ENVIRONMENTAL GEOLOGY (GEOLOGY 102)

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SECOND MATERIALS

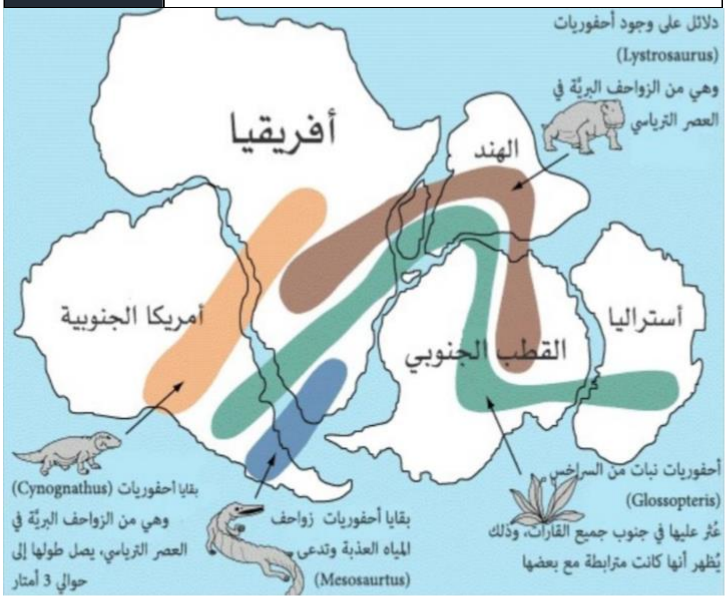
CHAPTER THREE

PLATE TECTONICS

CONTINENTAL DRIFT

- **Continental Drift Hypothesis**: Wegener began to publish his ideas & continued to do so for 2 decades, He proposed that all the continental had once formed a single supercontinent, called Pangaea, which had then split apart moving to their present positions

The observations that led to the development of continental drift hypothesis	
Fit of the continents	The similarity in the coasts of S-America & Africa, puzzle pieces are reassembled!
Paleo-climate	Rocks are preserve of ancient climate • Evidence of glaciation in tropical places (S-Africa, Australia, S-America) • Desert sand deposits in rocks of regions that now have moist temperate climates • Jungle plants in cool places (Antarctica) These observations, cannot be explained as the result of global climatic changes (don't show the same warming or cooling trends at same time) but are result from changes in continental latitude by continental drift
Fossils Evedance	Some animals lived in a few very restricted areas, which now are widely separated • Glossopteris (India, S-Africa, Antarctica) • Mesosaurus (S-Africa, & S-America) The organisms lived in a restricted area, & their remains moved by drifting continents
Rock structural similarity	The geologic features (rock ages, fossils, ore, mountains) at margin of different continents • Appalachian Mountains (N. America) continue into Greenland & British Isles



- Continental drift theory was rejected because (insurmountable obstacles to accepting the hypothesis):
  1. **Lack of mechanism for moving continents**: how continents drift on a solid earth, or why it should do (A major obstacle to accepting the continental drift: imagining solid continents moving over solid earth)
  2. **The continents not drift via solid ocean basins**: no evidence of the damage in crushed & shattered rock

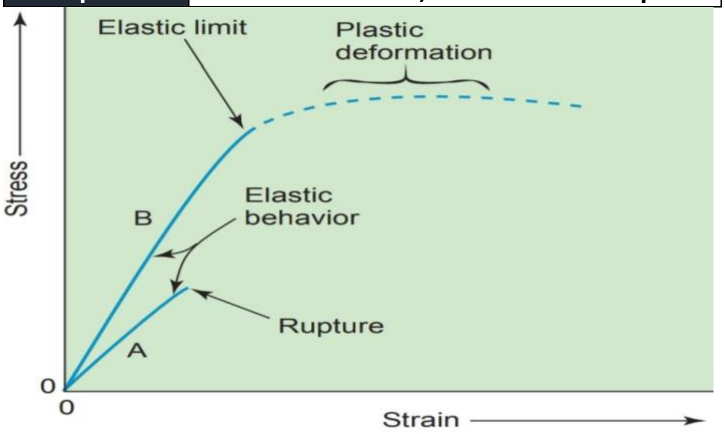
STRESS & STRAIN

- The earth in not rigid in all layers, a plastic zone lies close to the surface & rigid can move over this plastic layer
- The existence of plates & earthquakes occurrence reflect the way rocks respond to stress
- **Stress**: is the force applied on the object

