Introduction to Earthquake BASICS

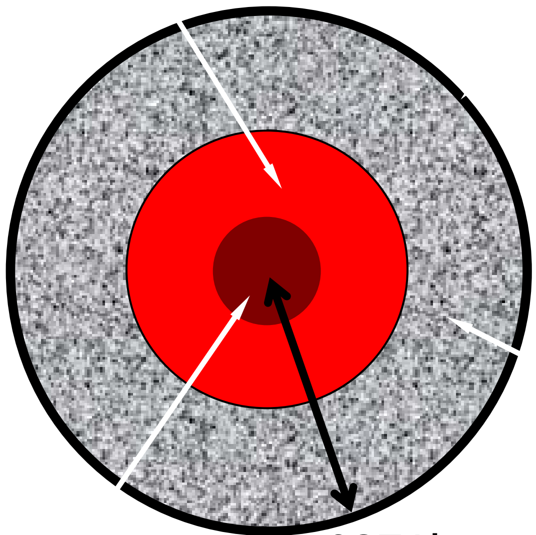
Seismic waves and the structure of the earth

III. Introducing Plate Tectonics

Chemical composition of the Earth

Outer Core (2250km)
Fe, Ni
(Mostly liquid iron)

Crust (20-60km)
O, Al, Si,
Fe, Mg, Ca, Na, K



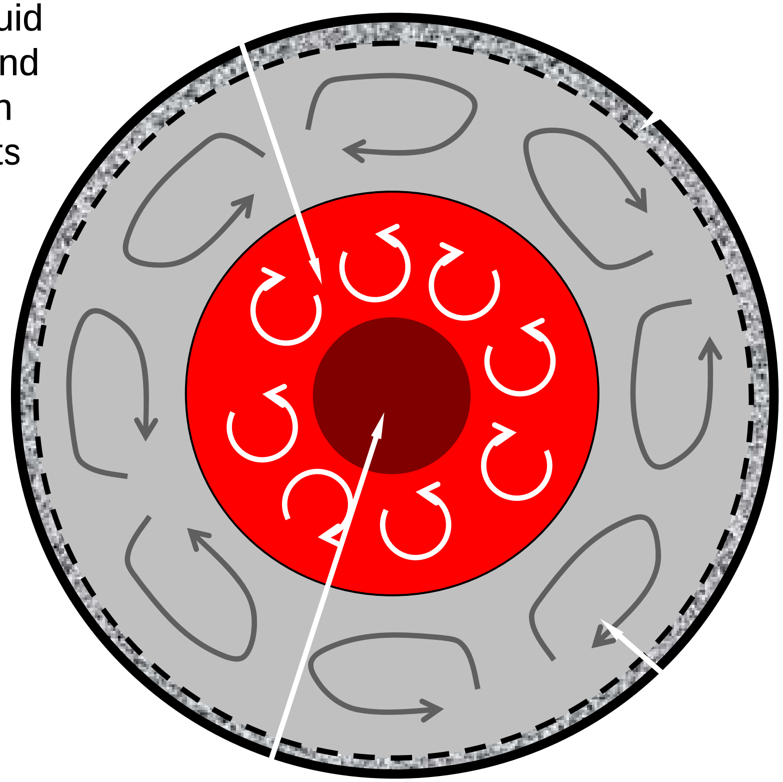
Mantle (~2800km)
Mg, Fe, Si (Silicates)

Inner Core (1250km)
Fe, Ni
(Mostly solid iron)

Internal structure of the Earth

Outer Core
High temp. and pressure induces liquid state. Convection and the Earth's rotation cause eddy currents

Plates / Lithosphere / "Strong layer"
Fairly rigid/brittle slabs of rock (crust and outermost mantle, 100-200km)

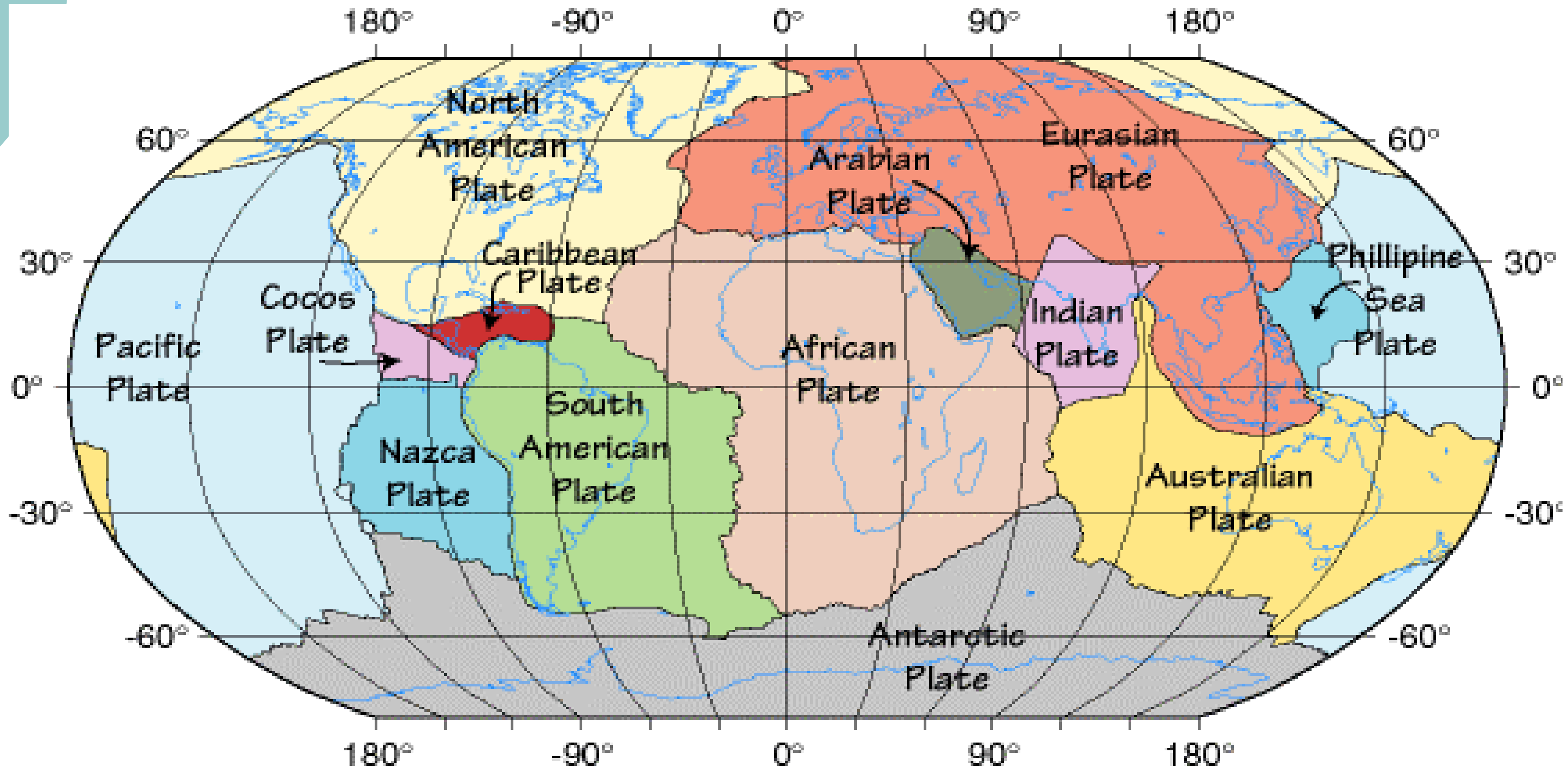


Inner Core
Solid. Heat of formation and Radioactivity are source of energy for convection currents

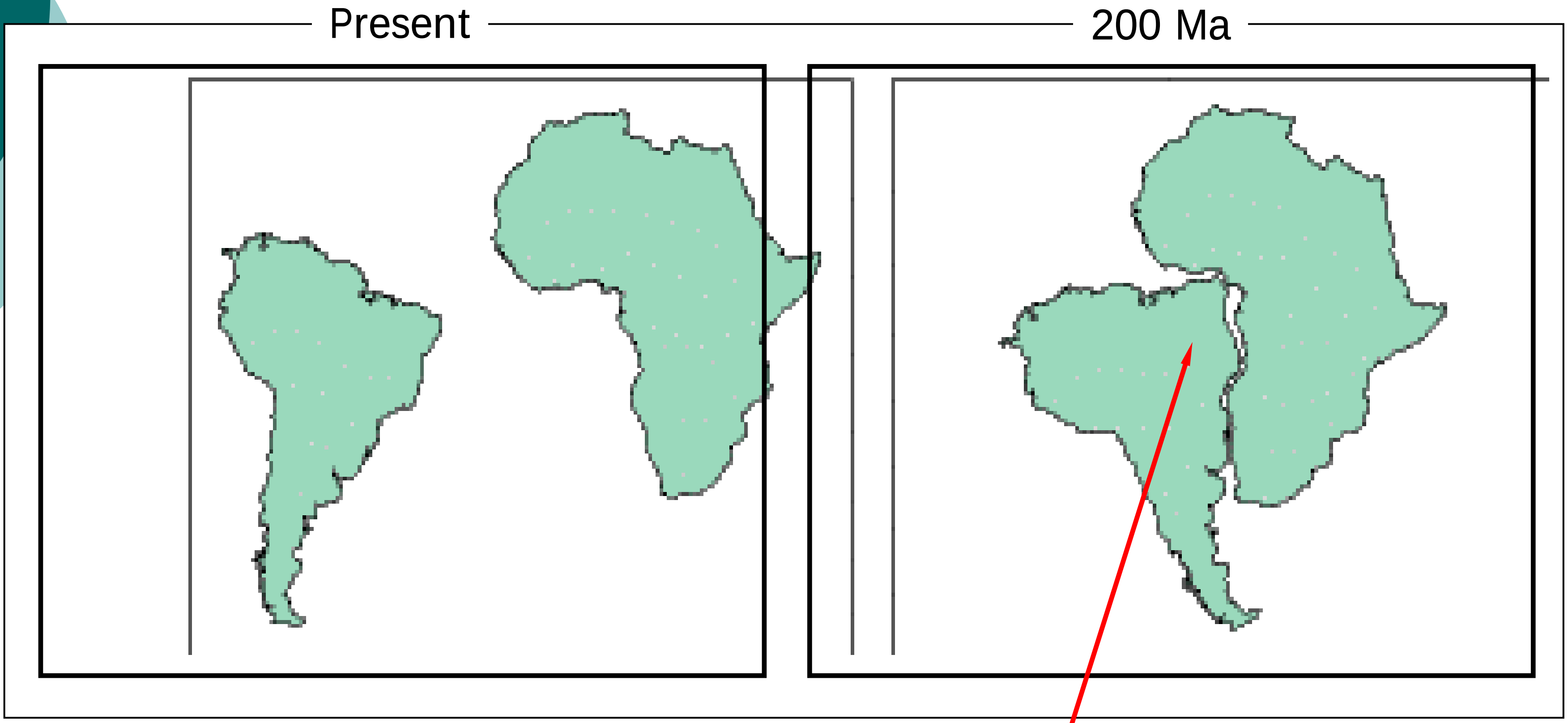
Asthenosphere / "weak layer"
High temp. and pressure induces viscoplasticity in solid rock.
On a geological time-scale, convection currents are present.
(mantle)

Currents pattern of Plates

- Major plates shown below
- Major plates are divide up into micro-plates. This gives a more complex picture
- Some of the plate boundaries are not clearly understood yet.



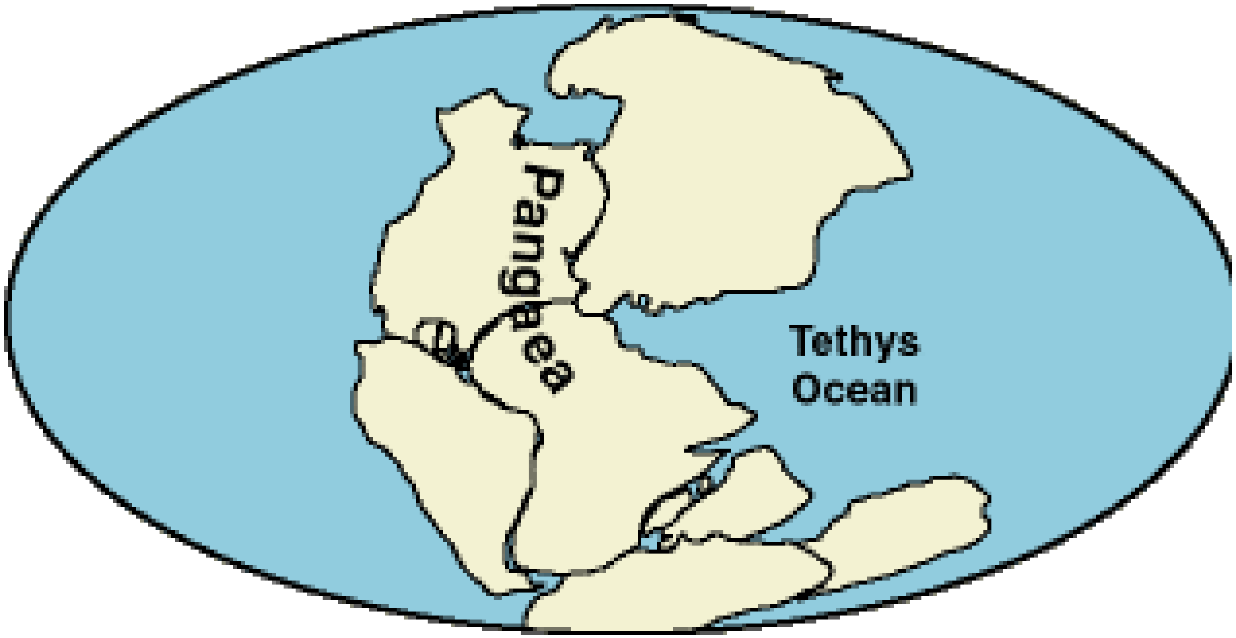
Africa/South America



Alfred Wegener (1920s) noted that surface geology and fossil records match at boundary indicating that Africa and South America where once united

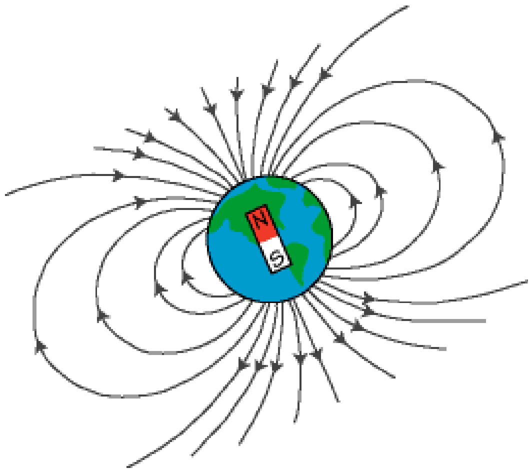
Pangaea/the ancient super-continent

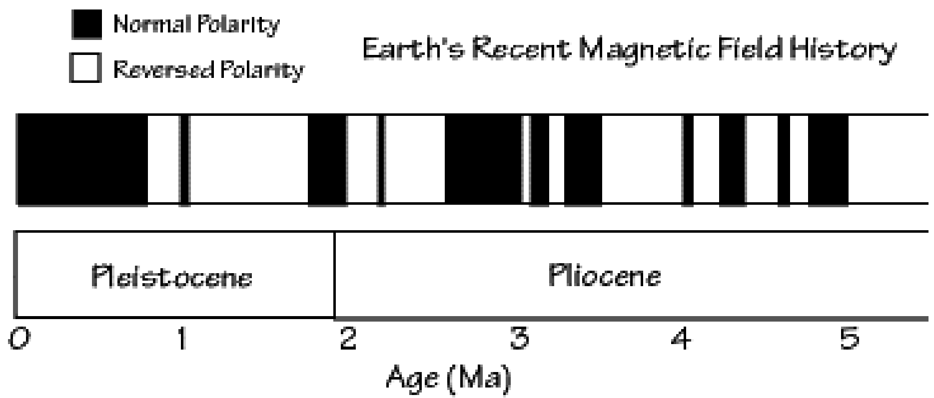
- The location of continental land masses appears to have changed over geological time.
- The motion of plates moves the continents.
- Wegener proposed an ancient super continent named Pangaea.



Geomagnetism

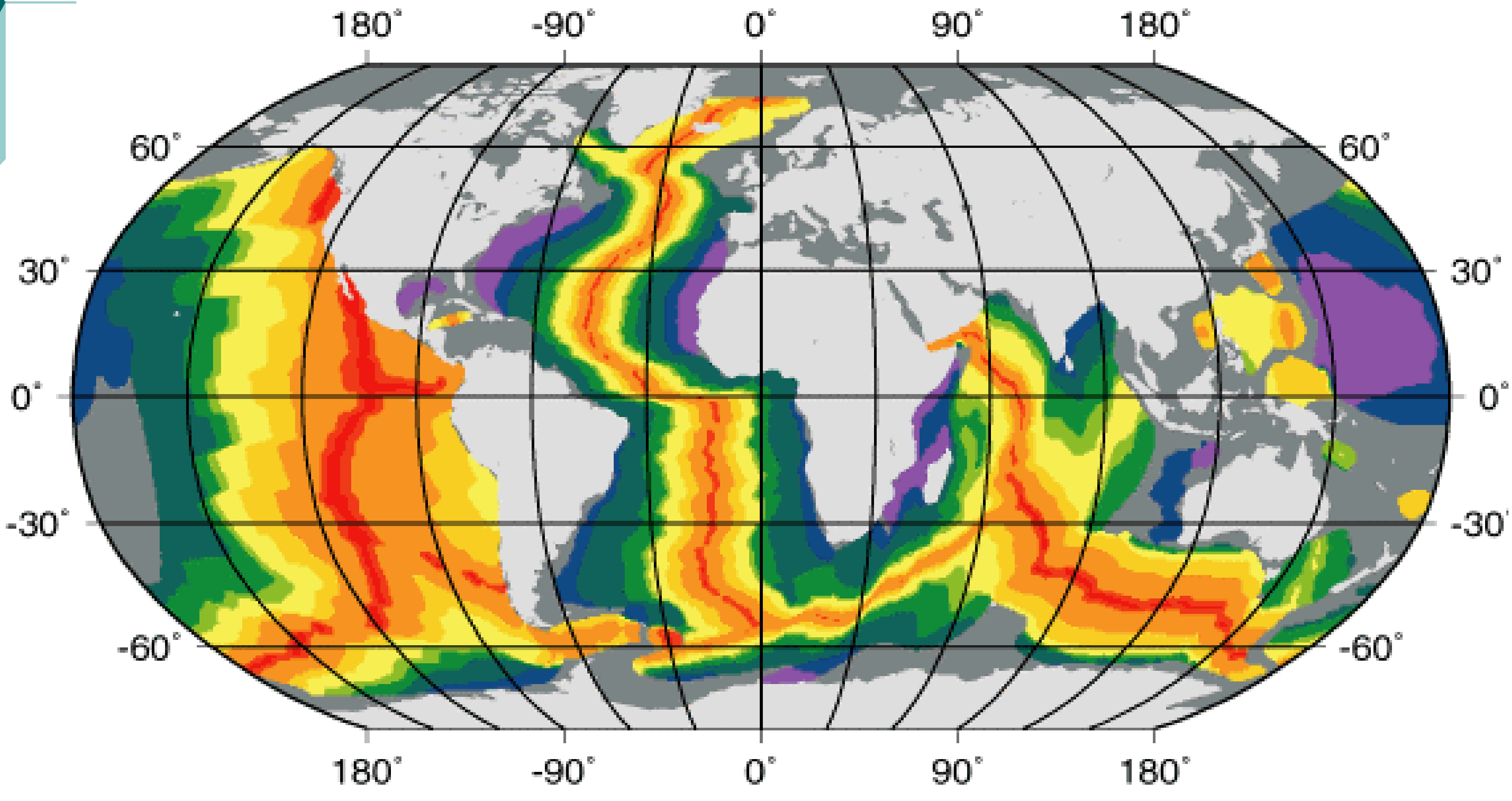
- The geomagnetic field is generated by the motions of the iron in the outer core.
- This magnetic field allows us to use a compass to navigate around Earth's surface.
- The direction of circulation of the convection currents in the outer core has changed over geological time resulting in a swaping of magnetic north for south.
- "New crust" is formed from cooling molten lava. The solidify lava freezes the orientation of the geomagnetism as this time.
- Hence analysing the magnetism of various parts of the crust gives an indication of its age.





Evidence for Sea-floor spreading

- The youngest regions are shown in red (age < 2 Ma) and red-orange (age 2 Ma < 5 Ma), the older regions in orange, gold, yellow, green, blue, and violet. The ocean ridge system shows up as an interconnected ribbon of red and red-range indicating that the ridges are the youngest part of the oceans. Spreading is slower in the mid-Atlantic than along the east-Pacific. The original digital data are courtesy of researchers at the Scripps Institute of Oceanography).

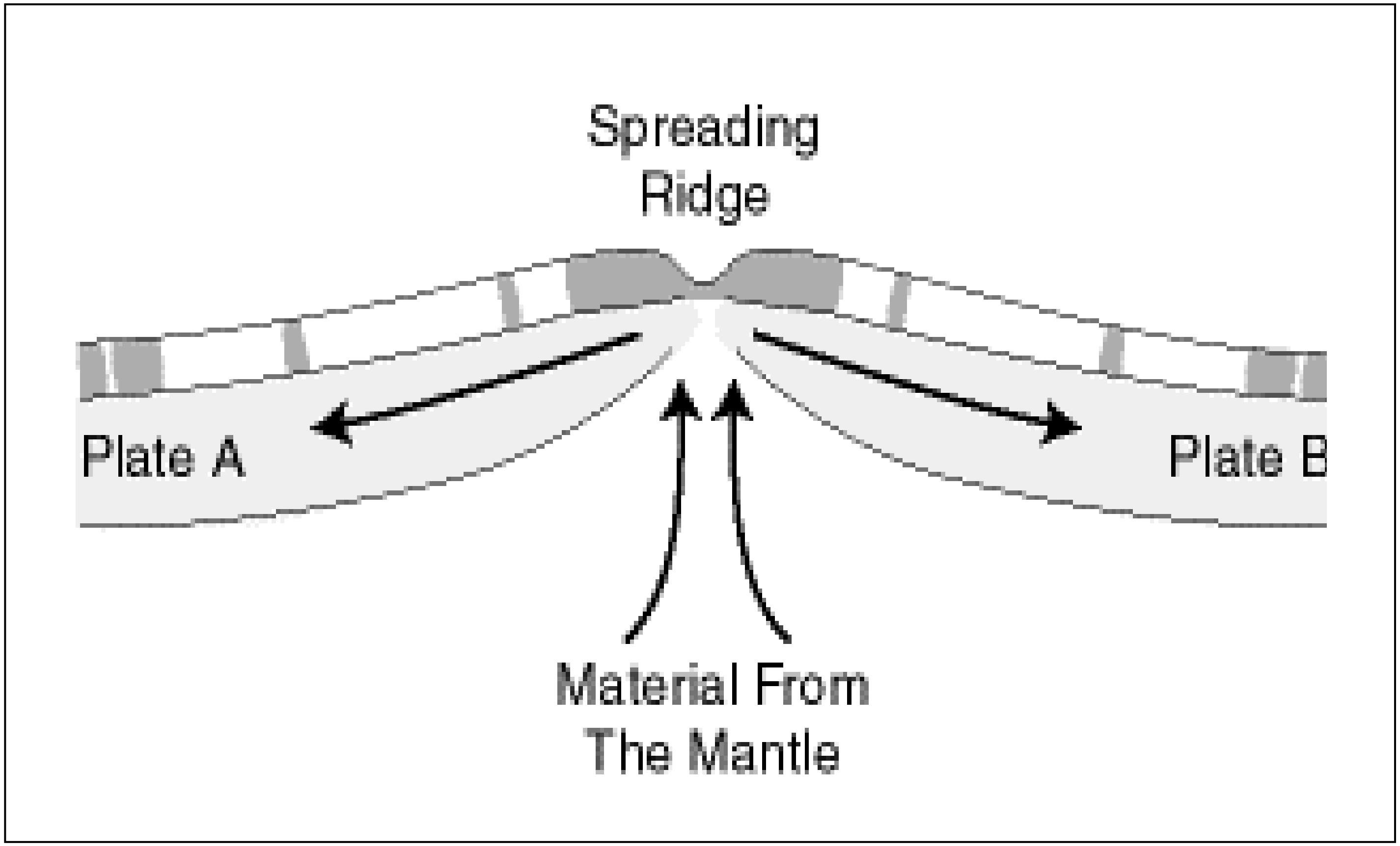


Seismic waves and the structure of the earth

VI. Plate boundaries

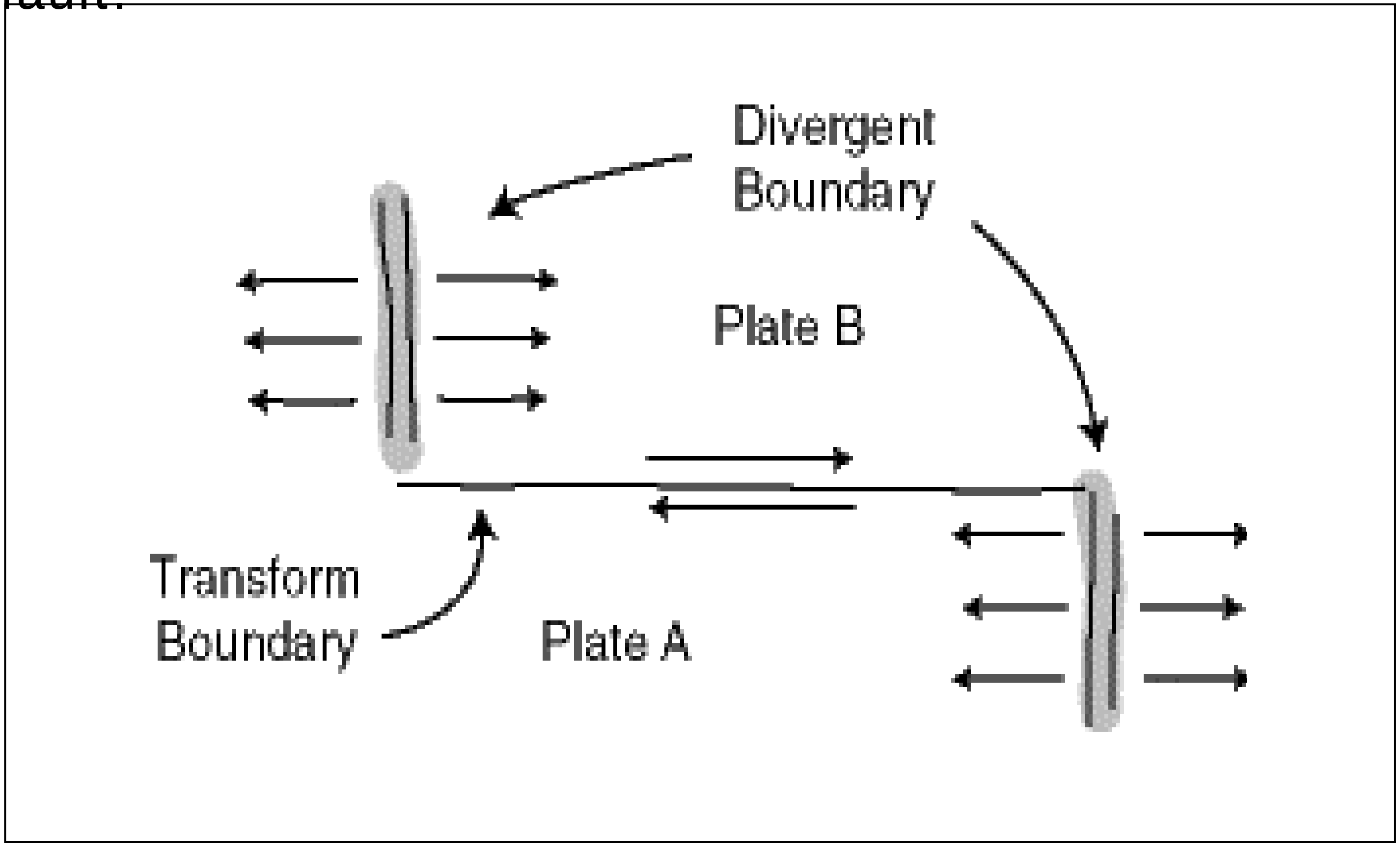
Divergent boundaries

- Movement of plates at a divergent boundary normally produces small, shallow earthquakes
- Mid-Atlantic ridge is an example of a divergent boundary



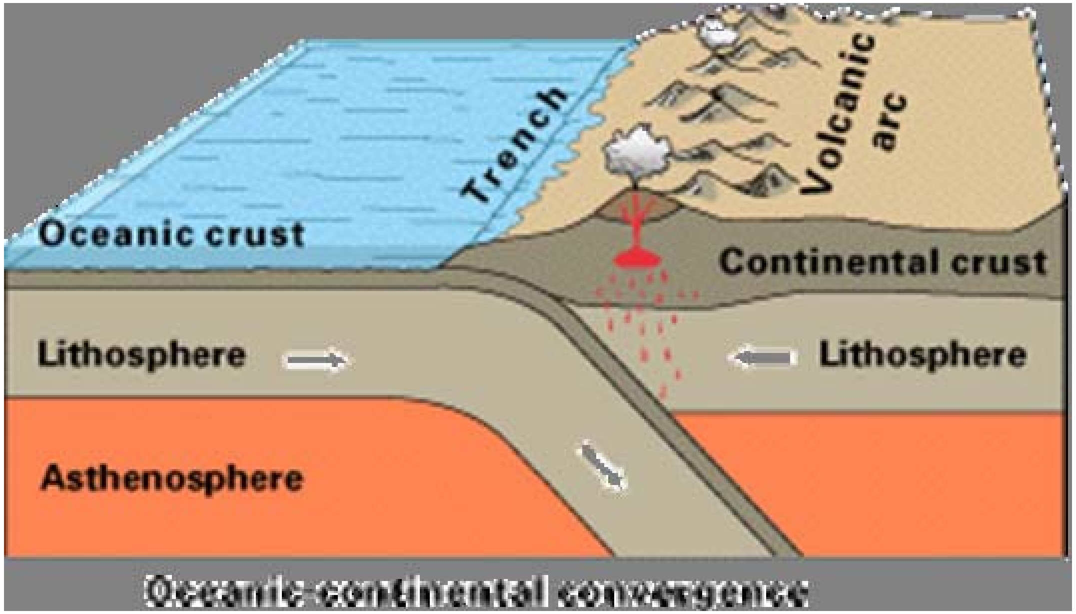
Conservative (transform) boundaries

- Movement of plates at a transform boundary can produce large, shallow to intemediate deeps (<300 km), earthquakes
- San-Andreas fault (USA) is an example of a transform fault.



