Tectonic geomorphology

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Outline:

1. Definition of active tectonics, tectonic processes and their types related to different tectonic regimes

2. Landforms characteristic for different types of tectonic movements (horizontal or vertical)

3. Tectonic geomorphology, tectonic control on landscape evolution

4. Response of tectonic processes in fluvial systems, asymmetry of river basins, related increased erosion and accumulation, river pattern analysis

5. Analyses of fluvial landforms affected by tectonic movements – river terraces, alluvial fans, analysis of longitudinal river profile and valley cross sections

6. Mountains uplift and its control on changes in relief, velocity of geomorphological processes, analysis of mountain fronts

7. Fault scarps, their evolution, erosion, possibilities of their dating

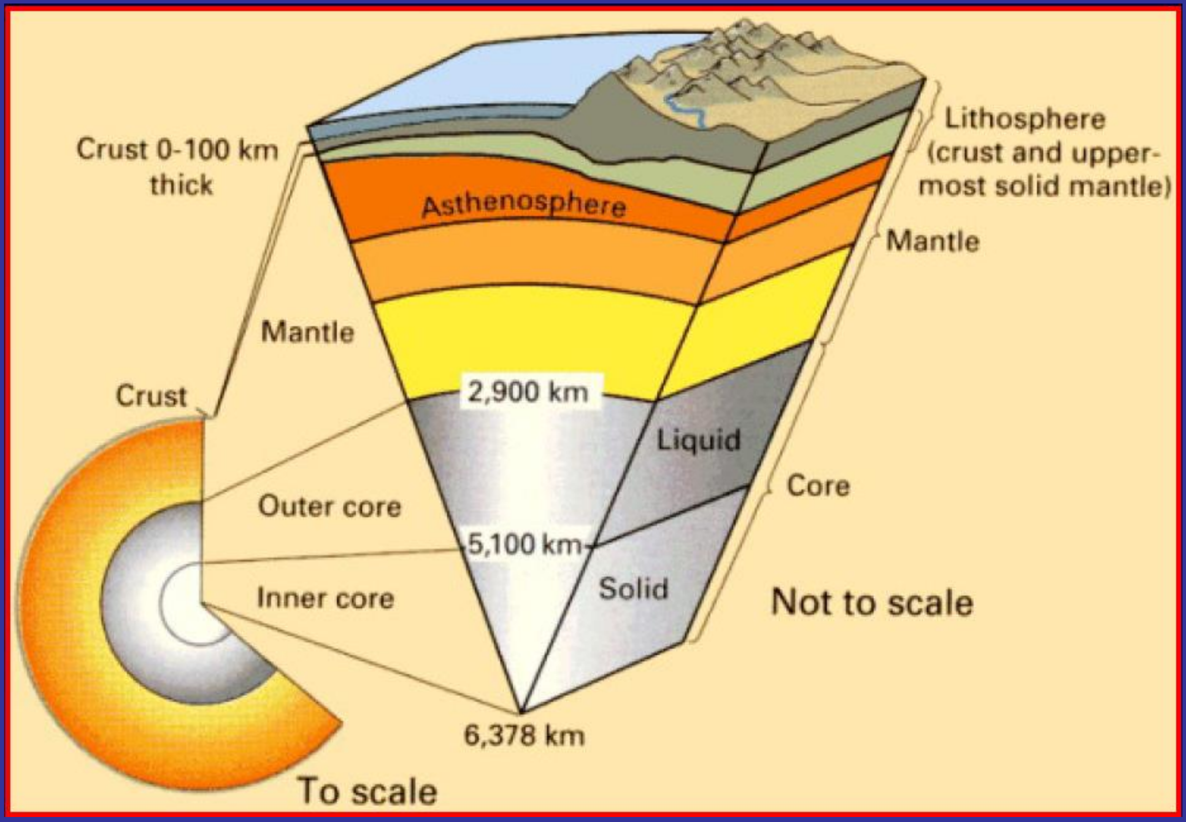
8. Morphometric methods in analysis of landforms controlled by tectonic processes and assessment of their intensity, planation surfaces and their different position as an indication of potential tectonic movements.

9. Paleoseismology, study of prehistoric earthquakes from geological record, reconstruction of movements

10. Study of paleoseismic parameters of active faults, intensity of movements, average slip rate, spatio-temporal distribution within the fault

1. Active tectonics, tectonic processes and their types resulting from different tectonic regimes

Tectonics – endogenous processes, structures and landforms associated with Earth´s crust deformation (movements of lithospheric plates)



Lithosphere = solid shell of the Earth (up to 100 km)

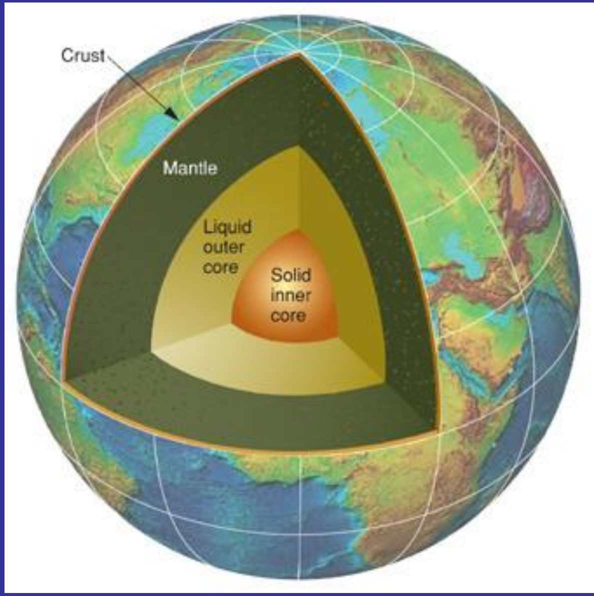
Earth´s crust + upper mantle

continental crust (30-80km), density 2.7 g/cm^3

Sedimentary, granitic, basaltic layer

oceanic crust (5-10km), density 2.9 g/cm^3

Sedimentary, basaltic layer



direct observations – drills, geologic information (xenolites)

Mohorovičič discontinuity – crust/mantle – density change, higher velocity P-waves

Lithosphere / asthenosphere (semifluid) 3.6 g/cm^3, lower viscosity – below lithospheric plates

– velocity of seismic waves

Global scale tectonics: origin of continents and ocean basins

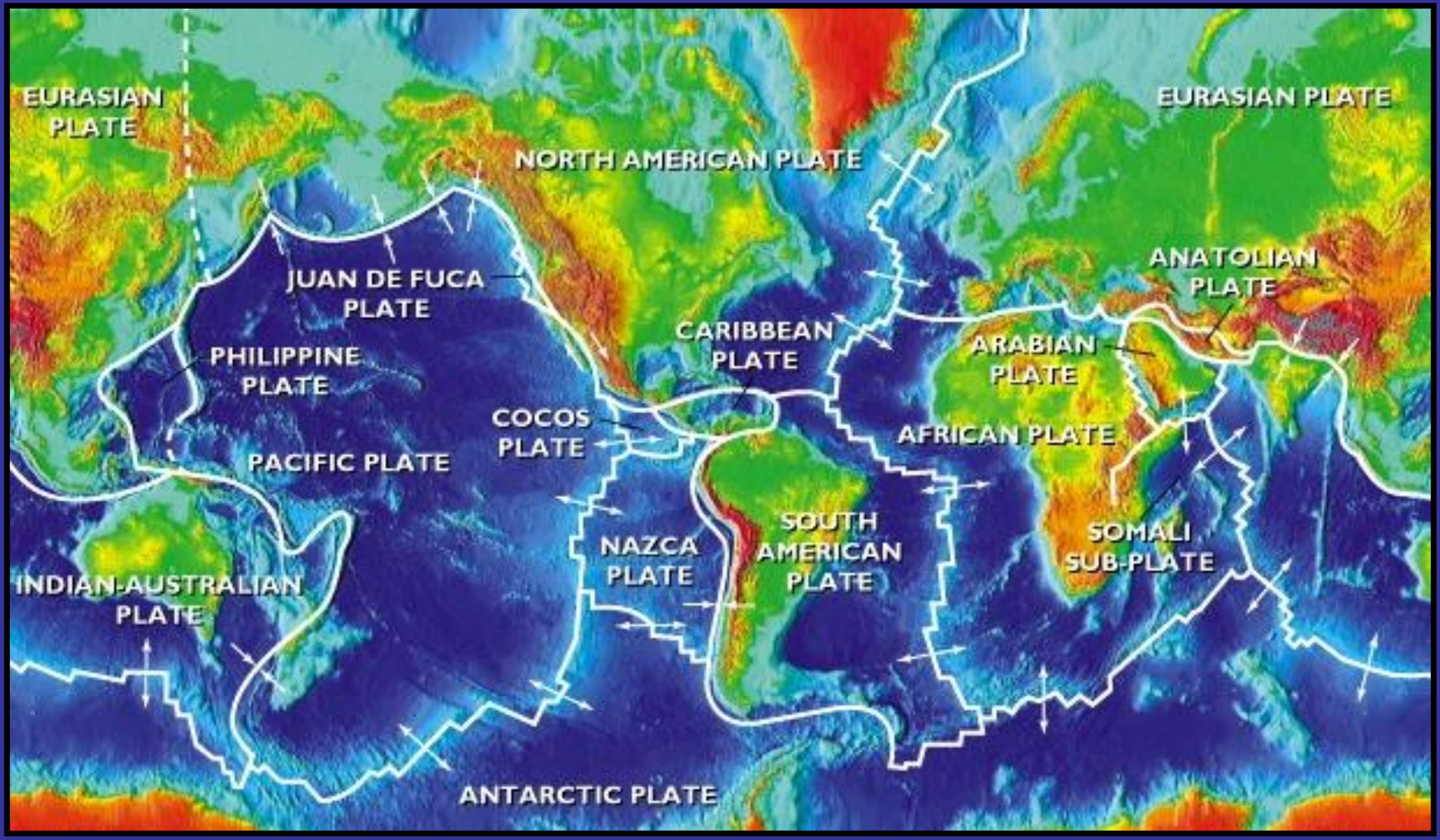
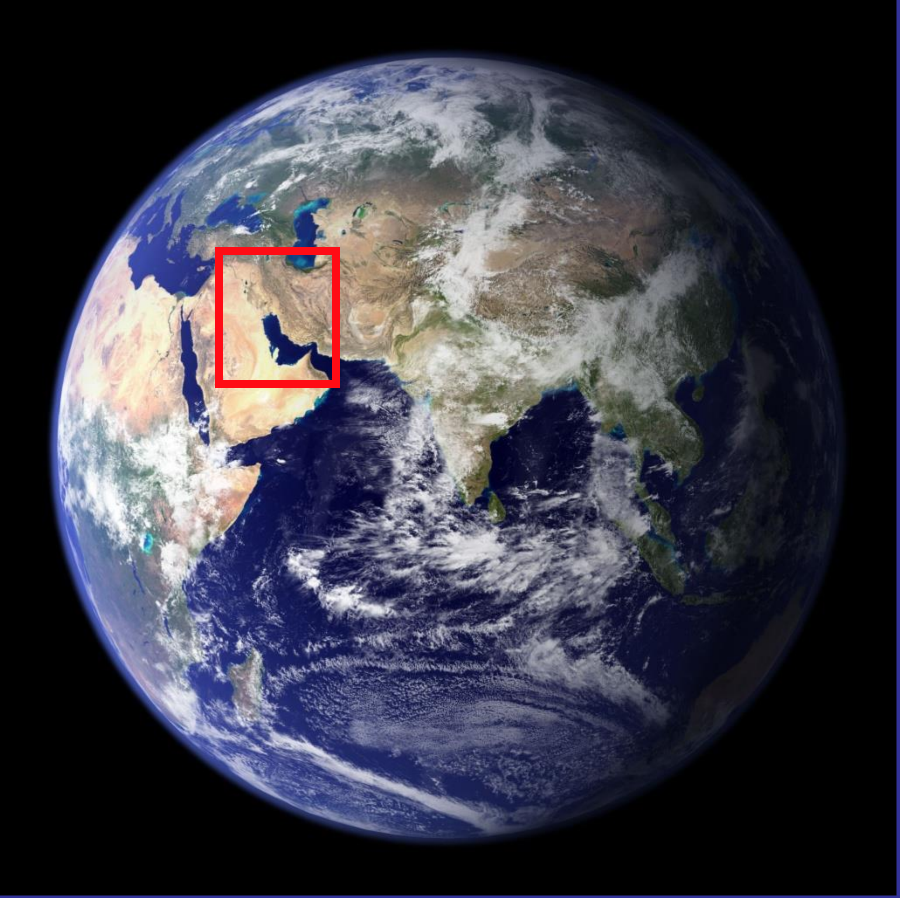