Stress Type	Behavior
Compressive	Squeeze or compress the object
Tensile	Pull the object apart
Shearing	Different parts move in different directions (slides past each other)

- **Strain**: deformation resulting from stress, & may be temporary or permanent (depending on the amount & type of stress & the physical properties of the material)

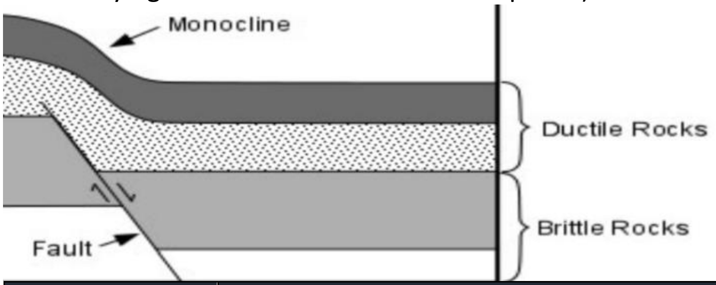
Deformation	Behavior
Elastic	**The material returns to its original size & shape when the stress is removed**
Plastic	**The changes are permanent (does not return to original size & shape after removal of stress)** Above elastic limit at higher stress, small stresses yield large corresponding strains • At higher T, rocks tend to behave more plastically (as cold & hot glass)
Rupture	**If stress increased, solids break or rupture**



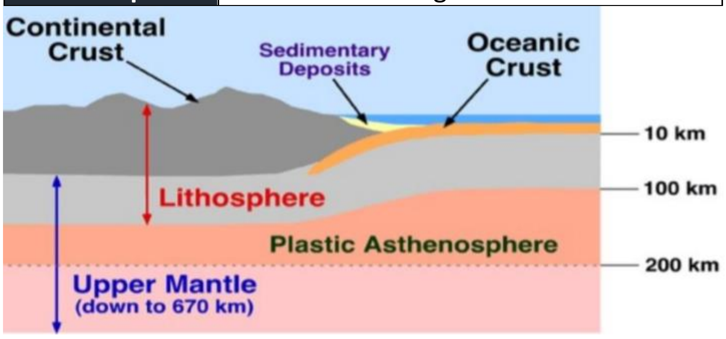
Materials	Behavior
Ductile	**High plastic deformation without breaking** • ***Rocks may behave elastically,*** but greater stress are needed to produce **detectable strain** **Folds** forms by plastic deformation (***ductile***)
Brittle	**Rupture before plastic deformation** Is characteristic of most rocks at near-surface, & leads to ***faults & fractures***

- **Confining pressure (uniform P)** promotes more-plastic, less-brittle behavior. Confining P & T increases with depth (so rocks such as gneiss metamorphosed deep in the crust, show the folds of plastic deformation)
- Rocks are stronger under compression than tension (a rock may fracture under a tensile stress only 1/10th as high as the compressive stress required to break it)
- Materials may respond differently to given stresses, depending on the rate of stress, time of stress applied

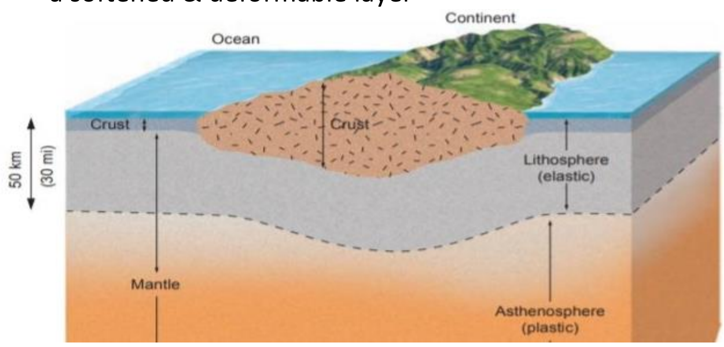
- Rocks can show elastic behavior if stressed suddenly (as by passing seismic waves), but ductile behavior in response to prolonged stress, (as from the weight of overlying rocks or slow movements of plates)



