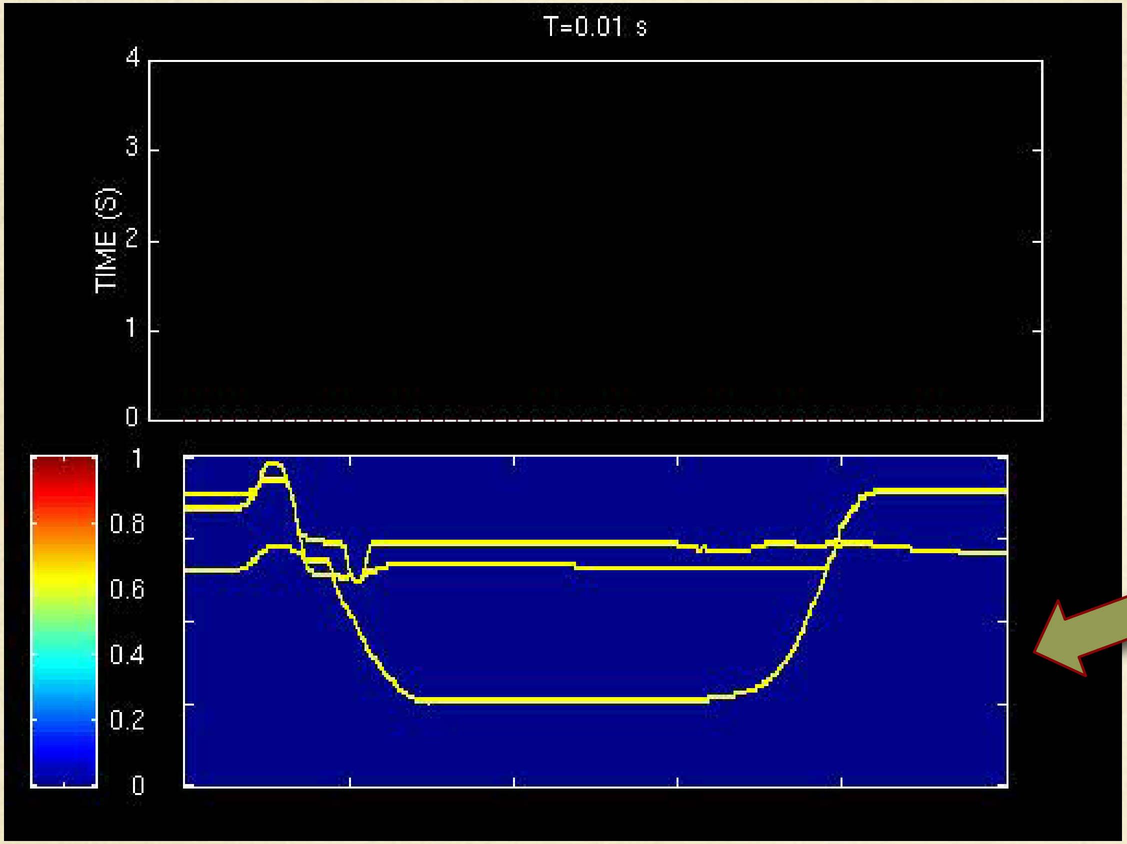
Progress in modeling seismic wave generation and propagation results in a better understanding of earthquake effects and impact on buildings and infrastructures

Probalistic shaking scenarios



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Predicting ground shaking and earthquake effects