Plate tectonics



Global Neotectonics

Regional Neotectonics

10^7 m

10,000 km

Scale 1:100,000,000

Satellite images

microplates

10^6 m

1000 km

Scale 1:10,000,000

mountain chains

Active Tectonics
Tectonic Geomorphology

10^5 m

100 km

Scale 1:1.000,000

10^4 m

10 km

Scale 1:100,000

10^3 m

1 km

Scale 1:10,000

Local scale: individual landforms such as folds, fault scarps etc.

satellite images

10^1 m

10 m

Scale 1:100

offset channels

outcrop/ hand sample

10^0 m

1 m

Scale 1:10

tectonic breccia

Structural Geology
Petrology

10^{-1} m

10 cm

Scale 1:1

Time scales of tectonics:

depend on ***spatial scale*** at which the processes act:

Development of continents - thousands of millions years

Large ocean basins - hundreds of millions years

Small mountain ranges - several millions years

Small folds to produce hills - several hundred thousands years

Fault scarps - suddenly during earthquake

Neotectonics **-** crustal movements starting after the youngest orogenic phase or related to the youngest stress field occurring in the late Neogene and Quaternary

Active tectonics **–** tectonic processes that caused deformation of the Earth´s crust of local scale and on a time scale significant for humans (EQs)

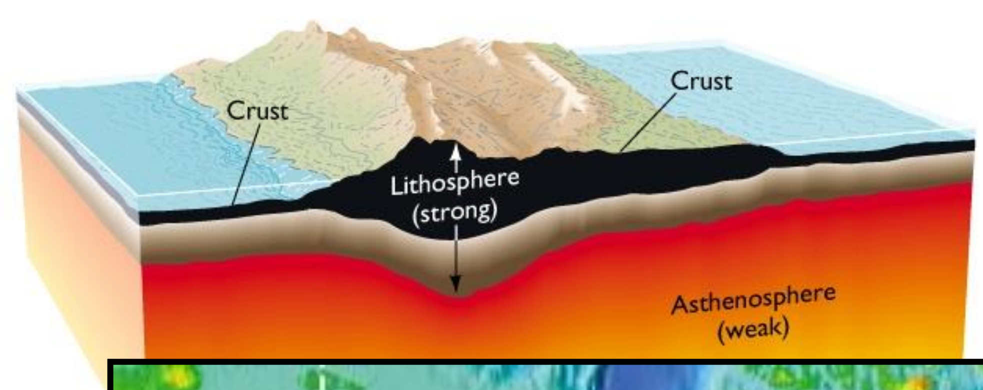
Active faults – moved during last 10.000 yrs – Holocene (paleoseismology)

Potentially active faults (capable faults) – moved during Quaternary (2.6 million yrs)

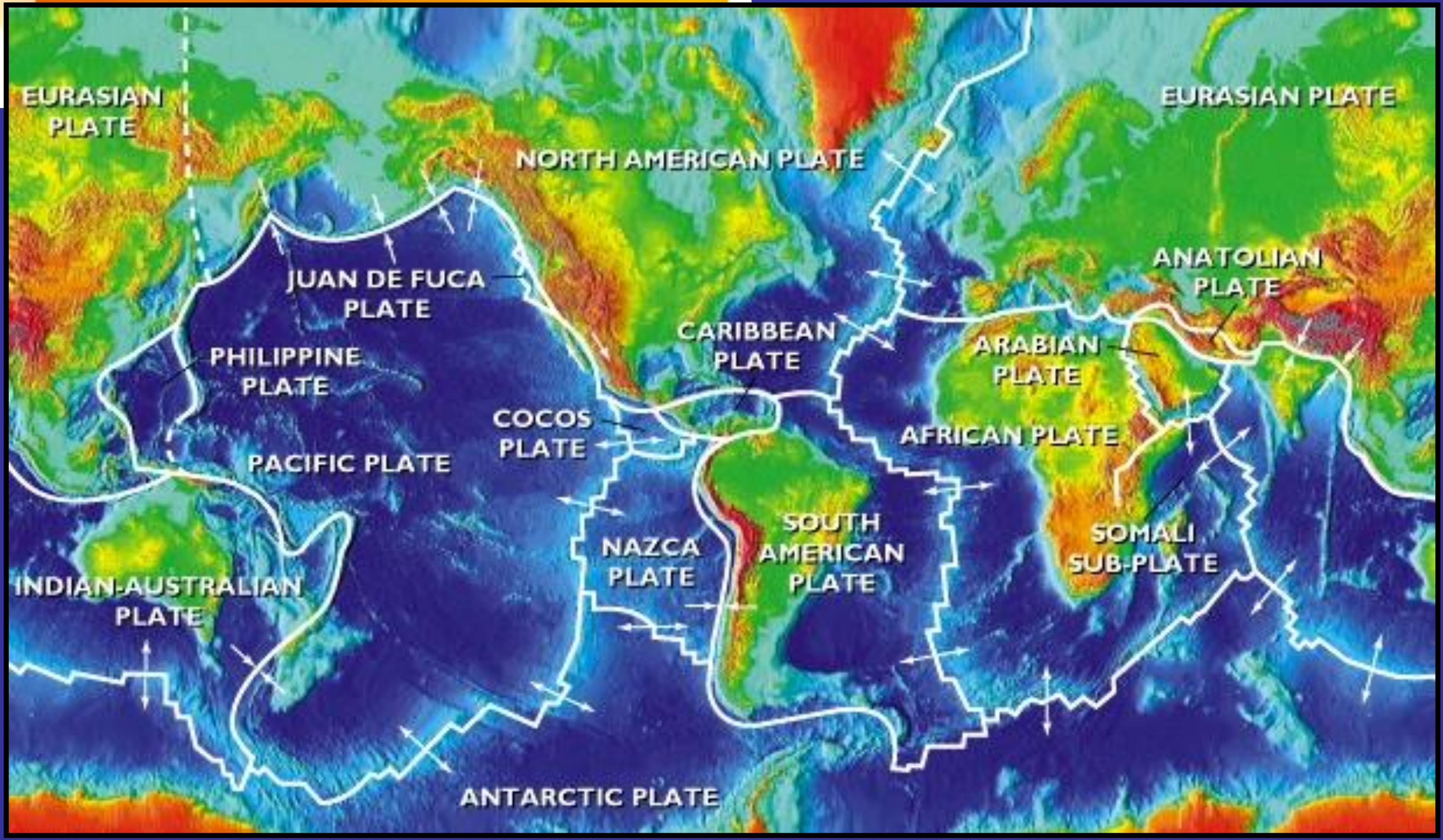
Rates of tectonic processes:

Very variable – 0.00X-X mm/year for fault displacement

X cm/year for movement on plate boundaries



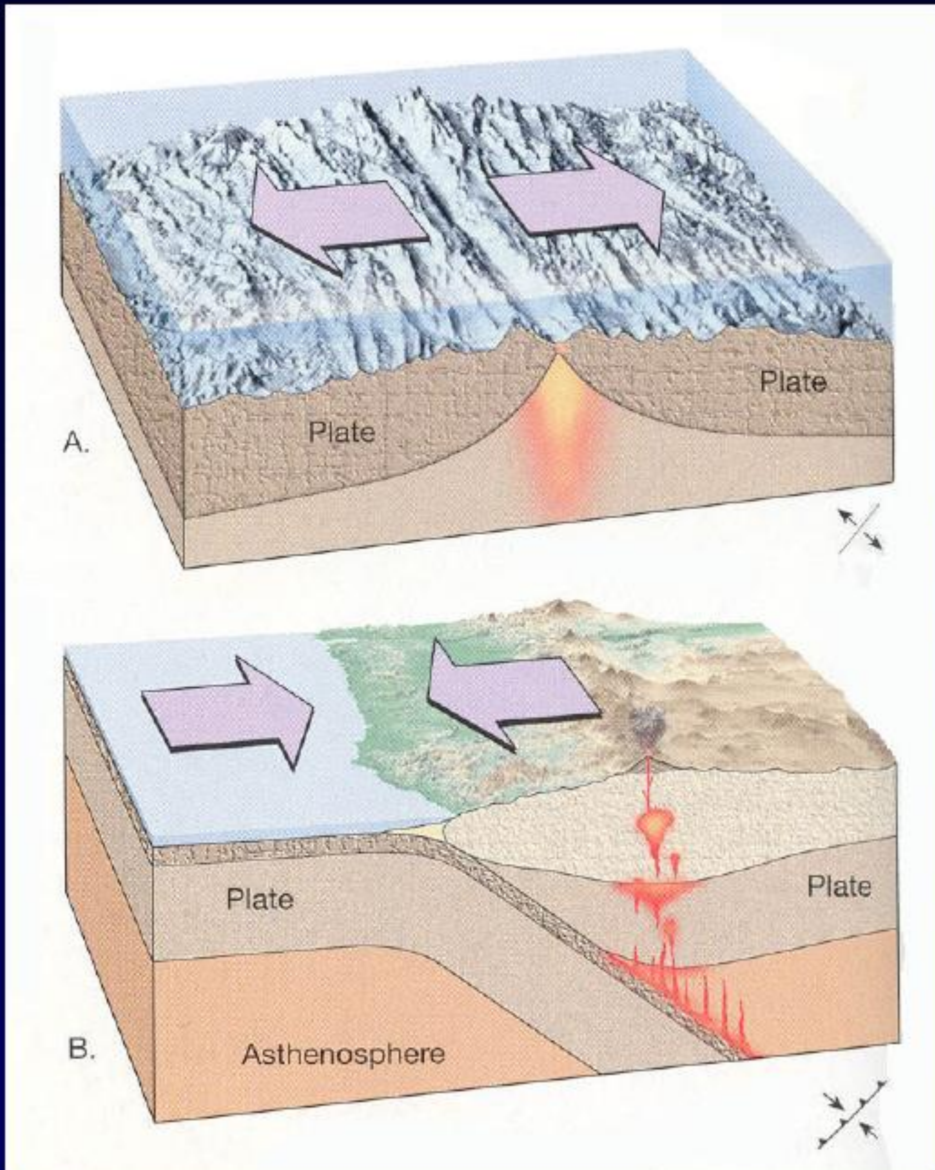
Tectonic processes - driven by forces in the depth that deform the crust => origin of ocean basins, continents, mountains