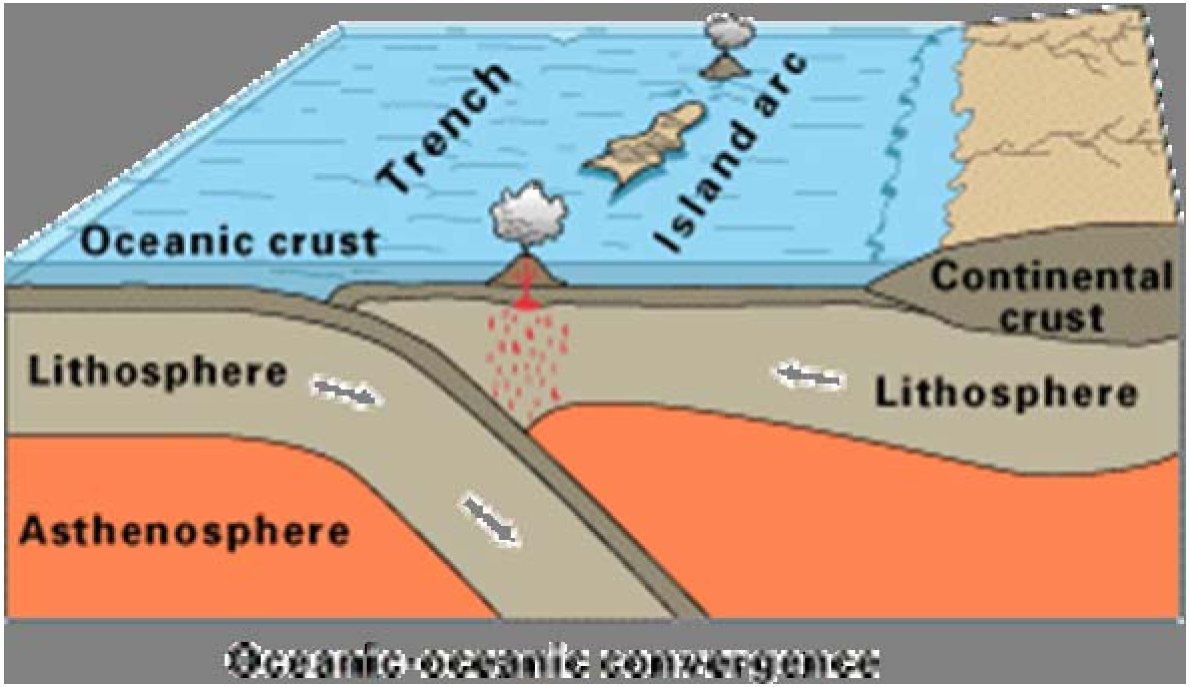
Convergent boundaries (a)

- Oceanic plate subducts (dives) underneath the continental plate forming a deep oceanic trench at the boundary.
- An example is the Mariana trench (10km deep).
- Volcano’s are produced by released water, at high temp. and pressure, from subducting plate.
- Large deep (>300km), earthquakes are produced.



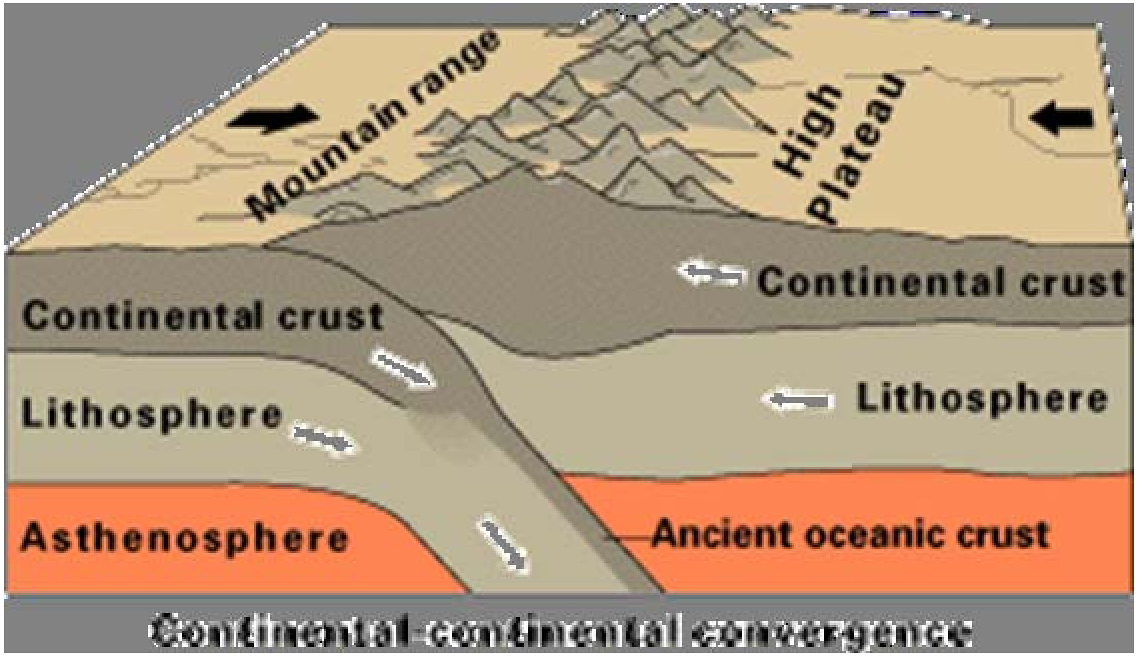
Convergent boundaries (b)

- One oceanic plate subducts under the other plate forming a deep oceanic trench at the boundary.
- Island volcanoes are produced by released water, at high temp. and pressure, from subducting plate.
- Large, deep (>300km), earthquakes are produced.

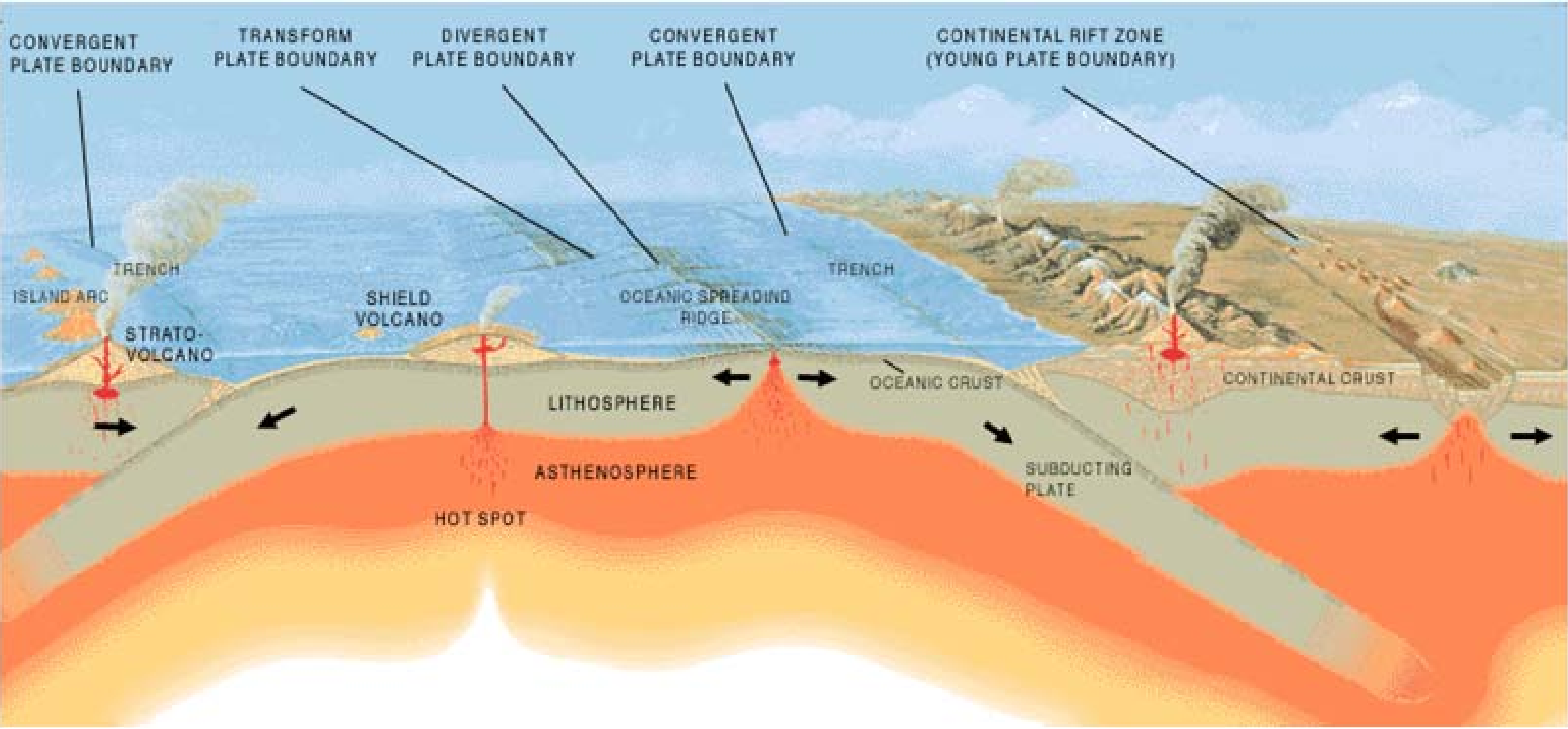


Convergent boundaries (c)

- One continental plate subducts under the other continental plate forming a mountain ranges and high plateaux,
- Himalayan mountain range (about 8.9km high) is an example a feature caused by of convergent boundary of the Indian and Eurasian plates
- Large, deep (>300km), earthquakes are produced



Panorama of features



Features described by plate tectonic theory

- Recycling of ocean crust by rising material from mantle at divergent plate boundary creates oceanic crust, sea floor spreading, and finally oceanic crust returning to mantle at convergent boundaries.
- Presence of trenches at subducting oceanic plate boundaries
- Volcanoes are produced by rising water from subducting plates.
- Mountain ranges formed by continental subduction.
- Hot spots, geothermal plumes in the mantle punch through crust to produce isolated volcanoes that create new crust.
- Some argue that Hot spots are the mechanism for the creation of continental crust.
- Earthquakes are produced by movement of plate boundaries.

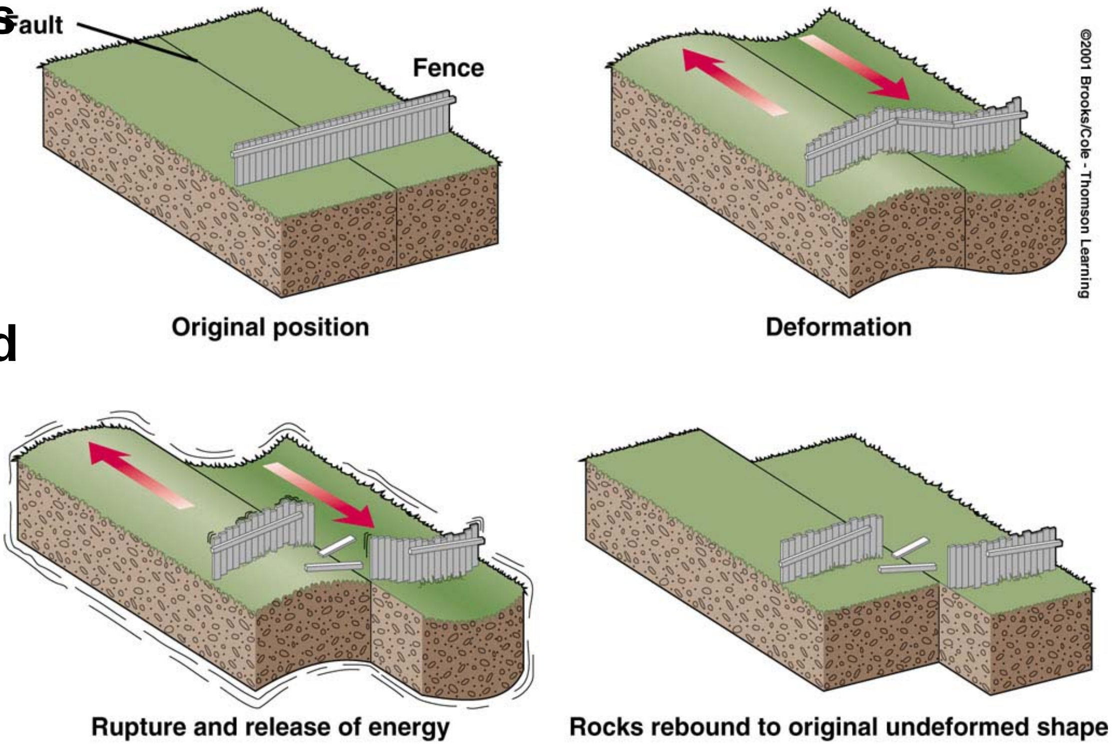
Earthquakes and volcanoes

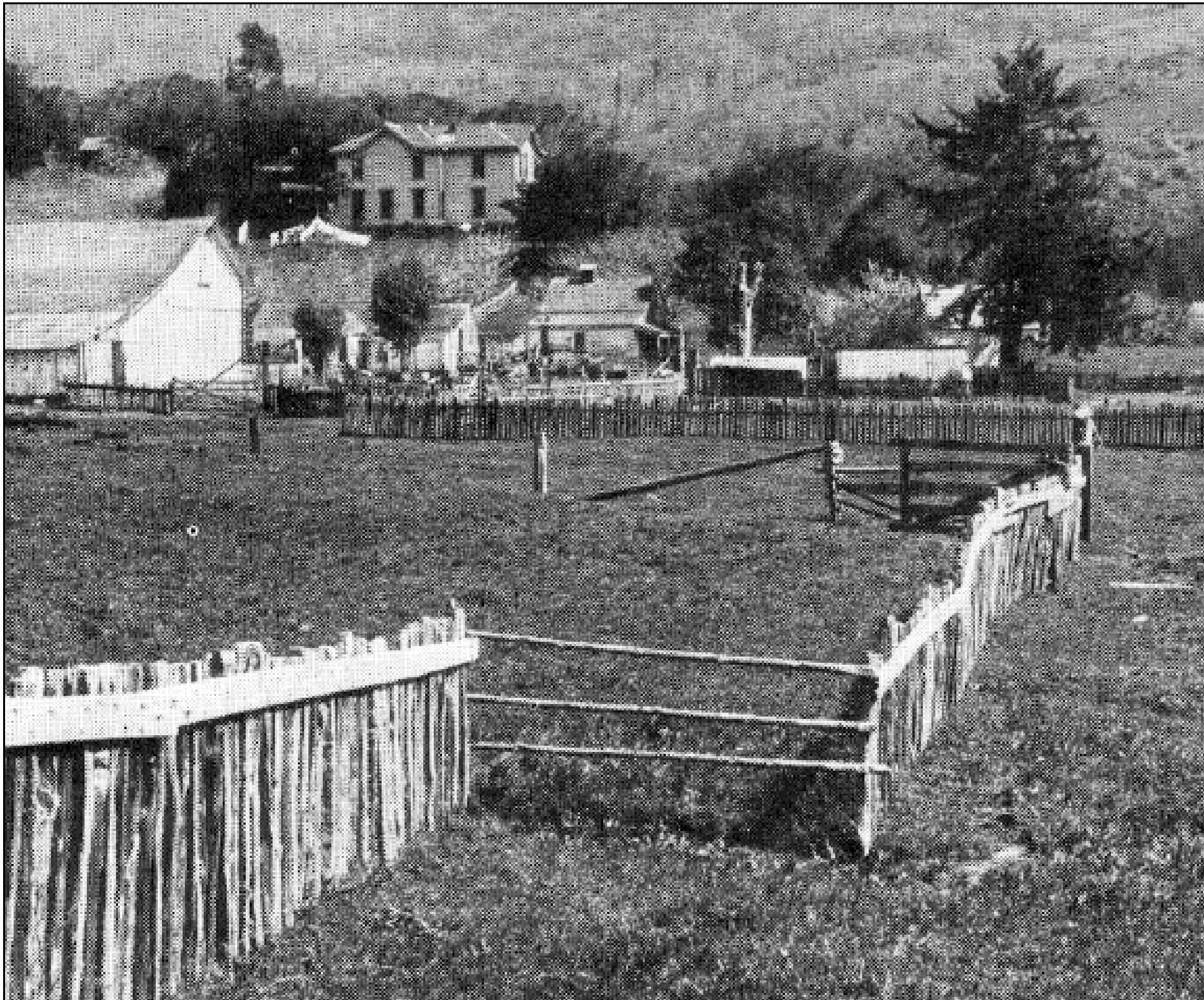
What are Earthquakes?

- The shaking or trembling caused by the sudden release of energy
- Usually associated with faulting or breaking of rocks
- Continuing adjustment of position results in aftershocks

What is the Elastic Rebound Theory?

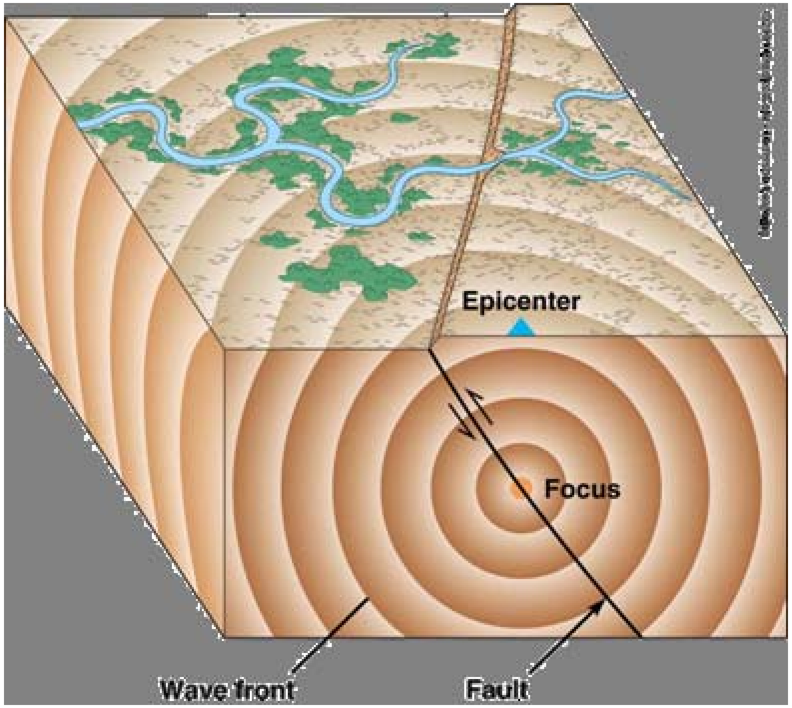
- Explains how energy is stored in rocks
  - Rocks bend until the strength of the rock is exceeded
  - Rupture occurs and the rocks quickly rebound to an undeformed shape
  - Energy is released in waves that radiate outward from the fault



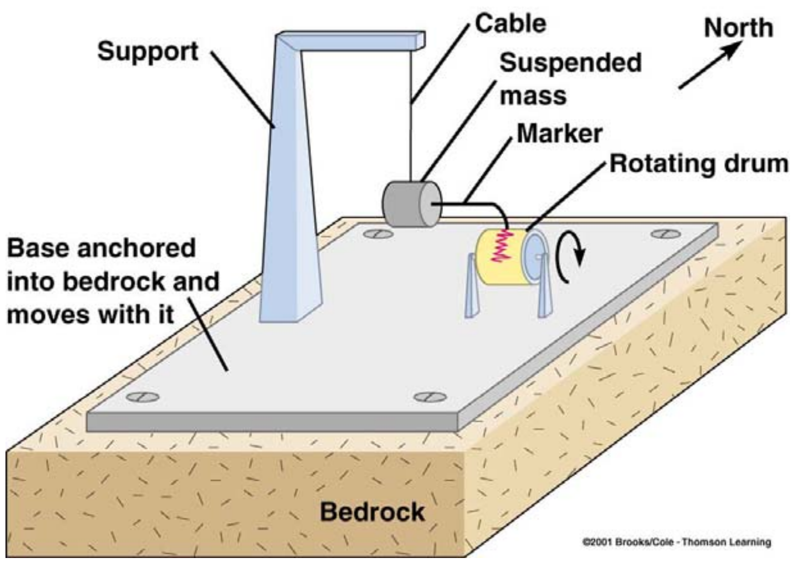


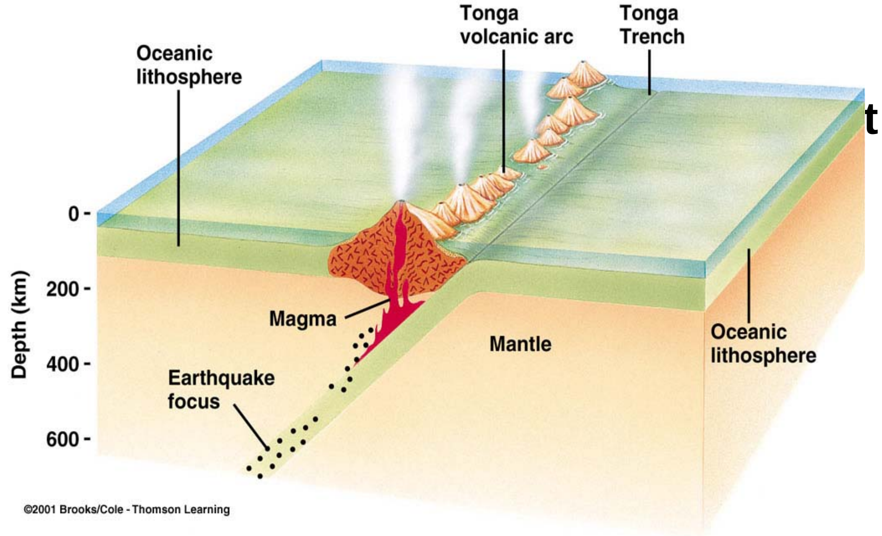
The Focus and Epicenter of an Earthquake

- The point within Earth where faulting begins is the focus, or hypocenter
- The point directly above the focus on the surface is the epicenter



Seismographs record earthquake events



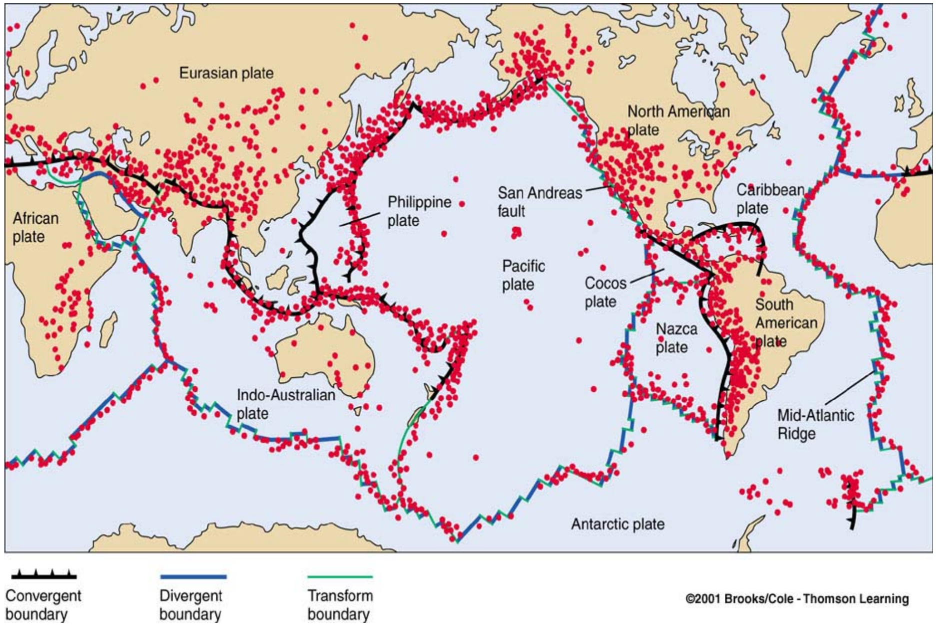


t convergent boundaries, focal depth increases along a dipping seismic zone called a Benioff zone

Where Do Earthquakes Occur and How Often?

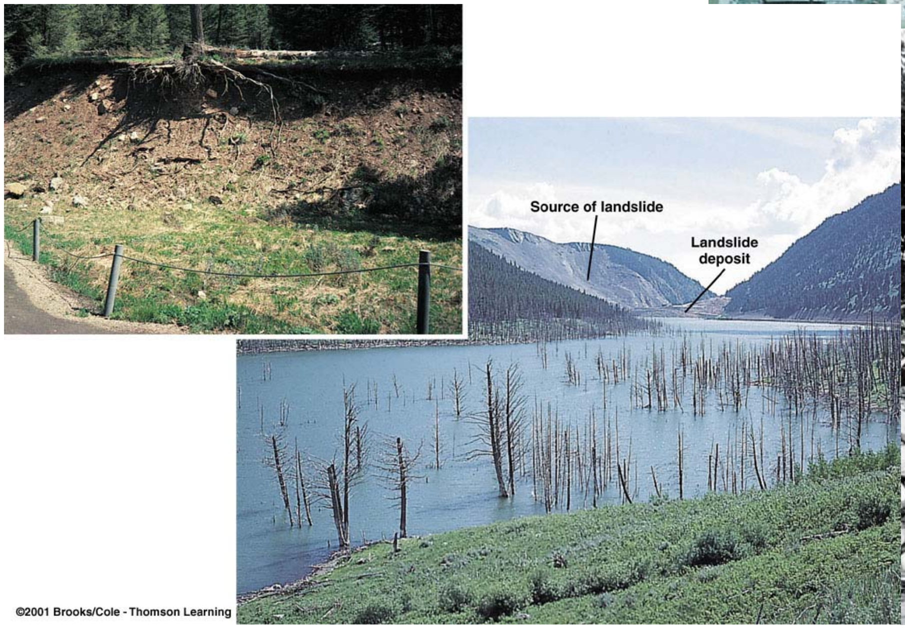
~80% of all earthquakes occur in the circum-Pacific belt

- most of these result from convergent margin activity
- ~15% occur in the Mediterranean-Asiatic belt
- remaining 5% occur in the interiors of plates and on spreading ridge centers
- more than 150,000 quakes strong enough to be felt are recorded each year



The Economics and Societal Impacts of EQs

- **Building collapse**
- **Fire**
- **Tsunami**
- **Ground failure**



Seismic waves and the structure of the earth

I. Description of seismic waves

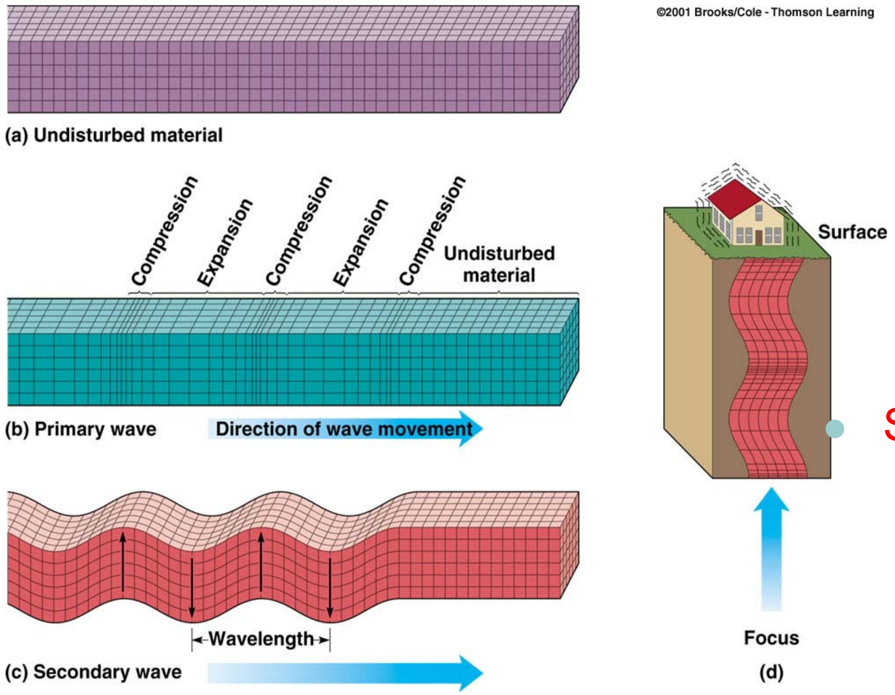
Seismic Wave

- Seismic waves are the vibrations from earthquakes that travel through the Earth
- Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs. In every earthquake, there are several different types of seismic waves.

What are Seismic Waves?

