Structural Dynamics and Earthquake Engineering

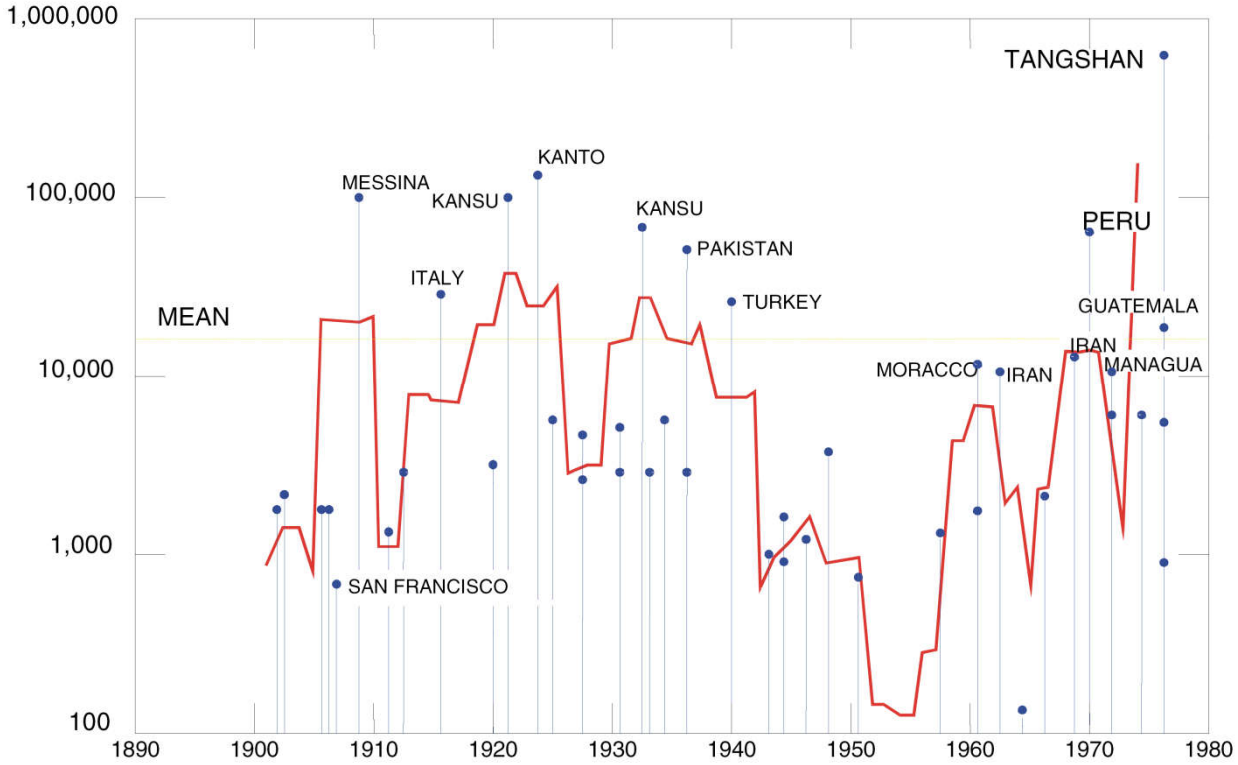
Course 4

Introduction to engineering seismology

Course notes are available for download at
https://www.ct.upt.ro/studenti/cursuri/stratan/dsis.htm

Introduction

- On average 10000 people die each year due to earthquakes
- 1994 Northridge (USA) earthquake ⇒ 40 billion USD economic losses
- 1995 Kobe (Japan) ⇒ 100 billion USD economic losses



Introduction

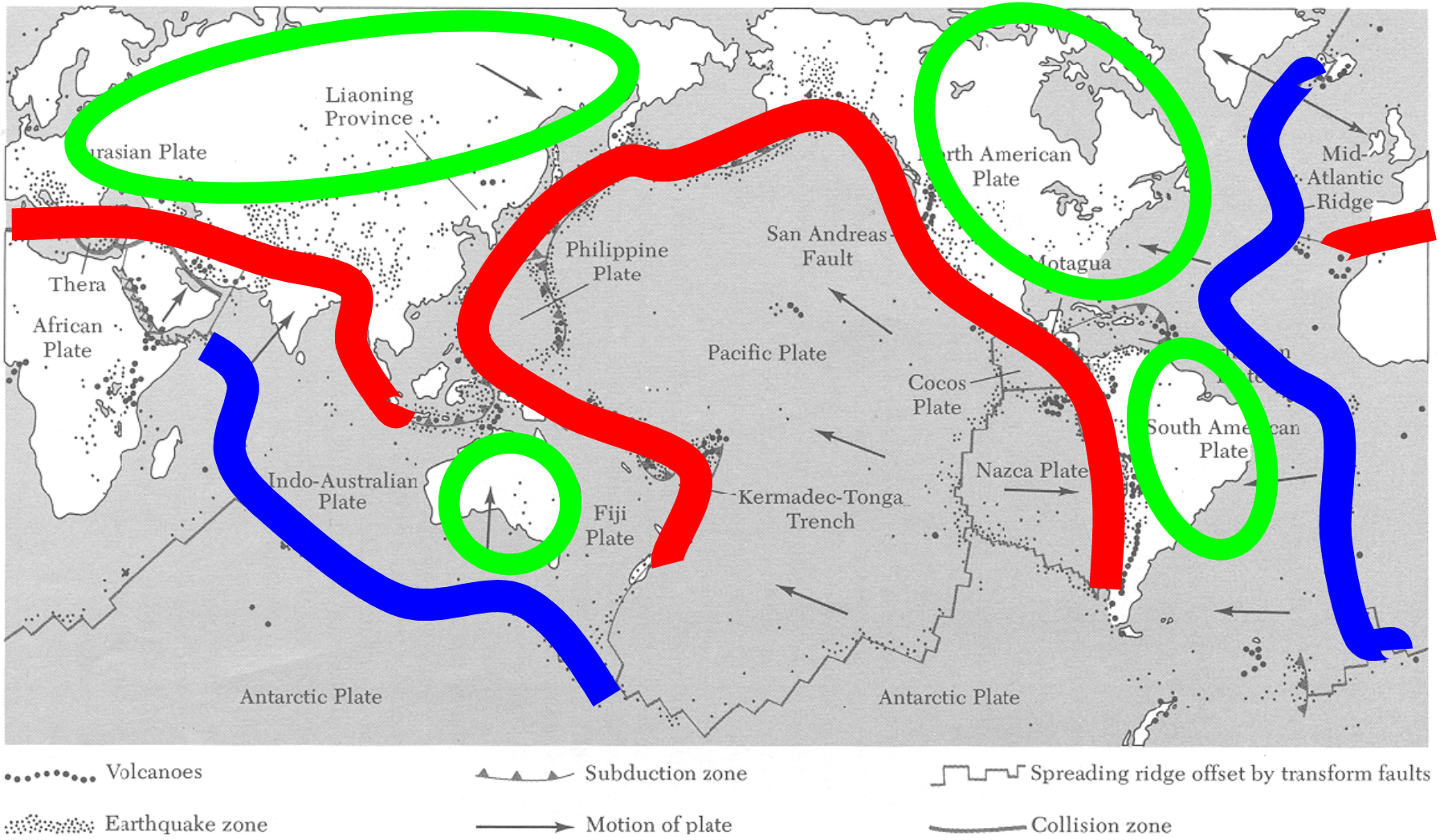
- **Earthquake engineering is the branch of engineering devoted to mitigating earthquake hazard, and involves:**
  - **interaction with seismology and geology**
  - **dynamic response of engineering structures**
  - **planning, design and constructing of earthquake-resistant structures and facilities**
- **Seismology is a branch of earth science dealing with mechanical vibrations of the Earth caused by natural sources like earthquakes and volcanic eruptions, and controlled sources like underground explosions**
- **Engineering seismology deals with explaining and predicting of earthquake-induced ground motion and study of its characteristics that are important from the structural point of view**

Introduction

- Modern seismology was pioneered by the Irish engineer Robert Mallet, who carried out extensive field work following the 1857 Neapolitan (Italy) earthquake
  - seismology
  - hypocenter
  - isoseismal
- 1900-1960: advances in seismologic investigations of distant earthquakes using sensible seismographs
- after 1970 - (1971 San Fernando earthquake): strong-motion instrumentation, measurements and research

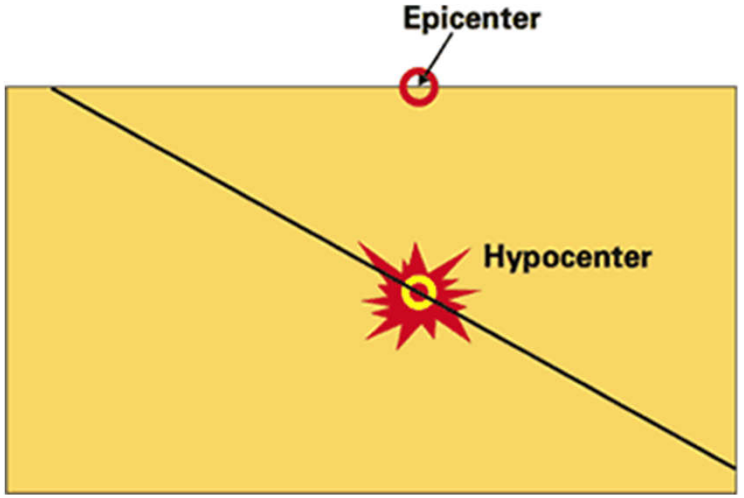
World seismicity

- **Determination of earthquake position: analysis of recordings from several seismic stations**