Layer	Characteristics
Lithosphere	crust & upper mantle, brittle & elastic, varies in thickness (thin under oceans up to 50km & thick in continents to 250km)
Asthenosphere	below lithosphere, extends to 300km in mantle, lack of strength & rigidity due to high T & moderate confining P (plastic), discovered by studying of seismic waves
Below asthenosphere	P increase faster than T, so the mantle becomes more rigid & elastic



- The asthenosphere makes the continental drift more plausible, because continents need not scrape across or plow solid rock but they can be pictured as sliding over a softened & deformable layer



- **Locating Plate Boundaries**
  - ➢ Earthquakes & volcanic eruptions are concentrated in belts or linear chains (at plate boundaries)
  - ➢ Fewer than a dozen large plates are identified, & many smaller ones have been recognized

PLATE TECTONICS THEORY

- Geologists studied the ocean basins & applying new instruments & techniques (measuring magnetism in rocks, or studying variations in local gravitational pull)
- Many of the new observations, & Wegener's, could be integrated into one powerful theory (Plate Tectonics)

The observation that leds to the existence of the theory	
Topography of Sea Floor	• **Mid oceanic ridge (MOR)**: long ridges (thousands of km) rising 2 km above the surrounding plains (like continental mountain ranges) • **Seamounts:** Some ocean basins are dotted with hills (volcanoes) some wholly submerged, others poking above the sea surface as islands (Hawaiian Islands) • **Trenches:** several kilometers deep • **The ages & magnetic properties of seafloor rocks** provided the keys to the significance of the ocean ridges and trenches
Paleomagnetism (fossil magnetism)	**The basis for the study of paleomagnetism**: The oceanic rocks are rich in ferromagnesian minerals (Basalt), & as magma cools & solidifies, Fe-minerals (i.e. magnetite) tend to line up in the same direction (parallel to lines of N-S magnetic field) & point to the magnetic north pole, & retain magnetic orientation unless they melted again • **Curie point**: below mineral remain magnetic & above which it loses magnetic properties, & always below mineral's melting T, so hot magma is not magnetic **Magnetic flipped, or reversed polarity**: N & S poles had switched places, some rocks magnetized in the opposite direction from the present (pointed S instead of N), the magnetic field has reversed many times, at variable intervals (millions-tens thousand of years) • **Normally magnetized:** when earth's field was in the same orientation as it is at present • **Reversely magnetized**: opposite to present fields **The explanation for magnetic reversals related to origin of the magnetic field**: The outer core is a metallic fluid (Fe), Motions in electrically conducting fluid can generate a magnetic field, & Perturbations or changes in the fluid motions, then, could account for reversals of the field
Seafloor Spreading	**Paleomagnetism**: across ridge the minerals recorded alternating bands of normal & reverse magnetized rocks • Bands "stripes" parallel & symmetrically arranged to the seafloor ridges so indicate seafloor spreading • As magma solidifies, rocks magnetized in prevailing direction of magnetic field, & if the polarity reverses during seafloor spreading, the rocks are polarized oppositely from those formed before it • The basalts of the seafloor have acted as a sort of magnetic tape recorder throughout that time **Age of the Ocean Floor** the analysis of sea floor sediment & drill into the basalt beneath, indicates the following • **Like the magnetic stripes age pattern is symmetric across each ridge:** the basalt are youngest close to MOR & oldest away from MOR on either side • **The oldest seafloor rocks** 180Ma, while Much older rocks are preserved on the continents 4Ga • **Ages of oceanic sediments reinforce the age pattern** deepest sediments are older at greater distances from the seafloor ridges, & Young sediments have been deposited close to the ridges.

Polar-Wander Curves

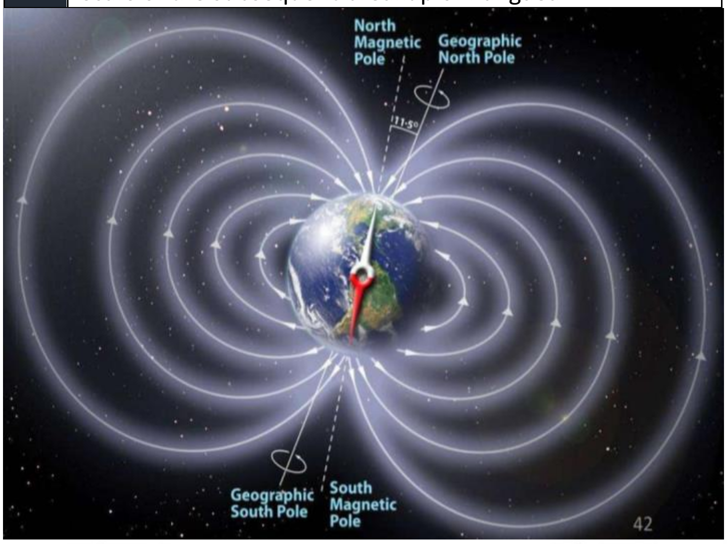
The lines of force of earth's magnetic field vary with latitude (N-S): vertical at the magnetic poles, horizontal at the equator, at varying intermediate dips in between