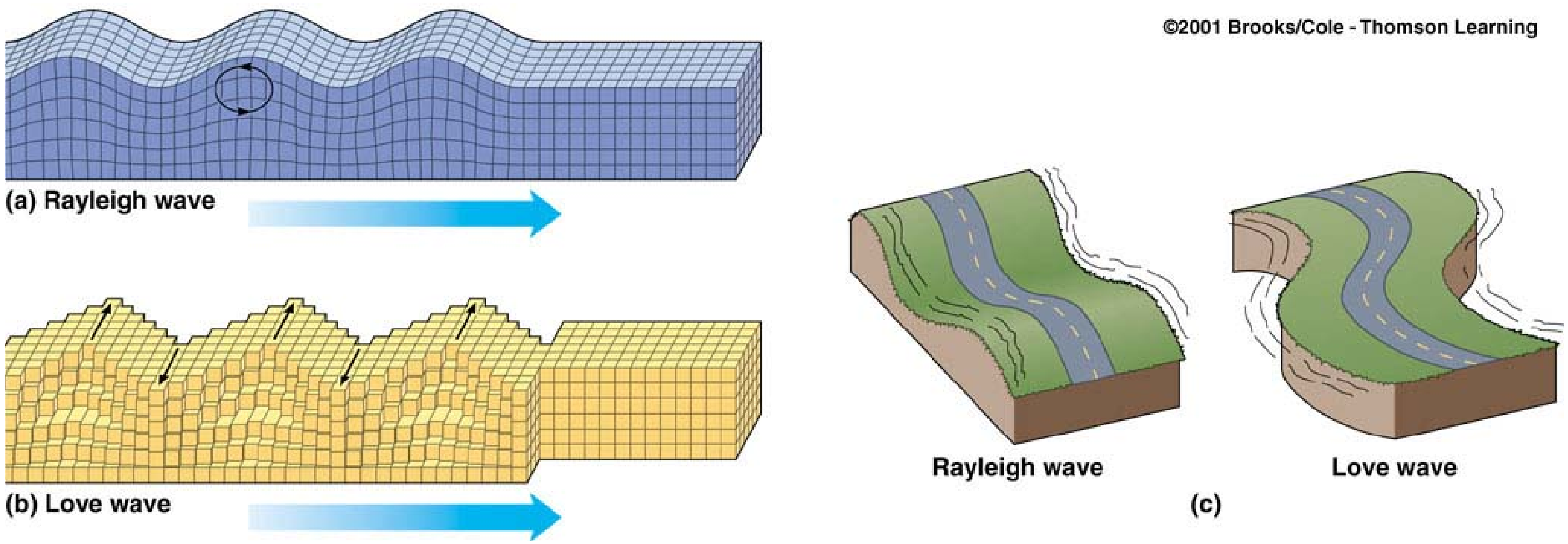
- Response of material to the arrival of energy fronts released by rupture
- Two types:
  - Body waves
    - P and S
  - Surface waves
    - R and L

Body Waves: P and S waves



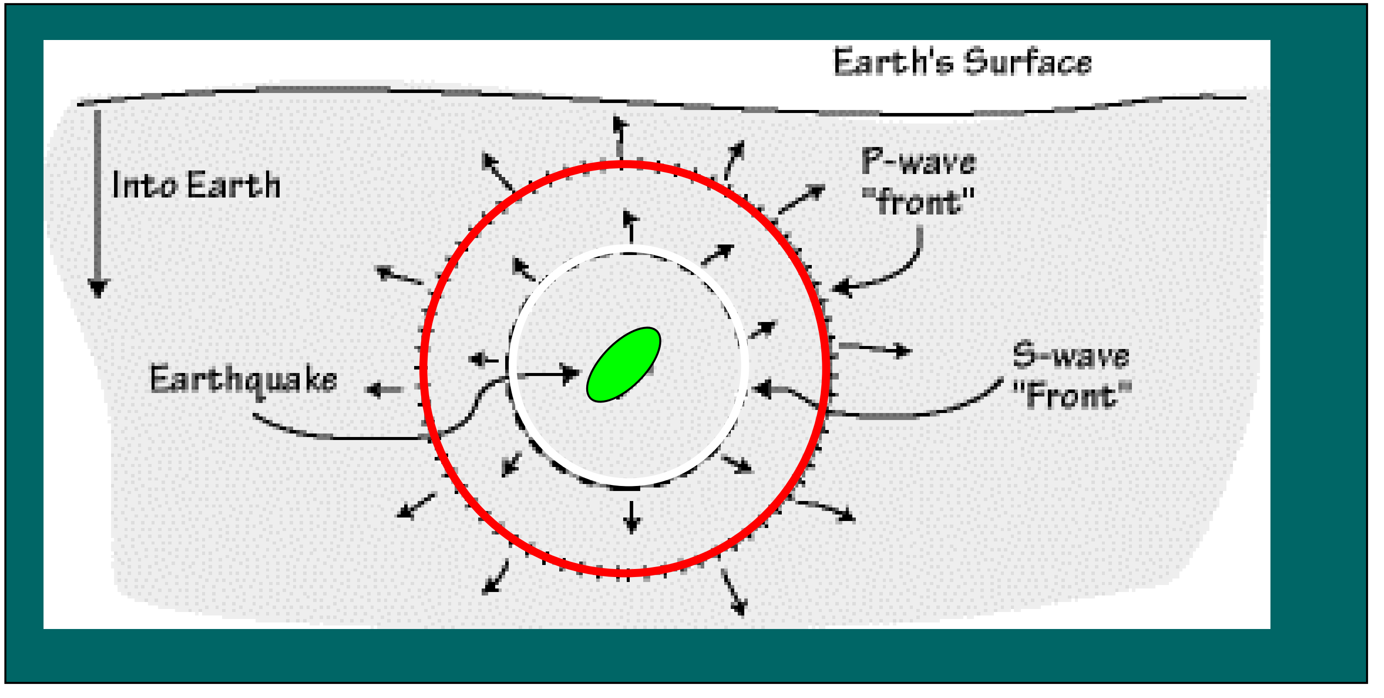
- Body waves
  - P or primary waves
    - fastest waves
    - travel through solids, liquids, or gases
    - compressional wave, material movement is in the same direction as wave movement
  - S or secondary waves
    - slower than P waves
    - travel through solids only
    - shear waves - move material perpendicular to wave movement

Surface Waves: R and L waves



- Surface Waves
  - Travel just below or along the ground’s surface
  - Slower than body waves; rolling and side-to-side movement
  - Especially damaging to buildings

- 4 Basic types of seismic waves
  - P (Primary) Axial oscillation body wave
  - S (Secondary) Shear oscillation, body wave
  - Love (Horizontal oscillation) surface wave
  - Rayleigh (Vertical oscillation) surface



P -waves (Compressional waves)

- The first kind of body wave is the **P wave, longitudinal wave** or **primary wave**.

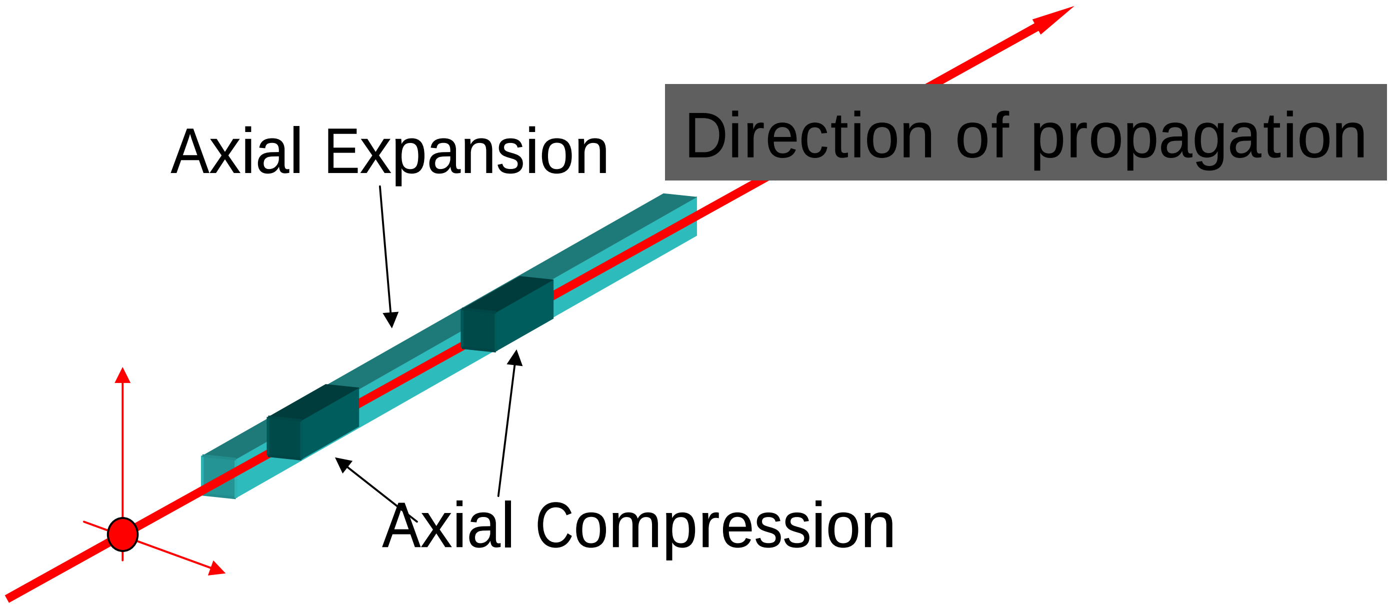
- P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and Surface-waves.

- The P wave can move through solid rock, fluids (liquids and gases)

- Alternating compressions ("pushes") and dilations ("pulls") which are directed in the same direction as the wave is propagating (along the ray path)

- V_P ~ 5 – 7 km/s in typical Earth's crust; >~ 8 km/s in Earth's mantle and core; ~1.5 km/s in water; ~0.3 km/s in air.

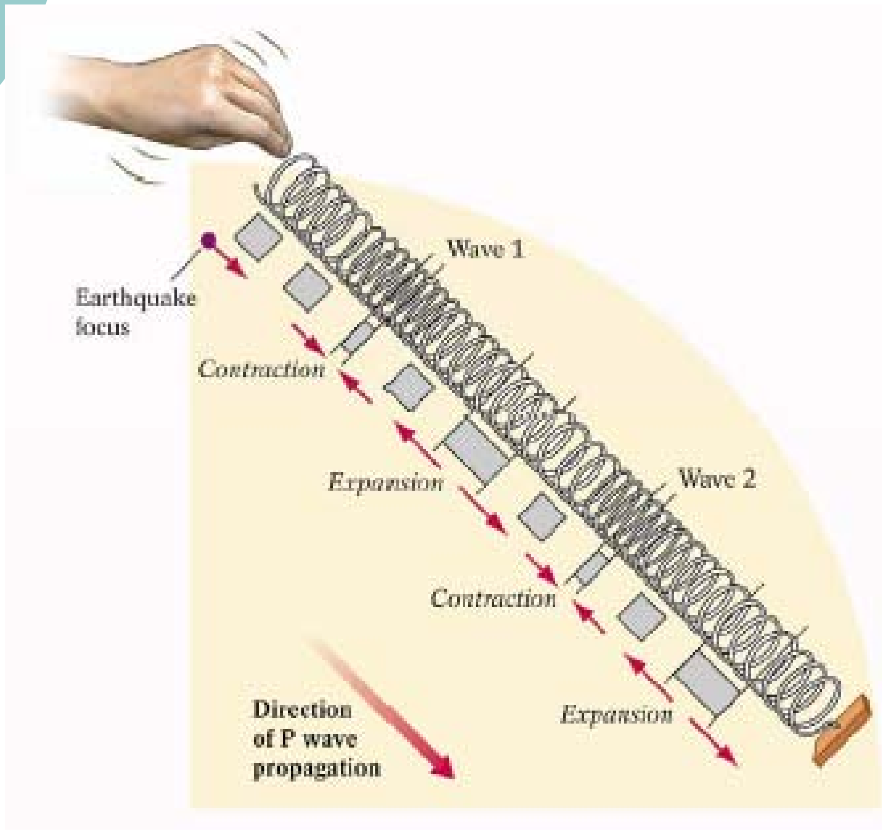
P, Primary (Body) Wave



- Deformation parallel to direction of propagation, e.g. like sound wave heard by human ear or pressure wave in a liquid. P waves can travel through solids, liquids or gases.
- Speed 1 km/s (in water) ~ 14 km/s (Lower part of mantle)

P –waves (Compressional waves)

- P waves in a liquid or gas are pressure waves, including sound waves.



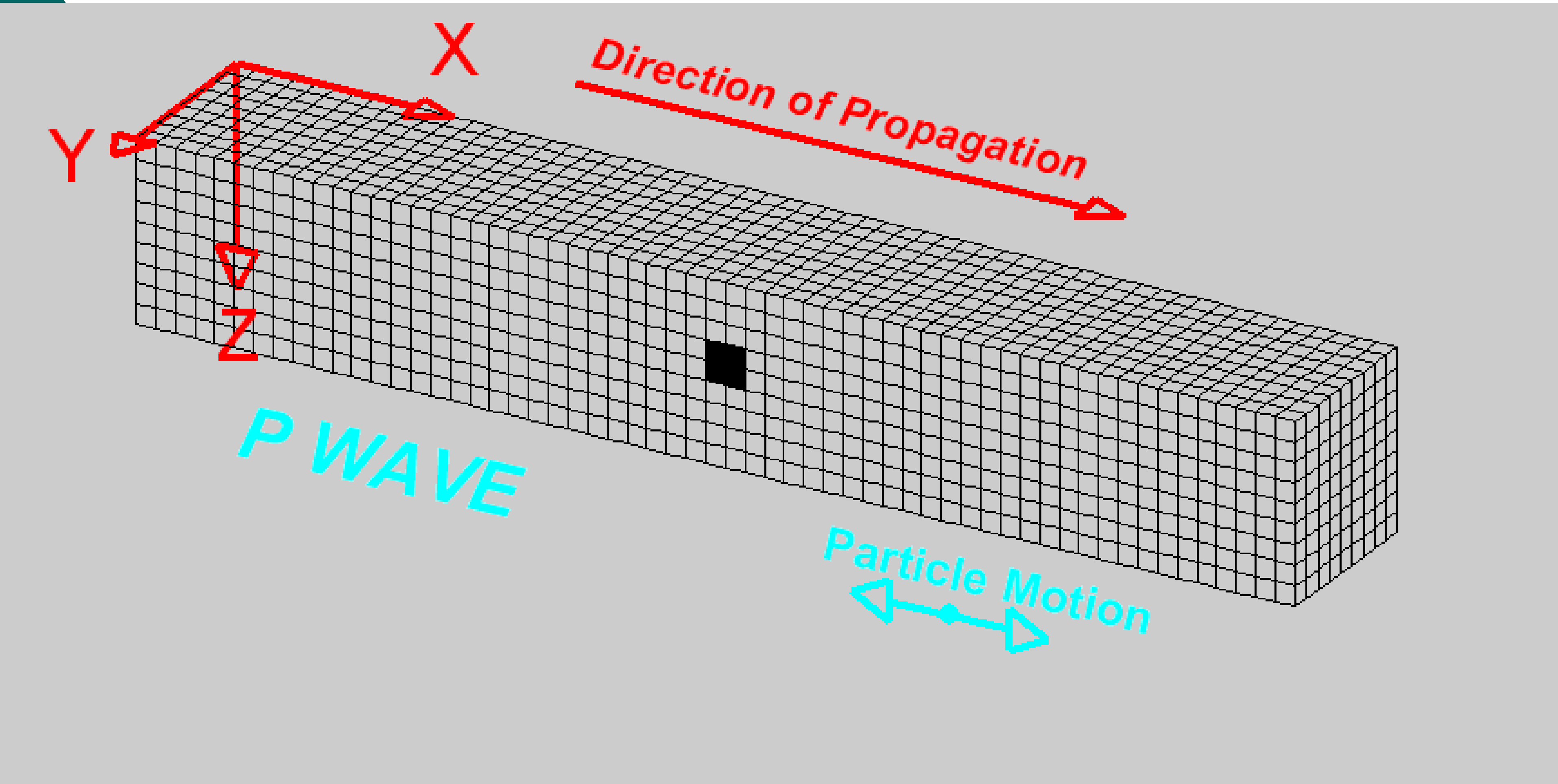
$$V_p = \left[\frac{k + 4/3\mu}{\rho}\right]^{1/2}$$

ρ density

μ shear modulus (rigidity)

k bulk modulus (rigidity)

Compressional Wave (P-Wave) Animation



Deformation propagates. Particle motion consists of alternating compression and dilation. Particle motion is parallel to the direction of propagation (longitudinal). Material returns to its original shape after wave passes.

S wave

- S waves (secondary waves) are transverse or shear waves.

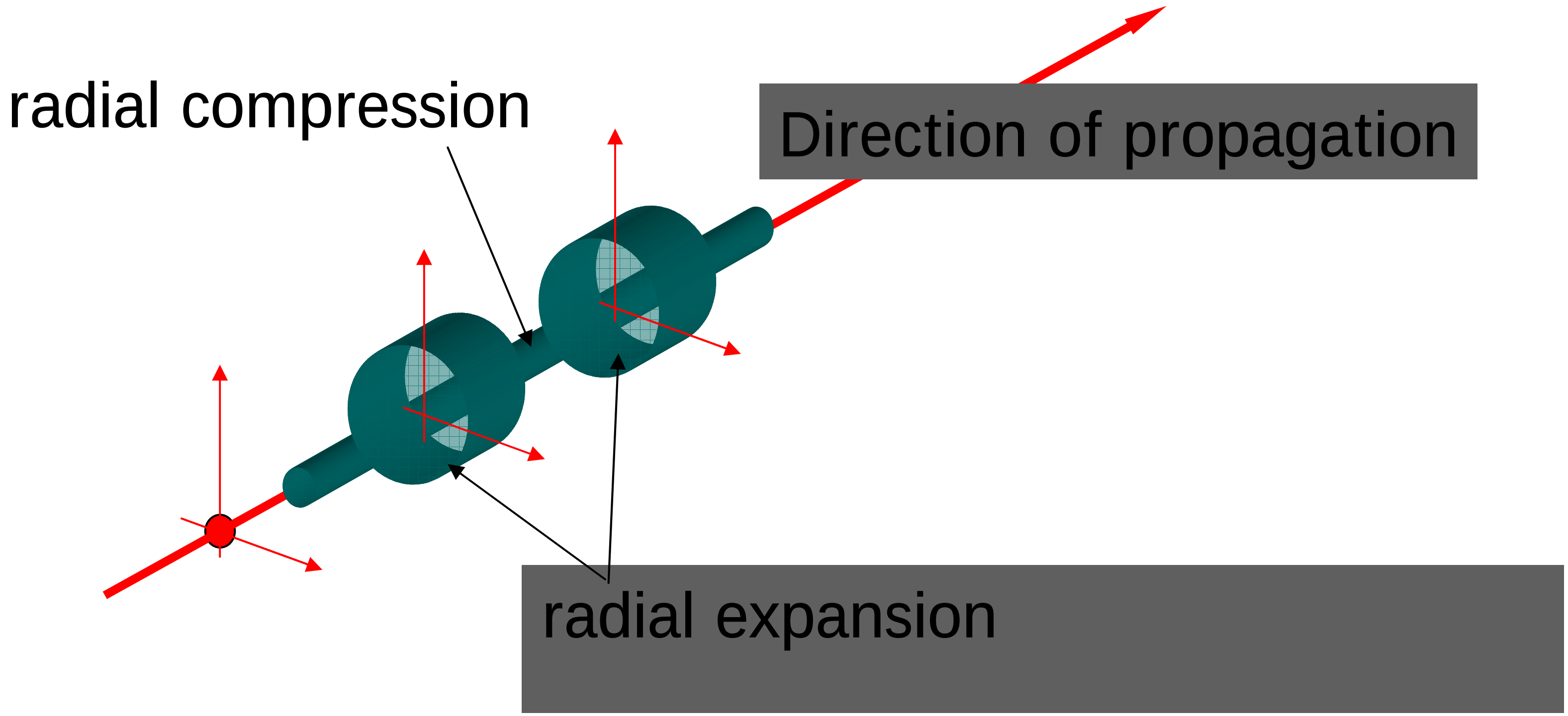
- Ground is displaced perpendicularly to the direction of propagation.

- S waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses.

- Their speed is about 60% of that of P waves in a given material. $V_S \sim 3 - 4$ km/s in typical Earth's crust, >~ 4.5 km/s in Earth's mantle, 2.5-3.0 km/s in (solid) inner core.

- S waves are several times larger in amplitude than P waves for earthquake sources.

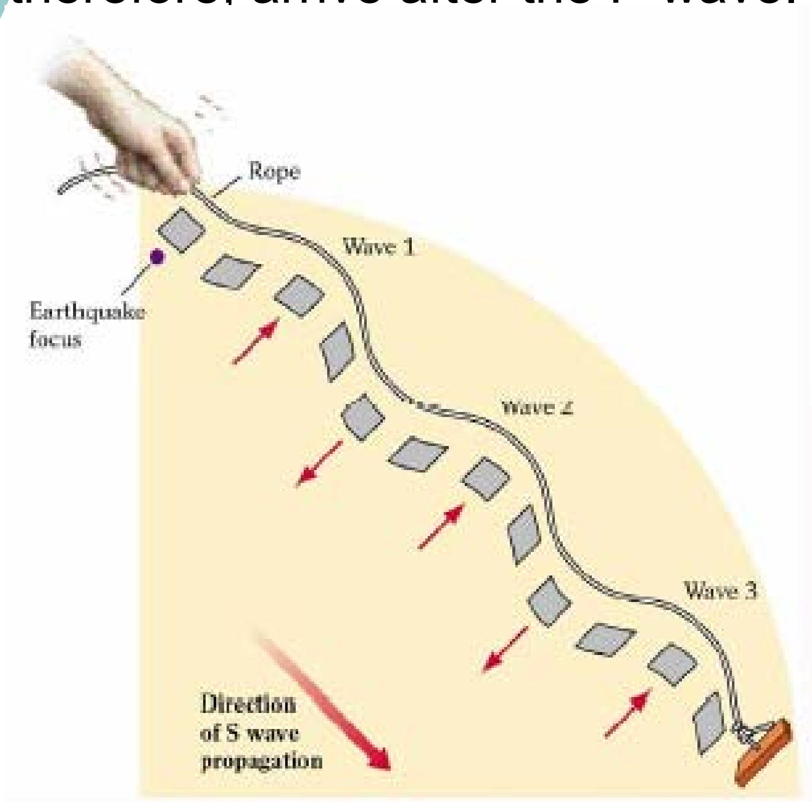
S, Secondary (Body) Wave



- Deformation perpendicular to direction of propagation, shear wave that cannot travel through gases or liquids
- Speed 1 km/s (in unconsolidated sediments) ~ 8 km/s (Lower part of mantle)

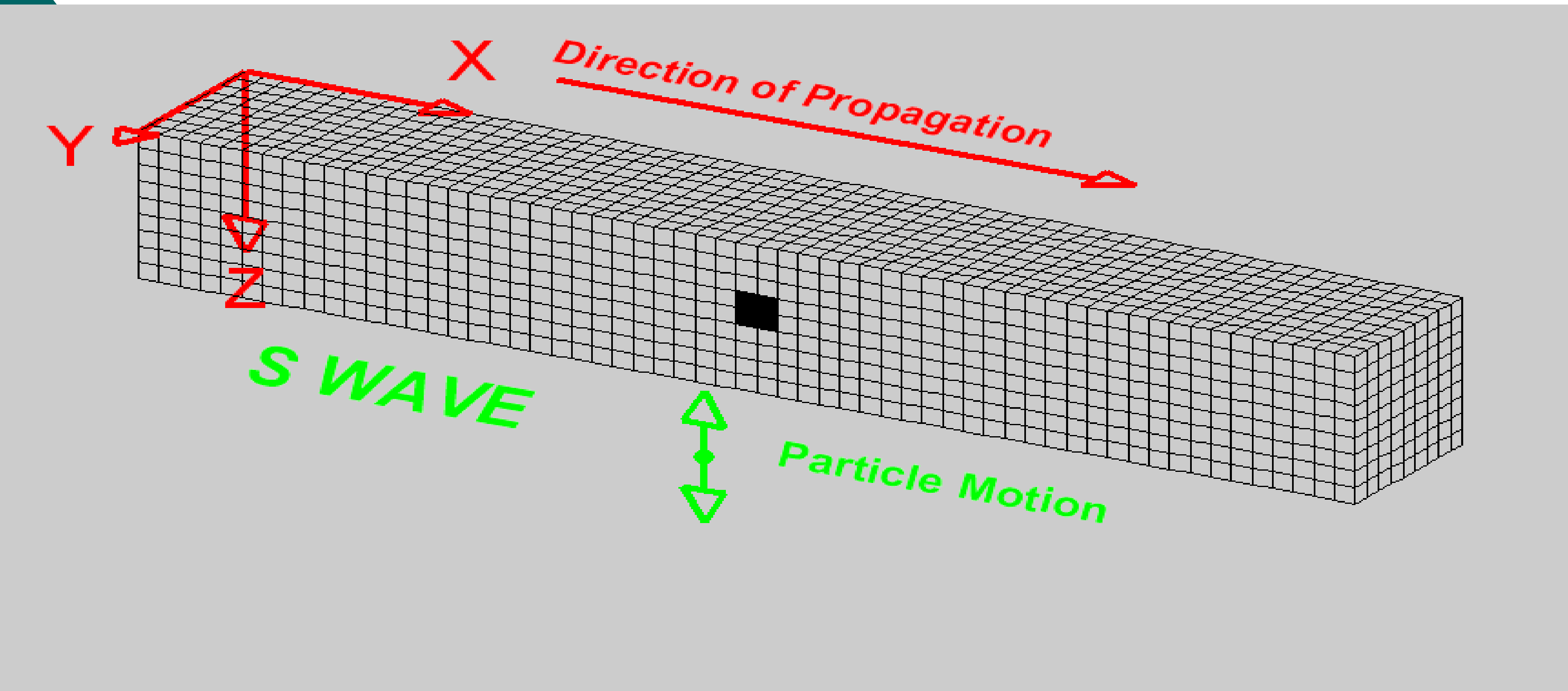
S waves

- S-waves do not travel through fluids, so do not exist in Earth's outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.



$$V_s = \left[\frac{\mu}{\rho} \right]^{1/2}$$

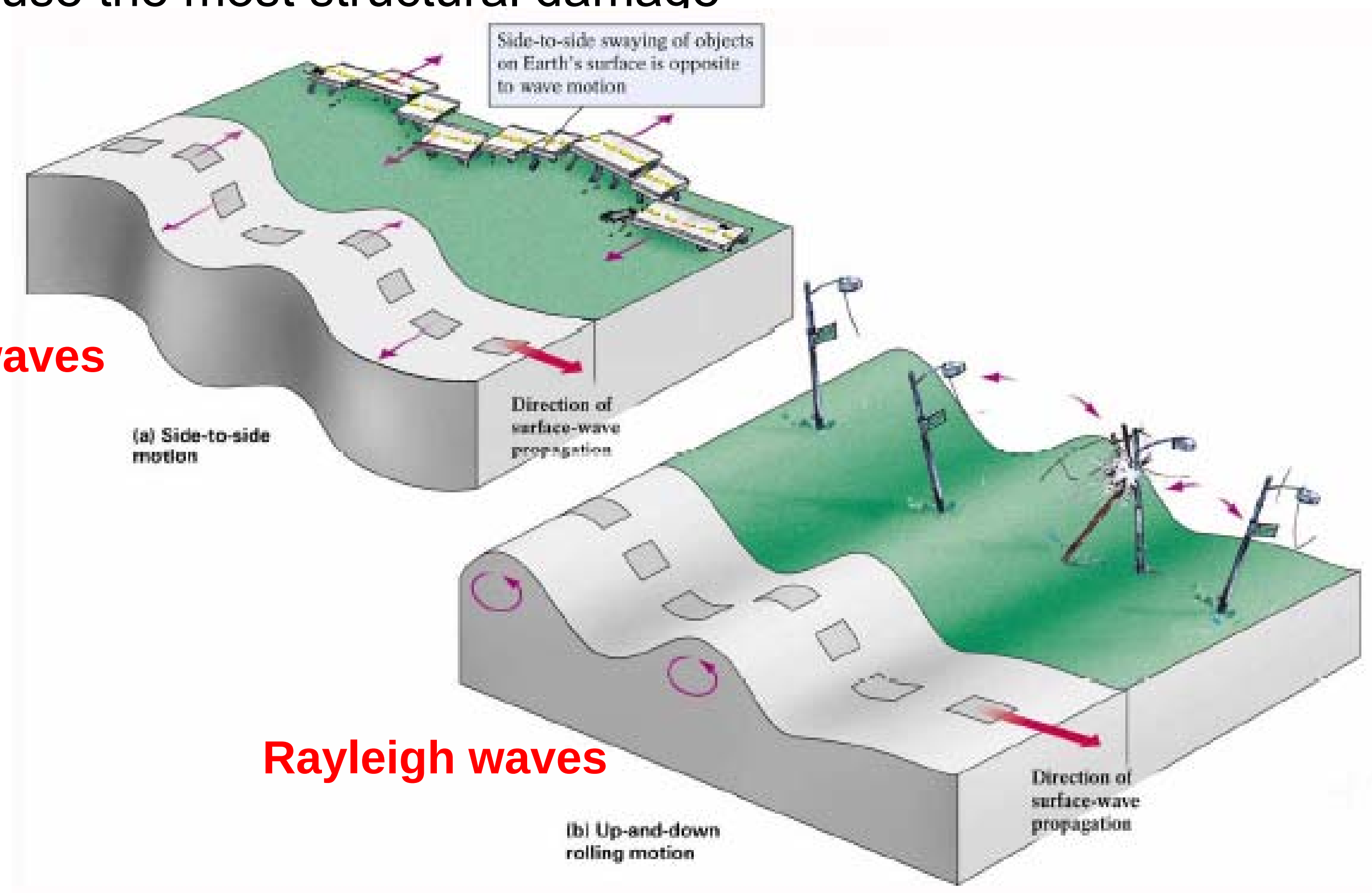
Shear Wave (S-Wave) Animation



Deformation propagates. Particle motion consists of alternating transverse motion. Particle motion is perpendicular to the direction of propagation (transverse). Transverse particle motion shown here is vertical but can be in any direction. However, Earth's layers tend to cause mostly vertical (SV; in the vertical plane) or horizontal (SH) shear motions. Material returns to its original shape after wave passes.