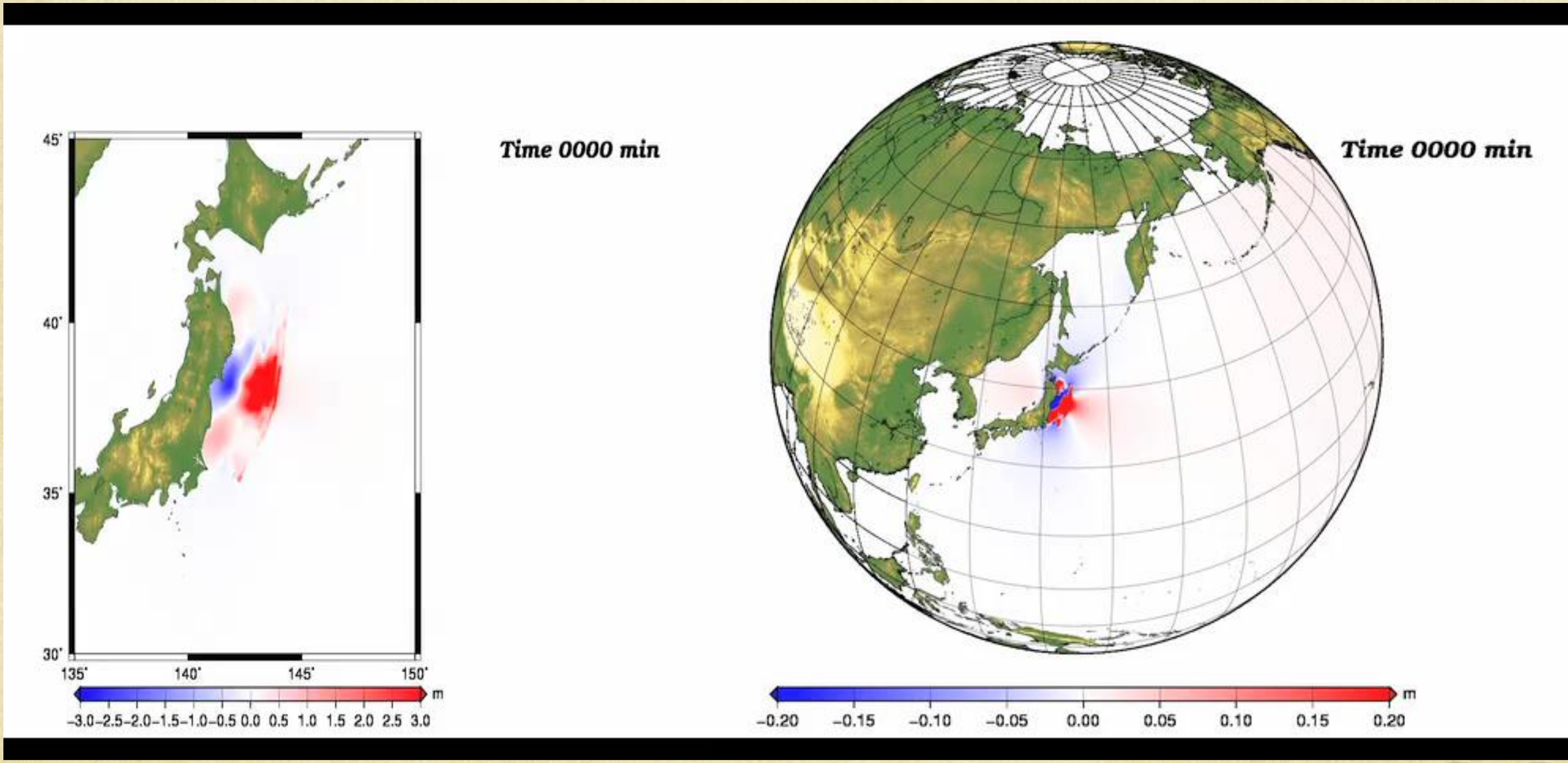


Ground shaking (amplitudes of ground motion) depends on:

- The earthquake size
- The propagation of seismic wave within the Earth lithosphere
- The amplification effects of ground motions due to the near surface geological conditions

Fluvial Basin

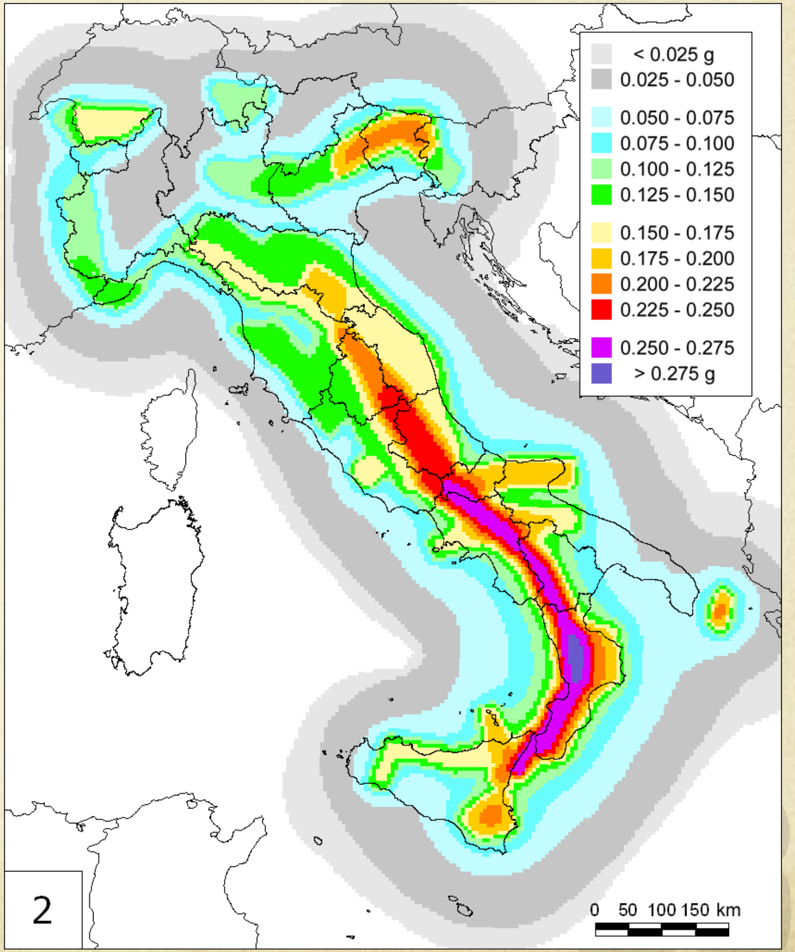
Tsunami hazard: predicting tsunami waves and coastal inundation