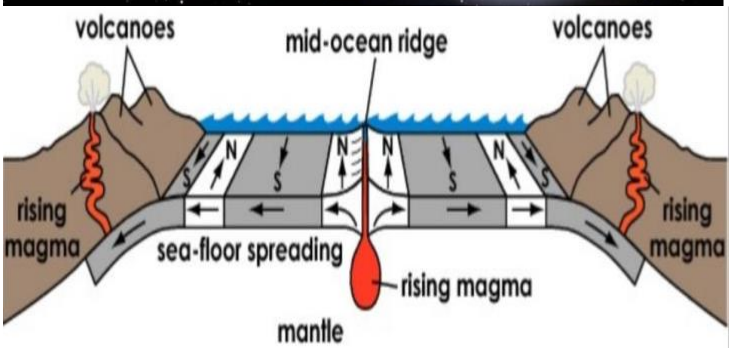
- When the orientation of magnetic minerals in a rock is determined in 3D, we can determine the direction of magnetic N, magnetic latitude, or how far removed that region was from magnetic north at the time

When the directions of magnetization & latitudes of many rocks of various ages from one continent are determined & plotted on a map, it appears that the magnetic poles have meandered far over the surface of the earth

- **Polarwander curve** showing the apparent movement of the magnetic pole relative to the continent with time (don't match for different continents, Rocks of the same age from different continents may seem to point to two very different magnetic poles)
- Magnetic have always remained close to geographic poles but the continents have moved & rotated

The polar-wander curves explained by plate tectonics theory: 200Ma, there was indeed a single supercontinent, the one that Wegener envisioned & named Pangaea. The present seafloor spreading ridges are the lithospheric scars of the subsequent breakup of Pangaea





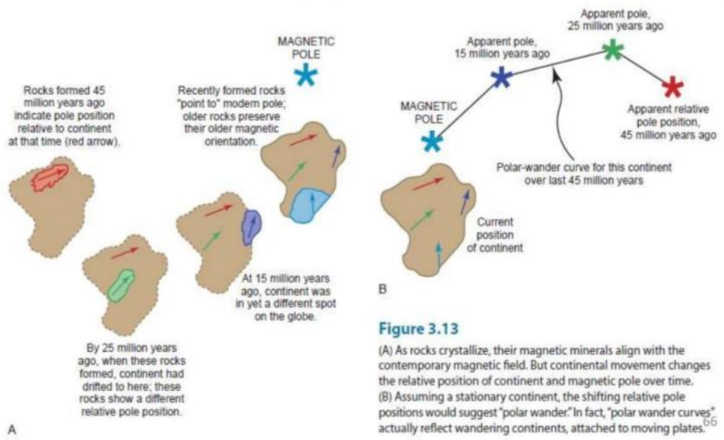


Figure 3.13

(A) As rocks crystallize, their magnetic minerals align with the contemporary magnetic field. But continental movement changes the relative position of continent and magnetic pole over time. (B) Assuming a stationary continent, the shifting relative pole positions would suggest "polar wander." In fact, "polar wander curves" actually reflect wandering continents, attached to moving plates.