World seismicity

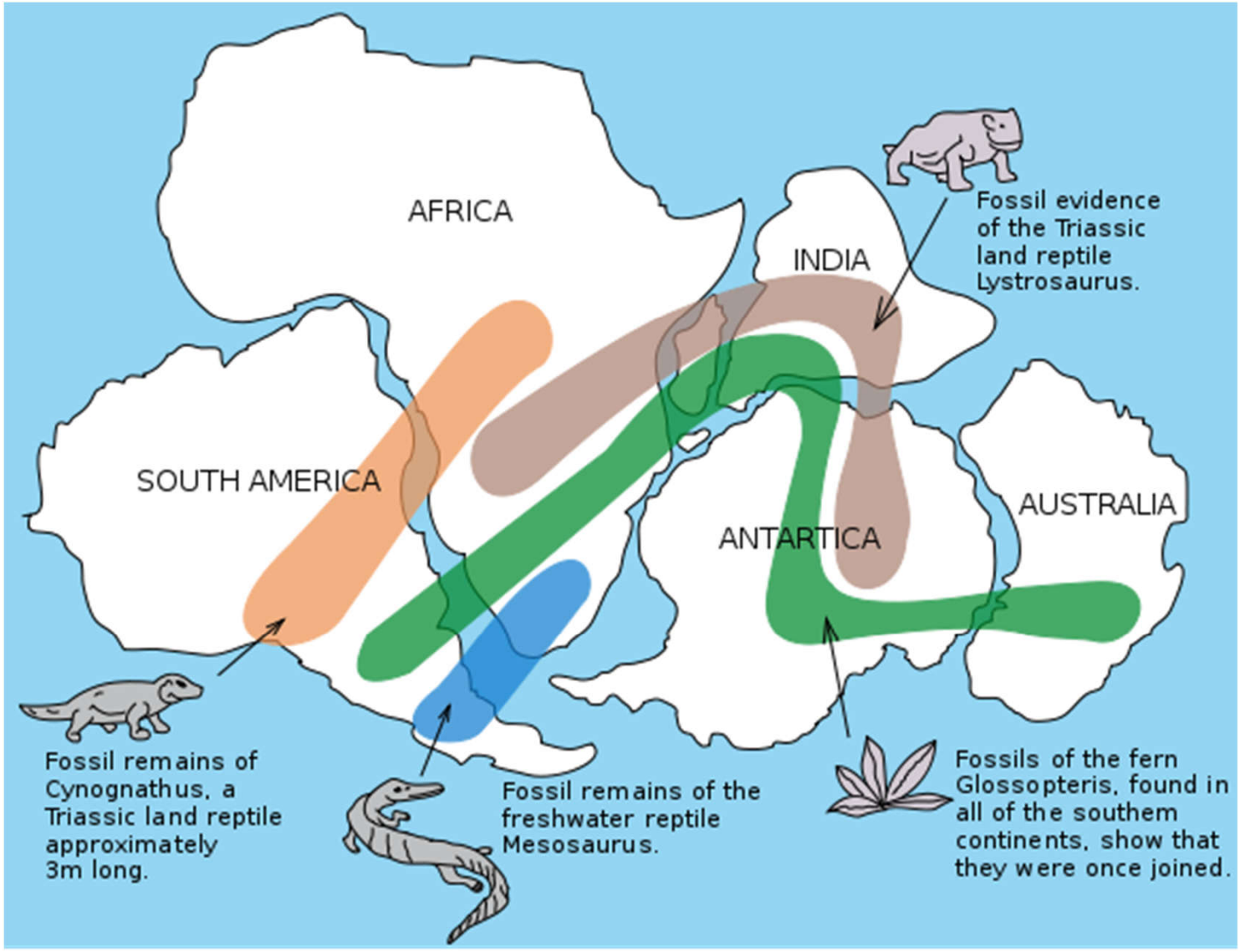
- **Seismic source:**
  - in reality (natural earthquakes) - distributed within a volume of rock
  - simplified - a point source where earthquake waves originate



- **Hypocenter - the point source where earthquake waves start**
- **Epicenter - projection of the hypocenter on the earth surface**
- **Hypocenter depth:**
  - shallow earthquakes, with hypocenter depth (H_p) less than 70 km $\Rightarrow$ 75% of seismic energy released on Earth. Examples: California (USA), Turkey, Banat (Romania), etc.
  - intermediate earthquakes, H_p between 70 and 300 km
  - deep earthquakes, H_p larger than 300 km
    intermediate and deep earthquakes: Romania (Vrancea), Aegean Sea, Spain, Andes in South America, Japan Sea, Indonesia, etc.

Causes of earthquakes, theory of plate tectonics

- **Continental drift**

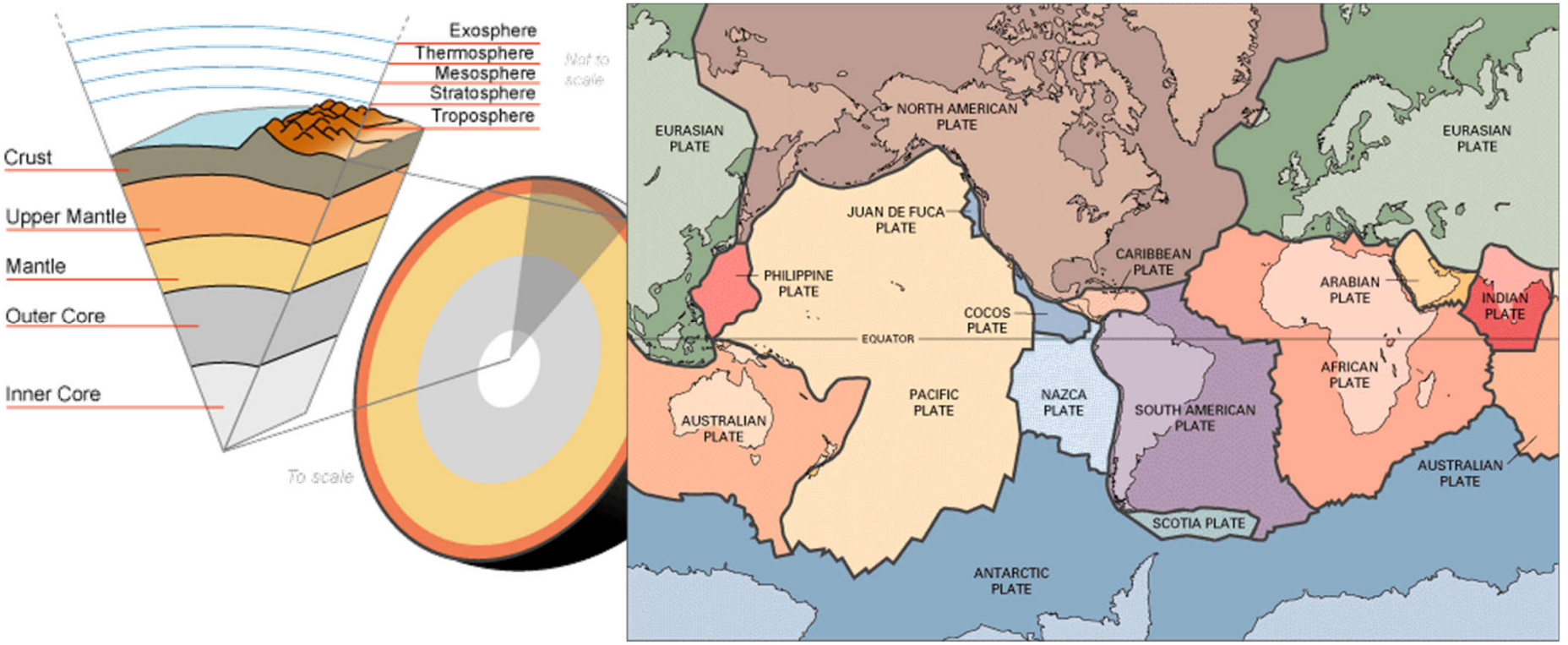


Causes of earthquakes, theory of plate tectonics

- Continental drift is the movement of the Earth's continents relative to each other by appearing to drift across the ocean bed.
- The speculation that continents might have 'drifted' was first put forward by Abraham Ortelius in 1596.
- The concept was independently and more fully developed by Alfred Wegener in 1912, but his theory was rejected by some for lack of a mechanism (though this was supplied later by Holmes) and others because of prior theoretical commitments.
- The idea of continental drift has been subsumed by the theory of plate tectonics, which explains how the continents move.