Litosphere broken into plates - relatively move; triple junction

Plate Boundaries

A. Divergent boundaries
B. Convergent boundaries
C. Transform boundaries



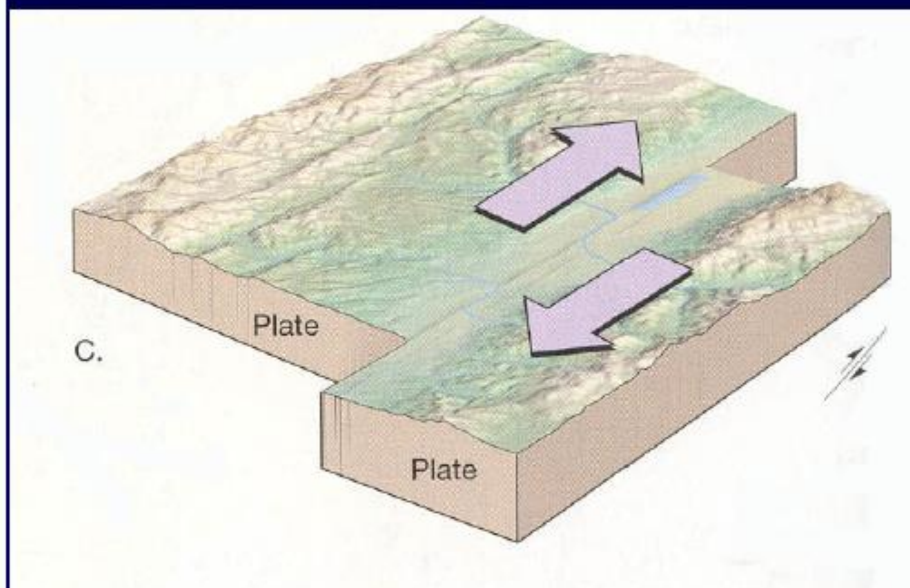
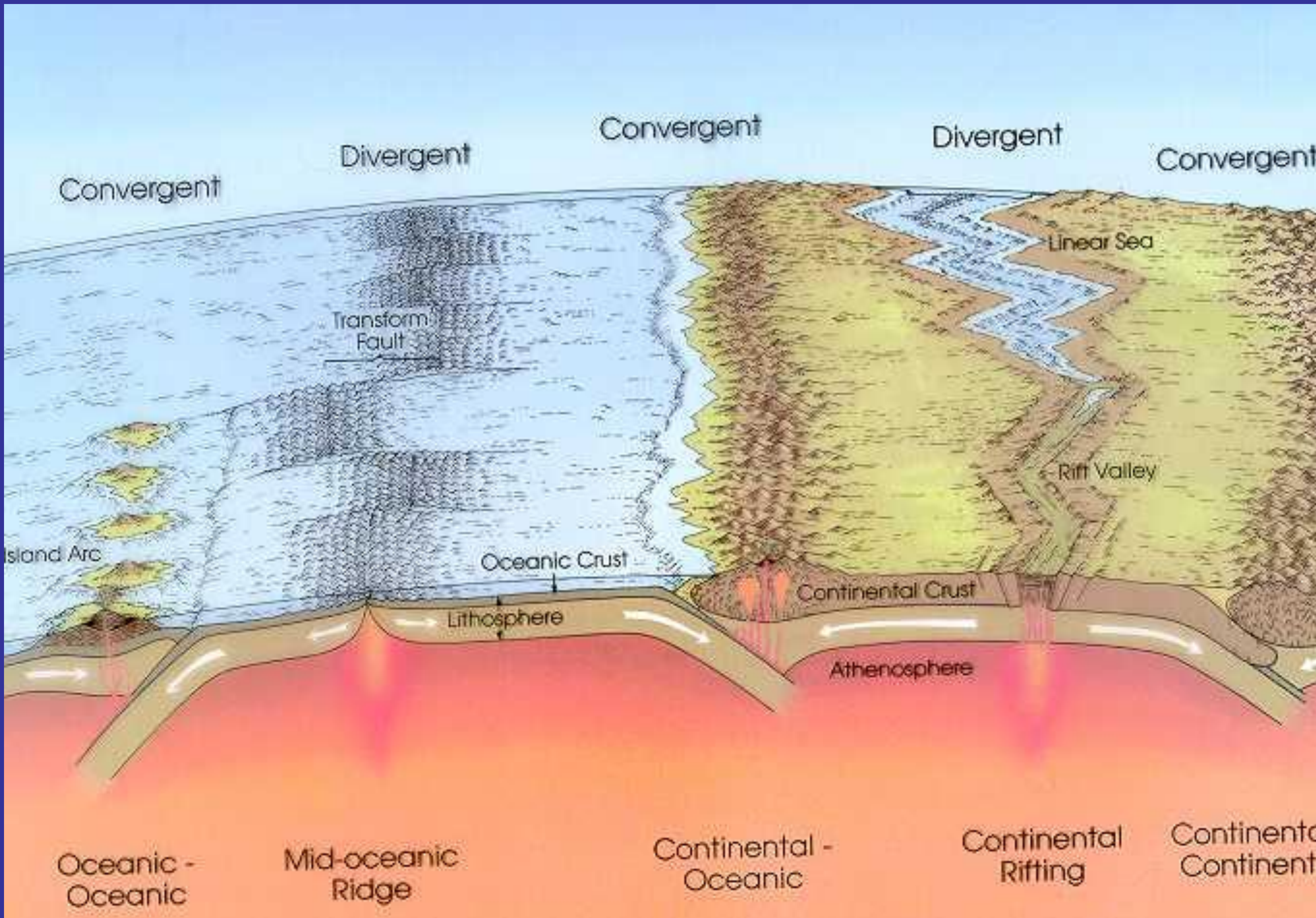


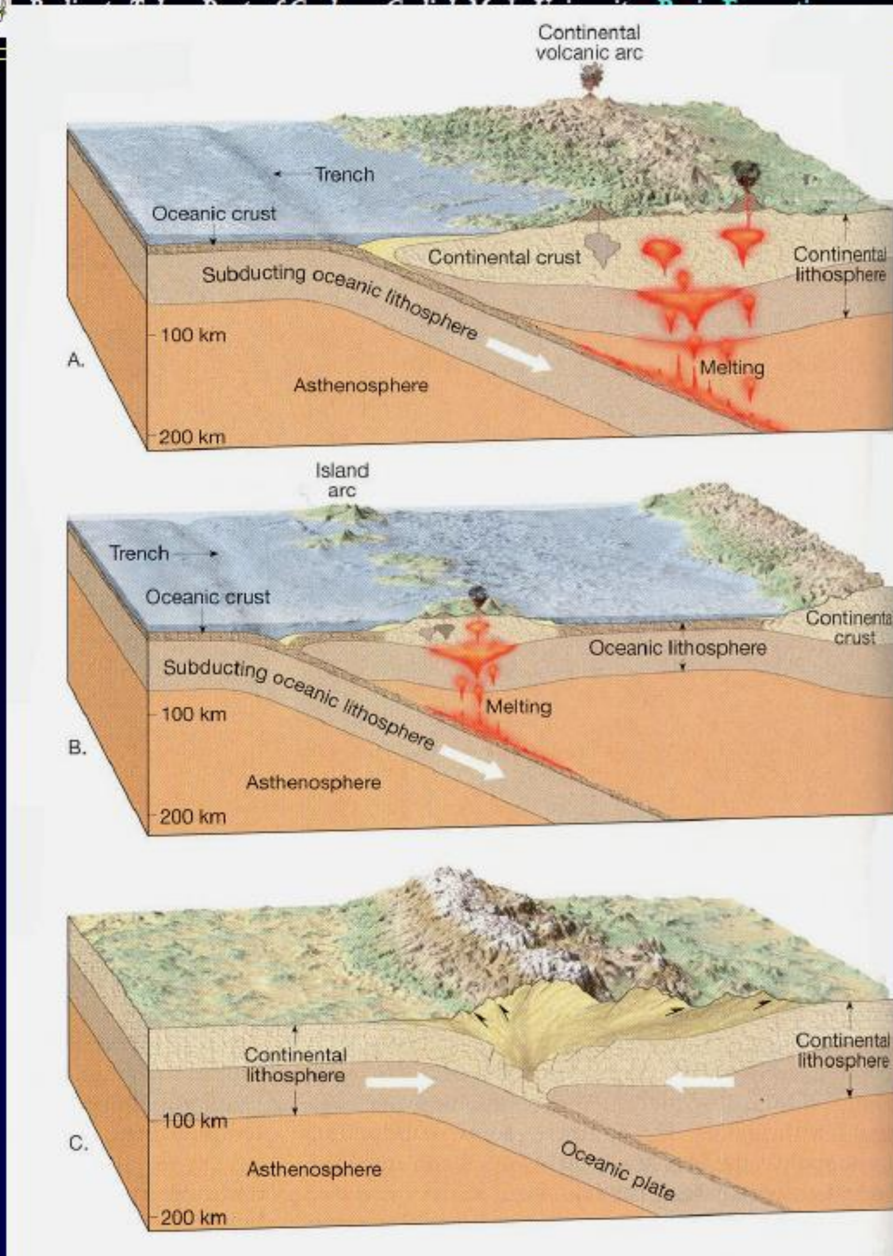
Figure 7.9 The three types of plate boundaries. **A.** Divergent boundary. **B.** Convergent boundary. **C.** Transform fault boundary.

divergent – extension (spreading), convergent – shortening (subduction) video!

Tectonic cycle



Video!