Surface waves

- propagate along a surface
- cause the most structural damage



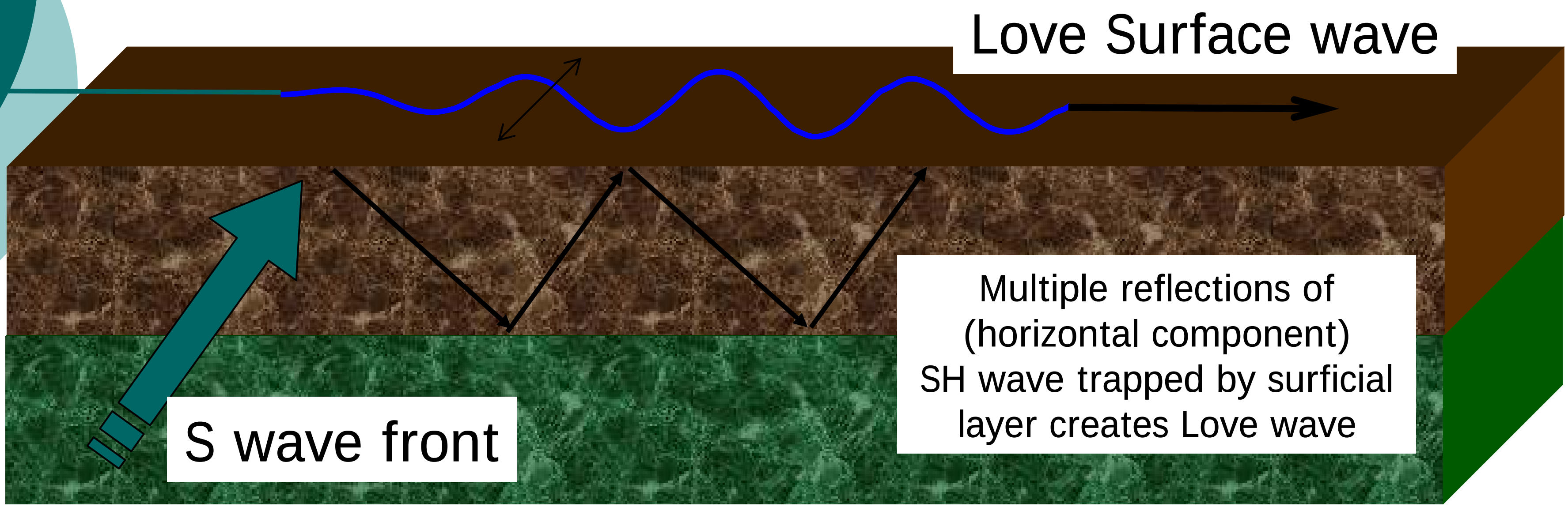
Love waves

Rayleigh waves

Love waves

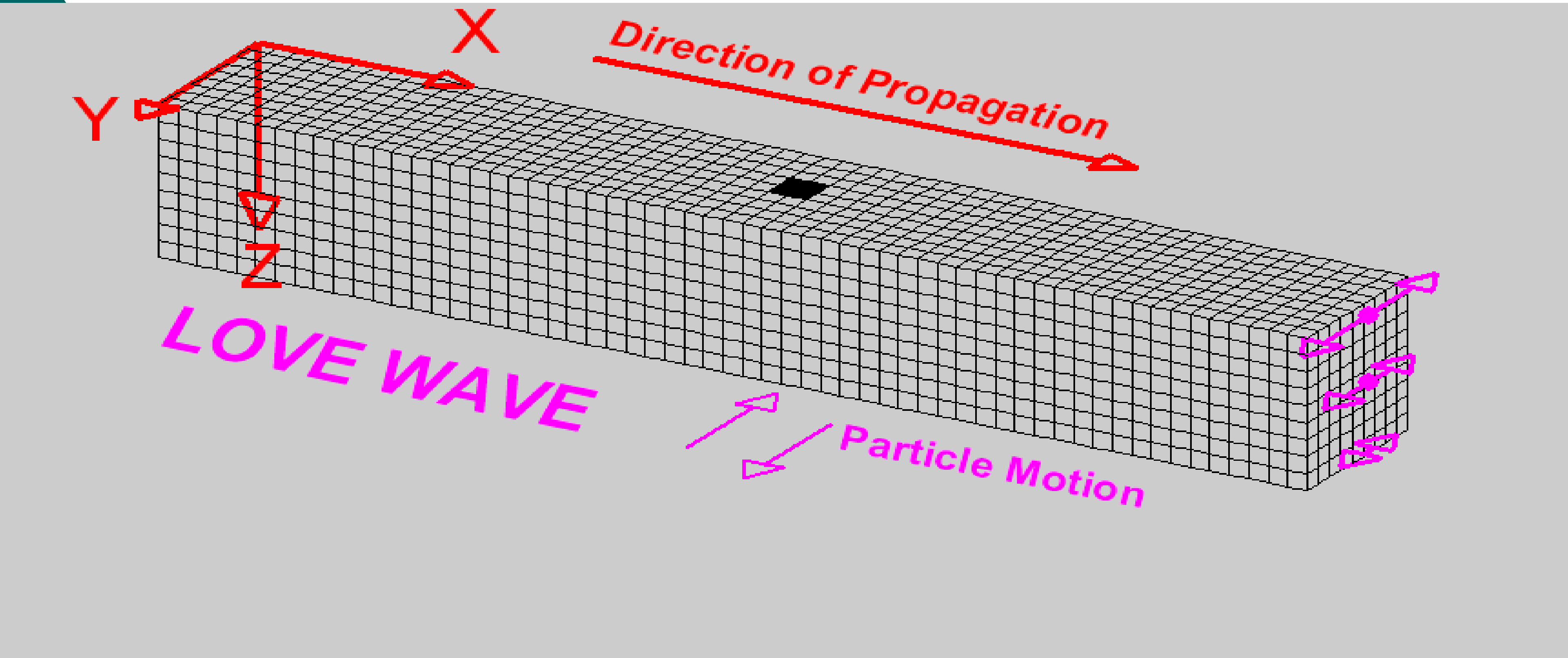
- The first kind of surface wave is called a **Love wave**, named after A.E.H. Love, a British mathematician who worked out the mathematical model for this kind of wave in 1911.
- It's the fastest surface wave and moves the ground from side-to-side.
- V_L ~ 2.0 - 4.4 km/s in the Earth depending on frequency of the propagating wave
- Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface.
- Seismic waves travel through water because gravity pulls the waves down causing friction of the waves.

Love (Surface) Wave



- Deformation (in plane of surface) eg. side to side motion, not recorded on vertical seismometer.
- Speed 1 ~ 7 km/s

Love Wave (L-Wave) Animation



Deformation propagates. Particle motion consists of alternating transverse motions. Particle motion is horizontal and perpendicular to the direction of propagation (transverse). To aid in seeing that the particle motion is purely horizontal, focus on the Y axis (red line) as the wave propagates through it. Amplitude decreases with depth.

Rayleigh wave

- The other kind of surface wave is the **Rayleigh wave**, named for John William Strutt, Lord Rayleigh, who mathematically predicted the existence of this kind of wave in 1885.

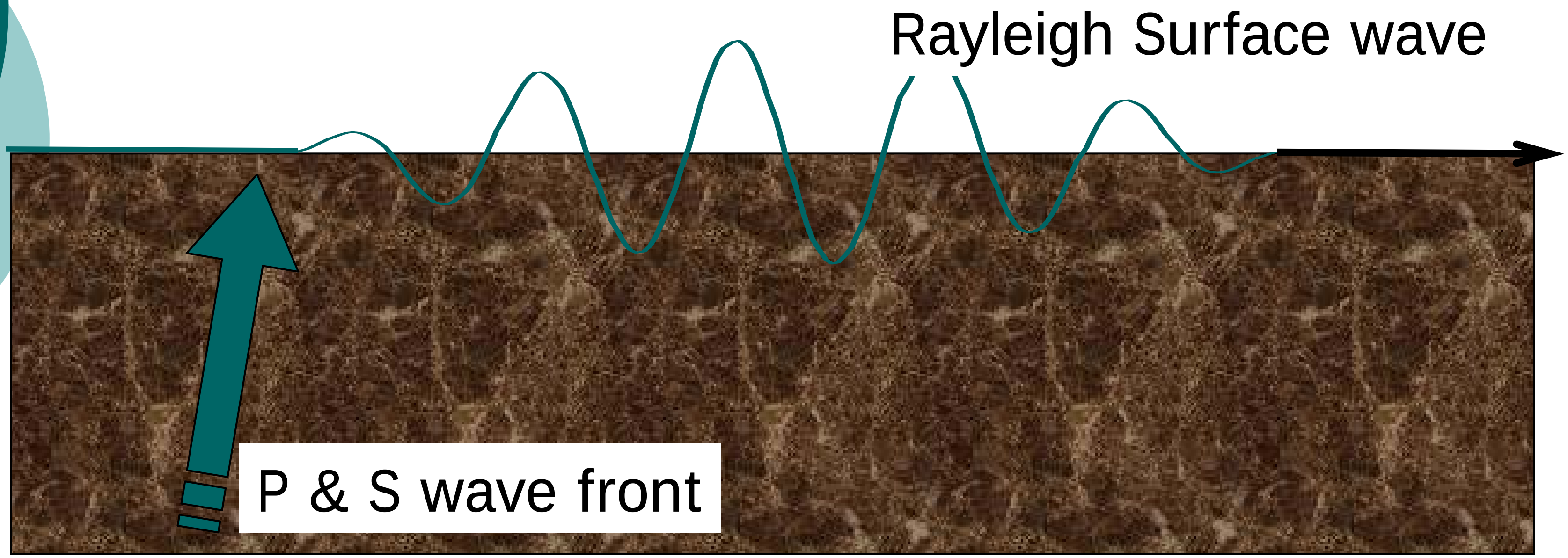
- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving.

- Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

- V_R ~ 2.0 - 4.2 km/s in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves.

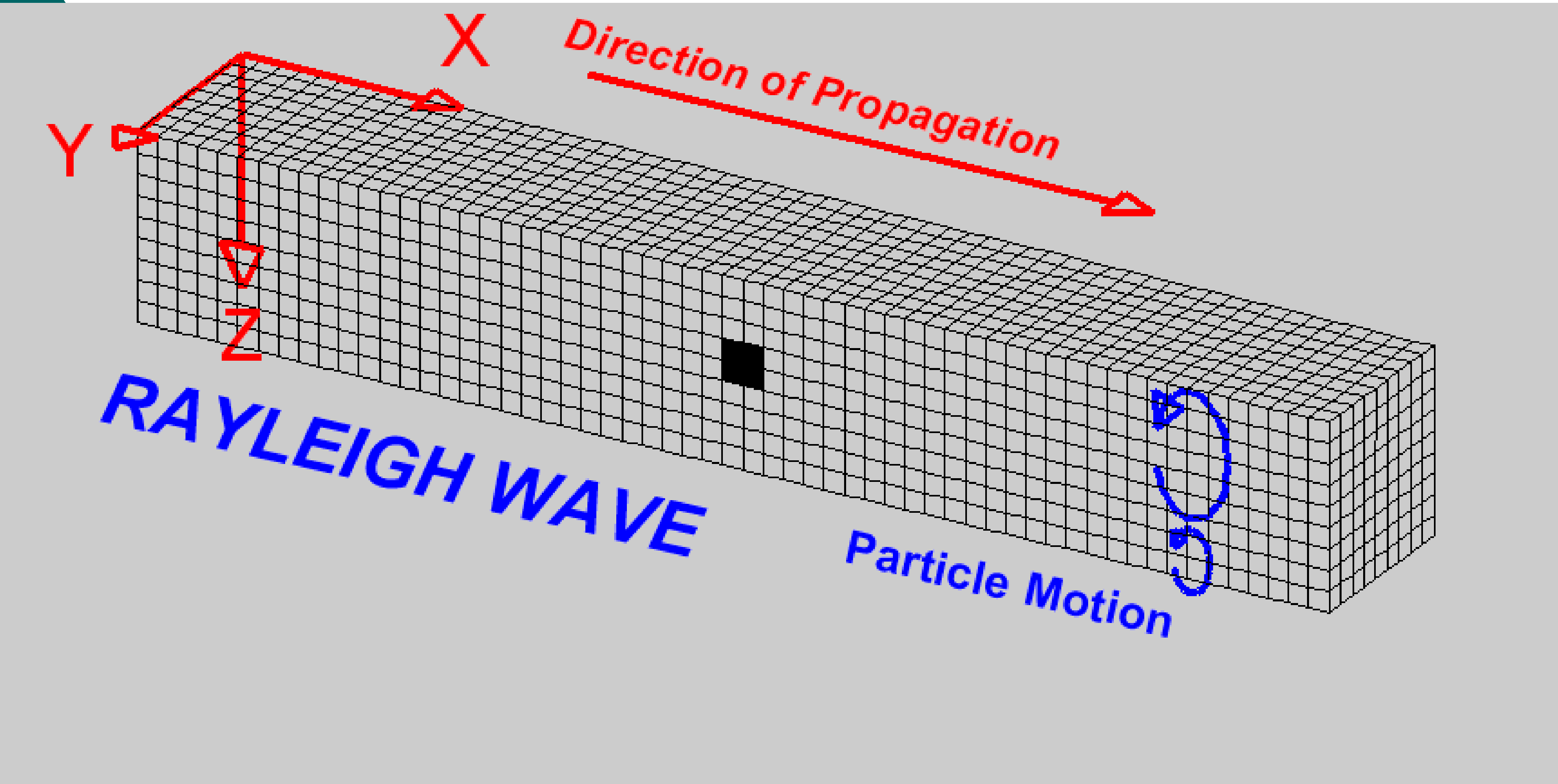
- Rayleigh waves is also dependent on frequency, with lower frequencies penetrating to greater depth.

Rayleigh (Surface) Wave



- Deformation (out of plane of surface) eg. up-down motion, similar to sea waves. Effects reduce quickly with depth.
- Speed 1 ~ 5 km/s

Rayleigh Wave (R-Wave) Animation



Deformation propagates. Particle motion consists of elliptical motions (generally retrograde elliptical) in the vertical plane and parallel to the direction of propagation. Amplitude decreases with depth.

Properties of seismic waves

1.Velocity depends on density and elasticity; faster in dense, rigid material; slower in less dense, plastic material.

2. Velocity increases with depth, because rocks are denser at depth

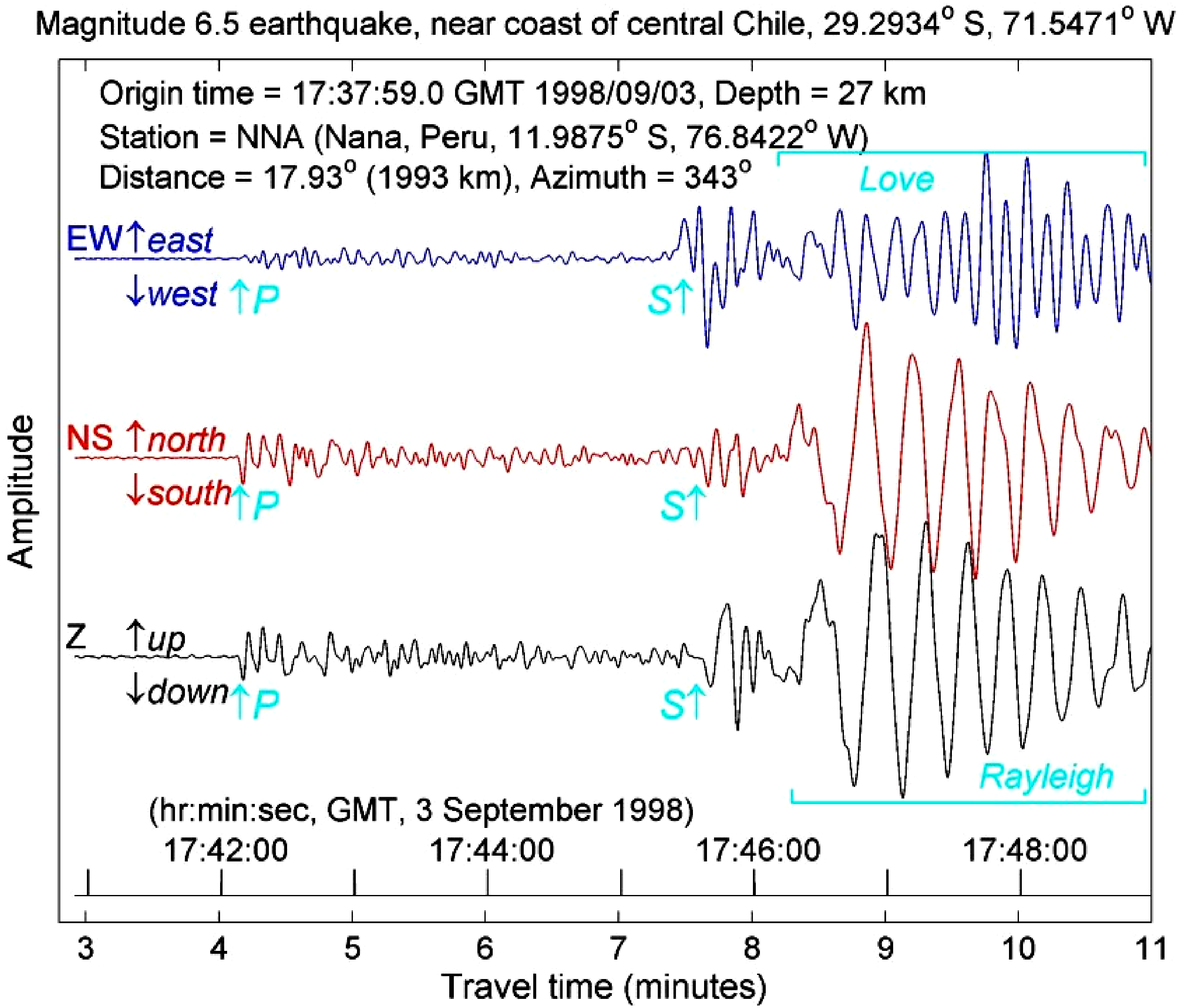
3. P-waves travel through solids and fluids

4. S-waves cannot travel through liquids

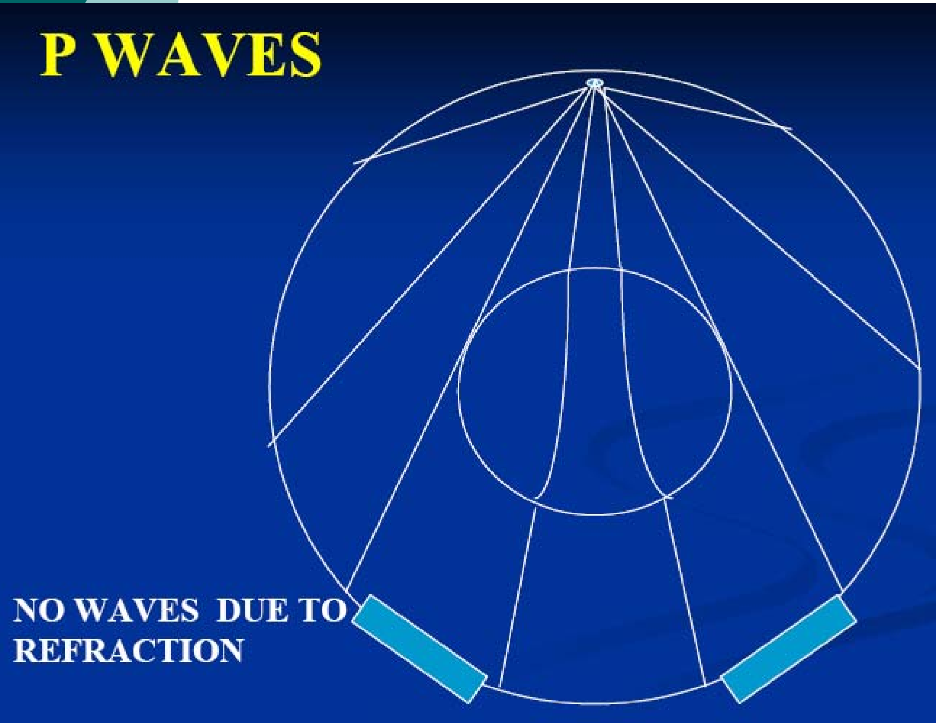
5. P-waves travel faster than S-waves.

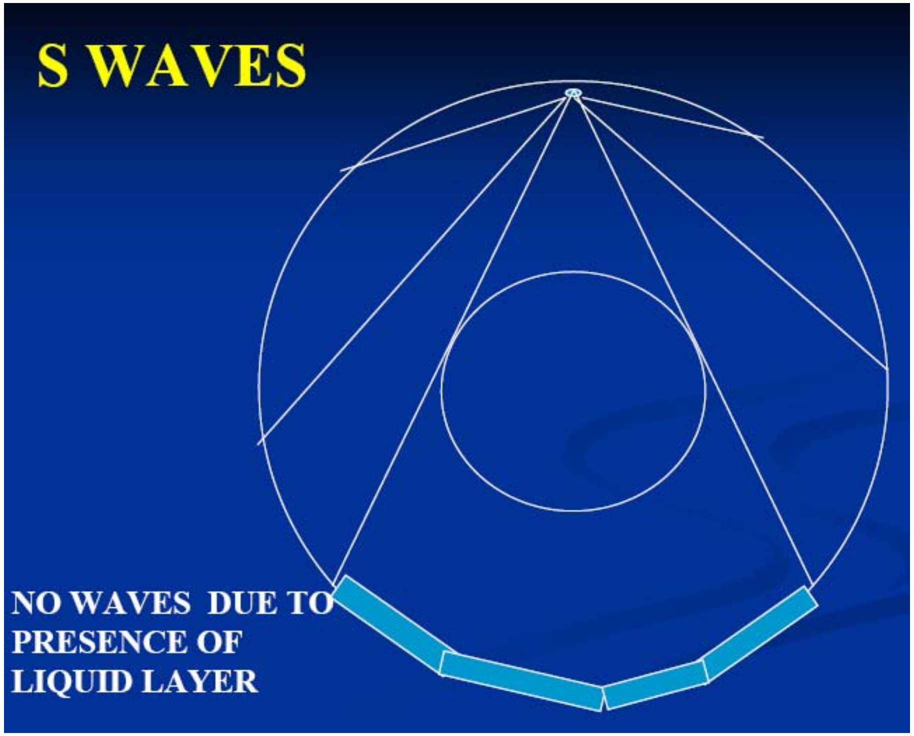
6. When seismic waves pass from one material to another, the path of the wave is refracted (bent).

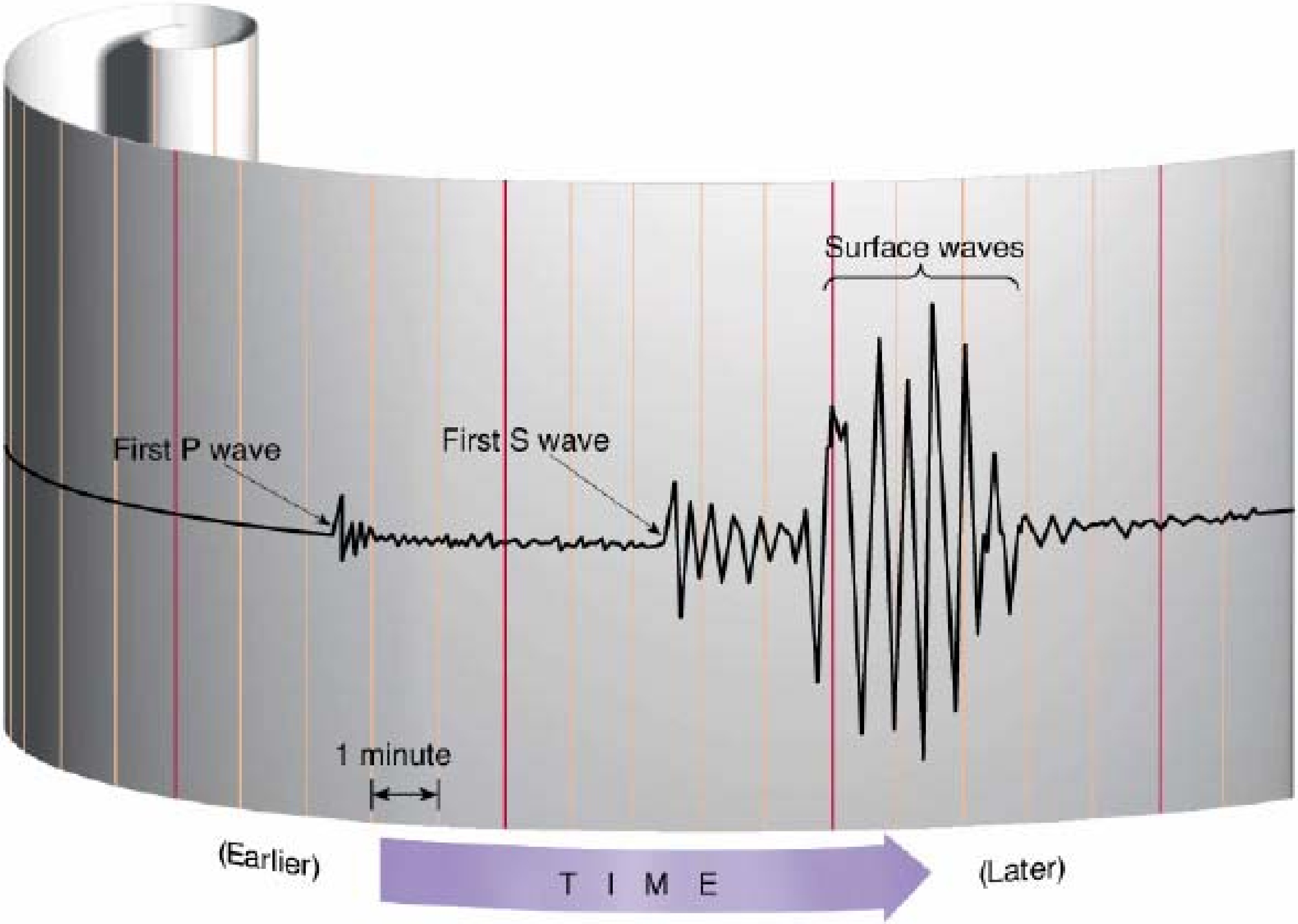
Three-component seismograms for the M6.5 west coast of Chile earthquake recorded at NNA



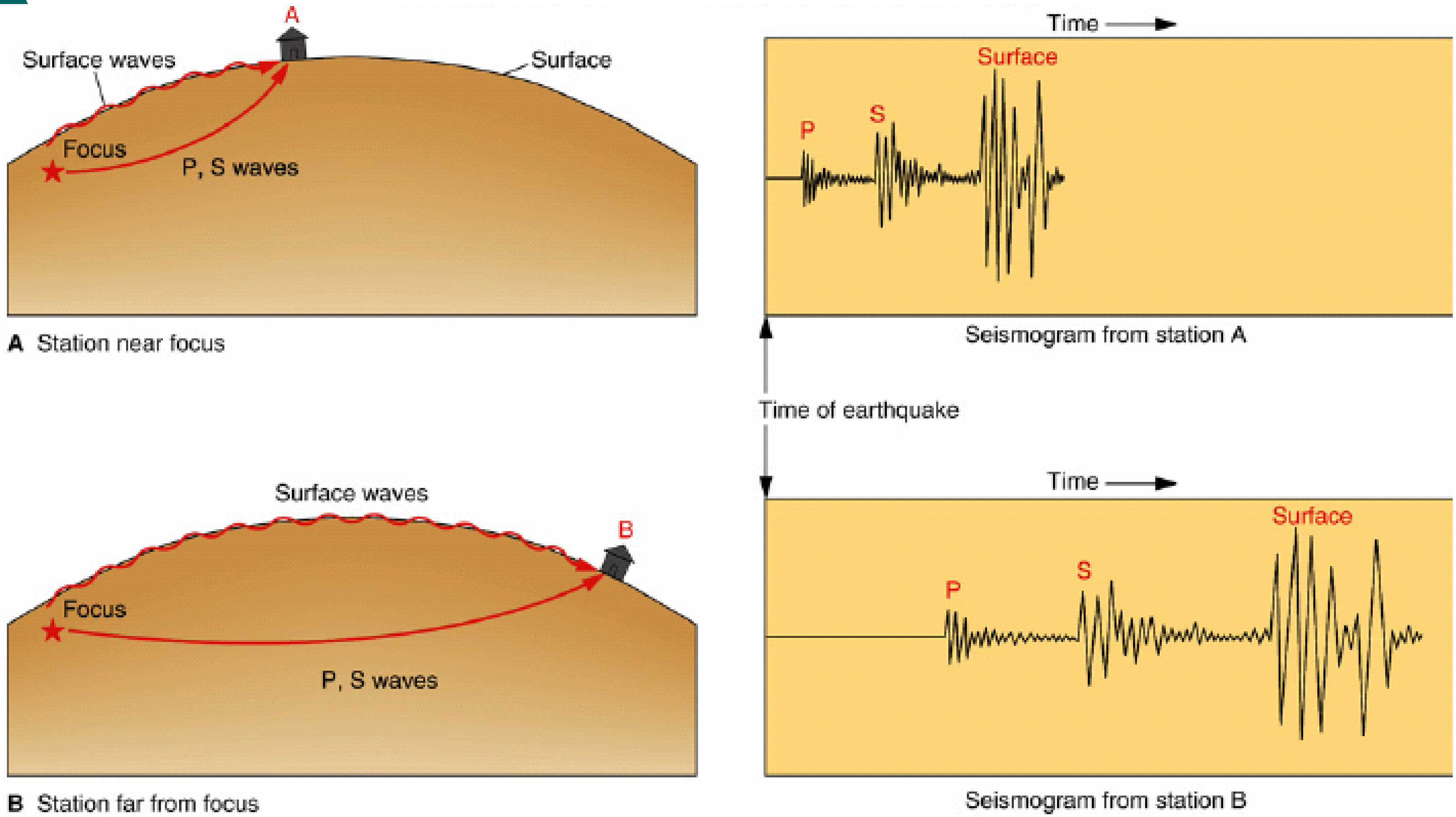
Earthquake waves are not measured everywhere on the surface of the Earth







Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)

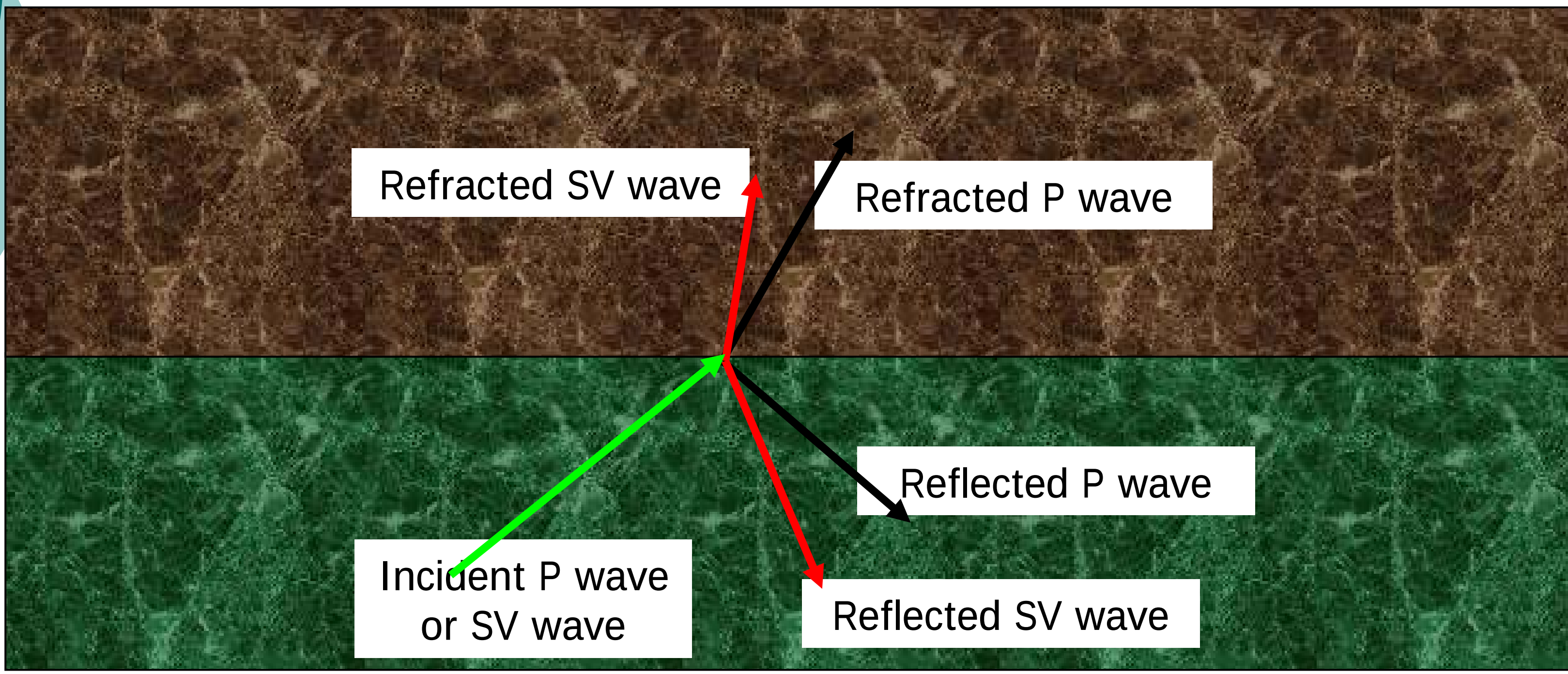


A
Surface waves
Surface
Focus
P, S waves
A Station near focus
Time
Surface
P
S
Seismogram from station A
Time of earthquake
Surface waves
B
Focus
P, S waves
B Station far from focus
Time
Surface
P
S
Seismogram from station B