Causes of earthquakes: tectonic activity

- **Relative movement of tectonic plates ⇒ an important part of world seismicity**

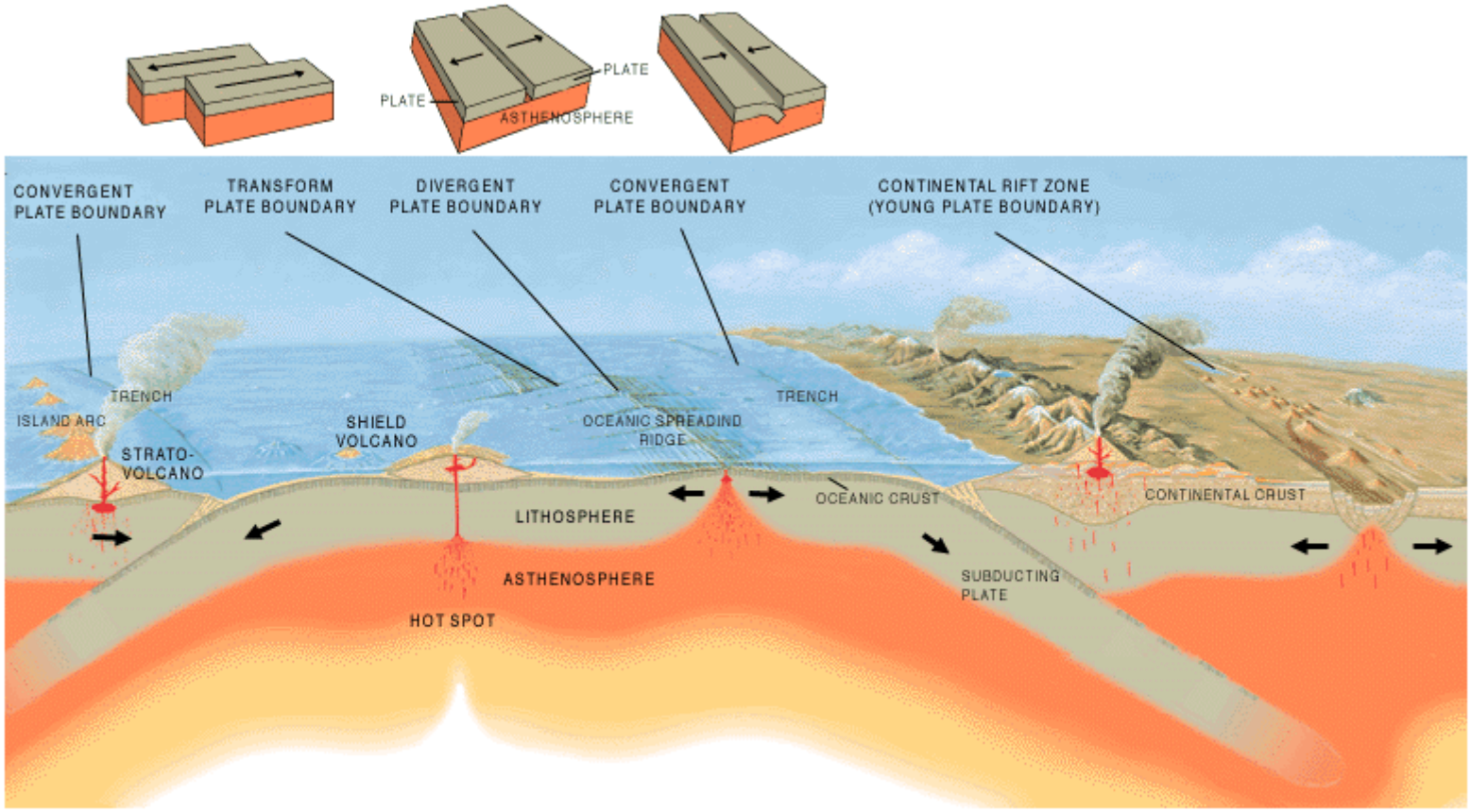


Theory of plate tectonics

- The lithosphere is broken up into tectonic plates. On Earth, there are seven or eight major plates and many minor plates.
- Where plates meet, their relative motion determines the type of boundary: convergent, divergent, or transform. Earthquakes, volcanic activity, mountain-building, and oceanic trench formation occur along these plate boundaries.
- The lateral relative movement of the plates typically varies from zero to 100 mm annually.
- Tectonic plates are composed of oceanic lithosphere and thicker continental lithosphere, each topped by its own kind of crust.

Causes of earthquakes: tectonic activity

- **Inter-plate earthquakes:**
  - convergent boundaries
  - divergent boundaries
  - transform boundaries
- **Intra-plate earthquakes**



Causes of earthquakes, theory of plate tectonics

- **Fault: sudden change in rock structure at contact between two tectonic blocks**

Fault in the Grands Causses

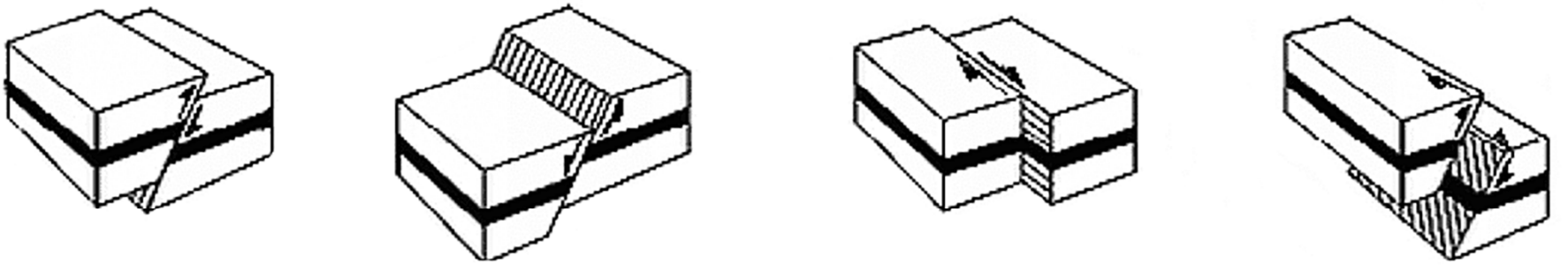
San Andreas Fault

Causes of earthquakes, theory of plate tectonics

- **Cause: relative slip between tectonic plates:**
  - **slow slip, which produces no ground shaking**
  - **sudden slip, that generates earthquakes**

Fault types

- **Strike-slip fault: are vertical (or nearly vertical) fractures where the blocks have mostly moved horizontally**
- **Normal fault: fractures where the blocks have mostly shifted vertically, while the rock mass above an inclined fault moves down**
- **Reverse fault: fractures where the blocks have mostly shifted vertically, while the rock above the fault moves up**
- **Oblique fault: the most general case, a combination of vertical and horizontal movement**

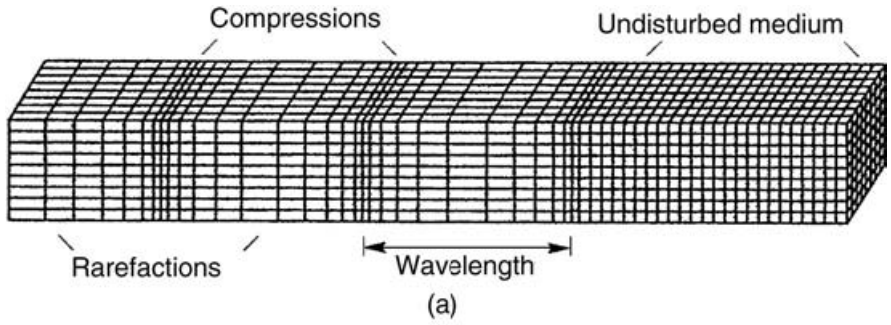


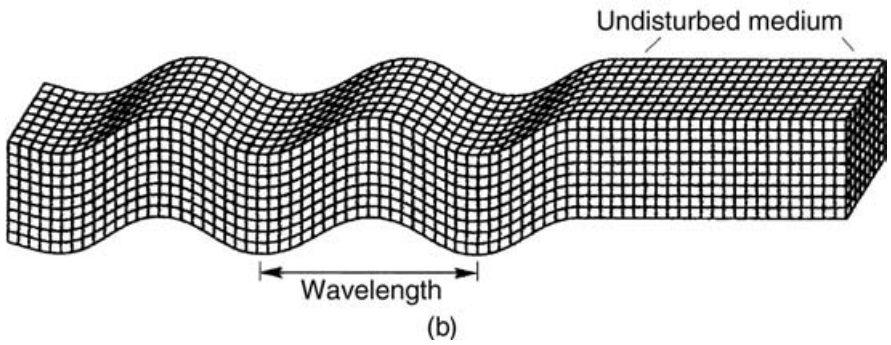
Other causes of earthquakes

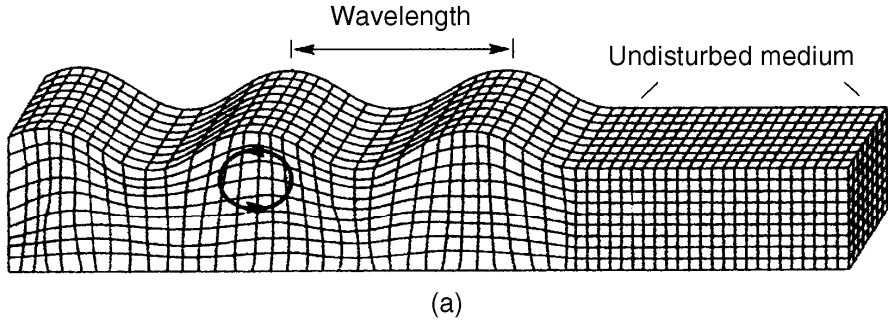
- Volcanic earthquakes
- Explosions (underground detonations of chemical or nuclear devices)
- Collapse earthquakes (roofs of mines and caverns)
- Reservoir induced earthquakes
- Impacts with extraterrestrial bodies (meteorites)

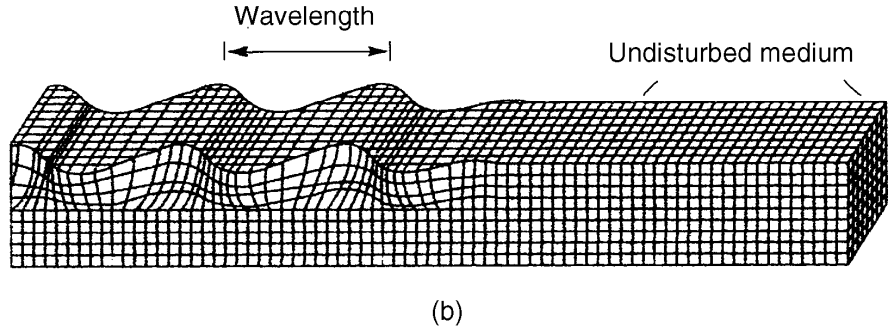
Seismic waves

- **Body waves**
  - P waves: primary, compression or longitudinal
  - S waves: secondary, shear or transversal
- **Surface waves**
  - Rayleigh waves: earth displacements occur in a vertical plane
  - Love waves: earth displacements occur in a horizontal plane