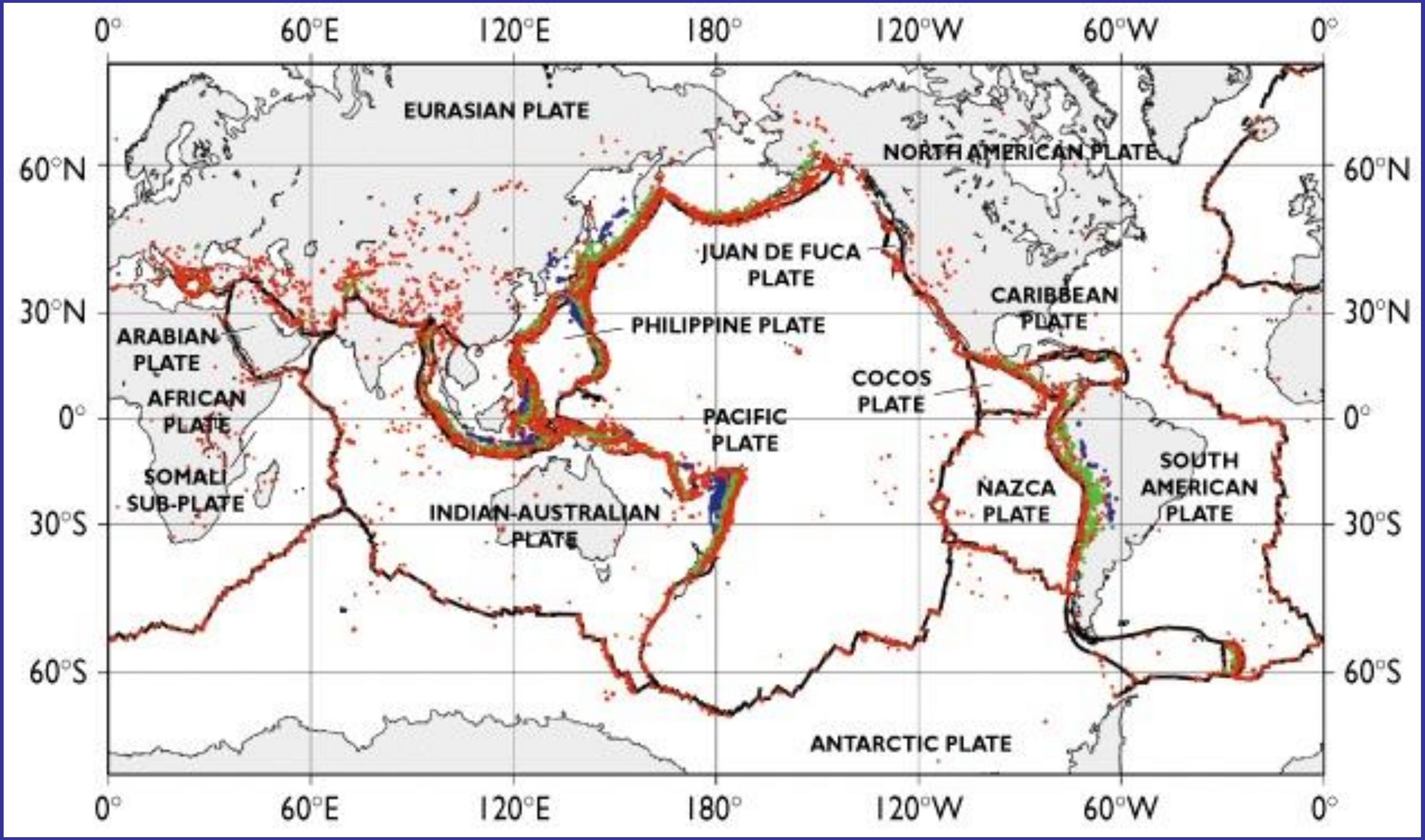


Three types of convergent Plate boundaries :

A. Oceanic-continental
B. Oceanic-oceanic
C. Continental-continental

Video!

Active Tectonics: confirmation of plate tectonics…



- Earthquakes
- Volcanoes
- Faults

- Topography
- Surface deformation

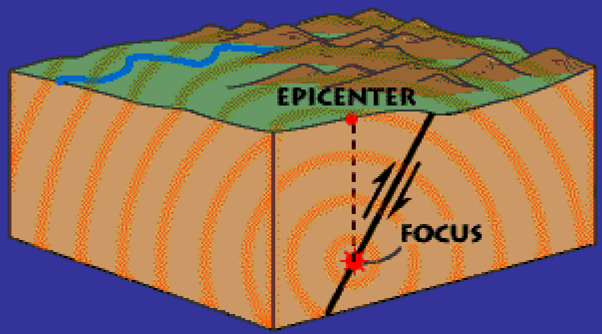
World Seismicity, 1963–2000

Video!

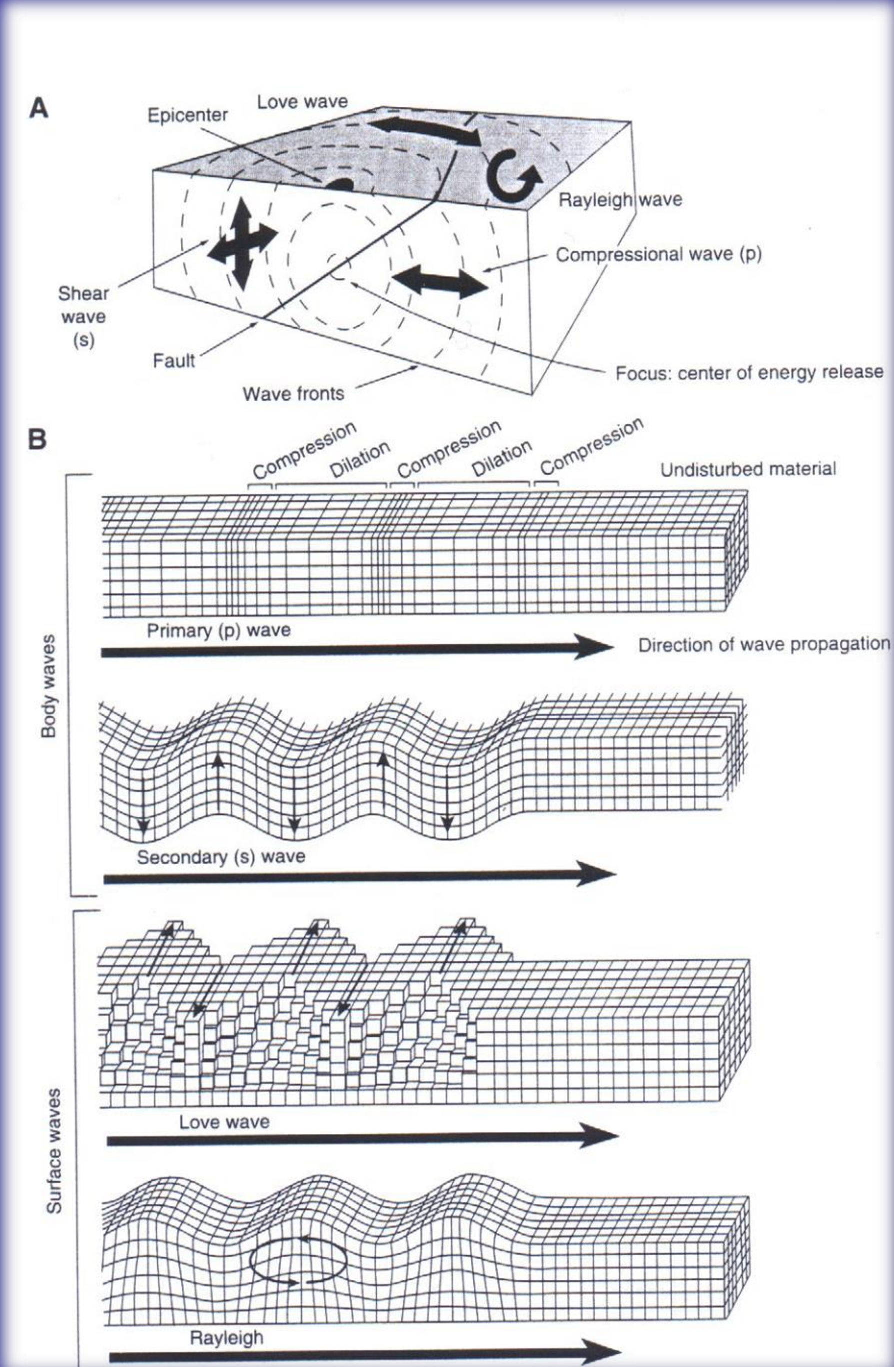
Producing new lithosphere in ocean ridges, subduction of old one and plates sliding along each other – produce stress (force per unit area) and strain (deformation – change in length, volume).

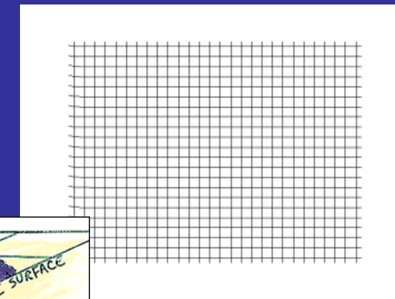
Seismic tectonic movements

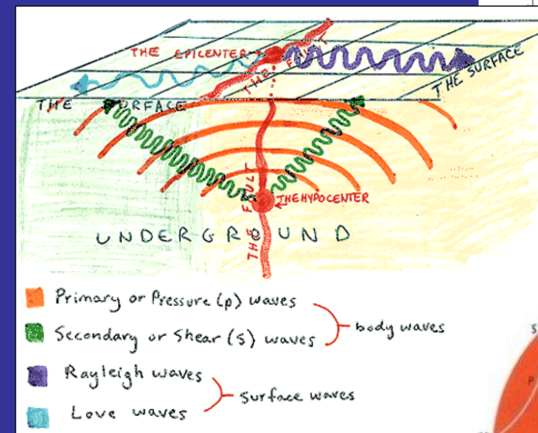
When the stress exceeds the strength of rocks, then rocks fail (rupture), energy is released in a form of an earthquake (seismic waves) and faulting (breaking the rocks, rock deformation).

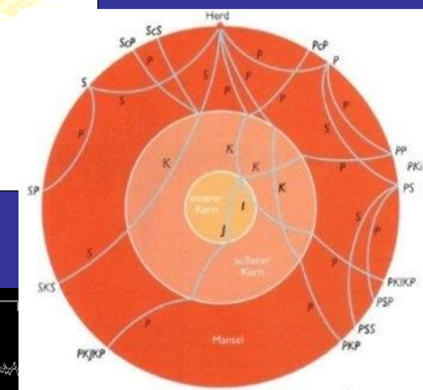


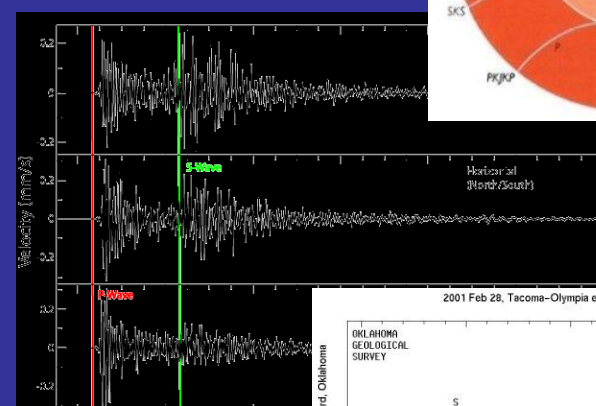
P-waves followed by S-waves

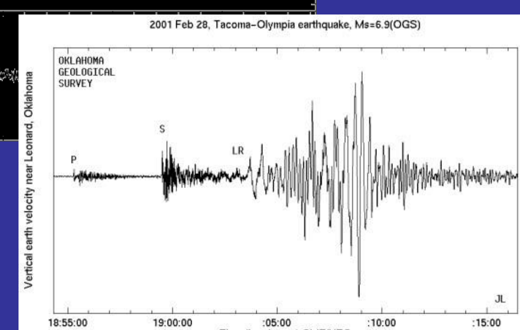












Video!