Seismic waves and the structure of the earth

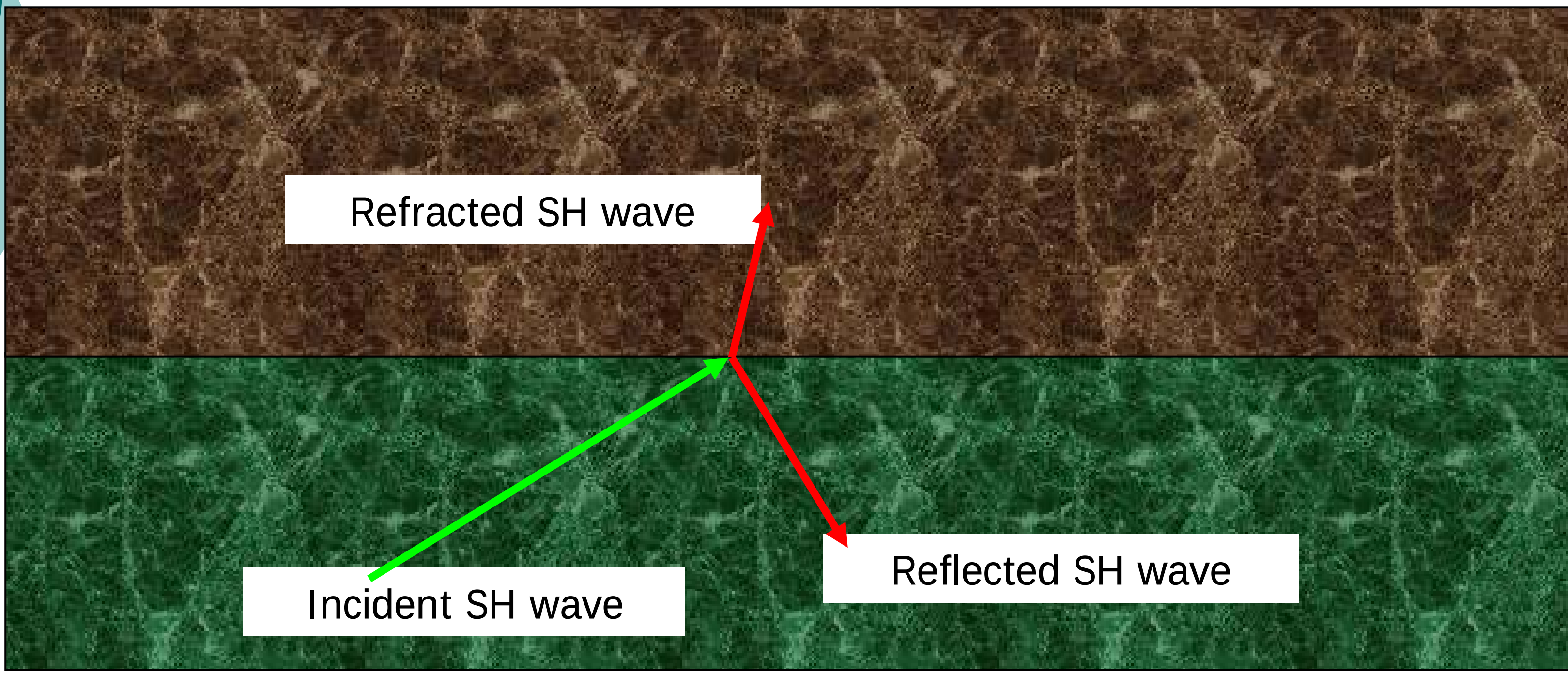
II. Propagation of Seismic waves

Reflection & Refraction



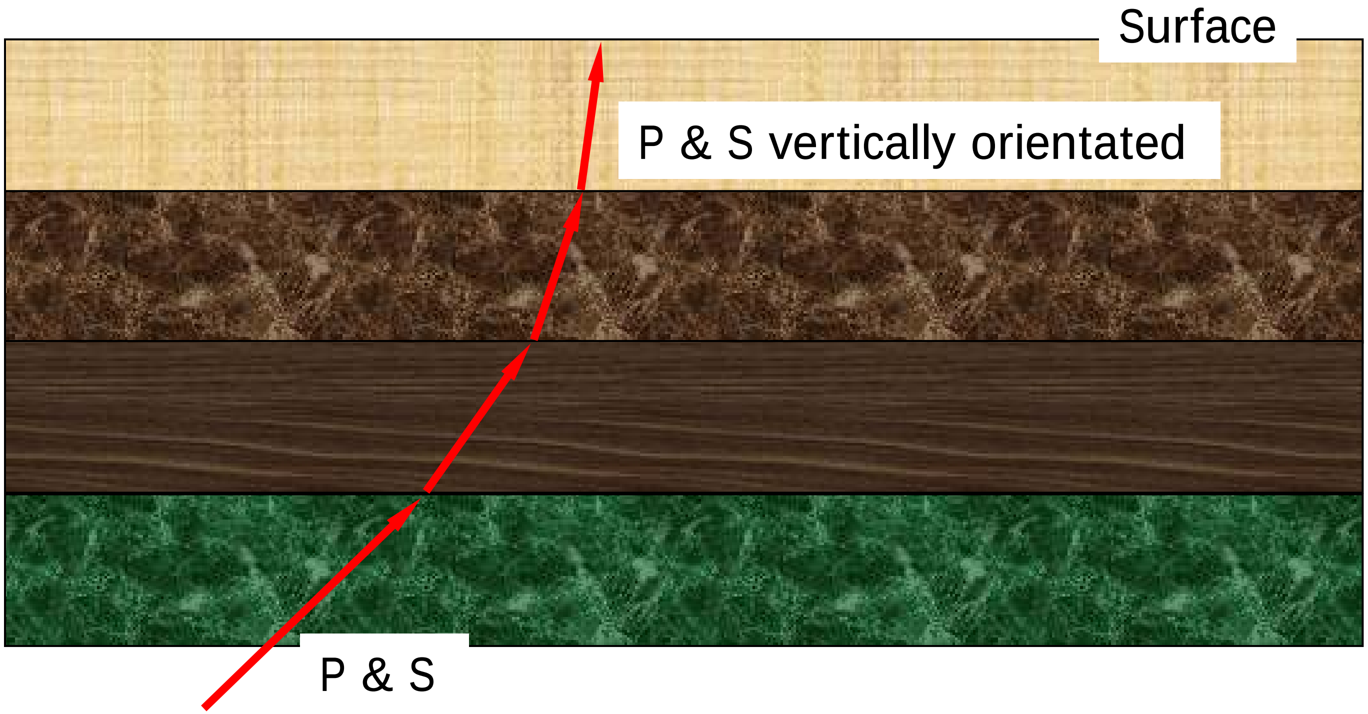
- P and SV (vertical component) waves, reflects and refracts at boundary layer between two rock/soil layer: producing both SV and P waves

Reflection & Refraction



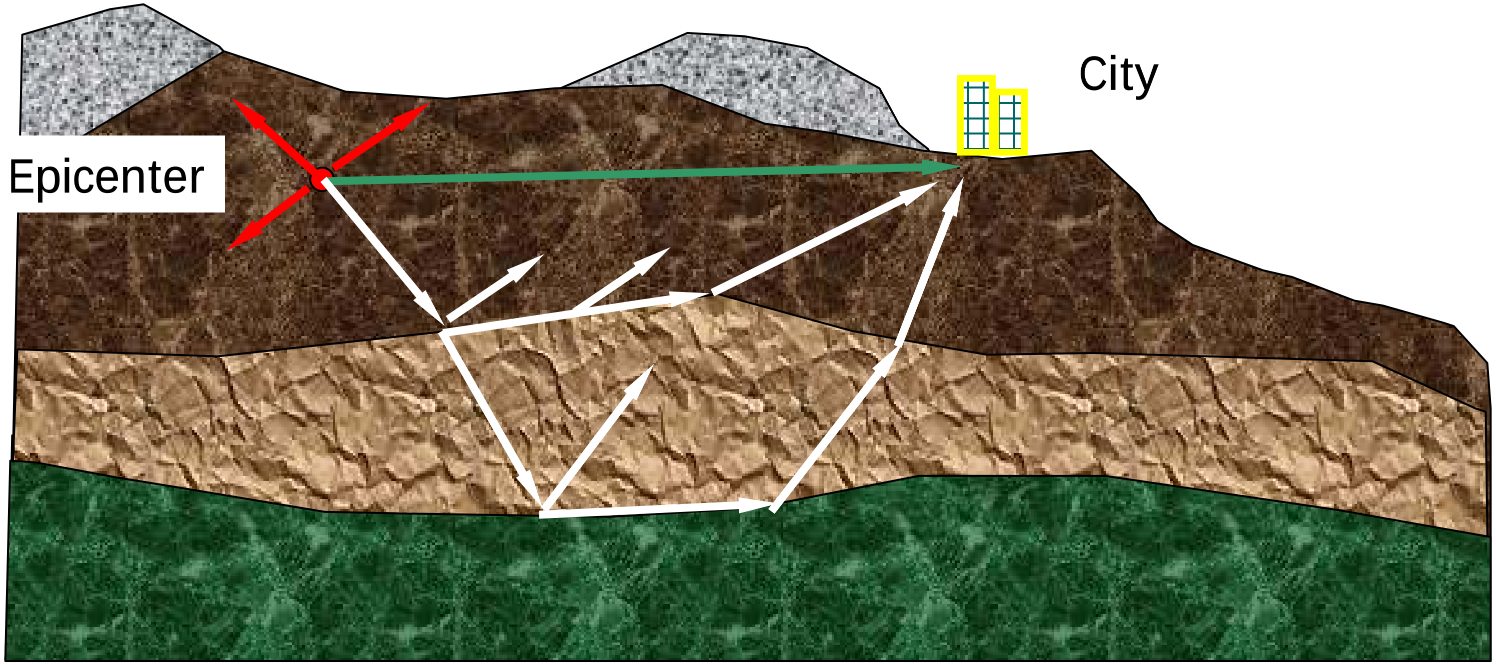
- SH (horizontal component) waves, reflects and refracts at boundary layer between two rock/soil layer but no P reflected or refracted waves are produced.

Refraction through stratified layers near surface

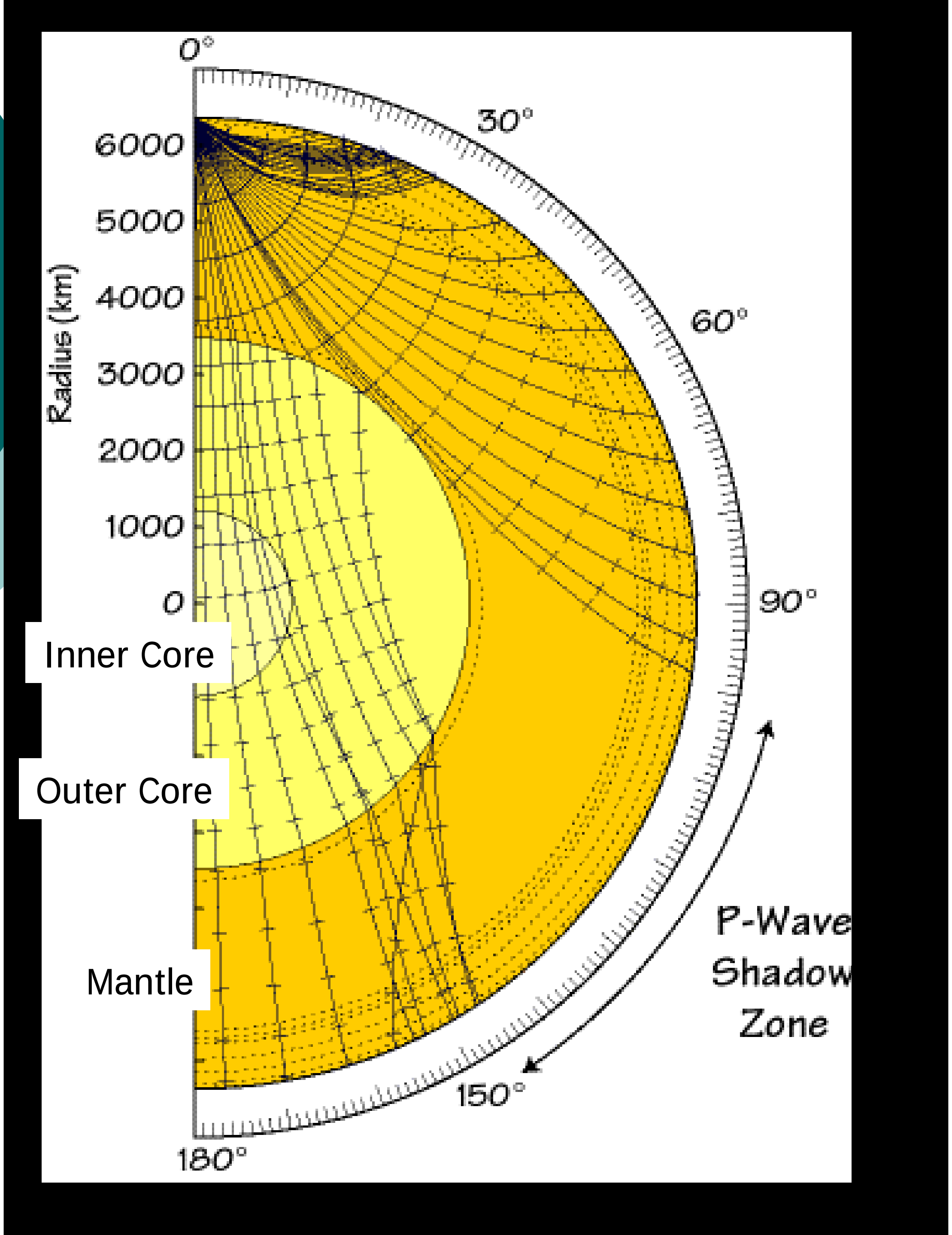


- Refraction tends to cause P and S waves to become vertically orientated as they approach the surface.

Scattering of P and S waves



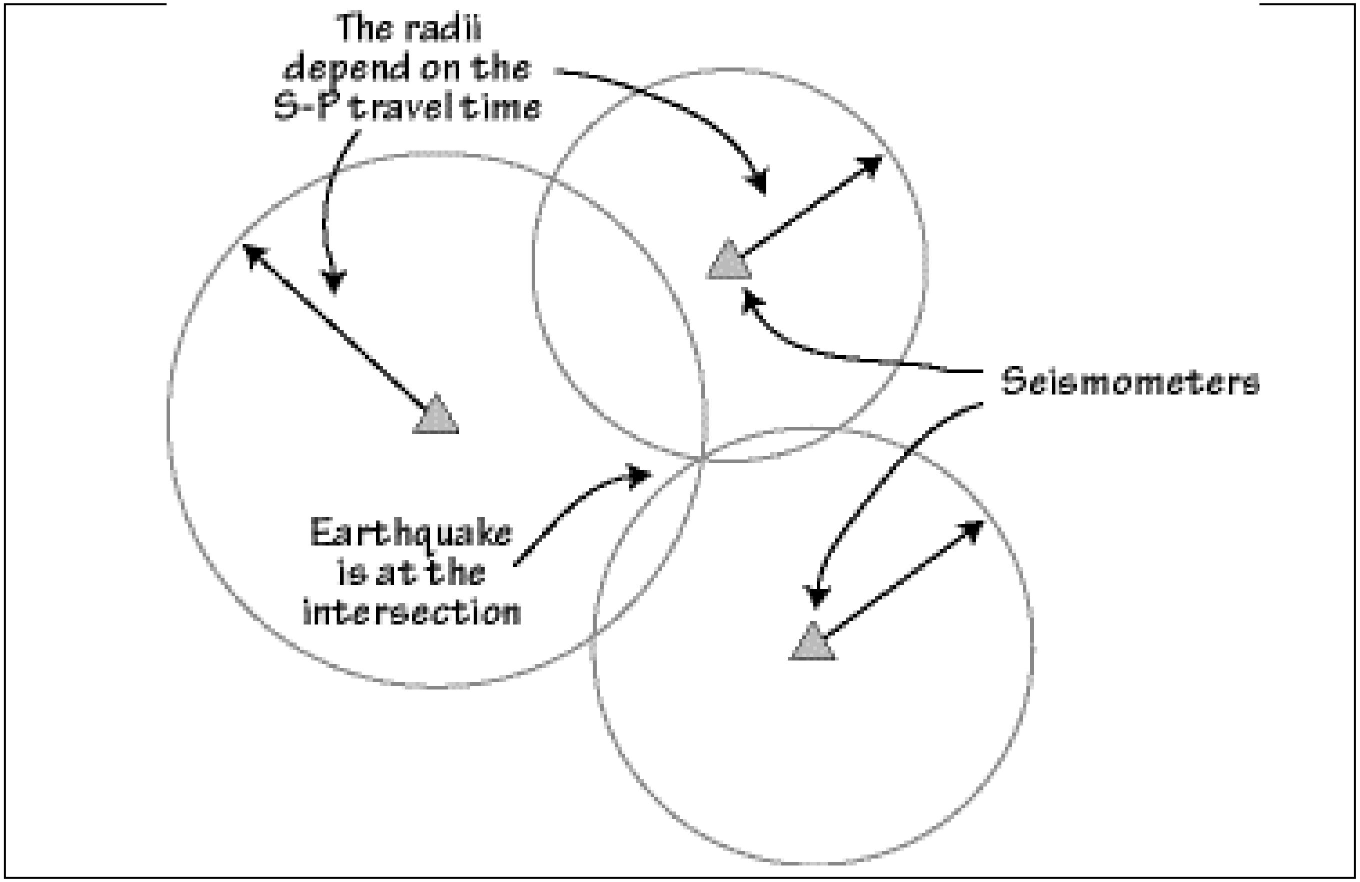
- Reflection and refraction, add complexity to seismograph recorded at the city.



Paths of P waves,
due to refraction only,
through inner earth

Seismic Wave Program

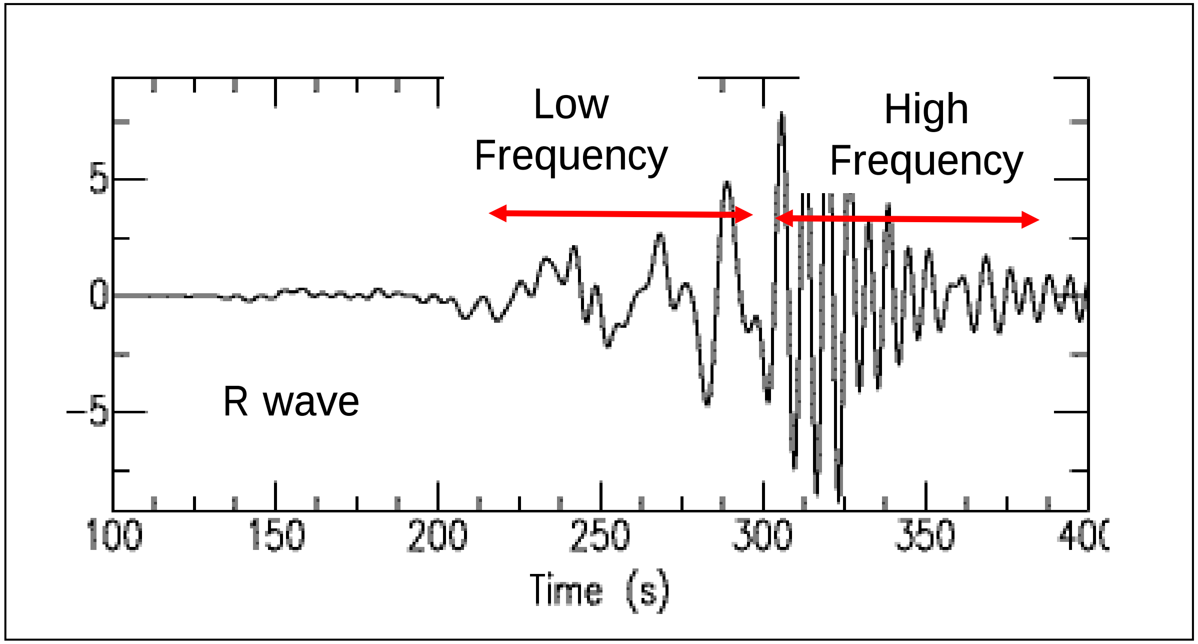
Location of epicenter



- Since S and P waves travel at different speeds the time between arrival of each is a measure of distance from the epicenter.
- The direction is unknown, so by using a triangulation from three different recording stations it is possible to locate the epicenter.

Dispersion

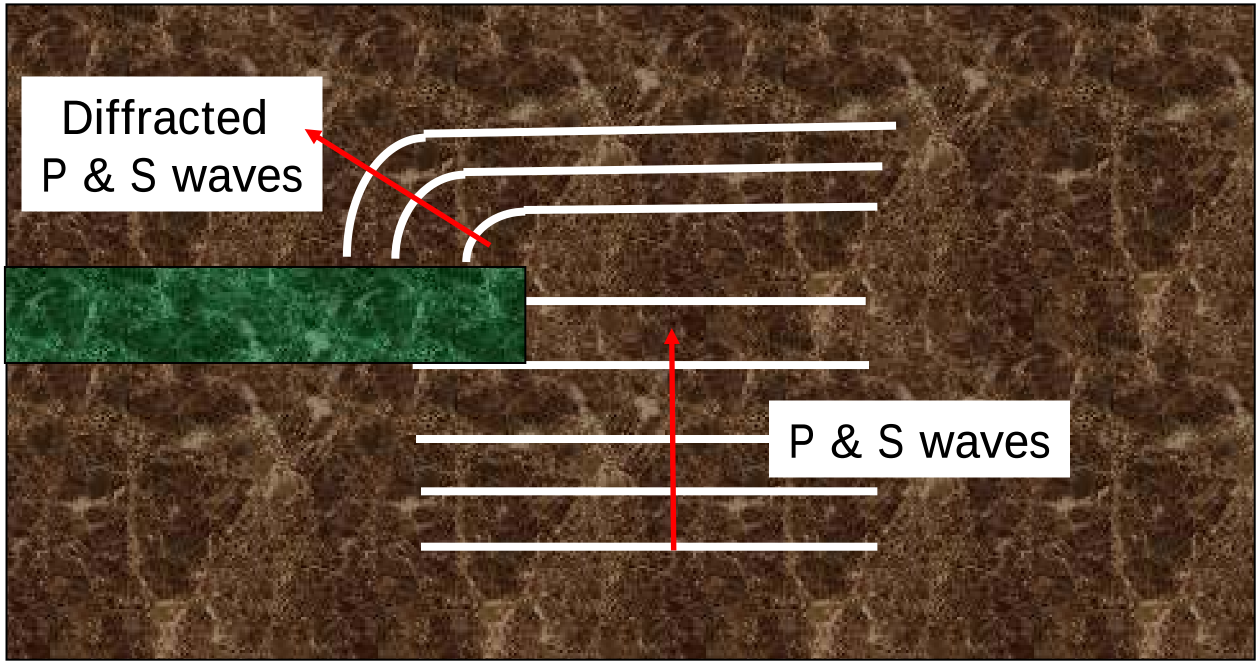
- Different frequency components of L and R waves travel at different speeds.
- High frequency arrive last - low frequency arrive first with increased distance from epicenter.



Attenuation

- Reduction in amplitude of seismic waves with increasing epicentral distance
- Caused by *Material Damping,* deformation of material produces energy dissipation
- Caused by *Radiation Damping*, i.e. energy gets spread out over a big area.

Diffraction



- Diffraction around a material with a much lower velocity (e.g. a void etc.)

Measuring earthquake characteristics

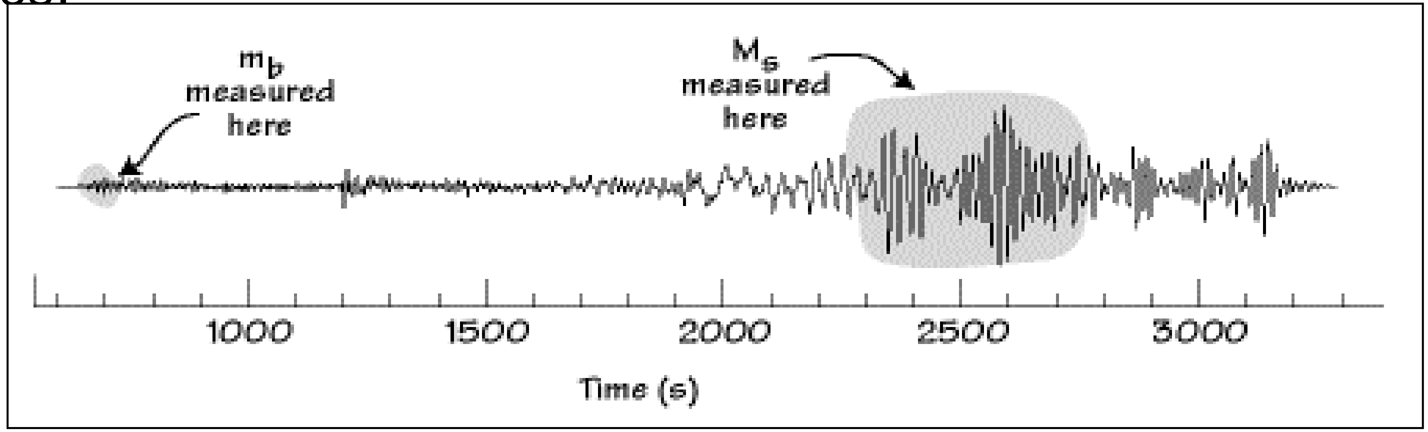
III. Magnitude measures

Richter's Magnitude

- As known as the local magnitude (M_L)
- Measured on a Wood-Anderson seismometer 100km from the epicenter.
- Wood-Anderson is a short period instrument that records 0 to 1s period accurately. Thus is records the shaking that will be structurally important range for buildings.
- M_L = Log (peak amplitude in micro-metres)
- Logarithmic scale means that each unit increase in Richter magnitude is a 10 fold increase in earthquake size. Thus 7.3ML earthquake is 100 times larger than a 5.3ML event.
- An event magnitude is usually recorded from as many seismometers as possible and an mean taken.
- Best known scale but is doesn't distinguish between different types of seismic waves.

Teleseismic Magnitudes

- Measured at great distance.
- Body wave magnitude (M_b), measure of size of P wave from first 5s on seismograph.
- Surface wave magnitude (M_S), measure of size of Rayleigh waves.

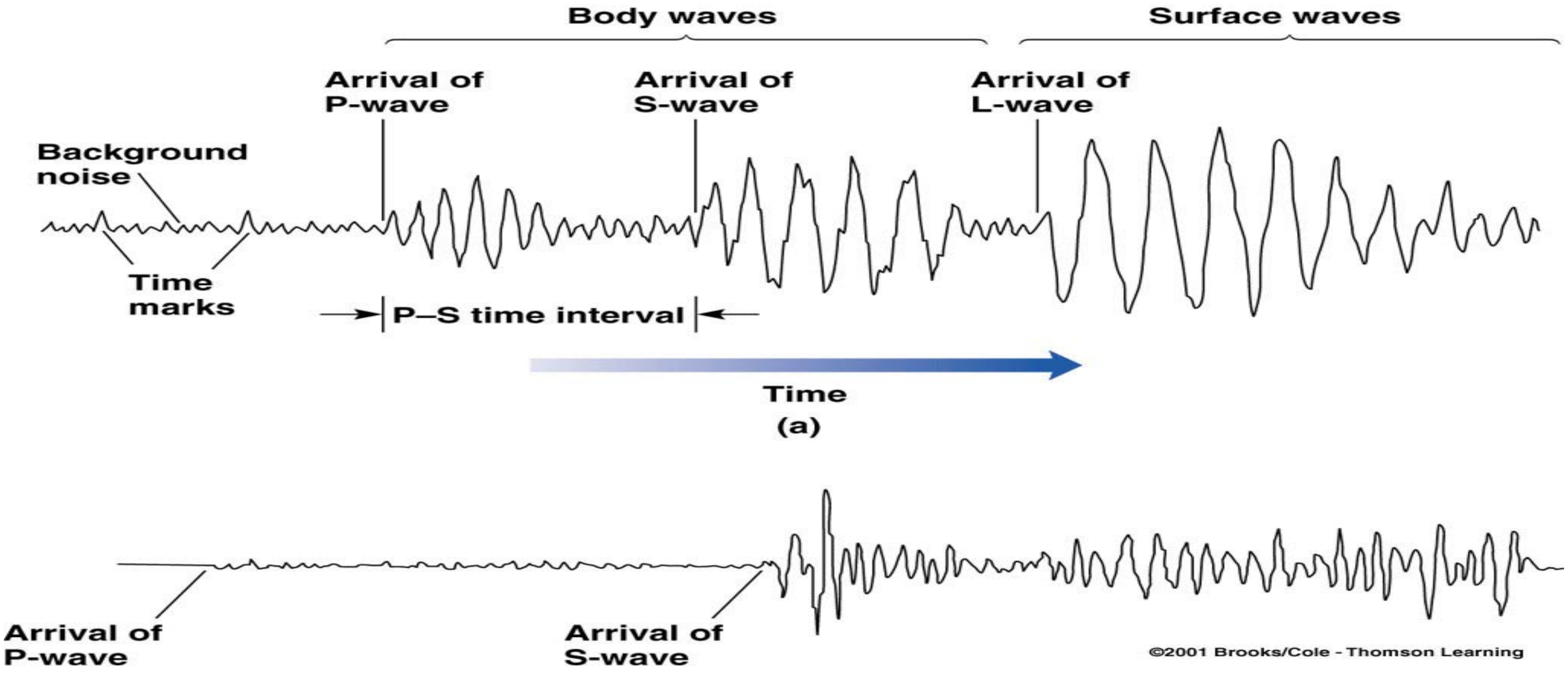


- Distance correction is difficult due to different regional geology
- Ms is biased towards shallow events as deep events tend not to produce surface waves
- Duration is longer for larger events. and hence Mb is effected

How is an Earthquake's Epicenter Located?