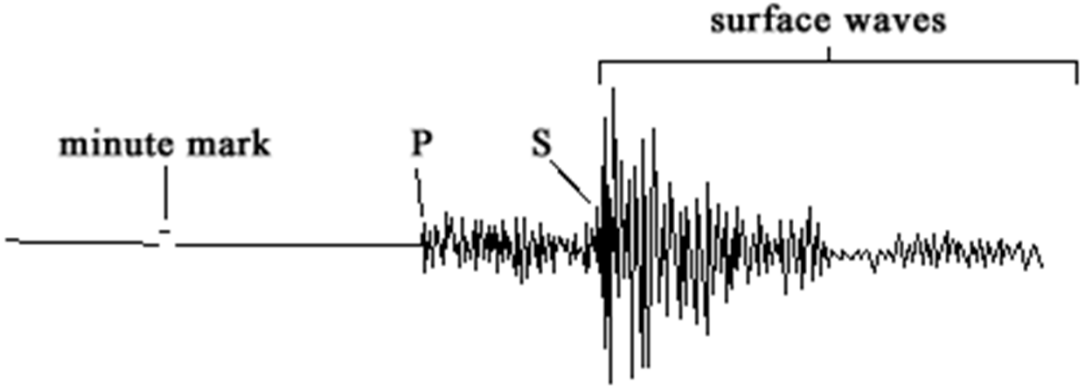


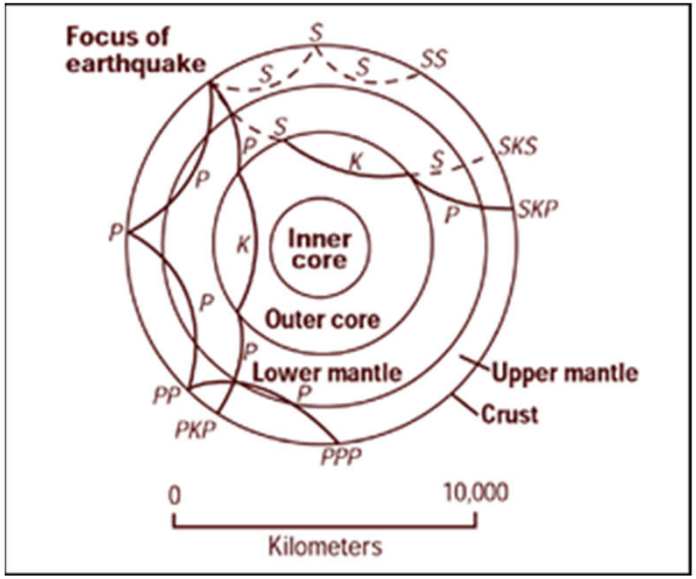


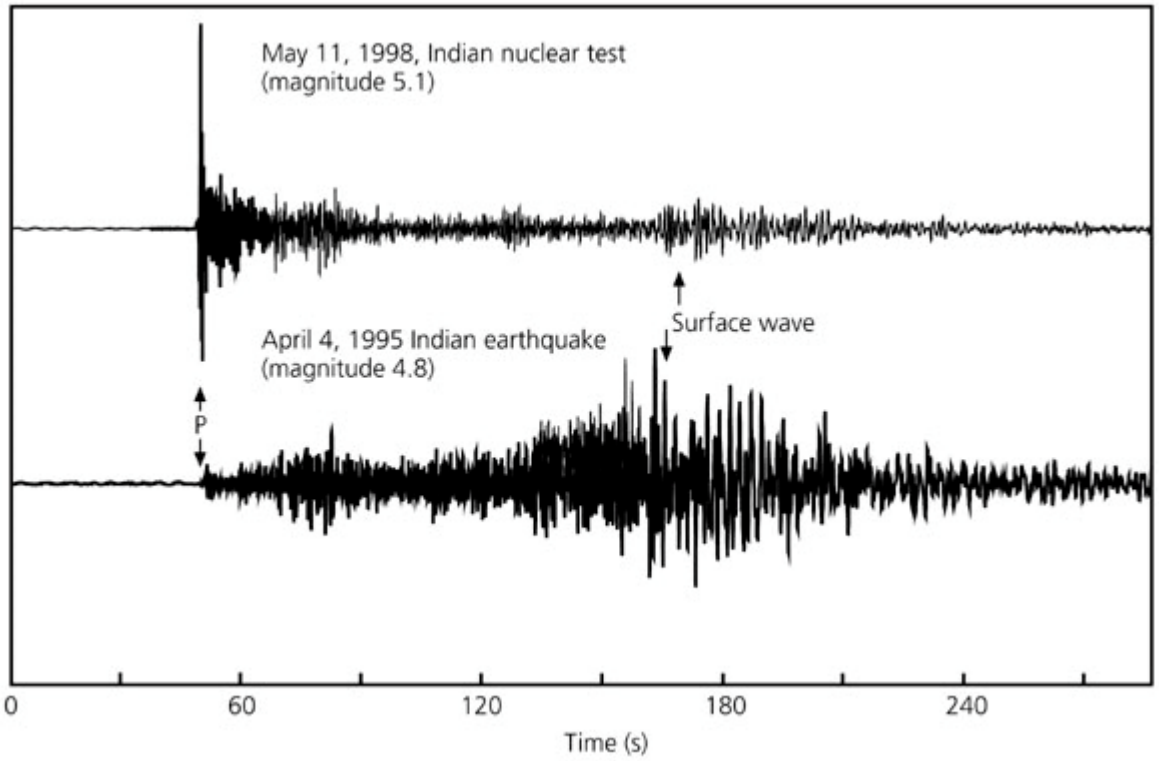




Seismic waves







Effects of earthquakes

- inertial forces generated by severe ground shaking
- earthquake induced fires
- changes in the physical properties of the foundation soils (e.g. consolidation, settling, and liquefaction)
- by direct fault displacement at the site of a structure
- by landslides, or other surficial movements
- large-scale tectonic changes in ground elevation
- by seismically induced water waves such as seismic sea waves (tsunamis) or fluid motions in reservoirs and lakes (seiches)

Inertial forces generated by severe ground shaking

- Partial collapse of r.c. frame structure in Bucharest during Vrancea earthquake, Mar. 4, 1977

- Office building with partially destroyed first floor during Kobe earthquake, January 16, 1995

Earthquake induced fires

- 1906 San Francisco Earthquake: 80% of losses were due to earthquake-induces fire that devastated the city for three days

- The Great Kanto Earthquake of 1923

Liquefaction / Direct fault displacement

- Tilting of apartment buildings at Kawagishi-Cho, Niigata, produced by liquefaction of the soil during the 1964 Niigata Earthquake

- Bent rails due to ground movement during 1906 San Francisco Earthquake

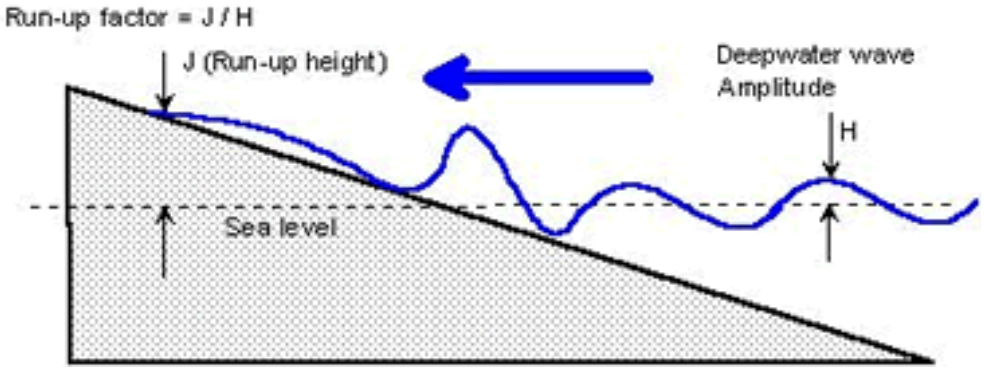
Landslides / Changes in ground elevation

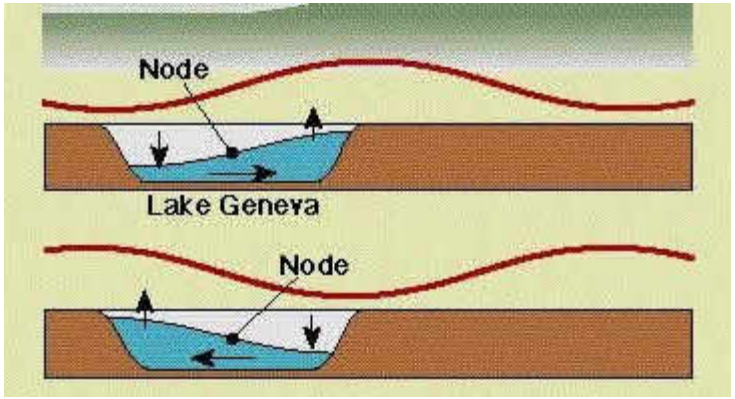
- 1995 landslide in La Conchita, California