location

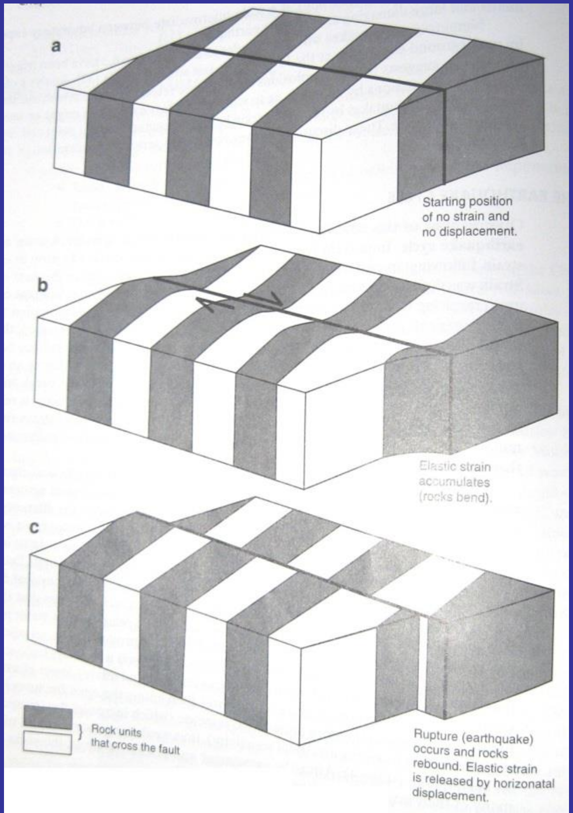
After the EQ, stress is accumulated again.

Earthquake cycle (seismic cycle):

1. accumulation of stress = produces elastic strain (not permanent)

2. during earthquake stress is released when rocks break and permanent displacement occurs, then strain also drops = **elastic rebound** (deformed material in original shape)

Video!



Magnitude vs Intensity

Richter´s magnitude

logarithmic scale obtained by calculating the logarithm of the amplitude of waves

$$M = \log a$$

Moment magnitude Mw

$$M_\mathrm{w} = \frac{2}{3}\log_{10} M_0 - 10.7,$$

energy is transformed in

- cracks and deformation in rocks
- heat,
- radiated seismic energy E_s.

The seismic moment M_0 is a measure of the total amount of energy that is transformed during an earthquake.

Rossi – Forei – X grades (1883)

XXII

MCS – Mercalli – Cancani - Sieberg (1902)

MSK -64 – Medvedev-Sponheuer-Kárník

MMI – Modified Mercalli (in USA)

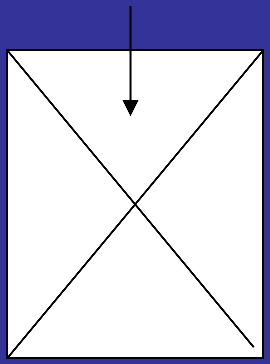
EMS-98 - European Macroseismic Scale

I. Nepocítěno	Zemětřesení nebylo pocítěno.
II. Stěží pocítěno	Pocítěno jen velmi málo jednotlivci v klidu v domech.
III. Slabé	Pocítěno uvnitř budov některými osobami. Lidé v klidu pociťují jako houpání nebo lehké chvění.
IV. Značně pozorované	Zemětřesení uvnitř budov cítí mnozí, venku jen výjimečně. Někteří lidé jsou probuzeni. Okna, dveře a nádobí drnčí.
V. Silné	Uvnitř budov cítí většina, venku někteří. Mnozí spící se probudí. Někteří jsou vystrašení. Budovy vibrují. Visící objekty se značně houpají. Malé předměty se posouvají. Dveře a okna se otvírají a zavírají.
VI. Mírně ničivé	Mnozí lidé jsou vystrašeni a vybíhají ven. Některé předměty padají. Mnohé budovy utrpí malé nestrukturální škody jako např. vlásečnicové trhliny nebo odpadnuté malé kousky omítky.
VII. Ničivé	Většina lidí je vystrašena a vybíhá ven. Nábytek se posouvá. Předměty padají z polic ve velkém množství. Mnohé dobře postavené běžné budovy utrpí střední škody: malé trhliny ve zdech, opadá omítka, padají části komínů; ve stěnách starších budov jsou velké trhliny a příčky jsou zřícené.
VIII. Těžce ničivé	Mnozí lidé mají problémy udržet rovnováhu. Mnohé domy mají velké trhliny ve stěnách. Některé dobře postavené běžné budovy mají vážně poškozené stěny. Slabé starší struktury se mohou zřítit.
IX. Destruktivní	Všeobecná panika. Mnoho slabých staveb se řítí. I dobře postavené běžné budovy utrpí velmi těžké škody: těžké poškození stěn a částečně i strukturální škody.
X. Velmi destruktivní	Mnohé dobře postavené běžné budovy se řítí.
XI. Devastující	Většina dobře postavených běžných budov se řítí. I některé seismicky odolné budovy jsou zničeny.
XII. Úplně devastující	Téměř všechny budovy jsou zničeny.

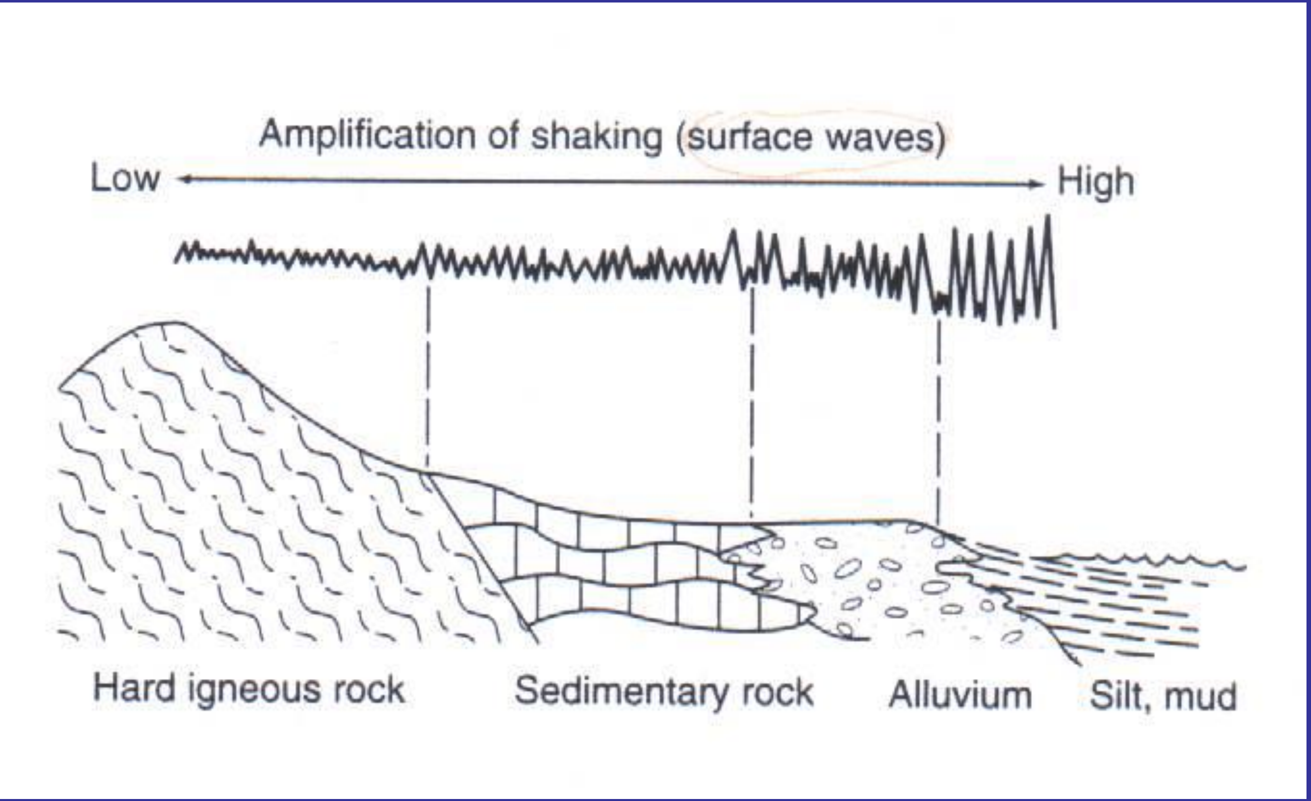
Macroseismic effects on the surface
- crucial factors

- Size of earthquake, depth of hypocentre (focus), distance from the epicentre, response of surficial layers
- Distance of faults, orientation of faults in epicentral area
- Locally – lithology and physical state of the rocks