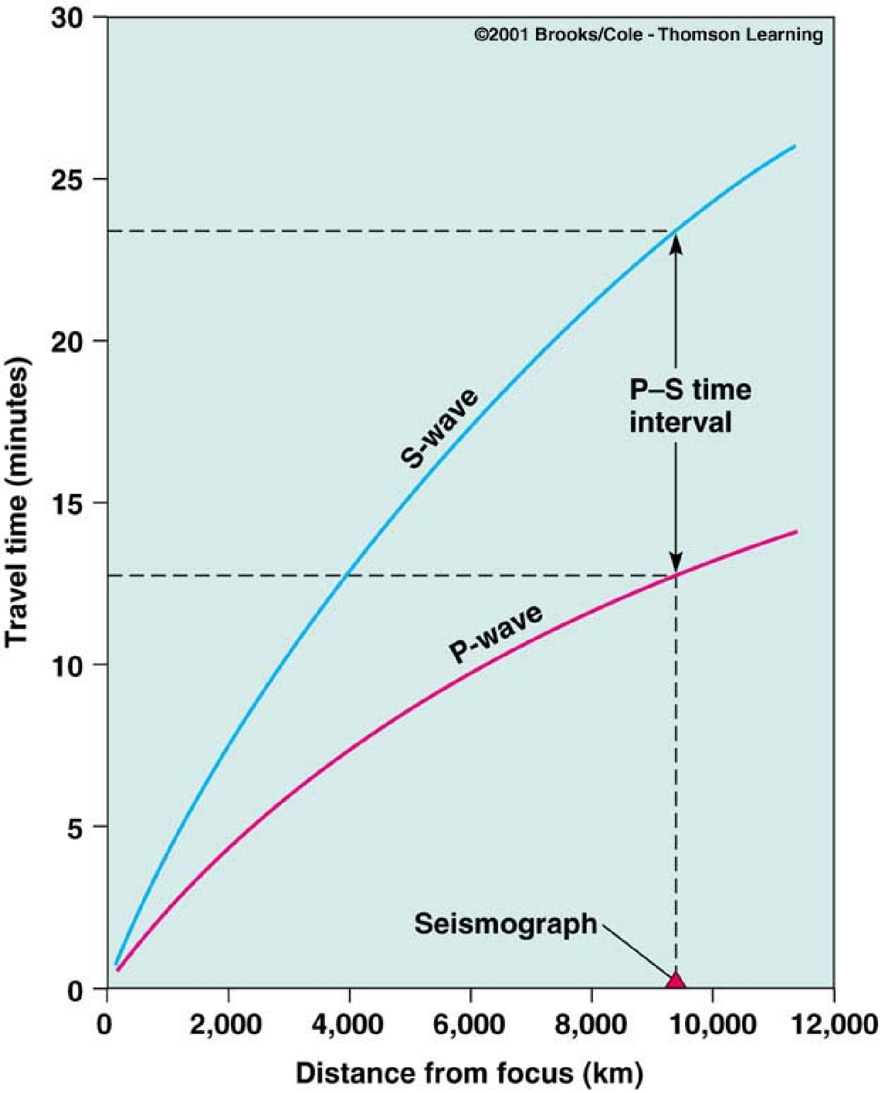
Seismic wave behavior

- P waves arrive first, then S waves, then L and R
- Average speeds for all these waves is known
- After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.



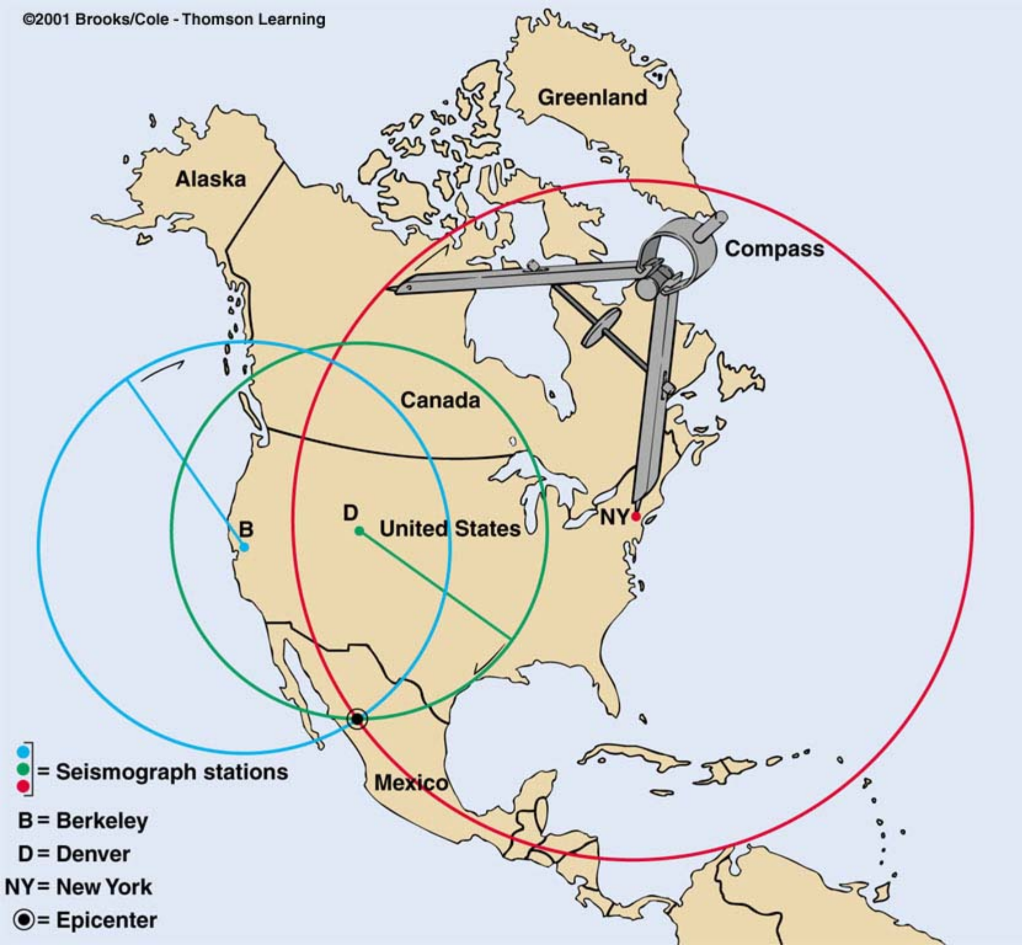
How is an Earthquake's Epicenter Located?

Time-distance graph showing the average travel times for P- and S-waves. The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S-waves



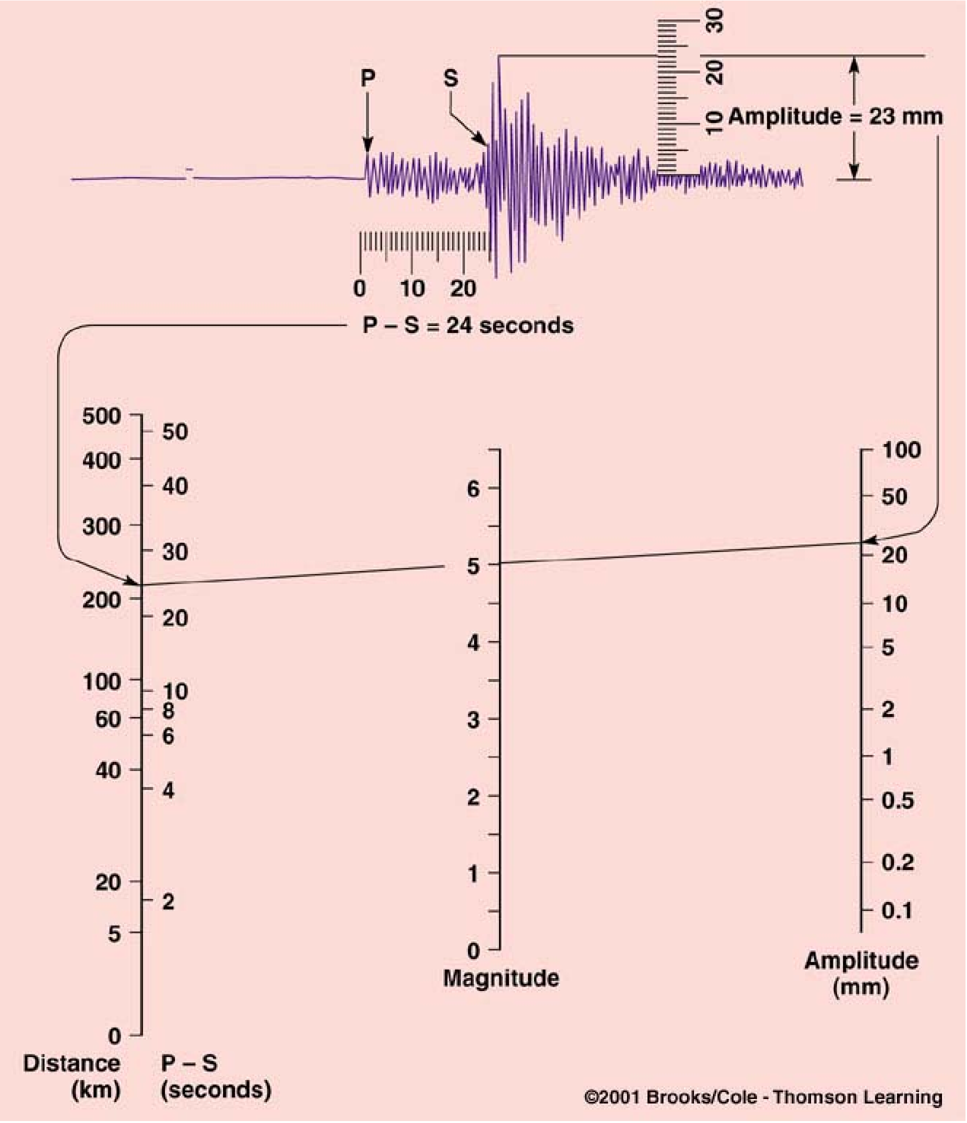
How is an Earthquake's Epicenter Located?

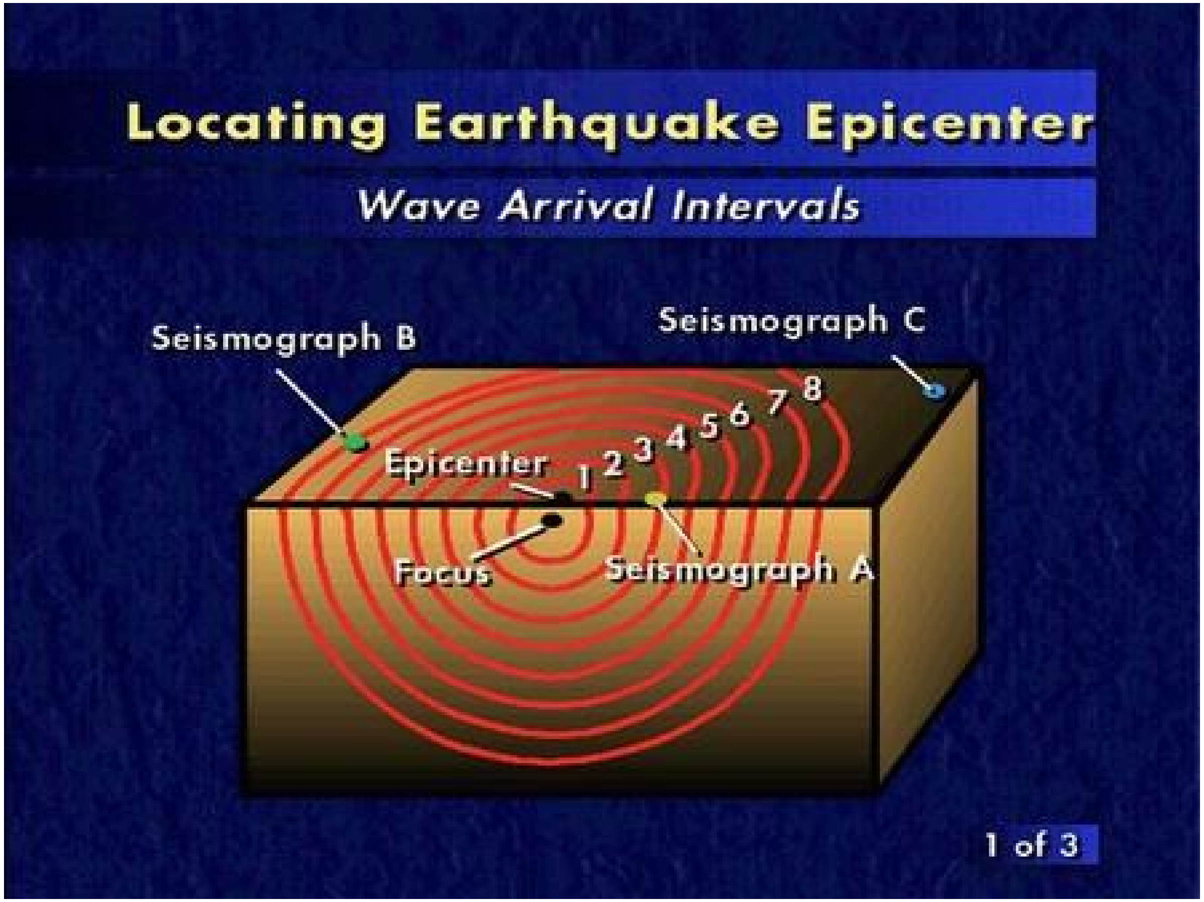
- **Three seismograph stations are needed to locate the epicenter of an earthquake**
- **A circle where the radius equals the distance to the epicenter is drawn**
- **The intersection of the circles locates the epicenter**

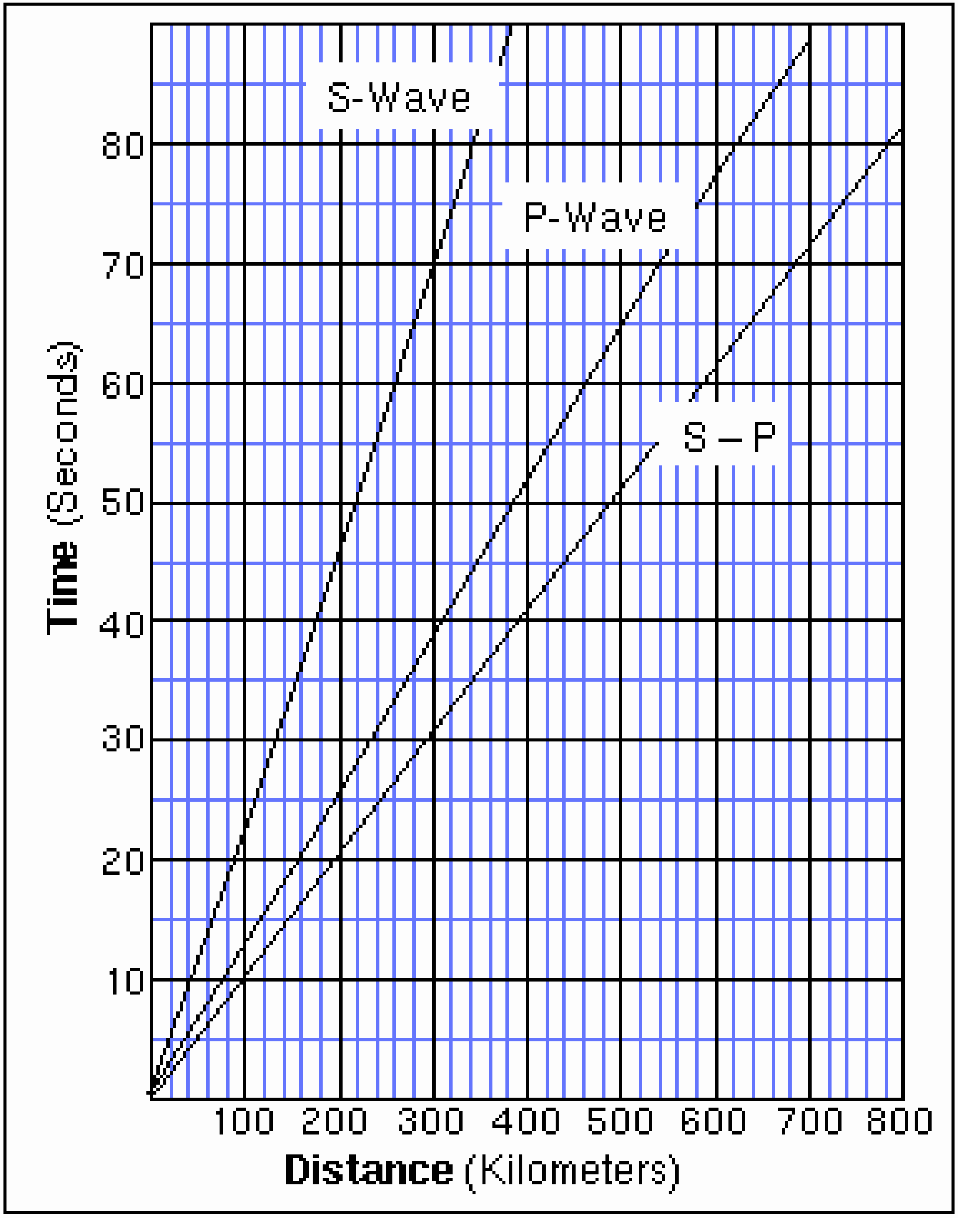


How are the Size and Strength of an Earthquake Measured?

- **Magnitude**
  - **Richter scale measures total amount of energy released by an earthquake; independent of intensity**
  - **Amplitude of the largest wave produced by an event is corrected for distance and assigned a value on an open-ended logarithmic scale**



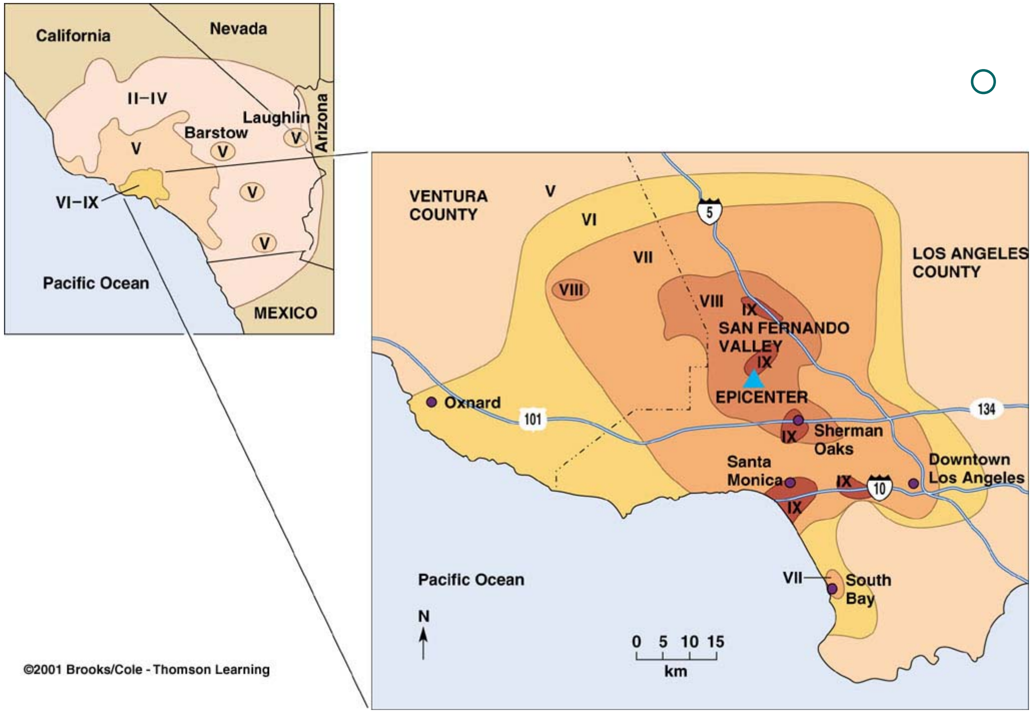

Locating Earthquake Epicenter
Wave Arrival Intervals
Seismograph B
Seismograph C
Epicenter
1 2 3 4 5 6 7 8
Focus
Seismograph A
1 of 3


S-Wave
P-Wave
S – P
80
70
60
50
40
30
20
10
Time (Seconds)
100
200
300
400
500
600
700
800
Distance (Kilometers)

Measuring earthquake characteristics

I. Shaking Intensity

How are the Size and Strength of an Earthquake Measured?



- Intensity
  - **subjective** measure of the kind of damage done and people's reactions to it
  - isoseismal lines identify areas of equal intensity

- Modified Mercalli Intensity Map
  - 1994 Northridge, CA earthquake, magnitude 6.7

Modified Mercalli Intensity (MMI) Scale

- Based on human observations of the effects of earthquake shaking on buildings and people.
- It is non-empirical a way of assessing how large the earthquake was.
- First developed in the USA, in 1933 and modified subsequently, useful for assessing historic events for descriptions of damage to buildings etc.
- 12 point scale ranging from (I) imperceptible shaking to (XII) total destruction.

Modified Mercalli Intensity (MMI) Scale

Intensity, PGAs and Effects

Modified Mercalli Intensity	Peak Ground Acceleration	Typical Effects
I		Not felt
II		Felt by few
III		Light shaking
IV	0.02g	Windows rattle
V	0.04g	Sleepers awakened
VI	0.07g	Small objects fall off shelves
VII	0.15g	Masonry damaged
VIII	0.30g	Chimneys fall
IX	0.50g	Substantial building damage
X	0.60g	Many structures heavily damaged
XI		Many structures destroyed
XII		Total damage

Modified Mercalli Intensity (MMI) Scale

1. Not felt except by a very few under especially favourable circumstances.
2. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
3. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.
4. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.
   [0.015g-0.02g]

Modified Mercalli Intensity (MMI) Scale

5. Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

   [0.03g-0.04g]
6. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.

   [0.06g-0.07g]
7. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.

   [0.10g-0.15g]

Modified Mercalli Intensity (MMI) Scale

8. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stack, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.

   [0.25-0.3g]

9. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

   [0.5-0.55g]

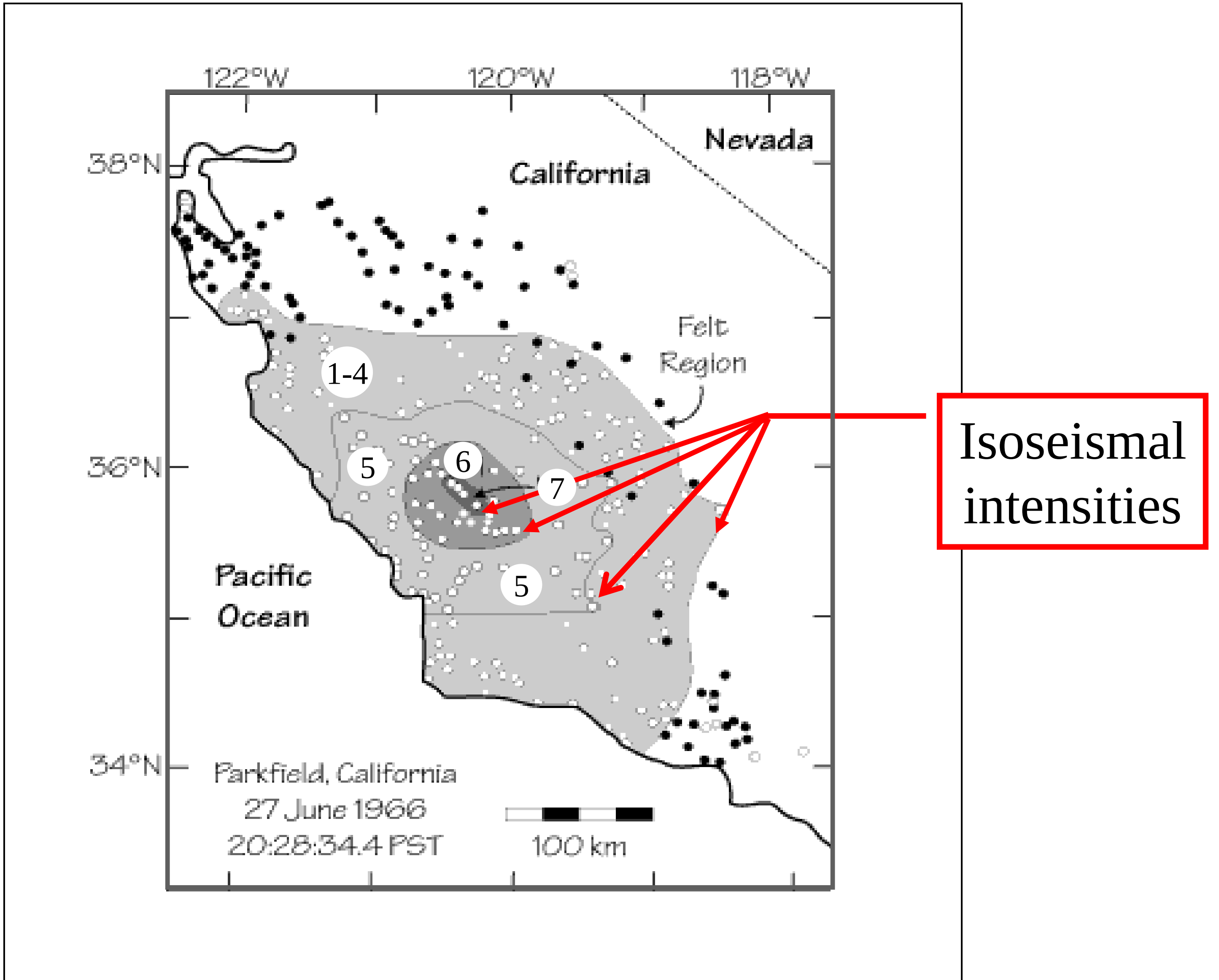
Modified Mercalli Intensity (MMI) Scale

10. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks

    [>0.60g]

11. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
12. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Intensity Patterns and Maps



Problems with MMI

- Deep earthquake events (>300km) are further away from surface than shallow (<70km) events. Thus deep events produces smaller shaking for the same size earthquake. Hence comparisons of deep and shallow events size using MMI is problematic.
- The response shaking of a building is effected by its natural frequencies. Hence MMI is looking at response of a building to the ground shaking not the ground shaking only.
- Intensity of shaking is effected by regional and near-surface geology (the soil or rock type etc.)
- Based on subjective assessment of observations. Different people have varying perceptions of shaking; i.e. psychologically some people are more sensitive to shaking than others.

Intensity

- is a classification of the strength of shaking at any place during an earthquake, in terms of its observed effects.
- not a physical parameter
- shorthand for longer descriptions
- written using integer values, Roman numerals

Macroseismic data

- are the data on behavior of people, objects, buildings and nature during the earthquake
- can range from “felt only by individuals at rest” to “total collapse of almost all buildings”

Intensity scales are

- series of descriptions of typical earthquake effects,
- each with an accompanying number,
- arranged so that increasing numbers reflect increasing severity.

Macroseismology

- is a part of seismology that deals with non-instrumental data about earthquakes
- collects and evaluates the evidence of earthquake effects on people, objects, buildings and nature
- has been long neglected but its importance was again recognised and today is taking an upward path, especially in Europe
- provides the possibility of calibrating the important historical earthquakes in comparison to the modern ones
- gives the essential base for the studies of seismic hazard and risk
- helps preventing the loss of life and property in future earthquakes

European Macroseismic Scale 1998 (EMS-98)

Arrangement of the scale

a) Effects on humans

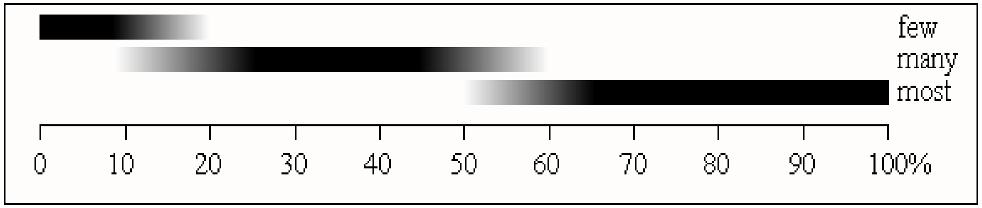
b) Effects on objects and on nature

c) Damage to buildings

Classification of damage

- Masonry buildings
- Buildings of reinforced concrete

Definition of quantity

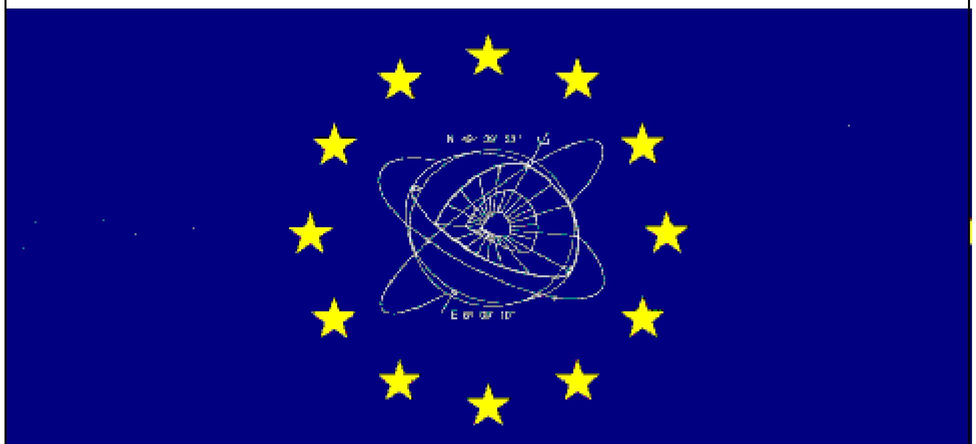


ACCORD PARTIEL OUVERT
en matière de prévention, de protection et
d'organisation des secours contre les risques naturels
et technologiques majeurs du

CONSEIL DE L'EUROPE

Cahiers du Centre Européen de Géodynamique et de Séismologie

Volume 15



European Macroseismic Scale 1998

Editor
G. GRÜNTHAL

Luxembourg 1998

EMS-98
IV. Largely observed

a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.

b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.

c) No damage.

EMS-98

VI. Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.

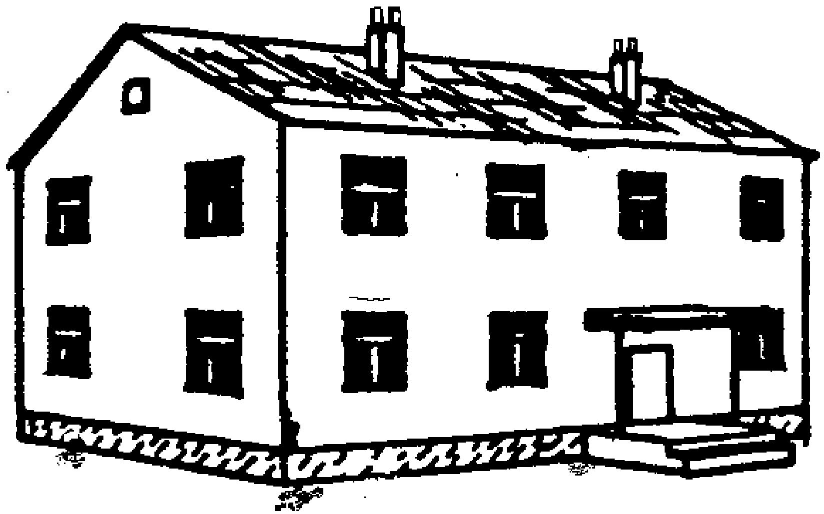
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.

c) Damage of **grade 1** is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of **grade 2**; a few of class C suffer damage of **grade 1**.