- Southeastern end of Izmit Bay showing coastal subsidence, Izmit, Turkey Earthquake, August 17, 1999

Tsunamis and seiches

- Tsunami is a sea wave that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands
- Seiche is the sloshing of a closed body of water from earthquake shaking





Seismic intensity

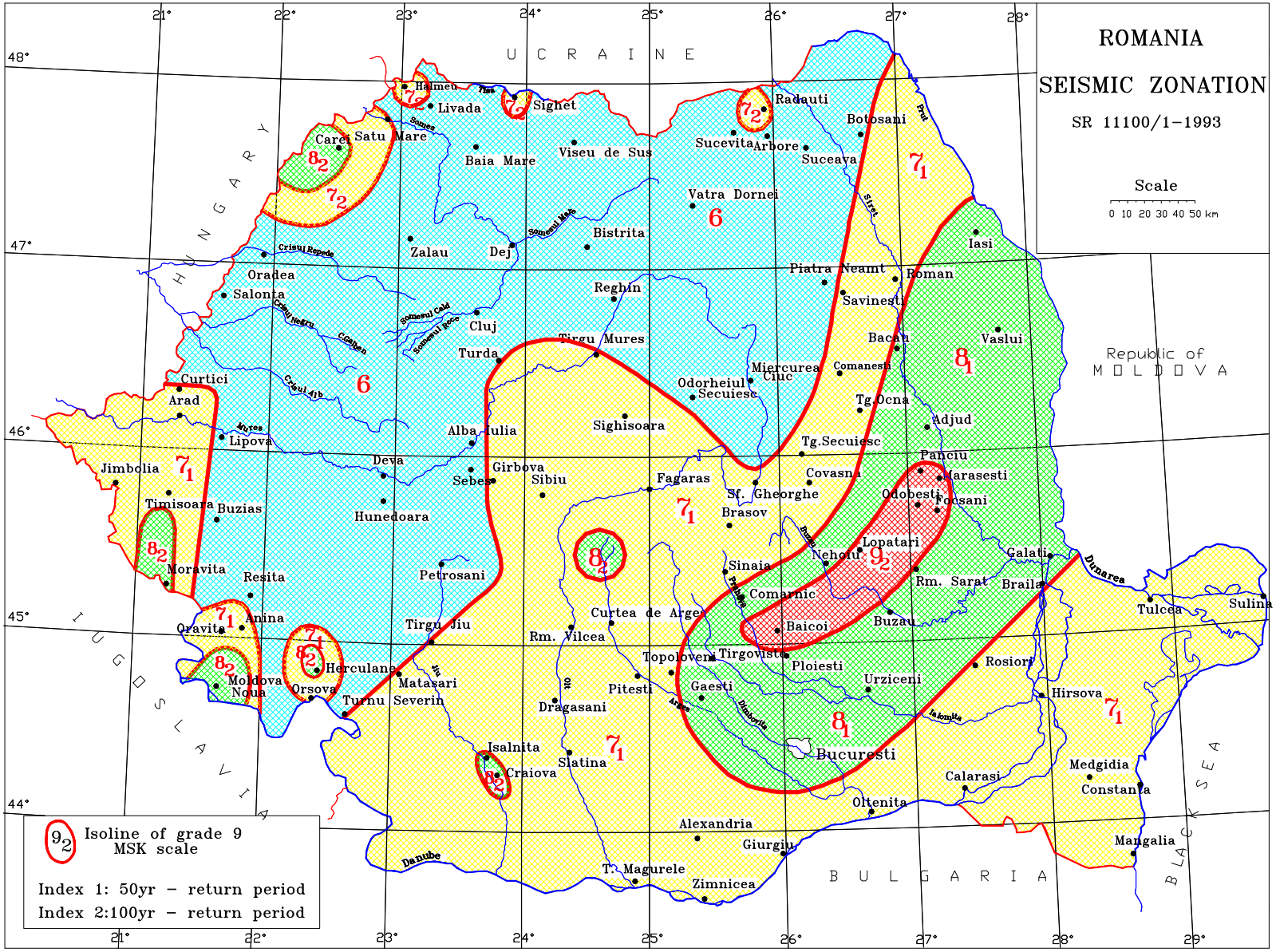
- **The oldest measurement of earthquake power**
- **Based on qualitative observations of earthquake effects on a site, such as structural damage and human behaviour**
- **Intensity scales most used today:**
  - **Modified Mercalli (MMI)**
  - **Rossi-Forel (R-F)**
  - **Medvedev-Sponheur-Karnik (MSK-64) ⇒ Romania**
  - **European Macroseismic Scale (EMS-98)**
  - **Japan Meteorological Agency Scale (JMA)**

II – abia simţit	simţit în case la etajele superioare de persoane foarte sensibile	
VII – provoacă avarierea clădirilor	stabilitatea oamenilor este dificilă; se simte chiar în vehicule aflate în mişcare; mobila se crapă; apar valuri pe suprafaţa lacurilor, sună clopotele grele; apar uşoare alunecări şi surpări la bancurile de nisip şi pietriş	se distrug zidăriile fără mortar, apar crăpături în zidării cu mortar; cade tencuiala, cărămizi nefixate, ţigle, cornişe parapeţi, calcane, obiecte ornamentale

Seismic intensity: EMS98 scale

I. Not felt	Not felt by anyone.
II. Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
III. Weak	The vibration is weak and is felt indoors by a few people. People at rest feel swaying or light trembling. Noticeable shaking of many objects.
IV. Largely observed	The earthquake is felt indoors by many people, outdoors by few. A few people are awakened. The level of vibration is possibly frightening. Windows, doors and dishes rattle. Hanging objects swing. No damage to buildings.
V. Strong	The earthquake is felt indoors by most, outdoors by many. Many sleeping people awake. A few run outdoors. Entire sections of all buildings tremble. Most objects swing considerably. China and glasses clatter together. The vibration is strong. Topheavy objects topple over. Doors and windows swing open or shut.
VI. Slightly damaging	Felt by everyone indoors and by many to most outdoors. Many people in buildings are frightened and run outdoors. Objects on walls fall. Slight damage to buildings; for example, fine cracks in plaster and small pieces of plaster fall.
VII. Damaging	Most people are frightened and run outdoors. Furniture is shifted and many objects fall from shelves. Many buildings suffer slight to moderate damage. Cracks in walls; partial collapse of chimneys.
VIII. Heavily damaging	Furniture may be overturned. Many to most buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse. Can be noticed by people driving cars.
IX. Destructive	Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely. Windows shatter.
X. Very destructive	Many buildings collapse. Cracks and landslides can be seen.
XI. Devastating	Most buildings collapse.
XII. Completely devastating	All structures are destroyed. The ground changes.

Zonation of seismic intensity in Romania



Magnitude

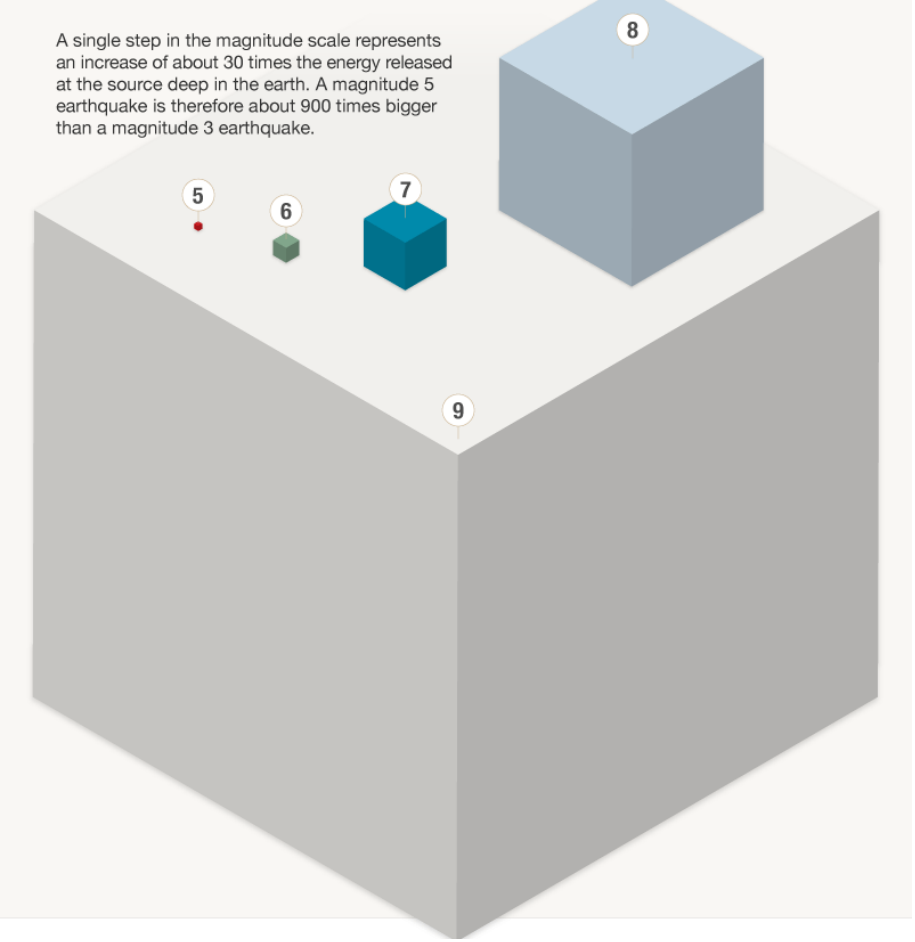
- Magnitude is a measure of the energy released by an earthquake, being a unique value for an earthquake
- Is based on instrumental measurements
- Local magnitude M_L (Richter): logarithm to base ten of the displacement amplitude in microns (10^{-3} mm) recorded on a Wood-Anderson seismograph located at a distance of 100 kilometers from the earthquake epicenter