Depth of groundwater level



Geology



Higher amplitudes – worse effects

Mexico city 1985, M = 8, epicentre 350km far away, 10,000 casualties

Distance from the epicentre

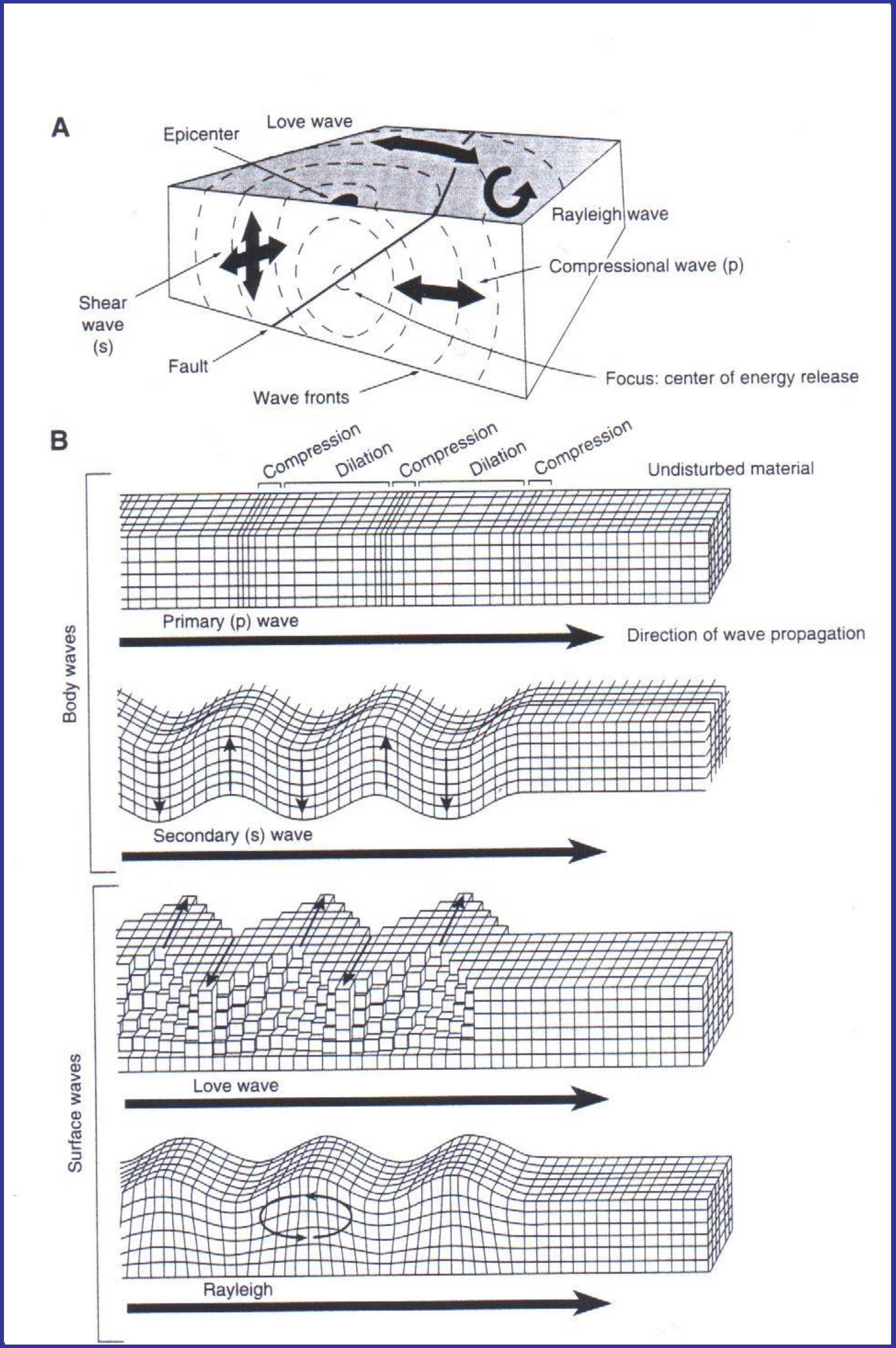
- wave type

P, S waves – high frequency

Surface waves – low frequency

Low buildings – high proper frequency

High buildings, skyscrapers – low proper frequency



Acceleration of bedrock (ground motion)

Horizontal component
Vertical component (amplitudes over 50% lower than horizontal)

Magnitude	Area Felt Over (square kilometers)	Distance felt (kilometers)	Intensity (maximum expected Modified Mercalli)	Ground Motion: (Average peak horizontal acceleration g = gravity = 9.8 meters per second per second)
3.0–3.9	1,950	25	II–III	Less than 0.15 g
4.0–4.9	7,800	50	IV–V	0.15–0.04g
5.0–5.9	39,000	110	VI–VII	0.06–0.015g
6.0–6.9	130,000	200	VII–VIII	0.15–0.30g
7.0–7.9	520,000	400	IX–X	0.50–0.60g
8.0–8.9	2,080,000	720	XI–XII	Greater than 0.60g

Relation – magnitude and intensity

Effects of earthquakes

Primary effects: ground-shaking motion and rupture of the surface

(shear or collapse of large buildings, bridges, dams, tunnels, pipelines)

Chi-chi EQ Taiwan 1999 with M=7.6

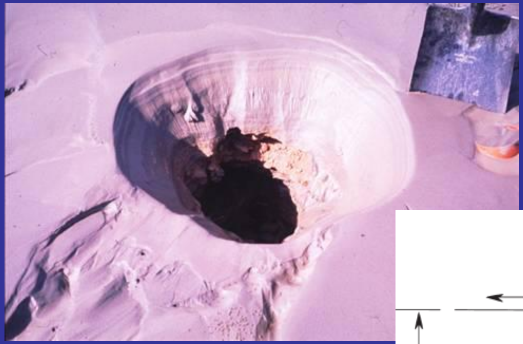
Landers EQ, Emerson fault, CA 1992, M=7.3

Secondary effects:

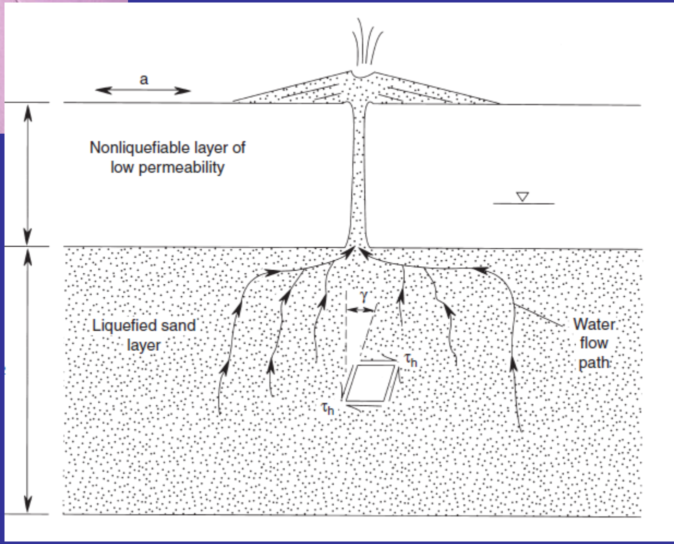
Short-term

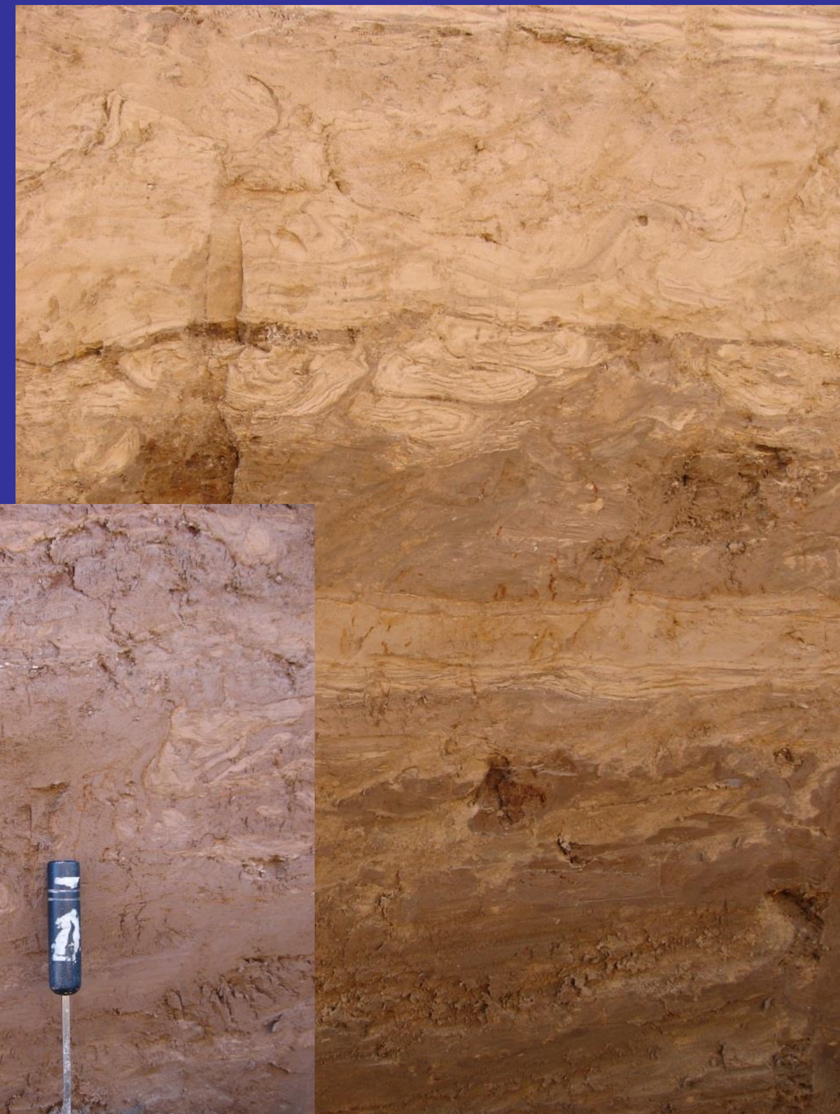
Liquefaction – water-saturated material transforms to liquid state (loose soil into mud) during shaking, compaction causes an increase of pore-water pressure = material loses shear strength and flows.

Water under the soil rises and the ground sinks causing extensive damage to buildings, roads and other structures.



Buildings tilted due to soil liquefaction, 1964 earthquake, Japan.



Landslides

Seismic Seawaves – Tsunami

Fires

Floods – following collapse of dams

Costarica, 2009, Mw=6.2,
180 landslides

Long-term

Regional subsidence

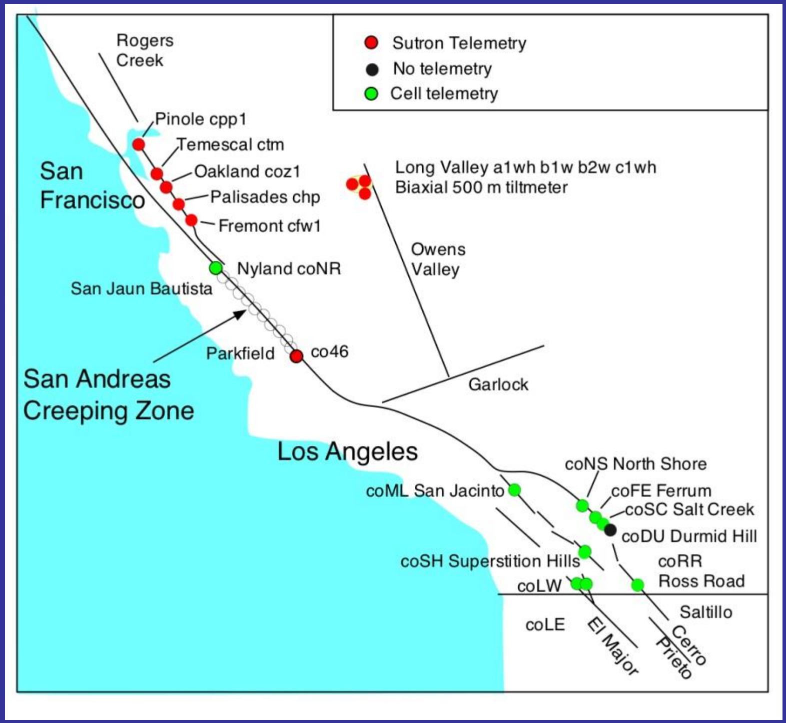
Change in groundwater level

Tectonic creep – aseismic movements

Displacement along a fault zone **accompanied by minimal earthquakes**, **more or less continuous, narrow zone**

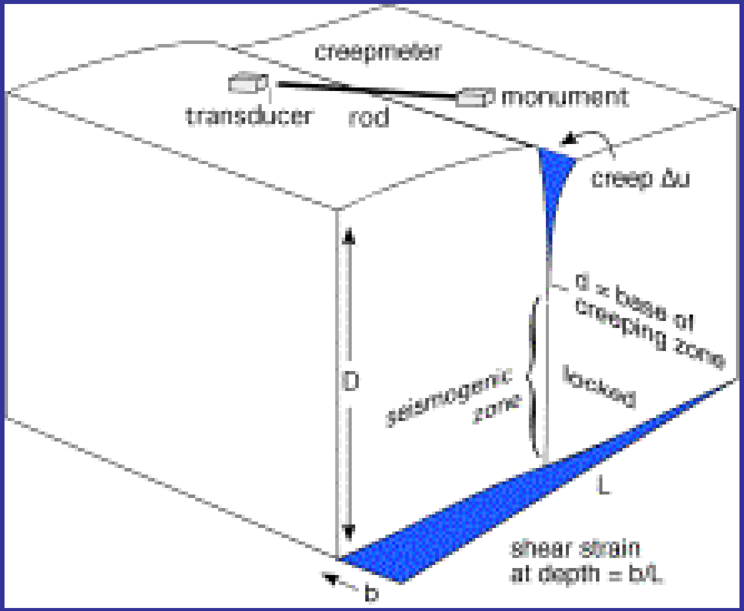
Geodetically detectable (GPS, SLR, etc....)