Courtesy of Fabrizio Romano

Hazard and Risk

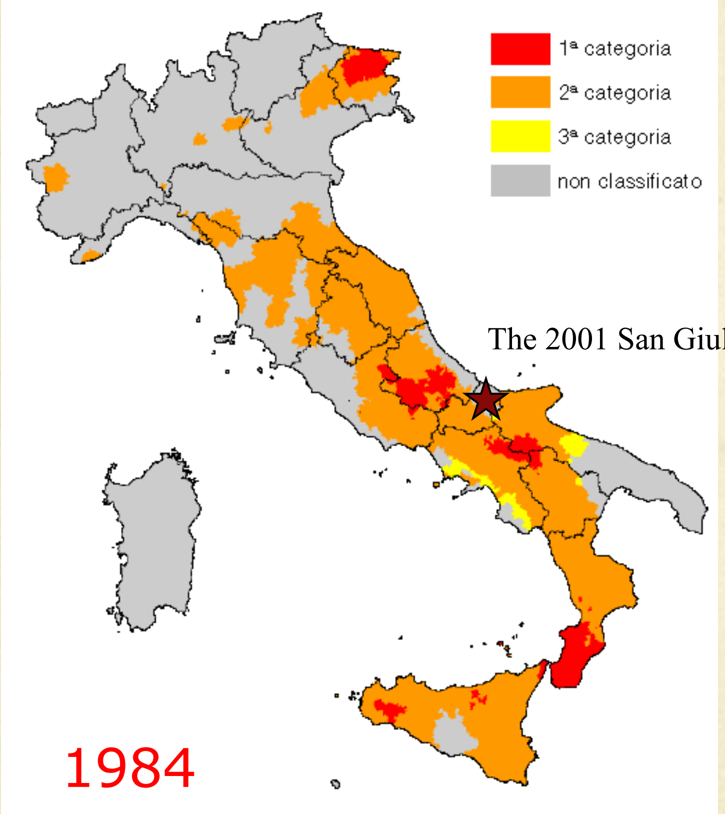
- The observations and the understanding of earthquake ground motions are therefore transferred in the seismic hazard map
- This is a scientific achievement directly applied to prevention and preparedness