$$M_L = \log A - \log A_0$$

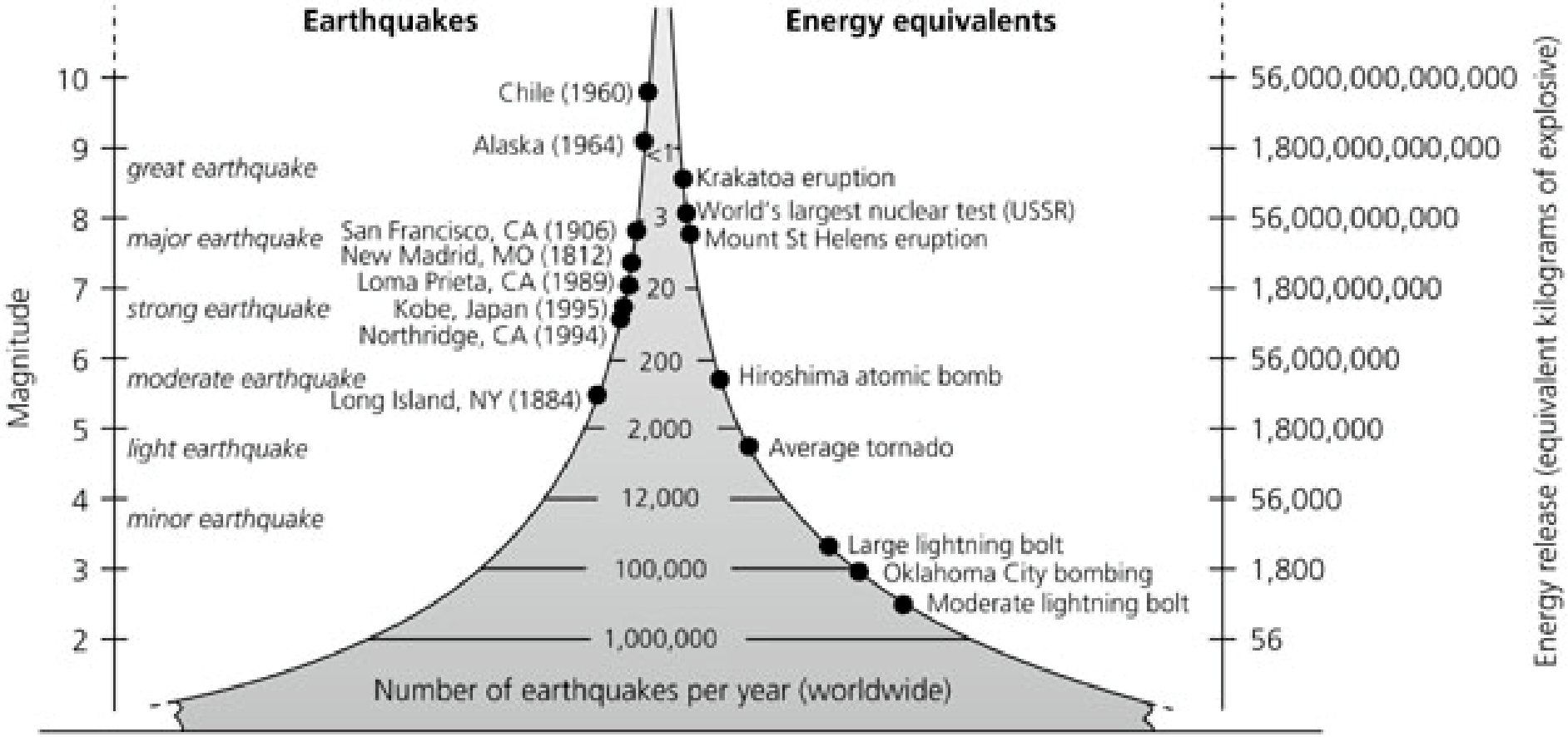
- Surface Wave Magnitude (M_s) - distant earthquakes >2000 km
- Body Wave Magnitude (m_b) - deep earthquakes
- Moment Magnitude (M_W) $M_W = (\log M_0)/1.5 - 10.7$

Magnitude

- Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude;
- In terms of energy, each whole number increase corresponds to an increase of about 31.6 times the amount of energy released, and each increase of 0.2 corresponds to a doubling of the energy released.

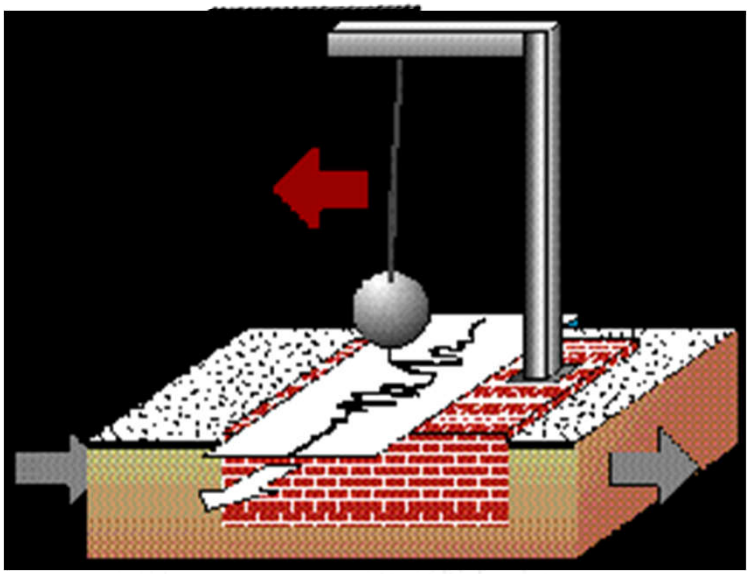


Magnitude


Earthquakes
Energy equivalents
Magnitude
10
9
8
7
6
5
4
3
2
great earthquake
major earthquake
strong earthquake
moderate earthquake
light earthquake
minor earthquake
Chile (1960)
Alaska (1964)
San Francisco, CA (1906)
New Madrid, MO (1812)
Loma Prieta, CA (1989)
Kobe, Japan (1995)
Northridge, CA (1994)
Long Island, NY (1884)
<1
3
20
200
2,000
12,000
100,000
1,000,000
Krakatoa eruption
World's largest nuclear test (USSR)
Mount St Helens eruption
Hiroshima atomic bomb
Average tornado
Large lightning bolt
Oklahoma City bombing
Moderate lightning bolt
Number of earthquakes per year (worldwide)
56,000,000,000,000
1,800,000,000,000
56,000,000,000
1,800,000,000
56,000,000
1,800,000
56,000
1,800
56
Energy release (equivalent kilograms of explosive)

Recording of seismic motion

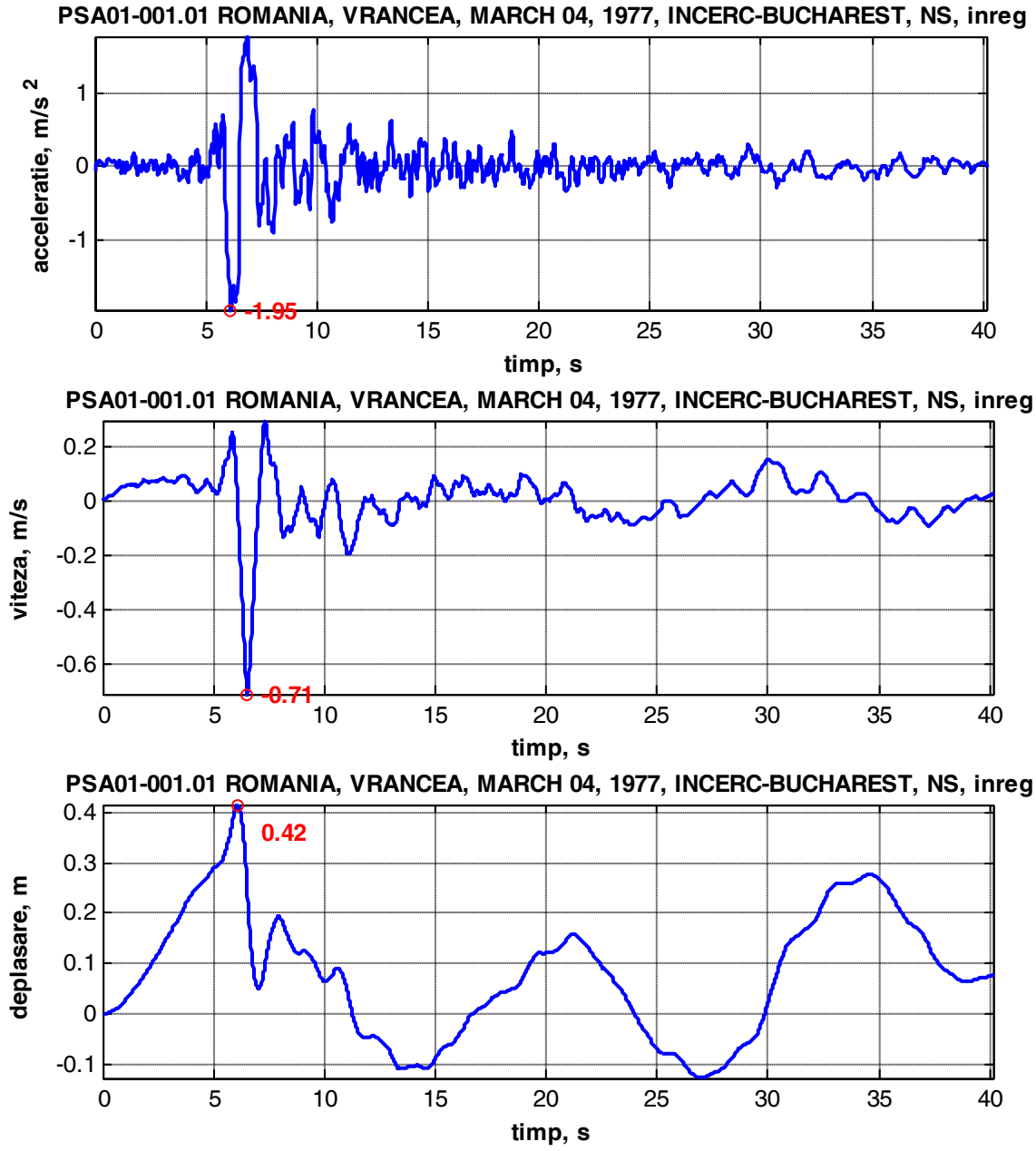
- A seismograph is an instrument that records, as a function of time, the motion of the earth's surface due to the seismic waves generated by the earthquake