EMS-98

Classification of damage to masonry buildings

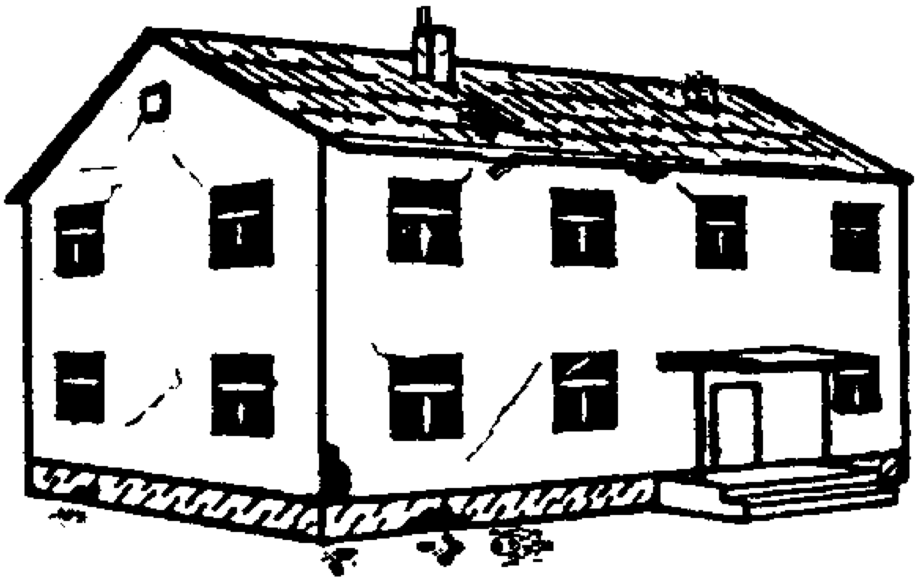
- **Grade 1**: Negligible to slight damage (no structural dama slight non-struct damage)
- Hair-line cracks very few walls.
- Fall of small piec plaster only.
- Fall of loose stor from upper parts of buildings in very few cases.



EMS-98
Classification of damage to masonry buildings

<u>Grade 2</u>: Moderate damage (slight structural damage, moderate non-structural damage)

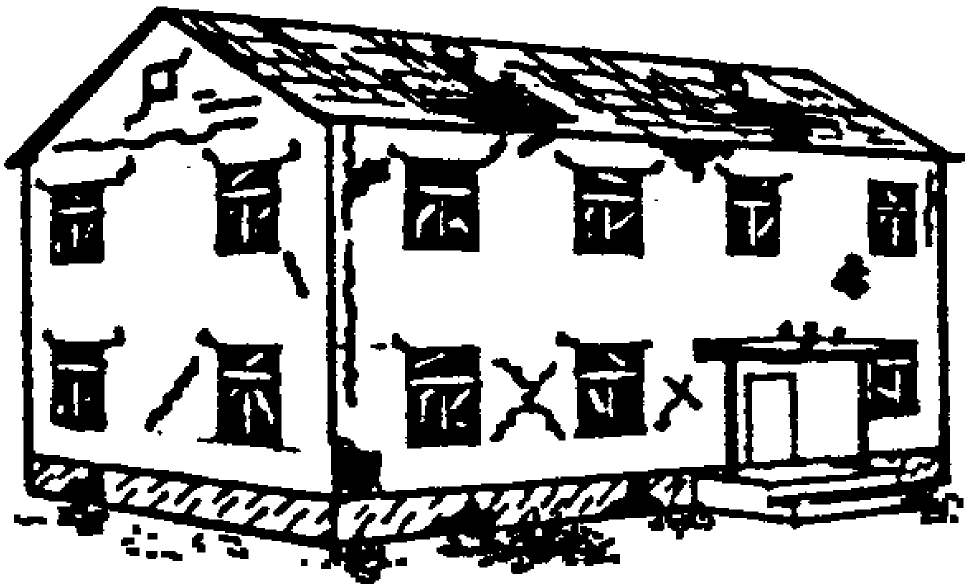
- Cracks in many walls.
- Fall of fairly large pieces of plaster.
- Partial collapse of chimneys.



EMS-98
Classification of damage to masonry buildings

<u>Grade 3</u>: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)

- Large and extensive cracks in most walls.
- Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).



EMS-98

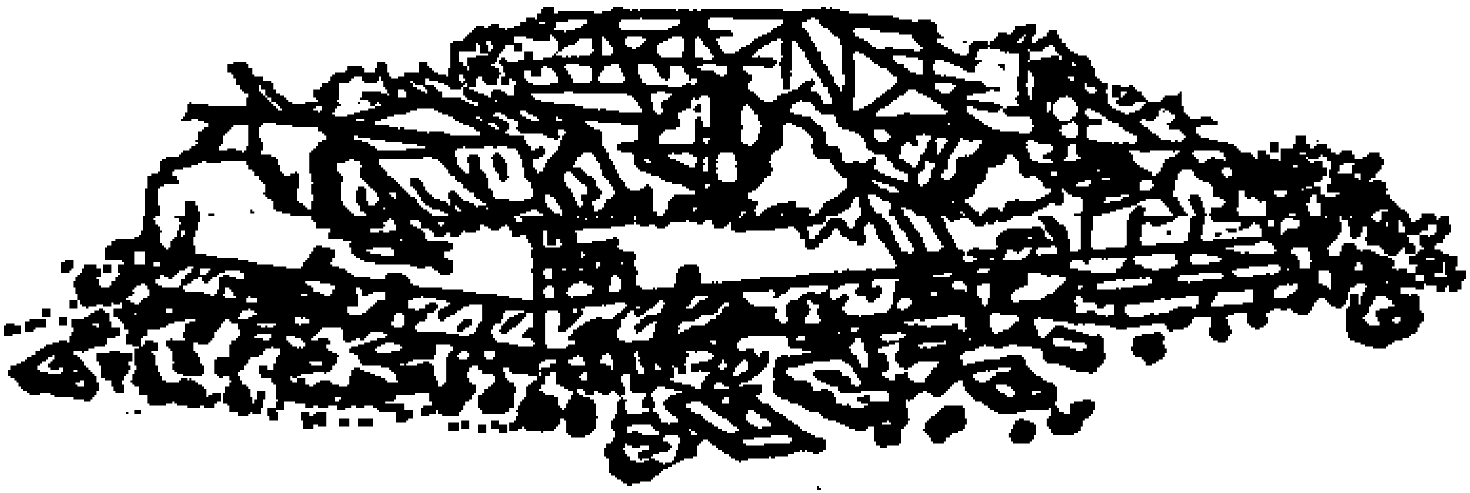
Classification of damage to masonry buildings

<u>Grade 4</u>: Very heavy damage (heavy structural damage, very heav non-structural damage)

- Serious failure of walls; partial structural failure of roofs and floors.

EMS-98

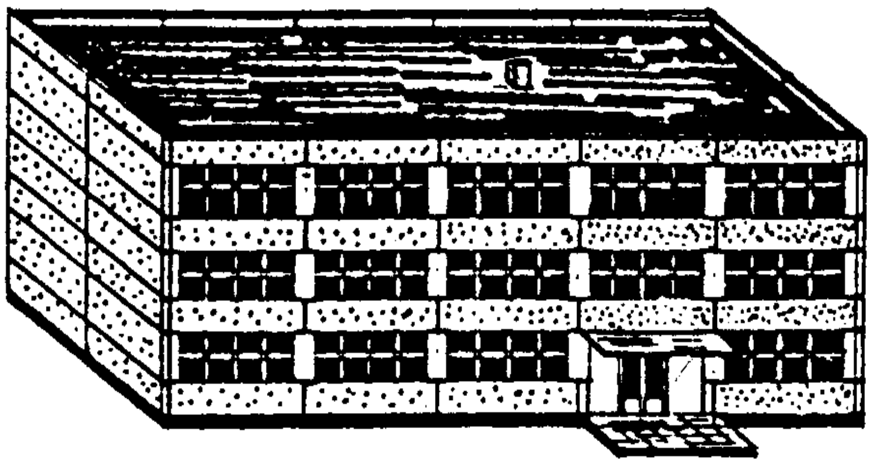
Classification of damage to masonry buildings



- **Grade 5:** Destruction (very heavy structural damage)
- Total or near total collapse.

EMS-98
Classification of damage to buildings of reinforced concrete

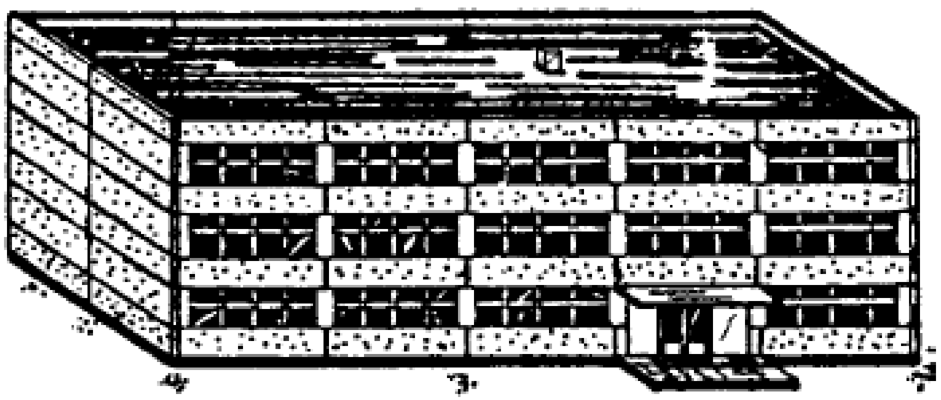
- **<u>Grade 1</u>**: Negligible to slight damage (no structural damage, slight non-structural damage)
- Hair-line cracks in plaster over frame members or in walls at the base,
- Fine cracks in partitions and infills.



EMS-98

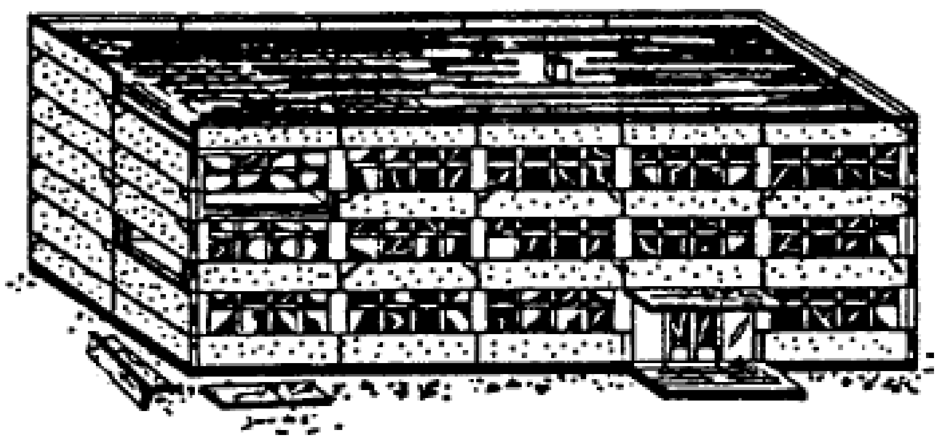
Classification of damage to buildings of reinforced concrete

- **<u>Grade 2</u>: Moderate damage (slight structural damage, moderate non-structural damage)**
- Cracks in columns and beams of frames and in structural walls.
- Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.



EMS-98
Classification of damage to buildings of reinforced concrete

- **<u>Grade 3</u>: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)**
- Cracks in columns and beam column joints of frames at the base and at joints of coupled walls.
- Spalling of concrete cover, buckling of reinforced rods.
- Large cracks in partition and infill walls, failure of individual infill panels

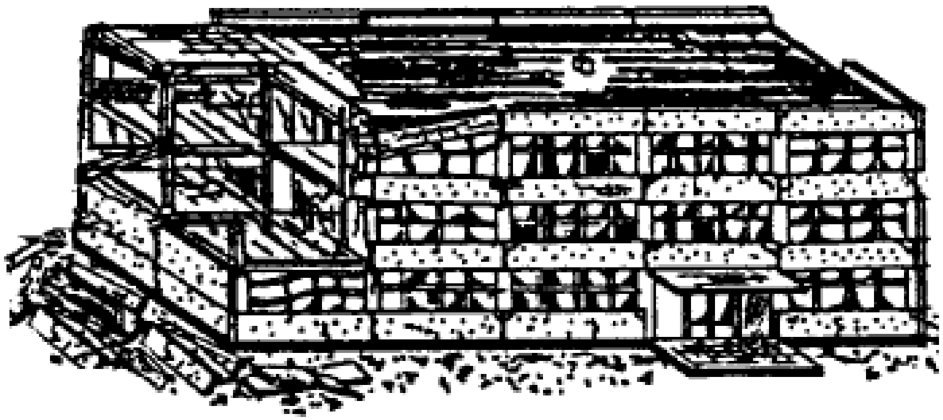


EMS-98

Classification of damage to buildings of reinforced concrete

<u>Grade 4</u>: Very heavy damage (heavy structural damage, very heavy non-structural damage)

- Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.



EMS-98
Classification of damage to buildings of reinforced concrete

- **Grade 5:** Destruction (very heavy structural damage)
- Collapse of ground floor or parts (e. g. wings) of buildings

EMS-98
Vulnerability table

- Differentiation of structures (buildings) into vulnerability classes

Type of Structure		Vulnerability Class A	B	C	D	E	F
MASONRY	rubble stone, fieldstone	O					
	adobe (earth brick)	O	—				
	simple stone	…	O				
	massive stone		—	O	…		
	unreinforced, with manufactured stone units	…	O	…			
	unreinforced, with RC floors		—	O	…		
	reinforced or confined			…	O	—	
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	…	—	O	…		
	frame with moderate level of ERD		…	—	O	—	
	frame with high level of ERD			…	—	O	—
	walls without ERD		…	O	—		
	walls with moderate level of ERD			…	O	—	
	walls with high level of ERD				…	O	—
STEEL	steel structures			…	—	O	—
WOOD	timber structures		…	—	O	—	

O most likely vulnerability class; — probable range;
…… range of less probable, exceptional cases

Type of structure:
field stone masonry
(in very weak mortar)

Grade of damage: 5

Type of structure:
unreinforced masonry

Grade of damage: 2

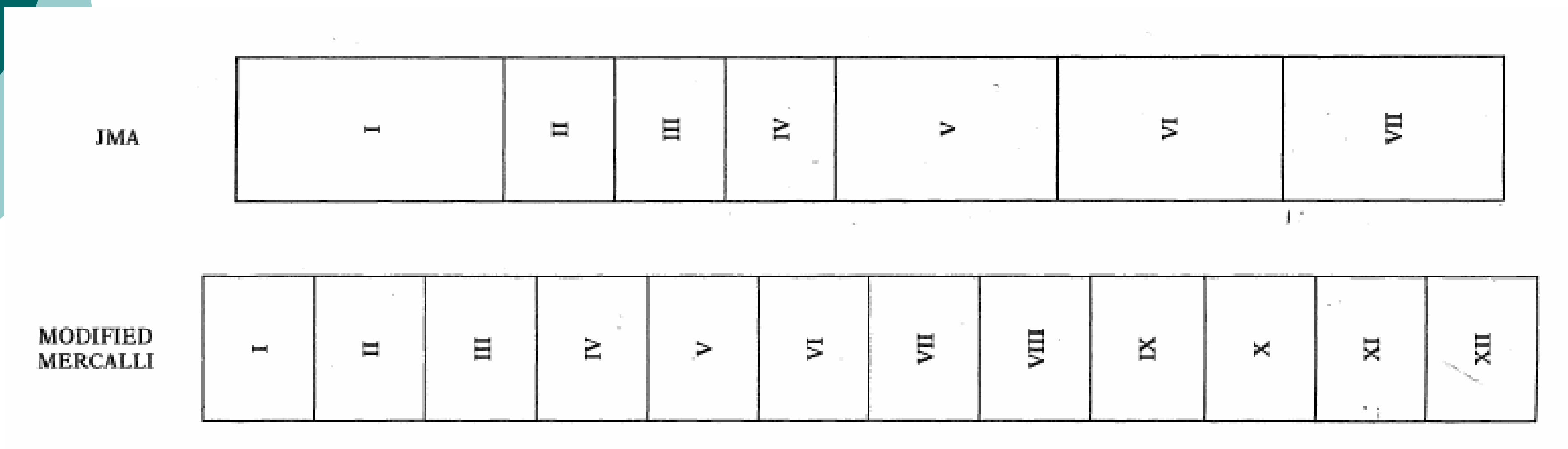
Japan Meteorological Agency

Intensity Scale

- **0 No sensation:** registered by seismographs but no perception by
- humans
- **I Slight:** felt by persons at rest or especially sensitive to EQs.
- **II Weak:** felt by most people, slight rattling of doors and Japanese latticed paper sliding doors (shoji).
- **III Rather Strong:** shaking of houses & buildings; heavy rattling of doors & shoji, swinging of chandeliers & other hanging objects; movement of liquids in vessels.
- **IV Strong:** strong shaking of houses & buildings; overturning ofunstable objects; spilling of liquids out of vessels 4/5 full.
- **V Very Strong:** cracking of plaster walls; overturning of tombstones & stone lanterns; damage to masonry chimneys & mudplastered warehouses.
- **VI Disastrous:** demolition of upto 30% of Japanese wooden houses; numerous landslides & embankment failures; fissures on flat ground
- **VII Ruinous:** demolition of more than 30% of Japanese wooden houses.

Japan Meteorological Agency

Intensity Scale



Medvedev-Sponheuer-Karnik Intensity Scale (MSK)

Necessary Descriptions encountered in MSK Scale:

- A type structures: village houses + adobe structures + rubble-stone structures
- B type structures: brick structures + cut-stone structures + light prefabricated strs.
- C type structures: R-C or Steel structures + wooden structures

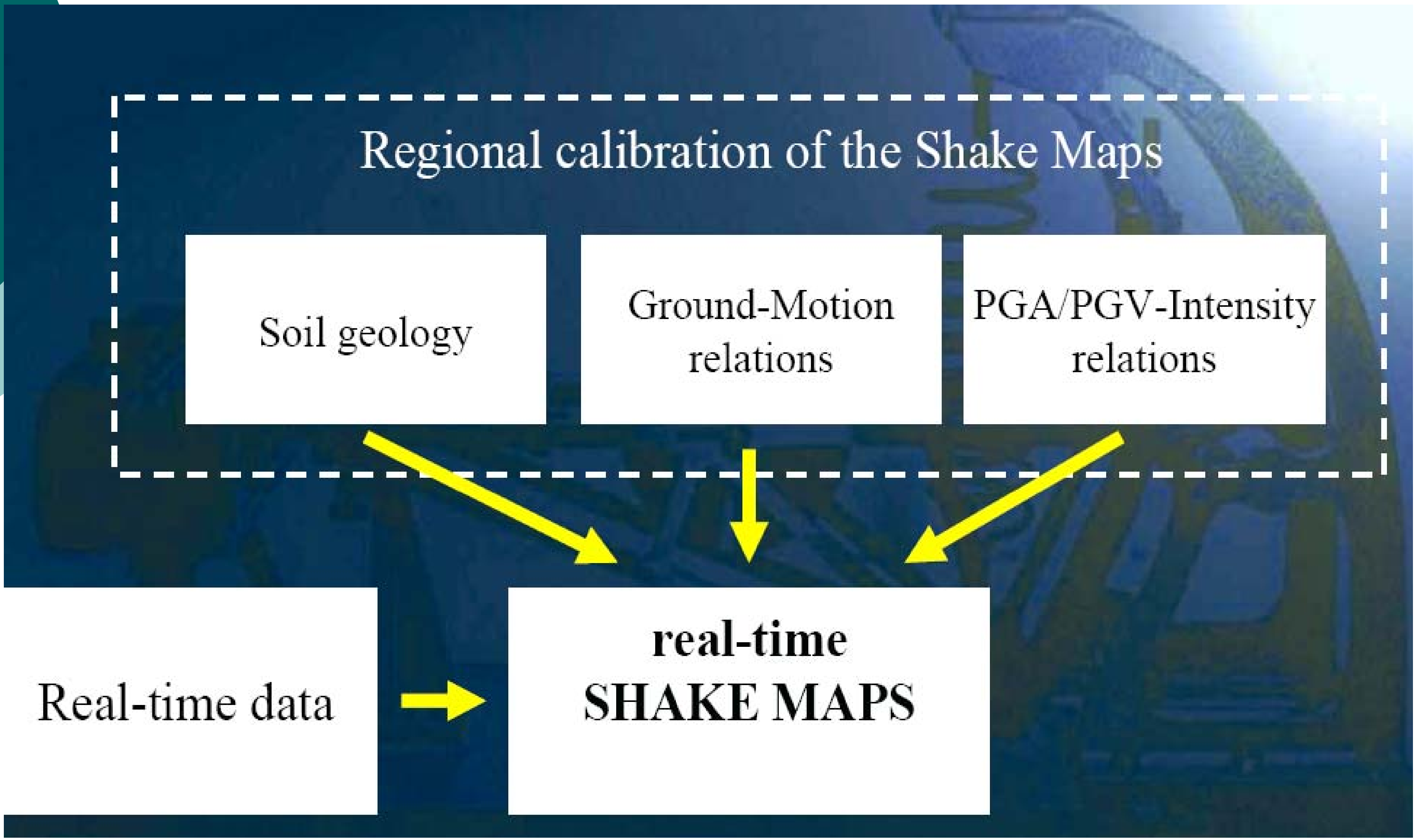
- Slight Damage (**SD**): spalling off plasters, fine cracks in mortar
- Moderate Damage (**MD**): sliding of tiles, fine cracks in walls, spalling off chimney parts
- Heavy Damage (**HD**): severe damage in walls, collapse of chimneys
- Partial Collapse (**PC**): splitting of walls, partial collapse in buildings
- Total Collapse (**TC**): Total collapse of structures

Medvedev-Sponheuer-Karnik Intensity Scale (MSK)

I	g (gals)	V_{ground} (cm/s)	Structural Type		
			A	B	C
V	12-25	1.0-2.0	5% SD	N/A	N/A
VI	25-50	2.1-4.0	5% MD 50% SD	5% SD	N/A
VII	50-100	4.1-8.0	5% PC 50% HD	5% MD	5% SD
VIII	100-200	8.1-16.0	5% TC 50% PC	5% PC 50% HD	5% HD 50% MD
IX	200-400	16.1-32.0	50% TC	5% TC 50% PC	5% PC 50% HD
X	400-800	32.1-64.0	75% TC	50% TC	5% TC 50% PC

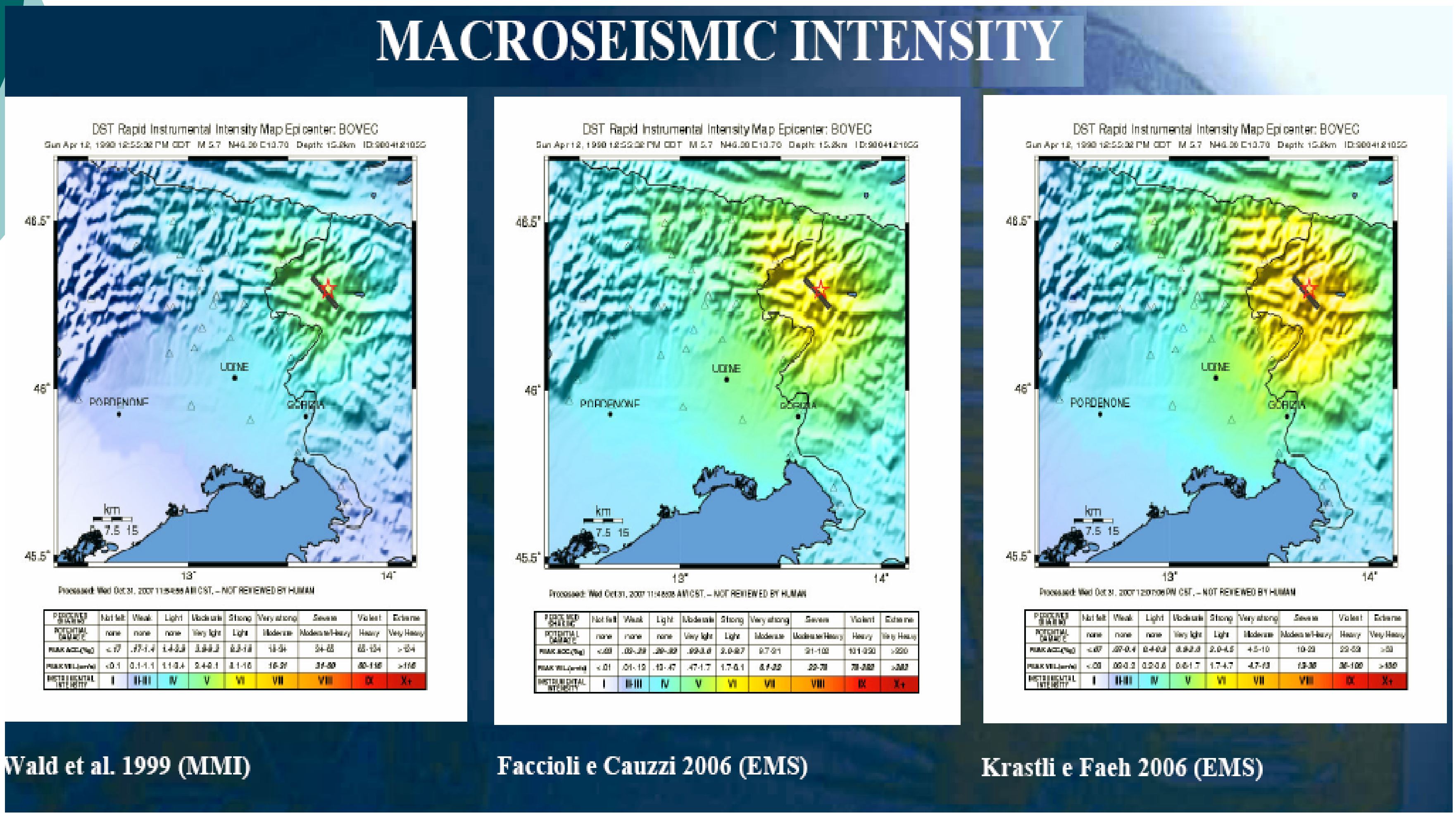
Shake Maps

Shake Maps



Regional calibration of the Shake Maps
Soil geology
Ground-Motion relations
PGA/PGV-Intensity relations
Real-time data
real-time SHAKE MAPS

Shake Maps


MACROSEISMIC INTENSITY
DST Rapid Instrumental Intensity Map Epicenter: BOVEC
UDINE
PORDENONE
GORIZIA
km
DST Rapid Instrumental Intensity Map Epicenter: BOVEC
UDINE
PORDENONE
GORIZIA
km
DST Rapid Instrumental Intensity Map Epicenter: BOVEC
UDINE
PORDENONE
GORIZIA
km
Wald et al. 1999 (MMI)
Faccioli e Cauzzi 2006 (EMS)
Krastli e Faeh 2006 (EMS)

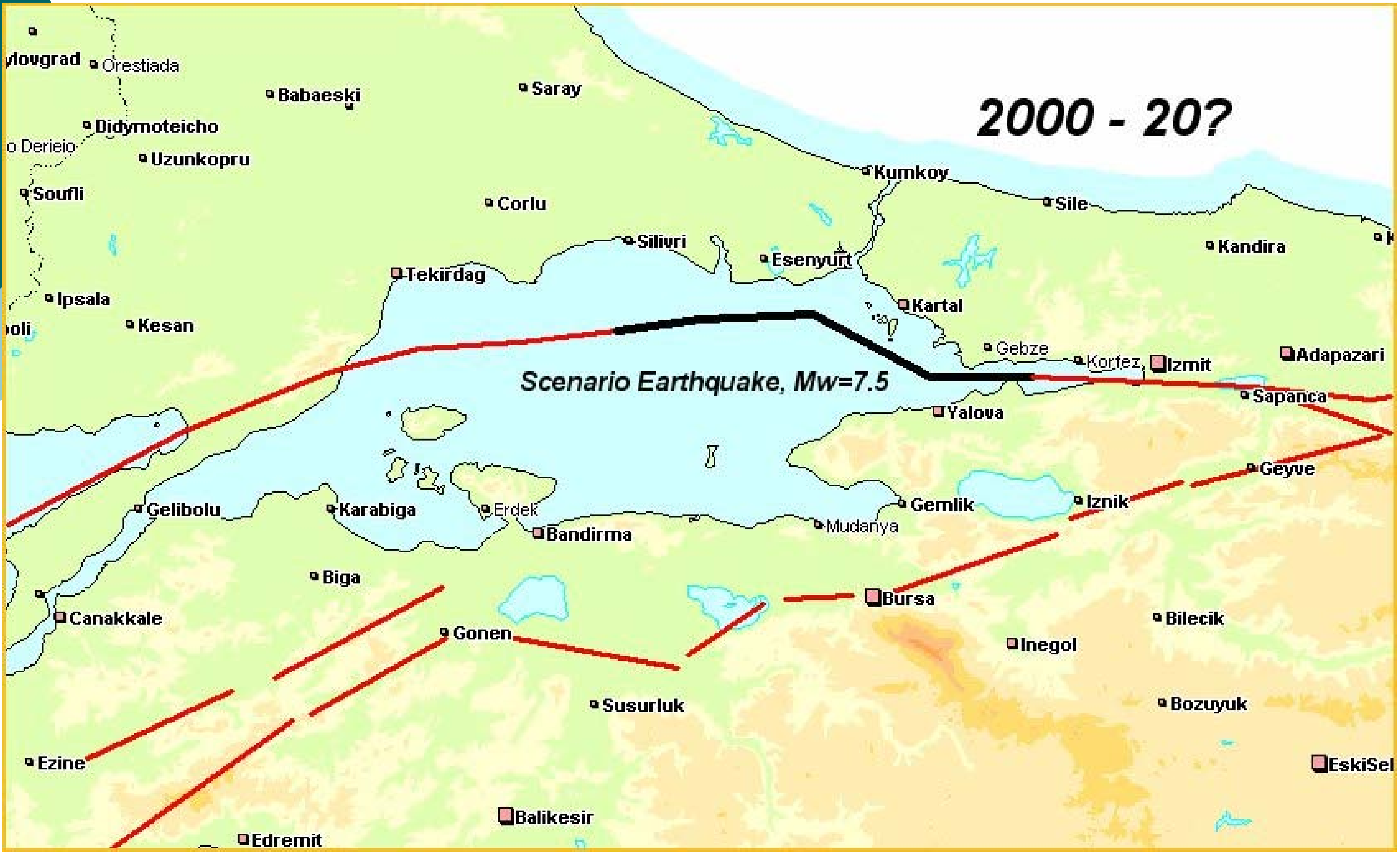
Istanbul Early Warning and Rapid Response System