Less damage from creep – generally along narrow fault zones subject to slow, not much studied in – no seismic hazard



Hayward fault – SAF zone, San Francisco Bay area

Creep rate measured by creepmeter installed across the fault – typically 5 mm/year, max in Fremont 7.8-8.5 mm/year



Between 5 and 12 km in depth is believed to slip entirely in earthquakes, but the surface and deepest part of the fault also slips by a process of aseismic creep.

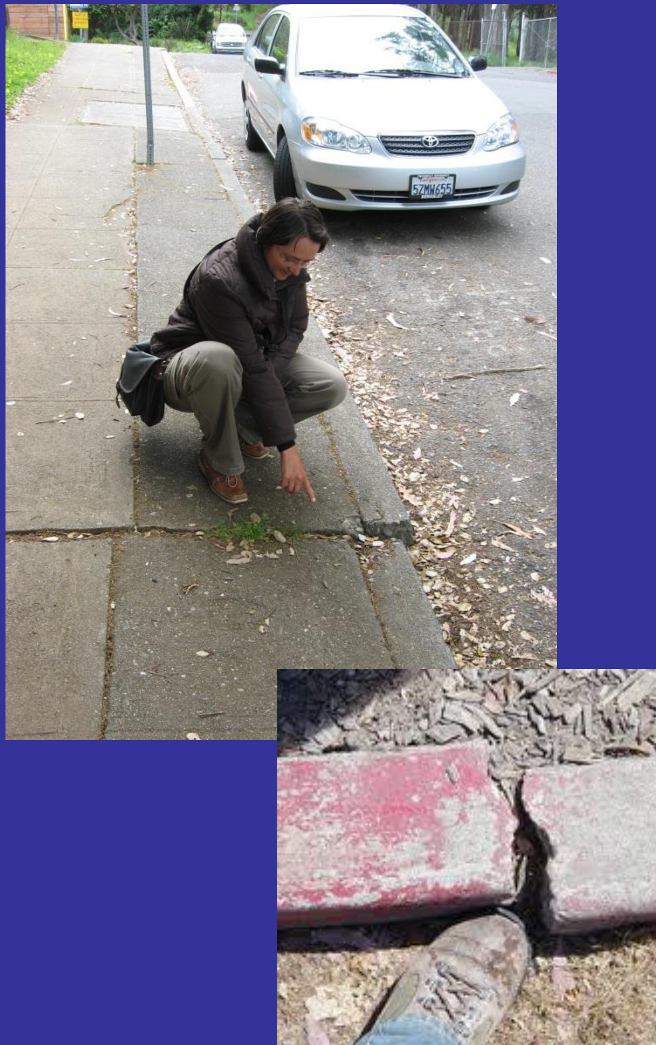
Creep since 1896 large EQ, the creep partially releases the strain energy on the fault

High rate: slow damage of roads, sidewalks, building etc.

Berkeley – Memorial stadium

3.2 cm in 11 years,
periodic repairs needed

Contra Costa, deformed road



Berkeley, offset sidewalk

Hayward, offset fence

Higher creep rate:

Calaveras fault (SAF zone)

Creep rate – varies

1910-1929 no creep, based on offset in two sidewalks constructed in 1910 and 1929, and pipeline laid in 1929

1929 ......- creep commenced, with 8 mm/yr (average)

1961 - 1967, slip rate about 15 mm/yr

1979....2 sites monitored in Hollister with 6.6 mm/yr and 12 mm/yr (2.3km NW)

Hollister, twisted house

20.000 earthquakes a year - small, strain not accumulated and released by slow creep – not able to produce a large EQ

Calaveras fault - vinařství

Creepující strom

2. Tectonic geomorphology, role of tectonics in relief formation

Landforms – surficial features which make up the landscape

All scales – mountains, alluvial fans, hills, canyons, slopes etc.

Geomorphology – study of nature, origin, and evolution of landscape

A) **Geological factors** – important, landform development is related to underlying structure of the Earth
Structure – includes rock and soil type, nature and abundance of fractures, faults, folds

B) **Geomorphic processes** - weathering (physical, chemical), fluvial erosion/deposition, glacial, eolian (wind), mass wasting (slope failure), tectonic, and volcanic

C) **Natural variables** - geology, climate, vegetation, base-level, human inteference - influence the type and rate of the processes

Process-response models

-qualitative and quantitative representations how processes influence landform development

-e.g. alluvial fans – result from tectonic, fluvial processes or/and changes in climate conditions (various causes)

We should understand all the processes to be able to distinguish between them (Spain vs Bohemian massif – fluvial terraces, alluvial fans)

Tectonic geomorphology – study of landforms produced by tectonic processes; study how tectonics controls erosion, deposition, landforms; from morphology we can infer fault kinematics

Geomorphology – valuable tool in active tectonic studies because the young tectonic processes are reflected in morphology and Quaternary deposits present on a site

e.g. study of stream channels and related deposits offset by faulting – may reveal amount of displacement, timing of the last few earthquakes at the site – critical for seismic hazard evaluation

Uplift

Different theories on interaction between tectonics and landscape developed

Not only pure uplift - combination of vertical + horizontal movements so there are not black-and-white definitions

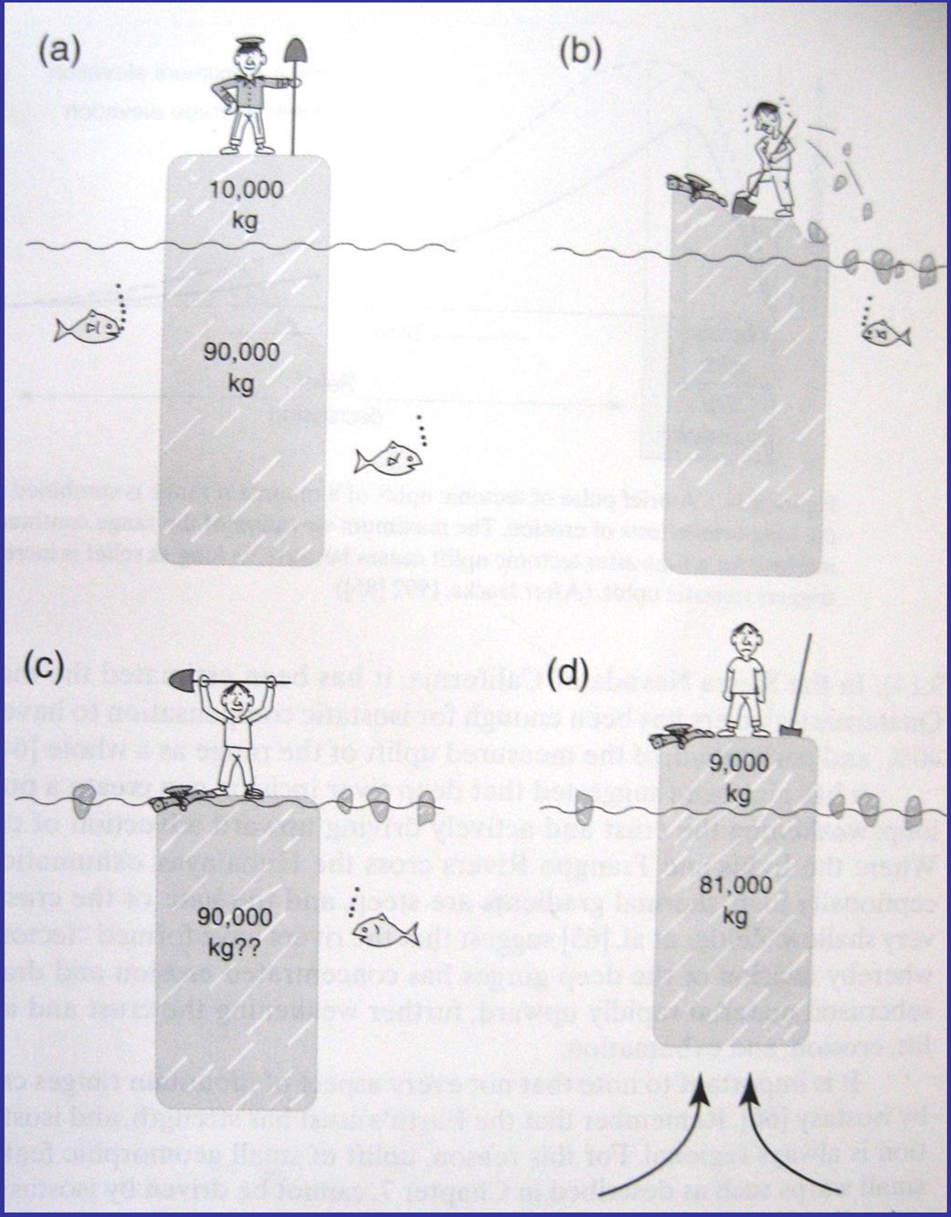
Vertical movements produce the large landforms on the Earth surface – uplift