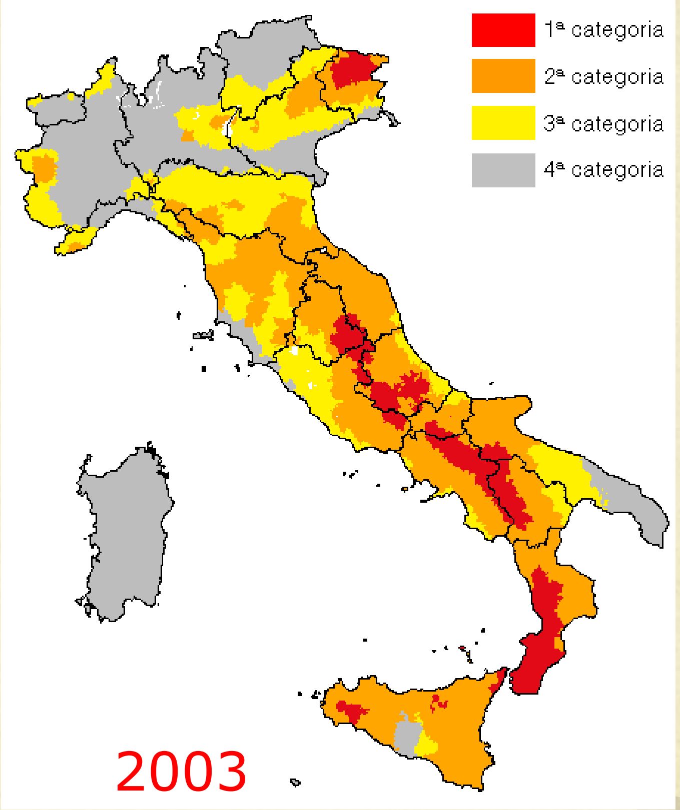


Vulnerabilty

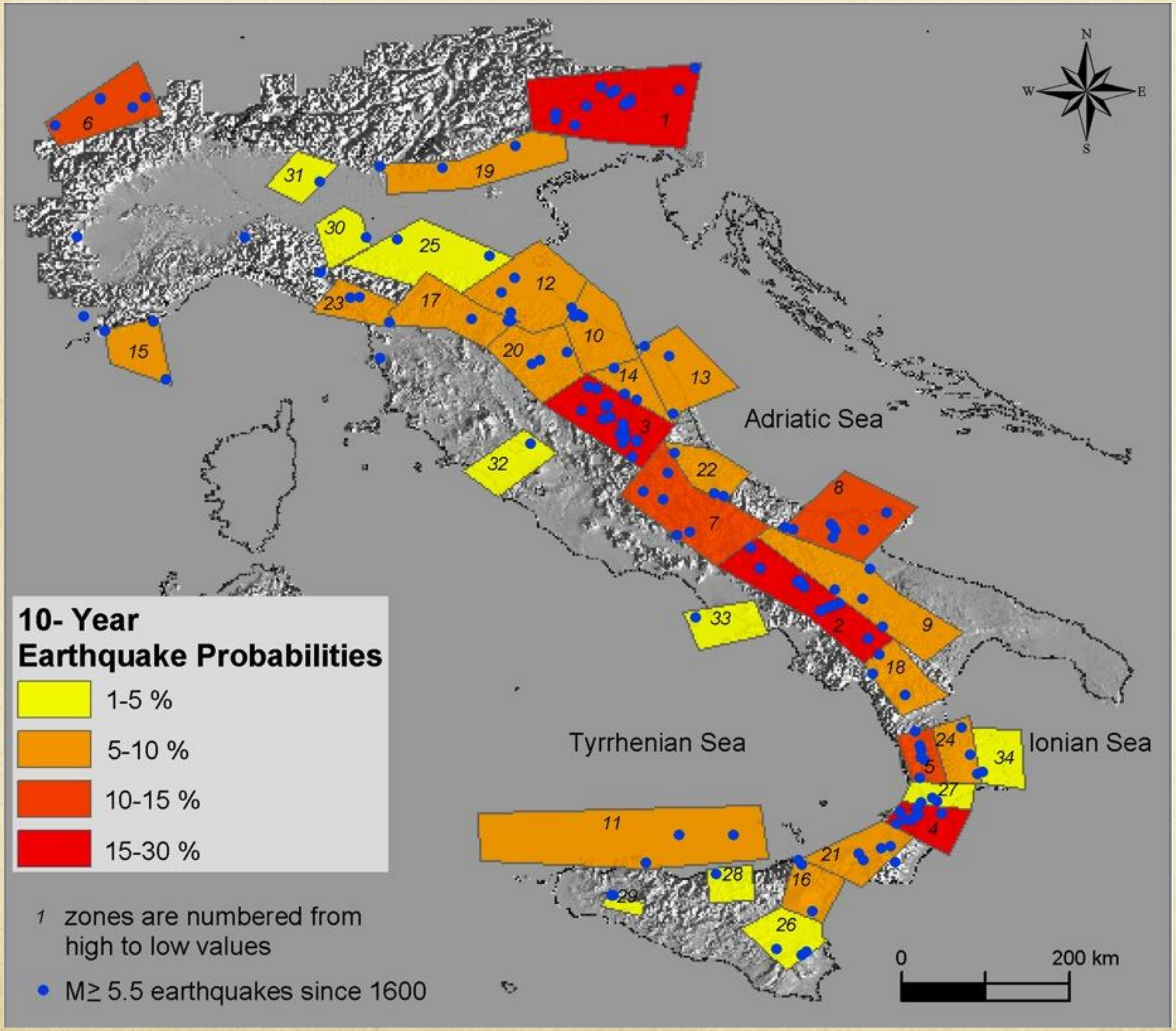
- Vulnerability is a set of prevailing or consequential conditions, which adversely affects an individual,
  a household or
  a community's ability
  to mitigate, prepare for
  or respond to the
  earthquake hazard