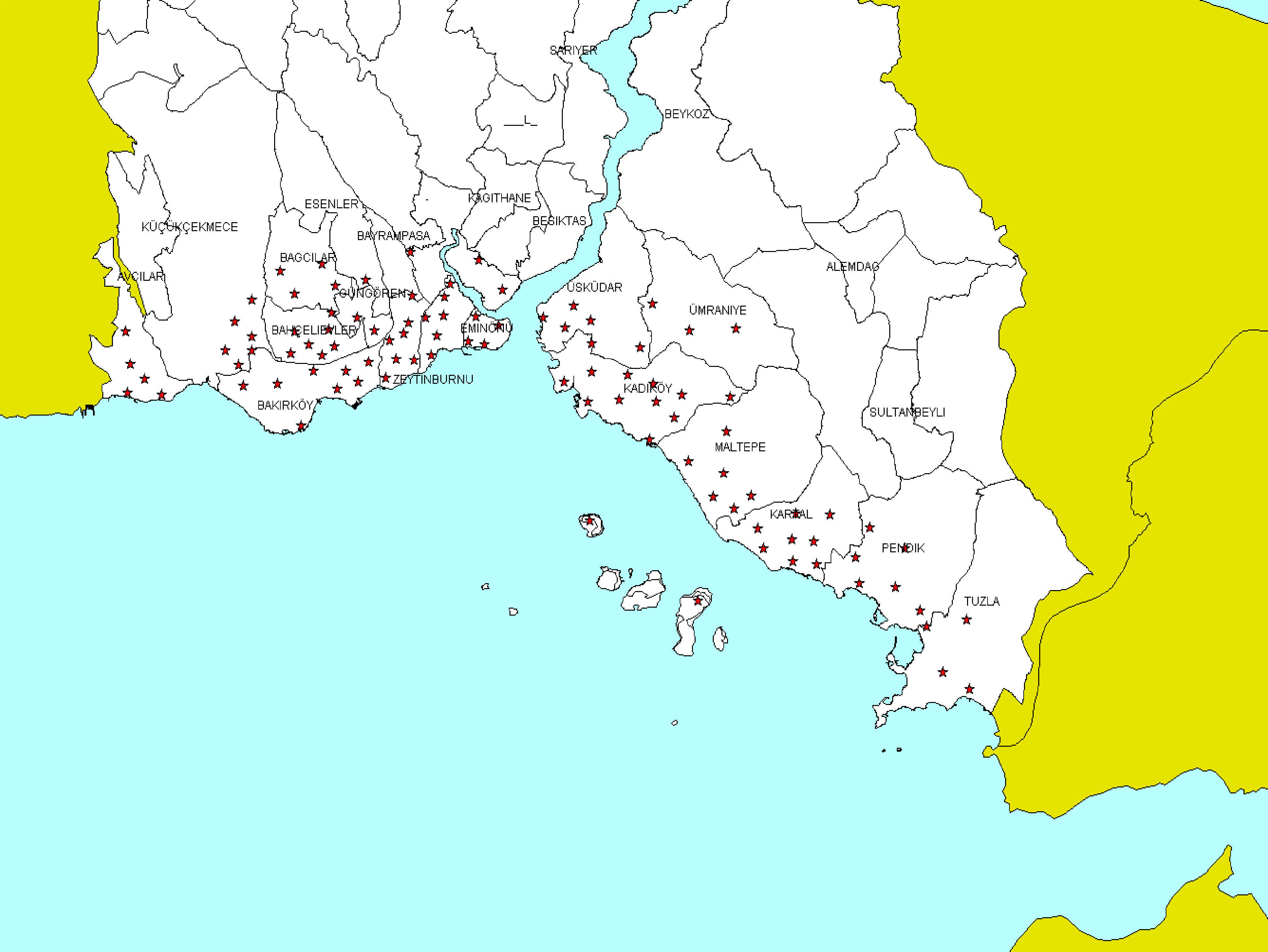
Istanbul Early Warning and Rapid Response System

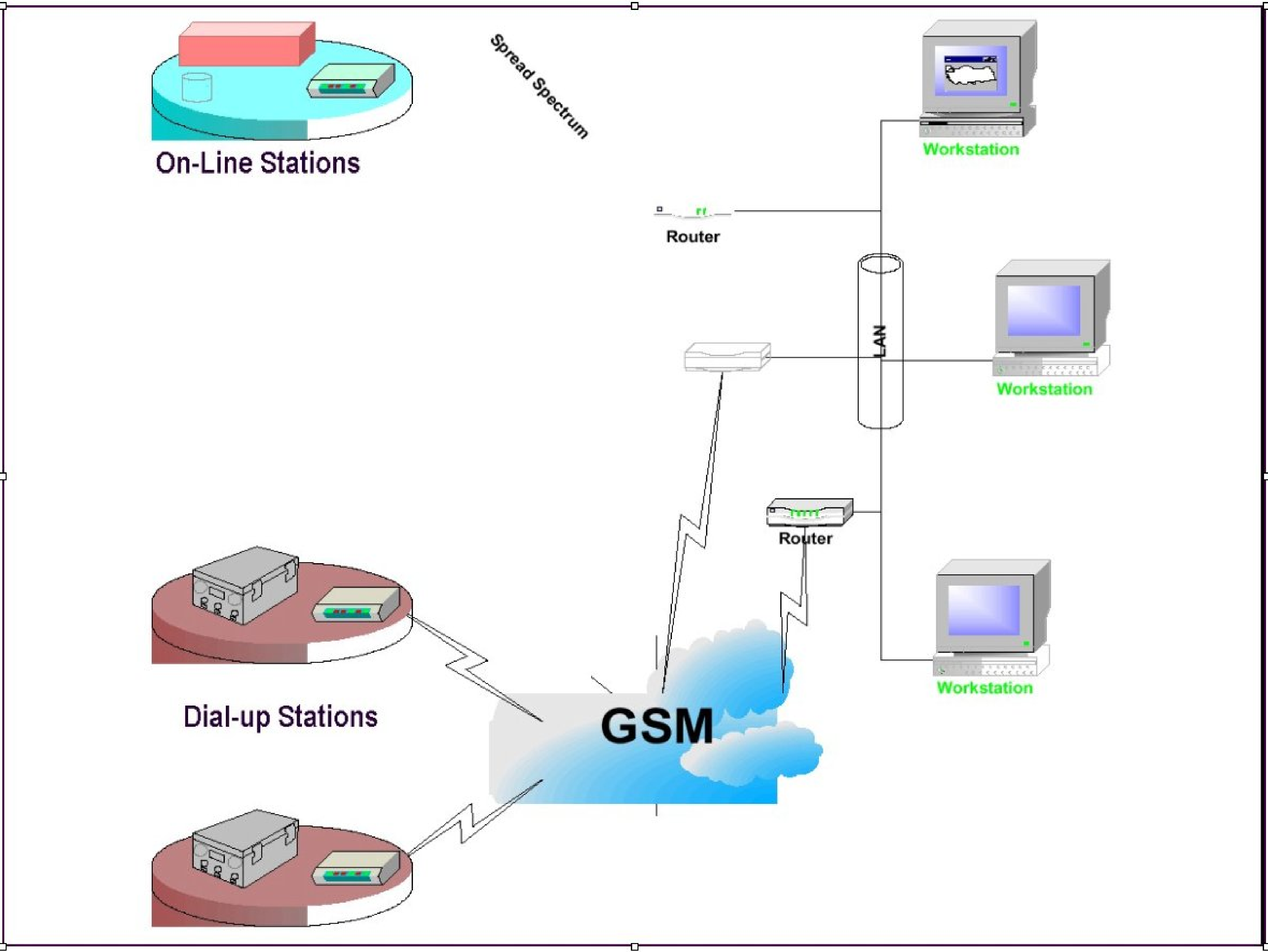
One hundred (100) of the strong motion recorders are stationed in dense settlements in the Metropolitan area of Istanbul in dial-up mode for Rapid Response information generation.

Ten (10) of the strong motion stations are sited in the Marmara region at locations as close as possible to the Great Marmara Fault in on-line data transmission mode to enable Earthquake Early Warning.

40 strong motion recorder units will be placed on critical engineering structures in addition to the already instrumented structures in Istanbul (Bosphorus and Fatih Sultan Mehmet Suspension Bridges, Hagia Sophia and Suleymaniye)


2000 - 20?
Scenario Earthquake, Mw=7.5
ylovgrad
Orestiada
Babaeski
Saray
Didymoteicho
o Derieio
Uzunkopru
Soufli
Corlu
Kumkoy
Sile
Silivri
Esenyurt
Kandira
Tekirdag
Kartal
Ipsala
Kesan
Gebze
Korfez
Izmit
Adapazari
Sapanca
Yalova
Geyve
Gelibolu
Karabiga
Erdek
Gemlik
Iznik
Bandirma
Mudanya
Biga
Bursa
Canakkale
Gonen
Bilecik
Inegol
Susurluk
Bozuyuk
Ezine
EskiSel
Balikesir
Edremit

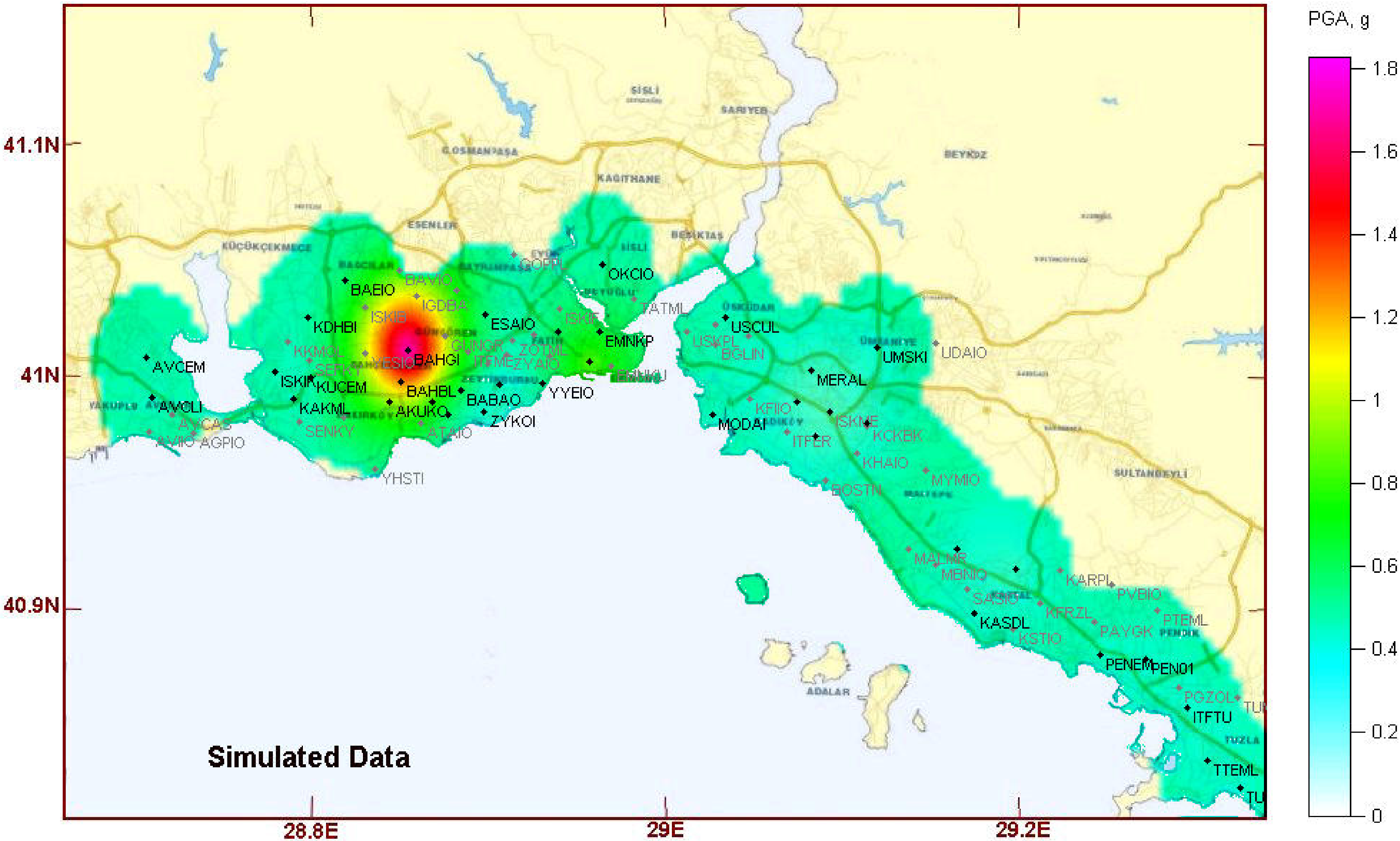

SARIYER
BEYKOZ
ESENLER
KAGITHANE
BESIKTAS
KÜÇÜKÇEKMECE
BAYRAMPASA
BAGCILAR
AVCILAR
GÜNGÖREN
ÜSKÜDAR
ALEMDAG
ÜMRANIYE
BAHÇELIEVLER
EMINÖNÜ
ZEYTINBURNU
KADIKÖY
BAKIRKÖY
SULTANBEYLI
MALTEPE
KARTAL
PENDIK
TUZLA



On-Line Stations
Spread Spectrum
Workstation
Router
LAN
Workstation
Router
Workstation
Dial-up Stations
GSM

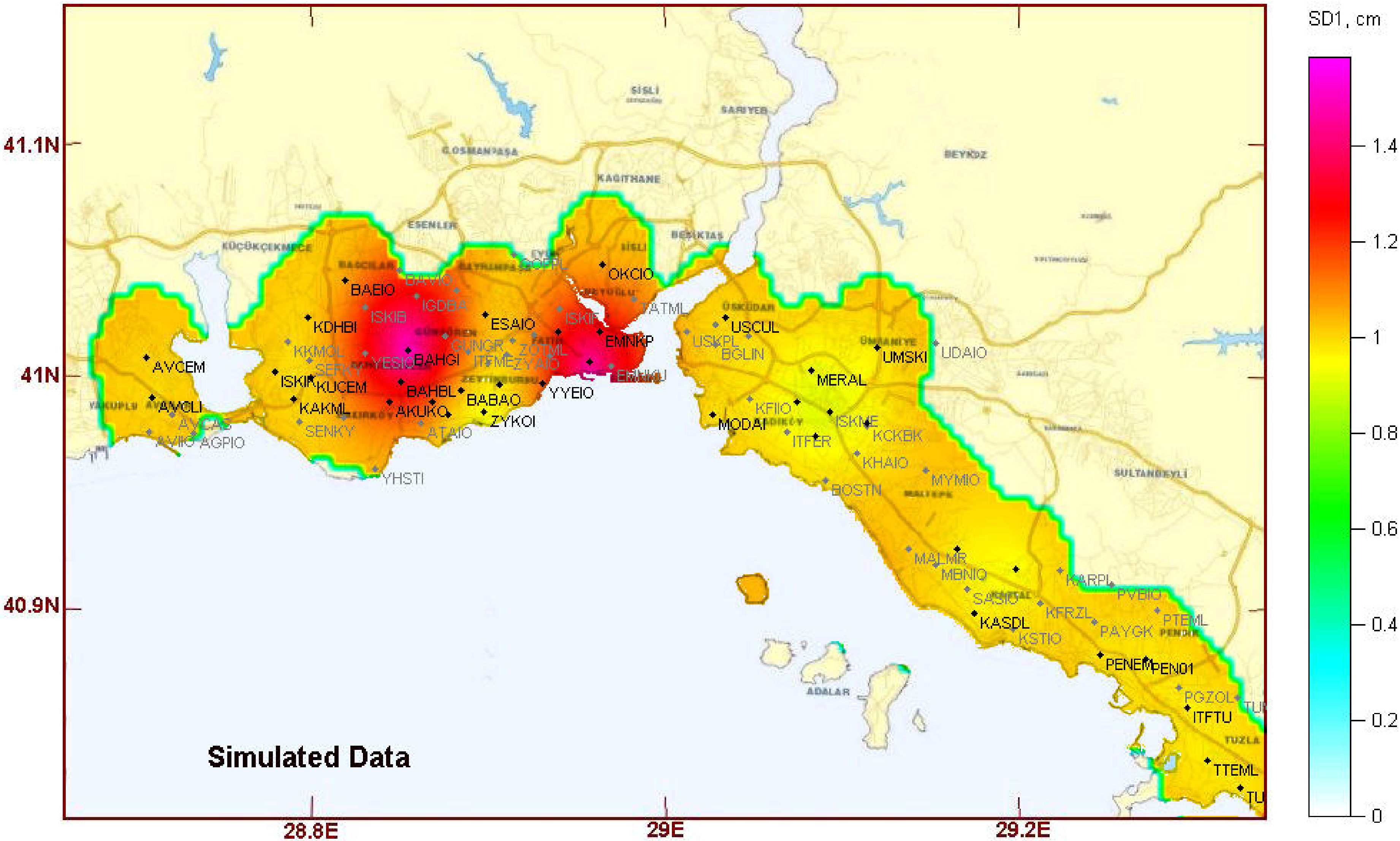
recorder

PGA, g



PGA, g
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41.1N
41N
40.9N
28.8E
29E
29.2E
Simulated Data
BAEIO
KDHBI
ESAIO
OKCIO
EMNKP
BAHGI
AVCEM
AVCLI
ISKIK
KUCEM
KAKML
BAHBL
AKUKO
BABAO
ZYKOI
YYEIO
USCUL
UMSKI
UDAIO
MERAL
MODAI
KASDL
PENEM
PEN01
ITFTU
TTEML
YHSTI
AGPIO

SD at 0.2Hz, cm



SD1, cm
1.4
1.2
1
0.8
0.6
0.4
0.2
0
41.1N
41N
40.9N
28.8E
29E
29.2E
Simulated Data
BAEIO
KDHBI
ESAIO
OKCIO
EMNKP
AVCEM
AVCLI
KUCEM
BAHGI
BAHBL
BABAO
AKUKO
KAKML
ZYKOI
YYEIO
USCUL
UMSKI
MERAL
MODAI
KASDL
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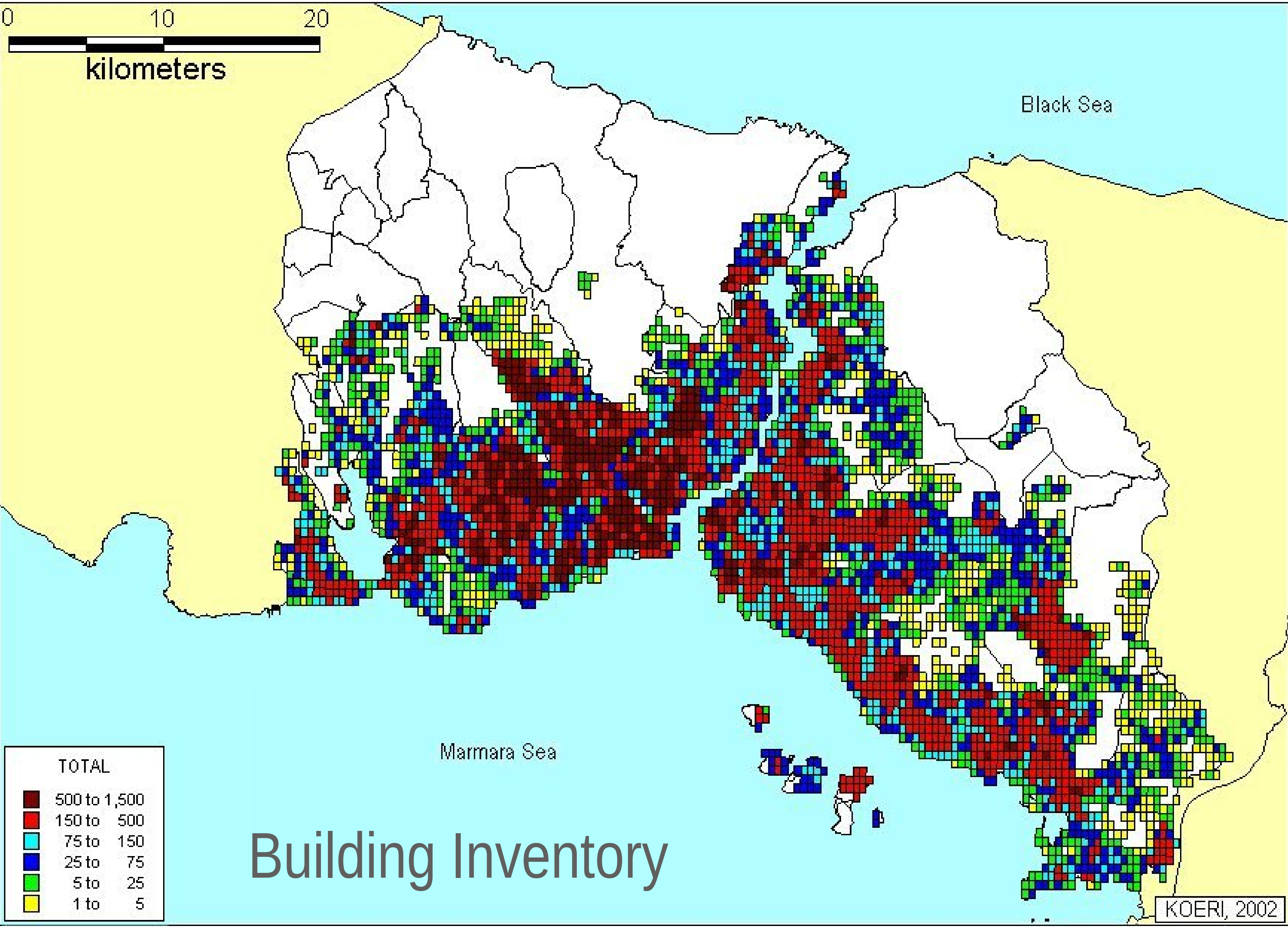
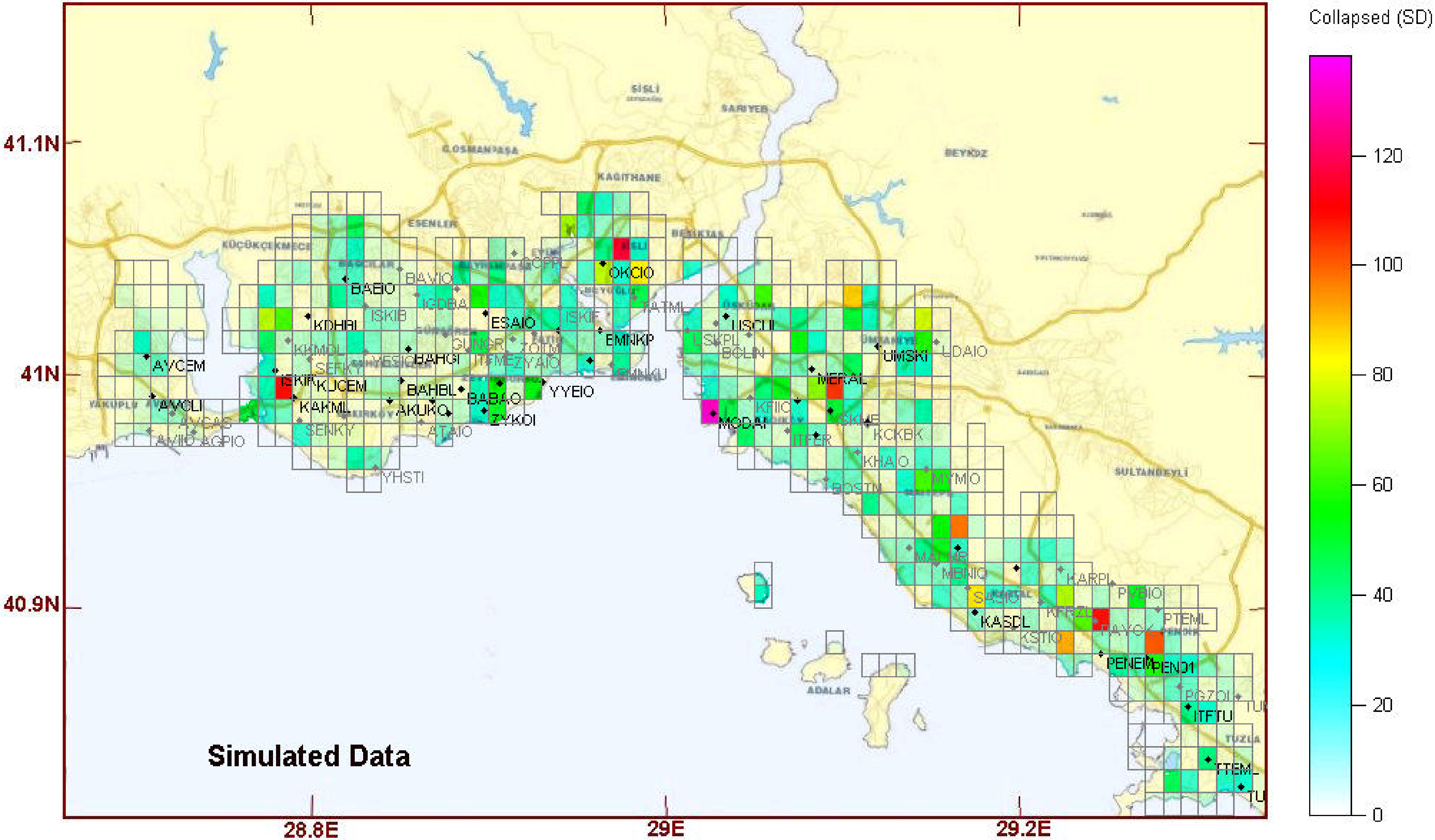
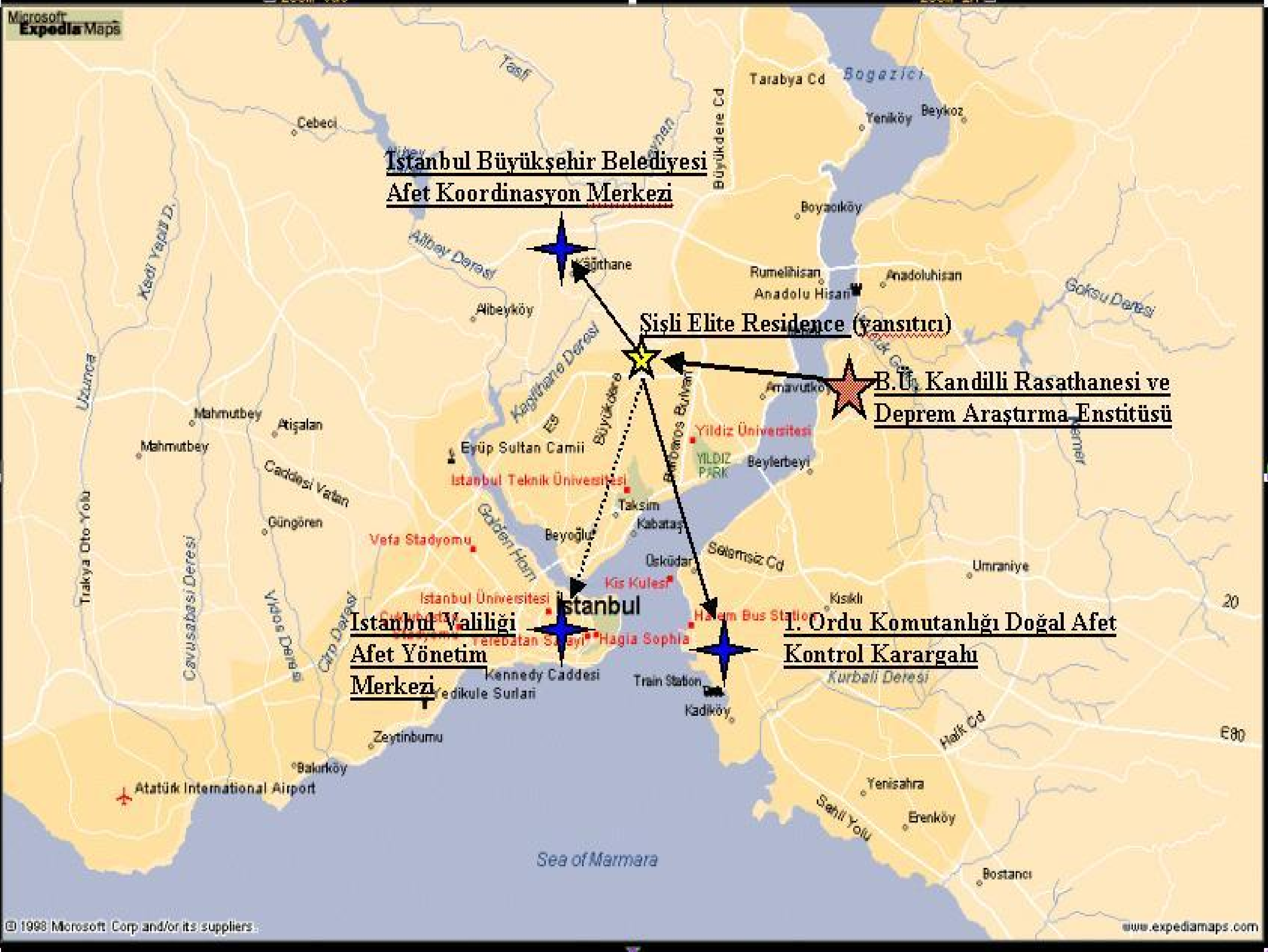
PEN01
ITFTU
TTEML
ISKIB
IGDBA
YESIO
SENKY
ATAIO
YHSTI
AGPIO
ATMLI
USKPL
BGLIN
UDAIO
KFIIO
ITFER
ISKNE
KCKBK
KHAIO
MYMIO
BOSTN
MALMR
MBNIO
SASIO
KSTIO
KFRZL
KARPL
PVBIO
PTEML
PAYGK
PGZOL



Building Inventory

Number of Collapsed Buildings per Cell





İstanbul Büyükşehir Belediyesi
Afet Koordinasyon Merkezi
Şişli Elite Residence (yansıtıcı)
B.Ü. Kandilli Rasathanesi ve
Deprem Araştırma Enstitüsü
İstanbul Valiliği
Afet Yönetim
Merkezi
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