Bedrock uplift – influenced by both tectonic and geomorphic processes

- geomorphic processes: erosion, denudation, deposition, weathering

Uplift – isostatic uplift + tectonic uplift = bedrock uplift

Isostatic uplift



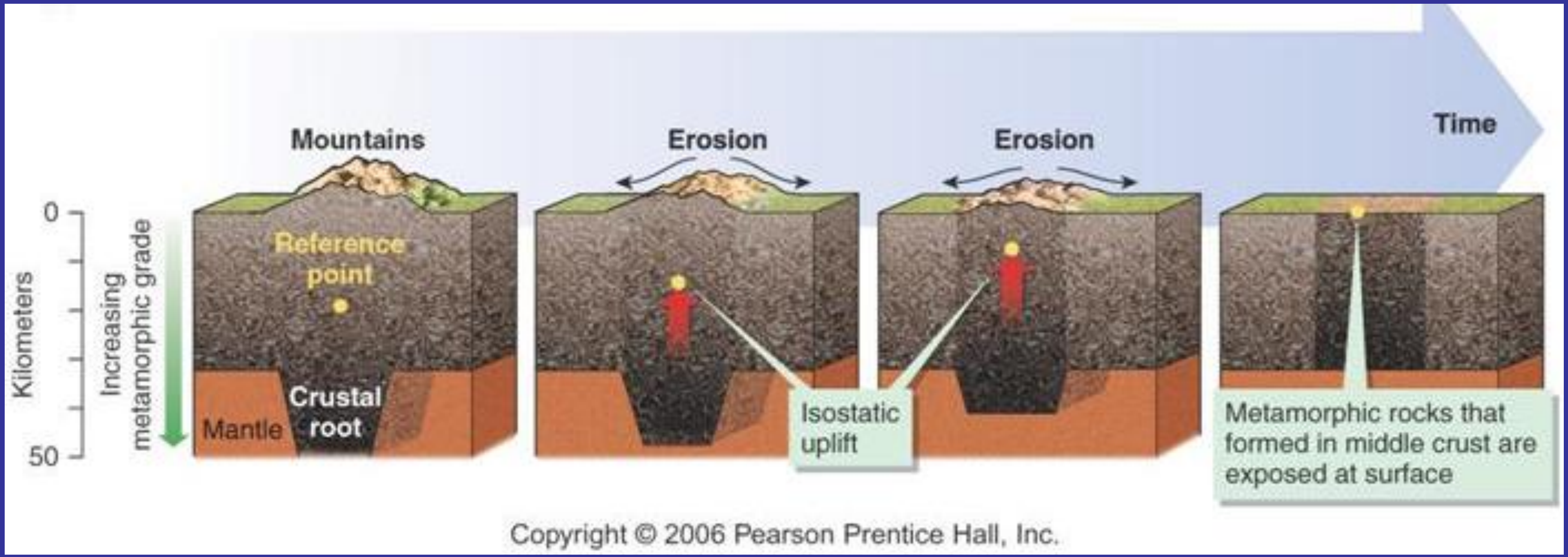
Rainfall can never melt enough ice to lower the surface of an iceberg to the water line. This is because ice melted above the waterline is largely replaced by "uplift" of submerged ice.

Isostatic uplift – ice has 90% of density of seawater

If 10 tons is melted from the exposed surface of an iceberg, it is compensated by 9 tons of ice raised by isostatic uplift – isostatic rebound

= pure uplift (no shear, no tensional failure of ice)

Isostasy in mountains



Continental crust (density of about 2,700 kg/m3) „floats“ on mantle with a density of about 3,300 kg/m3 – a density contrast of roughly 82% (90% contrast for oceanic crust with a density of 3,000 kg/m3) – analogy with ice

Fluvial and glacial denudation of 1,000 m only seems to significantly lower a mountain range because it is largely compensated by 820 m of concurrent isostatic rebound.

Video!

Fluvial and glacial erosion – isostatic uplift caused mainly in valley floors (video)

Mass removal (denudation) – pure isostatic uplift in all parts of the landscape

Larger **space and** longer **time** - for pure uplift, tectonic denudation, or burial

Smaller forms and shorter time - for tectonic displacements and geomorphic processes

Tectonic uplift

- driven by tectonic processes, mountain-building processes – convergent plate boundaries

Tectonic mountain-building forces may stop but the resulting isostatic adjustments will continue as long as streams transfer mass from mountains to sea.

Bedrock uplift = Tectonic uplift + Isostatic uplift

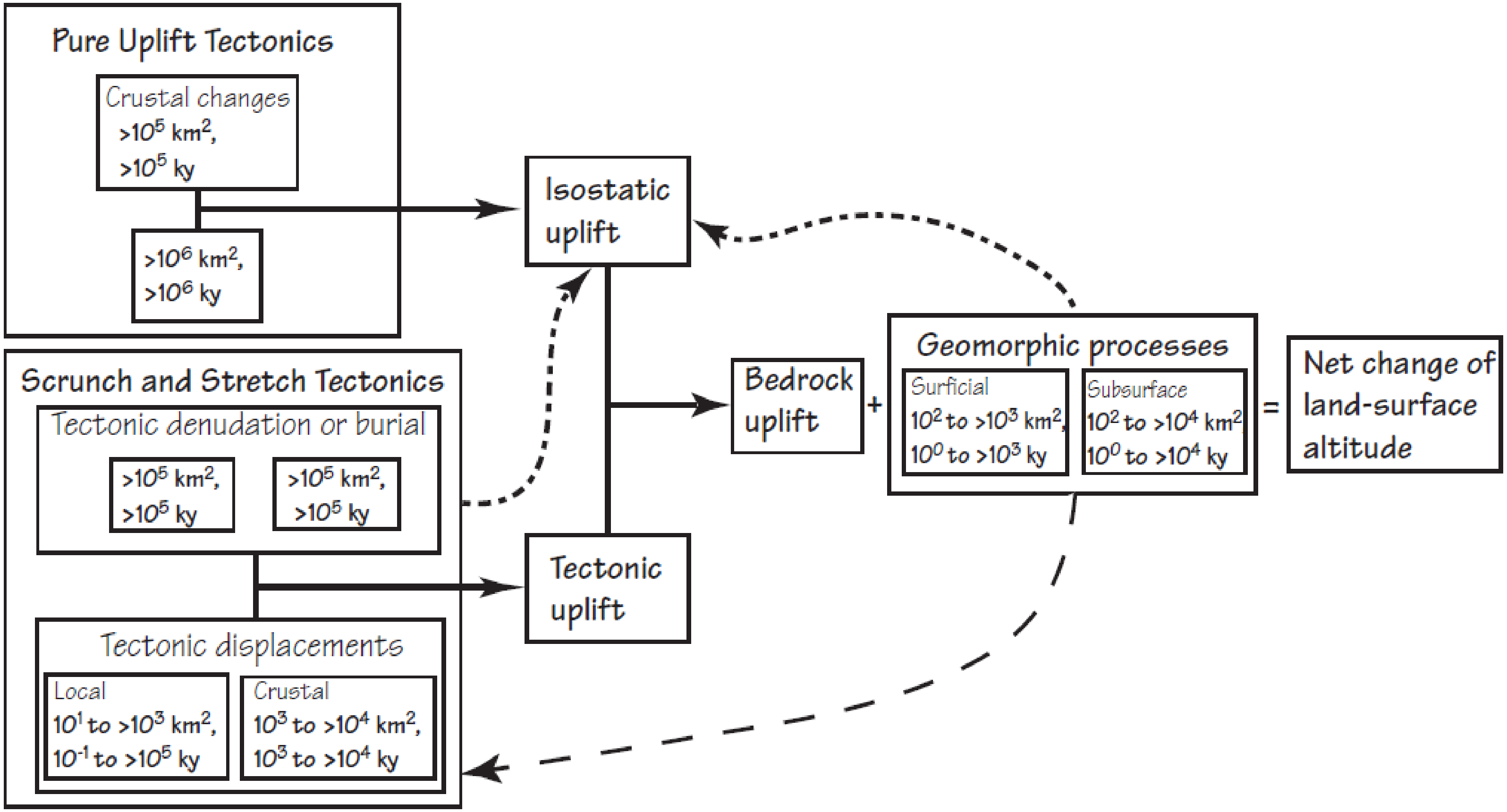


Figure 1.4 Links between tectonic, isostatic, and nontectonic variables affecting landscape altitudes and bedrock uplift. Feedback mechanisms to isostatic and tectonic uplift are shown with dashed lines.

Tectonic geomorpholgy of mountains, Bull 2007

Tectonic uplift – induce higher erosion,
Higher altitude – different processes, different climate - influence isostatical uplift

Surface uplift = change of altitude influence geomorphological processes

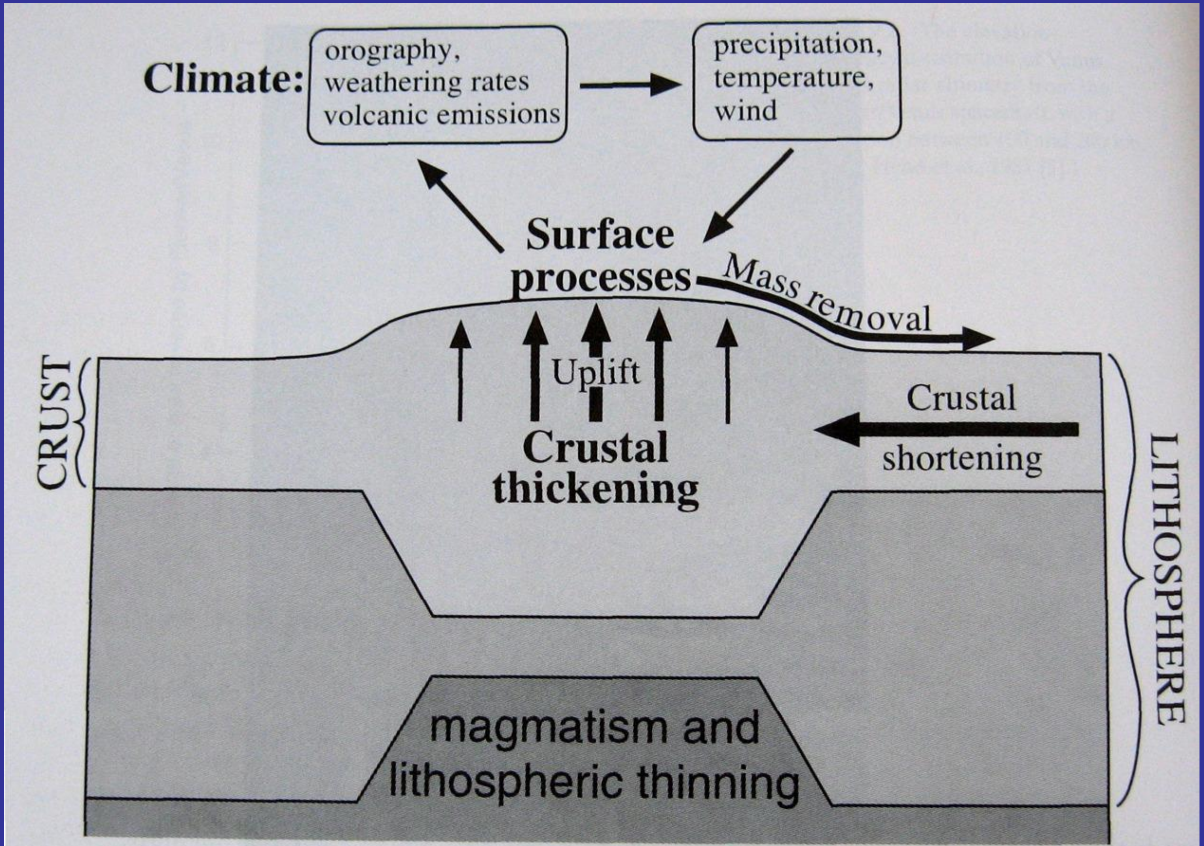


Figure 9.4 Highly simplified model of the mountain-building system. Tectonic processes thicken the crust, driving uplift of the surface. Climate-driven surficial processes act to remove that high-standing mass. Each set of processes influences the other sets in a number of ways. (After Isacks, 1992 [85].)

Climatic changes are dominant because they quickly affect geomorphic processes throughout a drainage basin – precipitation, discharge

X uplift on a fault zone is local and the resulting increase in relief progresses upstream relatively slowly

Tectonic uplift induced incision

The surface rupture of the 1999 Ch-Chi formed a waterfall (8 m high). River erosion tries to erase this step (several m retreat)