Seismic Classification



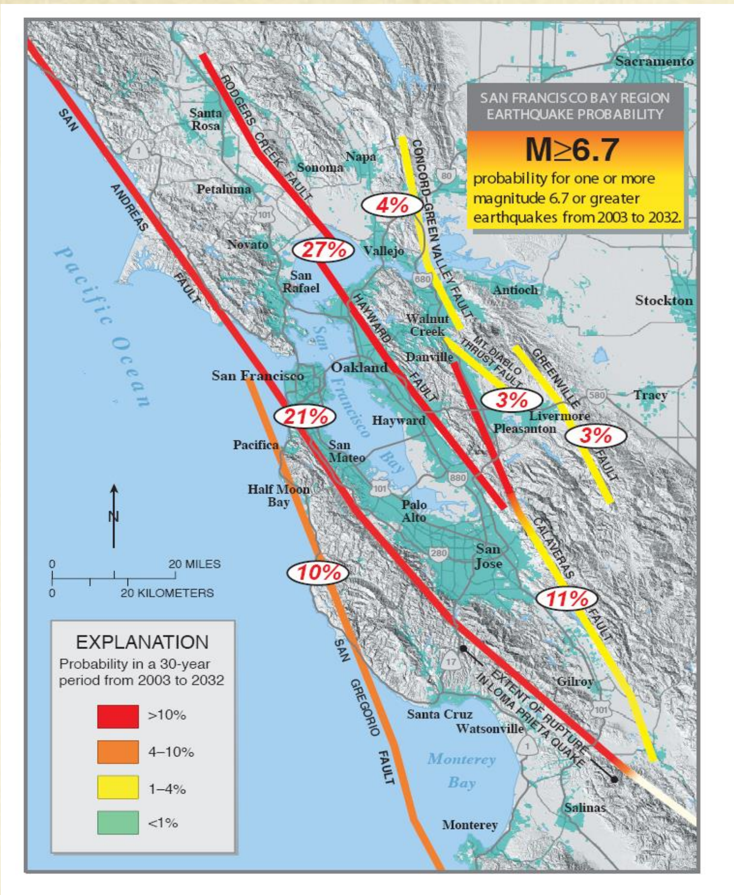


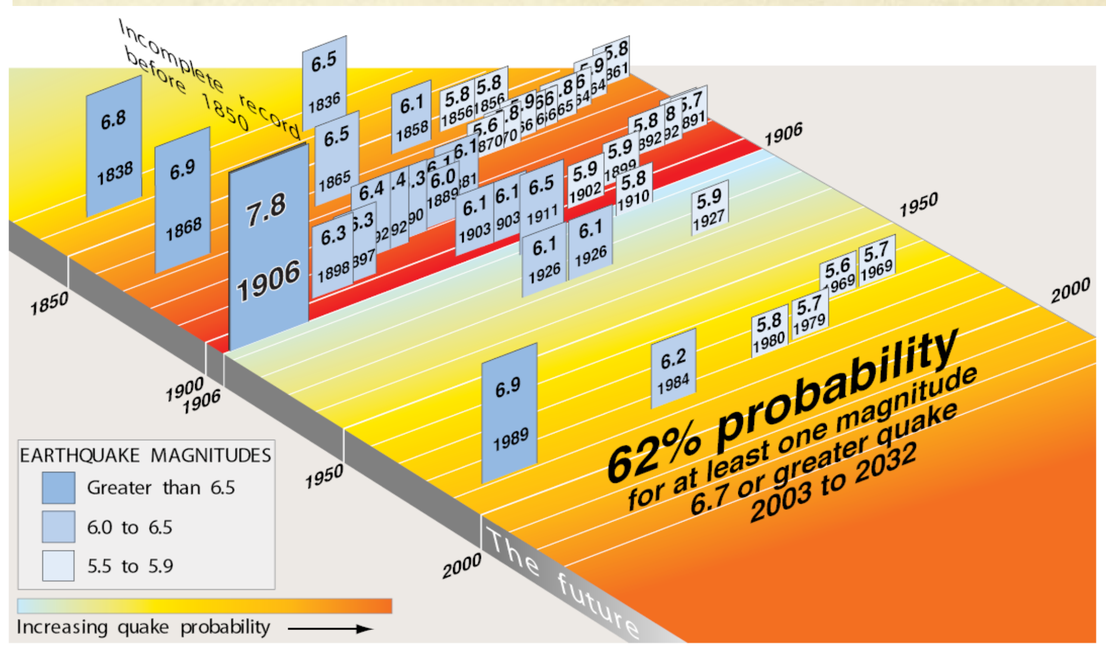
Earthquake Probabilities



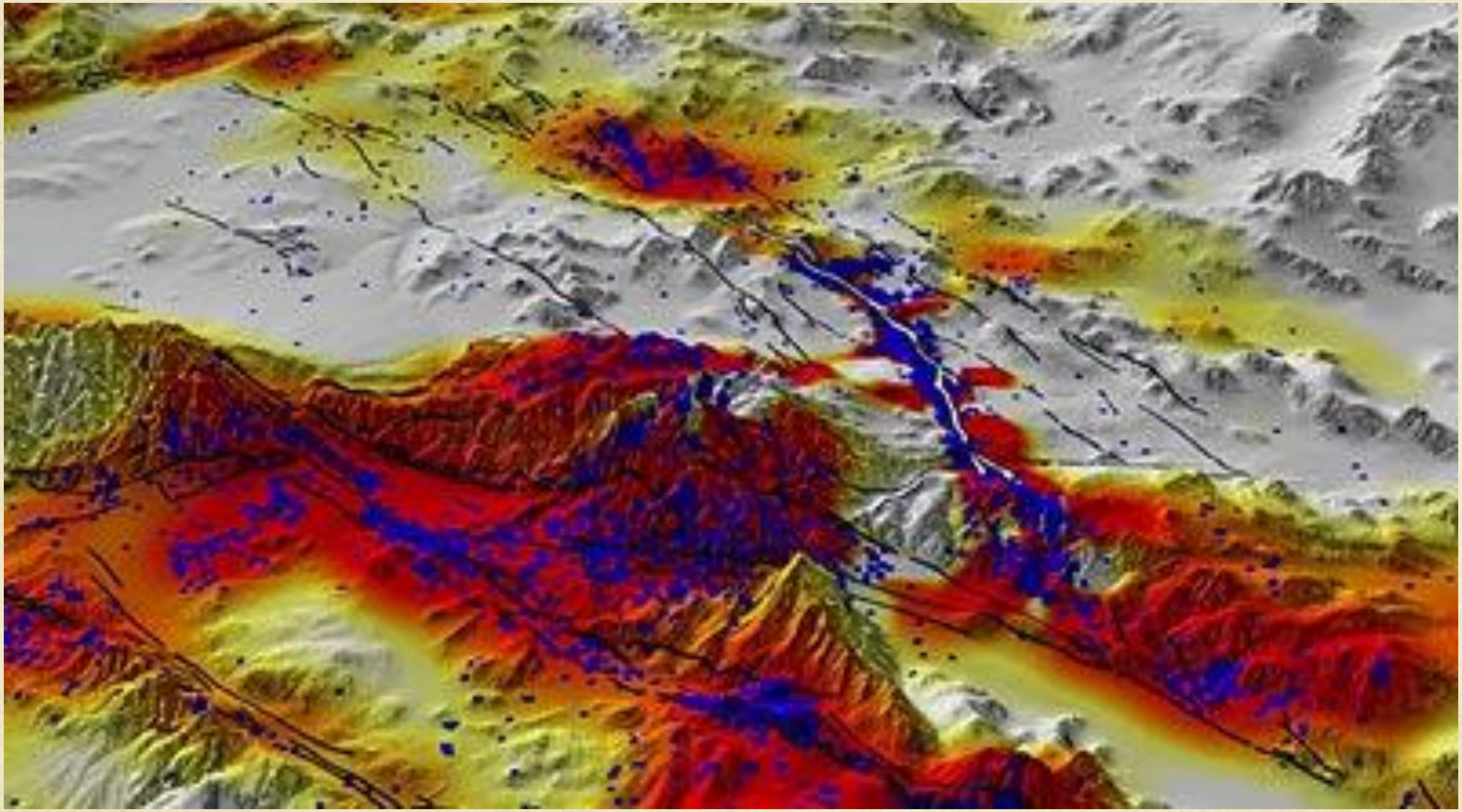
Faenza & Marzocchi, GJI 2003

Probabilities of earthquake occurrence on individual faults





Forecasting the rate of earthquake occurrence



Forecasted and real seismicity

Preliminary conclusions II

- Earthquake scientists have achieved important results in understanding the effects of ground shaking on human environment
- This progress represents a fundamental contribution to earthquake prevention, seismic hazard assessment and risk mitigation
- Substantial progress has been achieved in forecasting the rate of earthquake occurrence and the probability of occurrence
- These results have to be validated and transferred to decision makers and to the society
- Transferring this information requires shared procedures, awareness and preparedness

Science for Society: from understanding to increasing resilience to natural hazards

Fundamental Science
- Monitoring (implementing data infrastructures)
- Understanding physical processes
- Forecasting occurrence of events (probabilistic forecasts)

Applied Science
- Hazard assessment
- Vulnerability assessment
- Risk assessment and mitigation

Decision Makers
- Prevention actions
- Emergency management and planning
- Disaster management

Society and local communities
- Education and Training
- Outreach and dissemination
- Increasing resilience to natural hazards

Lessons from recent earthquakes

- Sumatra M 9.3 (Indonesia) 2004
- L'Aquila M 6.1 (Italy) 2009
- Haiti M 7.0 2010
- Maule M 8.8 (Chile) 2010
- Christchurch M 7.2 (New Zealand) 2010
- Tohoku M 9.0 (Japan) 2011
- Virginia M 5.8 (USA) 2011

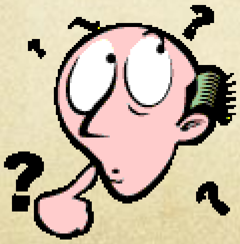
…. as well as from other events

- Eyjafjallajökull volcano (Iceland)
- Kathrina Hurricane
- Irene Hurricane

Caveat: all these events are characterized by hazard assessment and event forecast