- Modern instruments used to record seismic motion are generically called seismometers. Most used are accelerometers

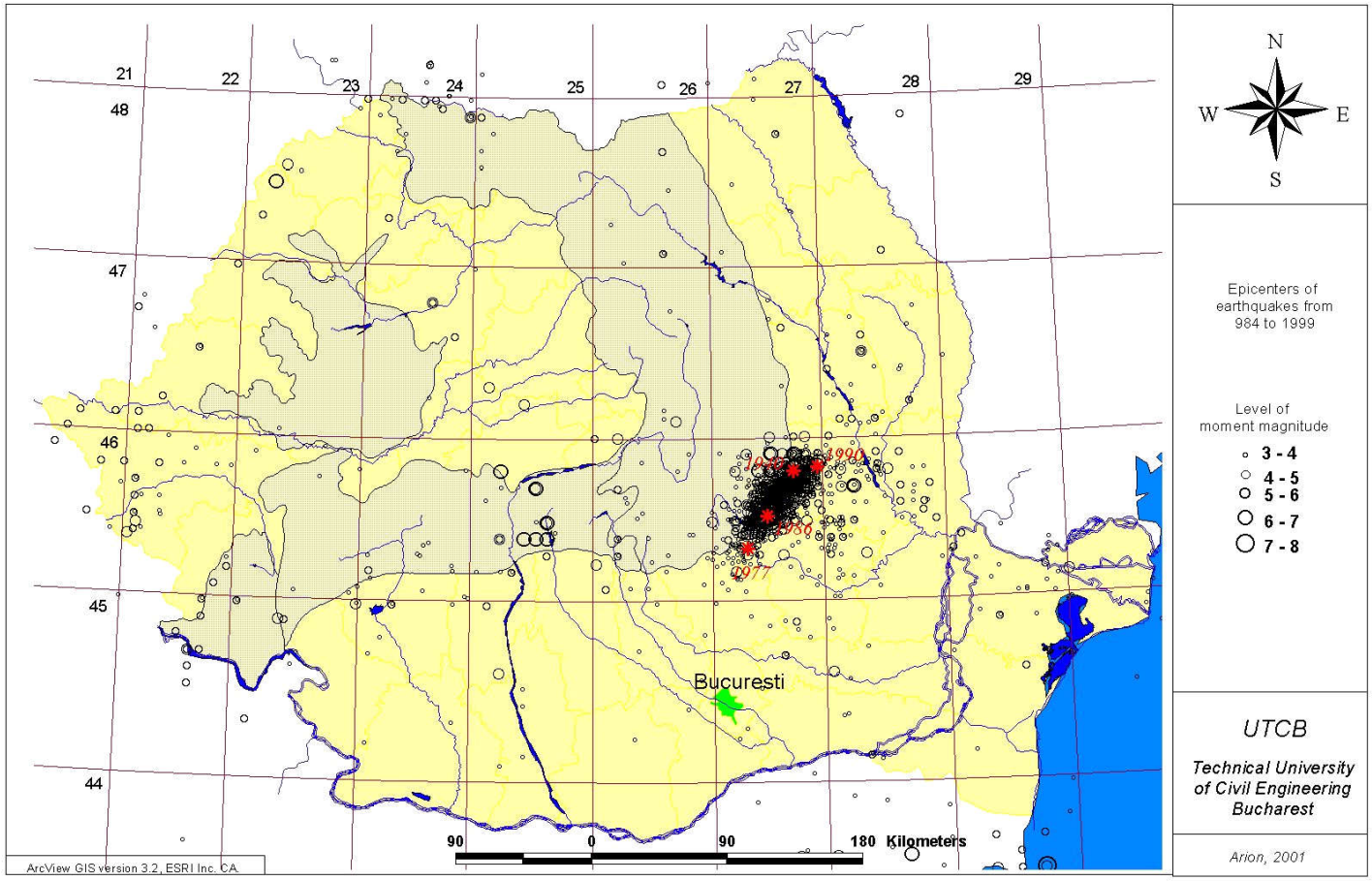
Seismogram

- **Maximum value of the recorded acceleration time history: Peak Ground Acceleration (PGA)**



Seismicity of Romania

- **Subcrustal Vrancea seismic zone**
- **Shallow seismogenic zones, distributed all over the country**