Key players in risk mitigation

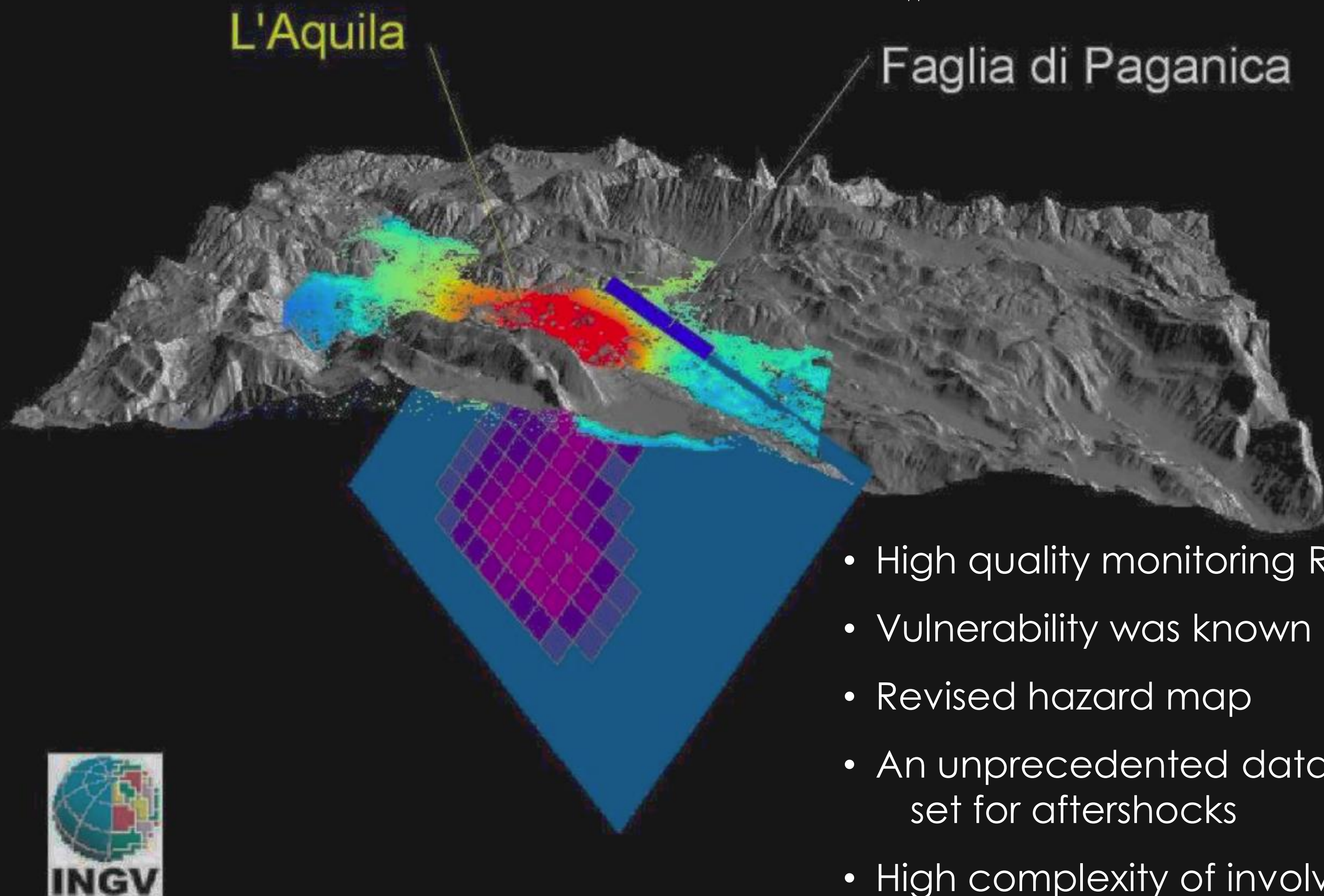
- Scientists are responsible to create the conditions for new discoveries and scientific progress
- They are also responsible to make these achievements available to society
- Transferring scientific results to decision makers requires formal approaches, protocols and distinction of roles
- Communicating scientific results to public requires a cross-disciplinary approach and the involvement of different stakeholders
- Promoting **Preparedness** and **Awareness** of society to natural hazards requires cross-disciplinary and tailored approaches



Are we ready to communicate risk to society?

The 2009 L'Aquila earthquake

April 6th 2009 M_w 6.3 at 03:32 am



- High quality monitoring Ris
- Vulnerability was known
- Revised hazard map
- An unprecedented data set for aftershocks
- High complexity of involved coseismic processes

nature

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World politics

L'Aquila's earthquake

…ists in the …

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By Larry Greenemeier | September…

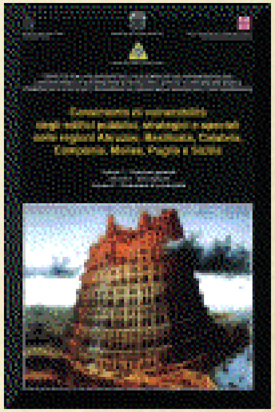
Published online 26 May 2011 | Nature | doi:10.1038/news.2011.325

News

Scientists face trial over earthquake deaths

Scientific achievements and products transferred to decision-makers

- Seismic hazard map for the region (updated in 2004 and law in 2005)
- Probability of occurrence of a M 5+ earthquake was relatively high (≈10-15%, at 10 - 50 years) and was published in several papers [Pace et al., 2006; Faenza et al., 2003; Cinti et al., 2006]
- Vulnerability of several building and historical heritage in L'Aquila city was known [GNDT-LSU, 1999; SIGOIS, 2006]
- Historical seismicity and measured tectonic strain in this area indicated high earthquake potential
- Several seismic sequences were registered in the area in previous years (i.e., 1985) with main shocks M ≅ 4 which were not followed by any destructive event



Censimento di vulnerabilità degli edifici pubblici strategici e speciali nelle regioni Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia Orientale

- This earthquake has left the scientific community and the involved stakeholders quite evident lessons concerning the necessary prevention actions, as well as the urgent need to train and educate the society to live in earthquake prone areas
- These lessons should spur all the public authorities towards a better use of seismic hazard maps and available information concerning the vulnerability of the Italian territory
- These lessons demand for urgent initiatives to increase the resilience of the Italian society to natural hazards
- Unfortunately, these lessons are still unheard
- It is in the best interest of all countries to reduce earthquake vulnerability through awareness, preparation, and mitigation.

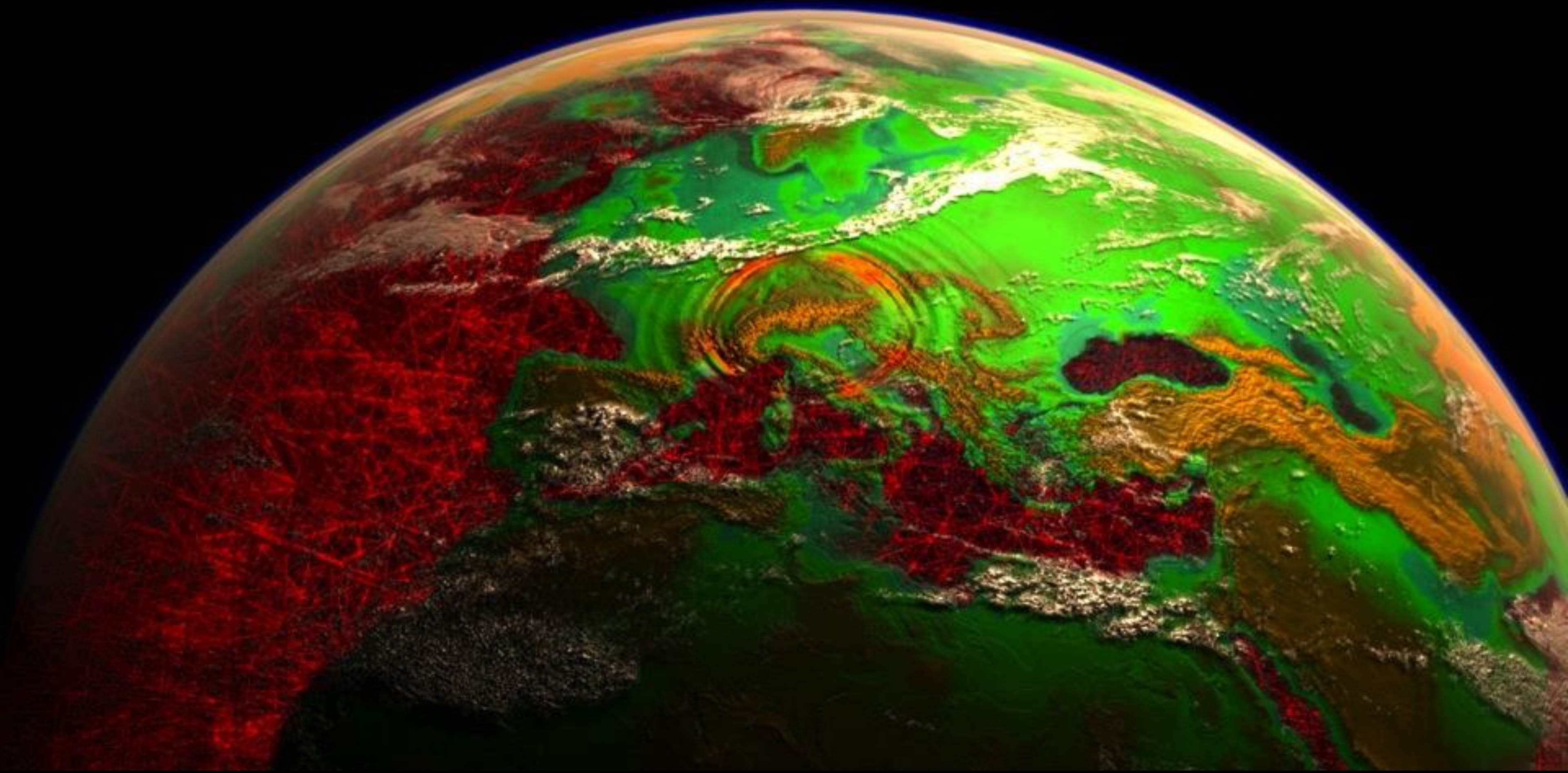
Progress in solid Earth sciences

- Data availability as well as high quality monitoring infrastructures and experimental facilities
- Development of Early warning systems
- Long-term hazard assessment
- Short term probability and operational forecasting
- Proper approach to face forecasting, but risks in focusing on prediction (misinterpreting forecasting)

Key actions requiring cross-disciplinary approaches

- Education, training, capacity building
- Empowerment of local communities
- Improving access to scientific results
- Dissemination exploiting new IC Technologies
- Emergency planning and disaster management

Thank you for attention



Massimo Cocco massimo.cocco@ingv.it Istituto Nazionale di Geofisica e Vulcanologia