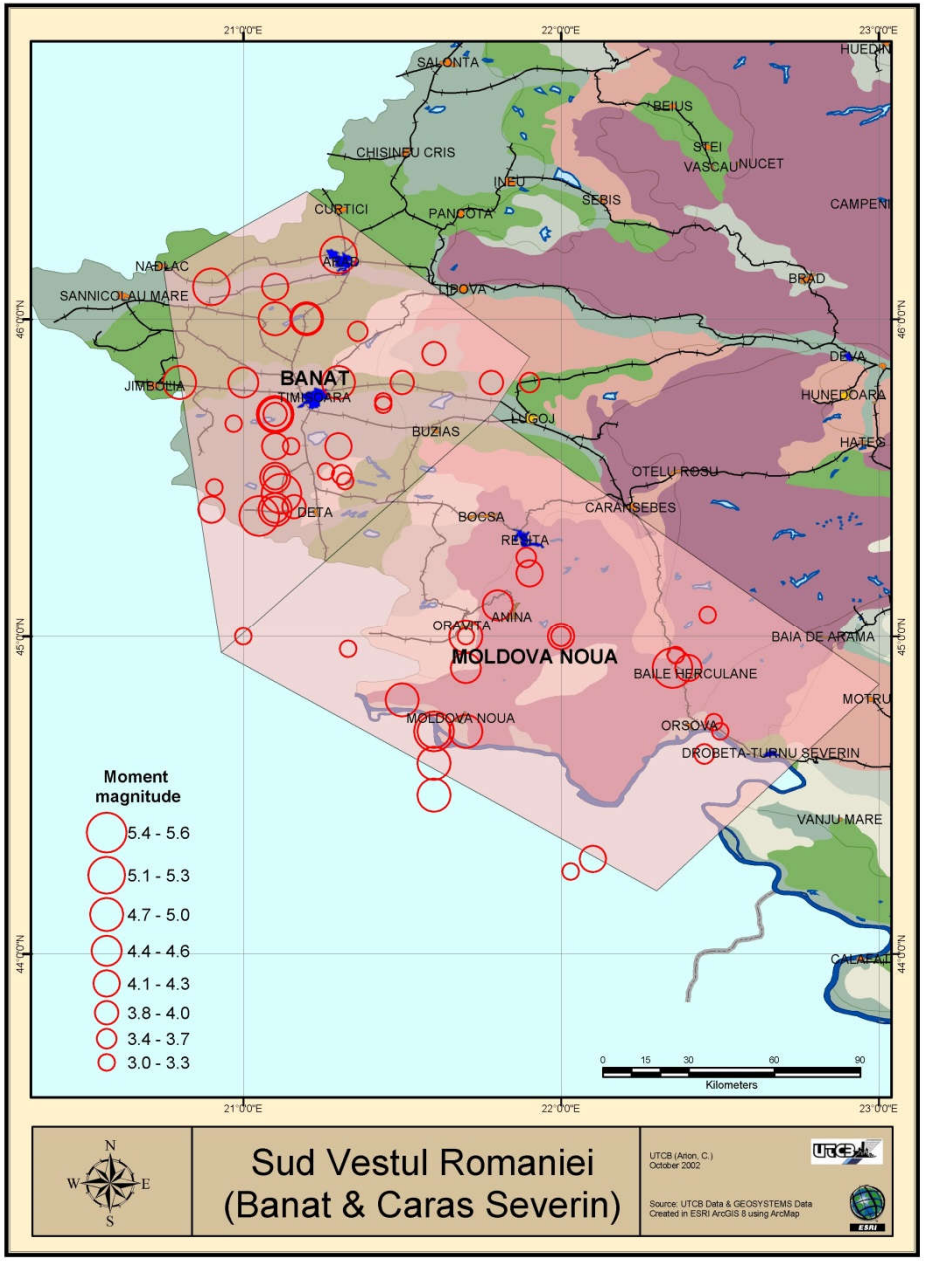


Vrancea seismic zone

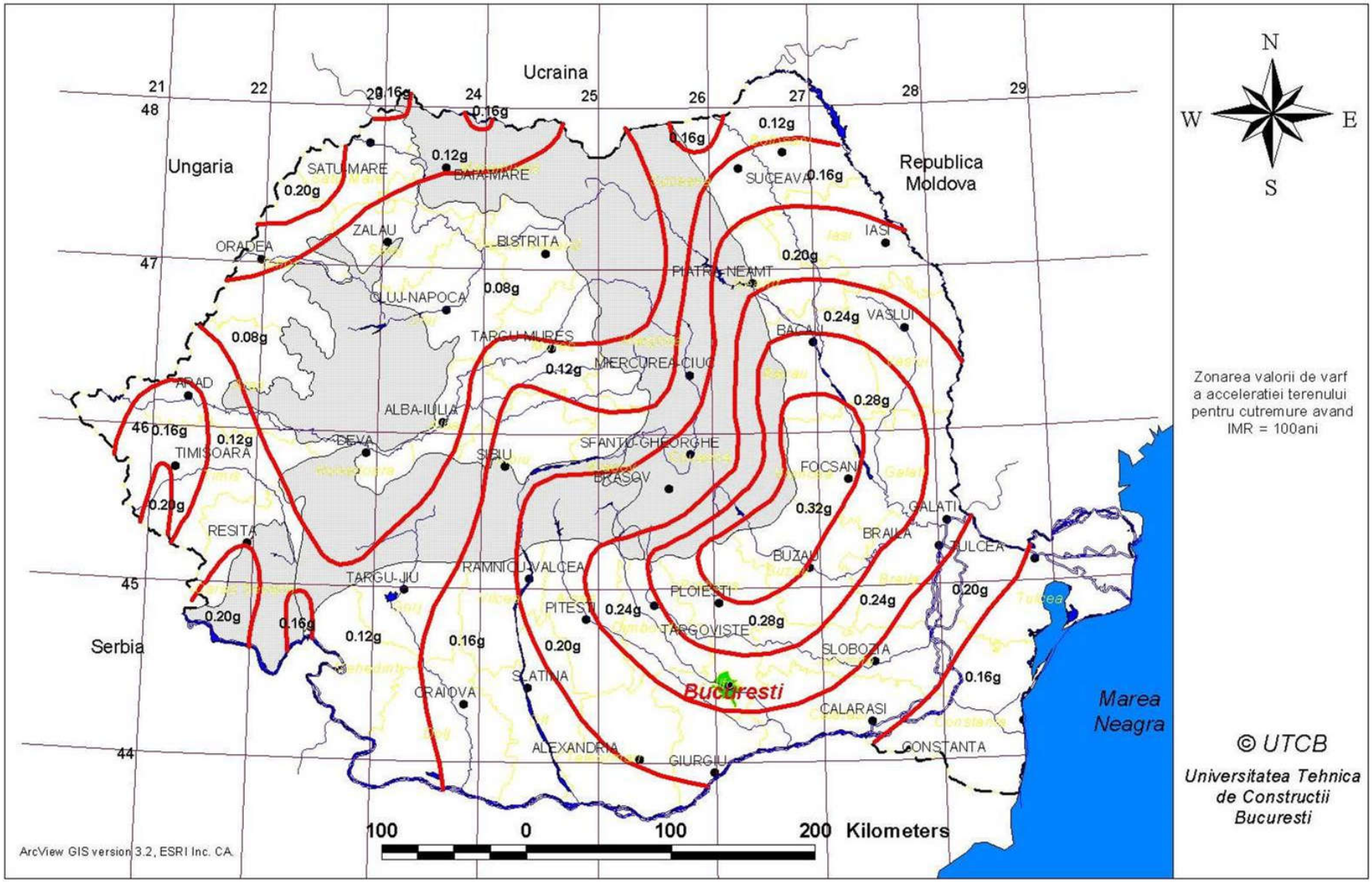
- Hypocenter depth between 60 and 170 km, and epicentral surface of about 40x80 km
- Economic losses of 1.4 billion USD in Bucharest alone, and over 2 billion USD in Romania in 1977
- Most powerful earthquake: October 26, 1802, M=7.5 - 7.7
- Largest magnitude in 20th century: November 10, 1940, M=7.4 and a hypocenter depth of 140-150 km
- March 4, 1977 earthquake:
  - most devastating effects on constructions
  - the first Romanian earthquake for which a strong-motion accelerogram was recorded
  - Gutenberg-Richter magnitude M=7.2, hypocenter depth h=109 km, epicentral distance from Bucharest 105 km
  - over 1400 people died in Bucharest and 23 high-rise r.c. buildings and 6 multistorey masonry buildings built before the 2nd world war, as well as 3 high-rise r.c. buildings built around ’60-‘70 collapsed

Banat Seismicity

- **Seismic regions:**
  - S-E of Banat (Moldova Nouă)
  - Timişoara
  - Sânicolaul Mare
  - Arad
  - Romanian - Serbian border
- **Largest earthquakes in the 20th century:**
  - Moldova Nouă source: July 18, 1991 earthquake, M=5.6, h = 12km
  - Timisoara source: July 12, 1991, M =5.7, h = 11km



Romanian seismic zonation map (PGA)



European seismic hazard map

European Seismic Hazard Map

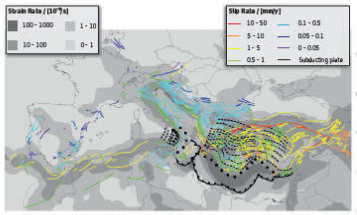
edited by D. Giardini, J. Woessner, and L. Danciu, Swiss Seismological Service, ETH Zurich, August 2013

The EU-FP7 SHARE Project

Europe has a long history of destructive earthquakes, and seismic risk can severely affect our modern society, as recently shown by the 1999 Izmit (Turkey) and the 2009 L'Aquila (Italy) events. Seismic hazard defines the likelihood of ground shaking associated with the occurrence of future earthquakes, and is the first step to evaluate seismic risk, the likelihood of damage and loss depending on vulnerability factors (e.g., the type, age and value of buildings and infrastructures, population density and land use). High hazard does not necessarily imply high risk: frequent large earthquakes result in high hazard but pose limited risk if they occur in remote areas, while even moderate earthquakes may expose densely populated areas to high seismic risk.

The collaborative project 'Seismic Hazard Harmonization in Europe (SHARE)' was supported by the EU-FP7 to deliver the first state-of-the-art reference hazard model for Europe, replacing older maps. The SHARE hazard contributes to the Global Earthquake Model (GEM) and serves as input for risk mitigation policies such as the design of earthquake-resistant multi-storey buildings and critical infrastructures such as bridges or dams.

Active Faults in Euro-Mediterranean Region



Active faults and subducting plates in the Euro-Mediterranean region, differentiated by color from rapidly slipping (red) to slowly slipping (violet). Over 1,100 active faults have been mapped, covering more than 64,000 km of fault length. The background depicts the estimated rate of deformation of the Earth's crust derived from geologic and geodetic data.

Map Content

The European Seismic Hazard Map displays the ground shaking (i.e. Peak Horizontal Ground Acceleration) to be reached or exceeded with a 10% probability in 50 years, corresponding to the average recurrence of such ground motions every 475 years, as prescribed by the national building codes in Europe for standard buildings. SHARE maps also the higher ground shaking recurring only every 1,000-5,000 years, of importance for critical infrastructures such as dams or bridges.

The ground shaking values depicted in the map reach over 0.5g (g is the gravitational acceleration). Low hazard areas (PGA<0.1g) are colored in blue-green, moderate hazard areas in yellow-orange and high hazard areas (PGA>0.25g) in red.

The SHARE seismic hazard is assessed with a time-independent, probabilistic approach. Models of future ground shaking are based on the history of earthquakes of the past 1,000 years, on the knowledge of active faults mapped in the field, on the style and rate of deformation of the Earth's crust from GPS measurements, and on the instrumental recordings of strong ground shaking generated by past earthquakes.

The SHARE results do not replace the existing national design regulations and seismic provisions, which must be obeyed for today's design and construction of buildings.

Acknowledgements

Supported by the EU 7th Framework Program, the 4-year SHARE program brought together a core-team of over 50 leading scientists from 16 research institutions and 12 countries from Europe, North Africa and Turkey, and more than 250 additional European experts participating in workshops, providing their expertise and data.

SHARE was funded by the EU-FP7 (2007-2013) under grant agreement no. 226967.

SHARE hazard was computed using the GEM OpenQuake software. Maps were created using GMT (Wessels and Smith, 1991) and the poster was produced with Adobe Illustrator CS5.

Cite this map with:

D. Giardini, J. Woessner, L. Danciu, H. Crowley, F. Cotton, G. Grünthal, R. Pinho and G. Valensise and the SHARE consortium, SHARE European Seismic Hazard Map for Peak Ground Acceleration, 10% Exceedance Probabilities in 50 years, doi: 10.2777/30545, ISBN-13, 978-92-79-25148-1.

Online Access

All SHARE products, data and results, are provided through the project website at www.share-eu.org and the European Facility for Earthquake Hazard and Risk at www.efehr.org.

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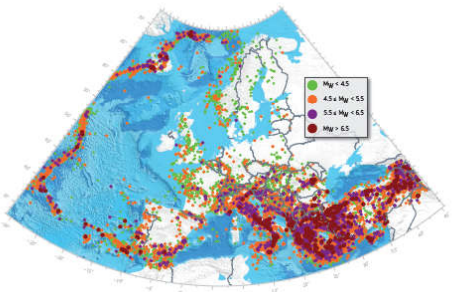
SHARE Partners

Earthquake History in Europe



Distribution of over 30,000 earthquakes with magnitudes larger or equal to 3.5 for the period 1000 – 2007, documented by their damaging effects through history or recorded with modern instrumental seismic networks.