THE PLATE BOUNDARIES

Types of Plate Boundaries

Divergent Plate Boundaries (DPB)

Lithospheric plates move apart

- P-release leds to melting in asthenosphere & magma wells up by deep fractures formed by tensional stress
- Volcanic activity & earthquakes occurs at DPB
- **Seafloor spreading:** is a divergent boundary where formation of new oceanic lithosphere take place
- As seawater circulates via fresh & hot lithosphere, it is heated, reacts with the rock, & become metal-rich, & as gushes back out of the sea floor, cooling & reacting with cold seawater, it precipitate valuable deposits (Economically unprofitable to mine now)
- Most ocean basins are originated through continental rifting, the process that initiated by:
  1. Tensional forces pulling the plates apart
  2. Rising hot asthenosphere along the rift zone

E.g. E-Africa, where 3 rift zones meet in a triple junction

- The Afar depression in Ethiopia is a rift valley
- Along two branches formed the Red Sea & the Gulf of Aden continental separation has proceeded to the point of formation of oceanic lithosphere

Convergent Plate Boundaries (CPB)

Plates are moving toward each other

- **Continental crust:** low density, buoyant with respect to the dense mantle, tends to float on asthenosphere
- **Oceanic crust:** denser, less buoyant & easily forced down into the asthenosphere
- **Subduction zone**: one plate pushed under the other & descend into the asthenosphere where subjected to higher P & metamorphosed into denser rocks

The subduction zones balance seafloor equation: as new oceanic plate created at ridges, equal amount destroyed in subduction zone (excess sea floor is consumed)

Subduction zones are, geologically, very active places:

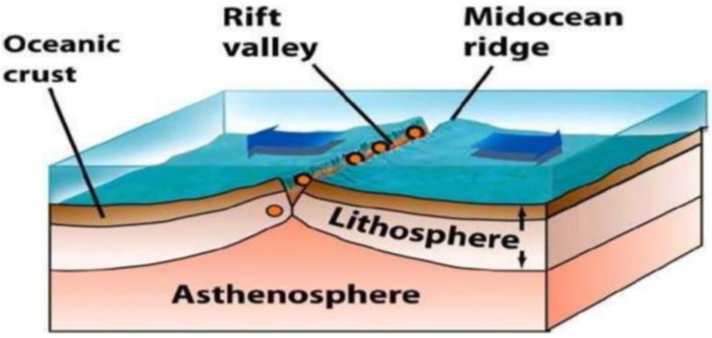
1. Sediments eroded from continents may accumulate in the trench & carried down into the asthenosphere
2. Volcanoes form where molten material rises up through the overlying plate to the surface
3. Island arcs: a line of volcanic islands at ocean-ocean
4. Great stresses near subduction zonw give rise to EQs
5. Is the place of mountain building, & its associated volcanic & earthquake activities

Most important subduction zones: The Andes region (America), China, Japan, & the rim of the Pacific Ocean

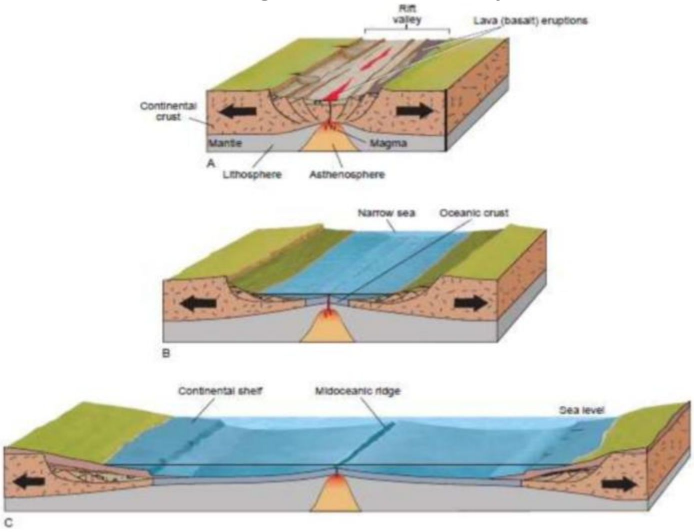
Earthquakes are frequent during continent-continent collision: Paleomagnetic evidence indicates that India was drifted toward Asia, & the Himalayas were built up, & Appalachian Mountains were built in the same way, as Africa & N-America converged prior to Pangaea breakup

Transform Boundaries

- The MOR consist of short segments slightly offset from one another (fault, or break in the lithosphere known as a **transform fault**)
- The opposite sides of a transform fault belong to two different plates, & moving in opposite directions
- As the plates scrape past each other, Eqs can occur
- Transform faults occur between trench (subduction zone) & spreading ridge, or between 2 trenches
- e.g. San Andreas fault, DeadSea transform fault both are between the subduction zone & spreading ridge
- The stress resulting from the shearing displacement across the fault leads to ongoing earthquake activity



Divergent Plate Boundary



Continental Rifting

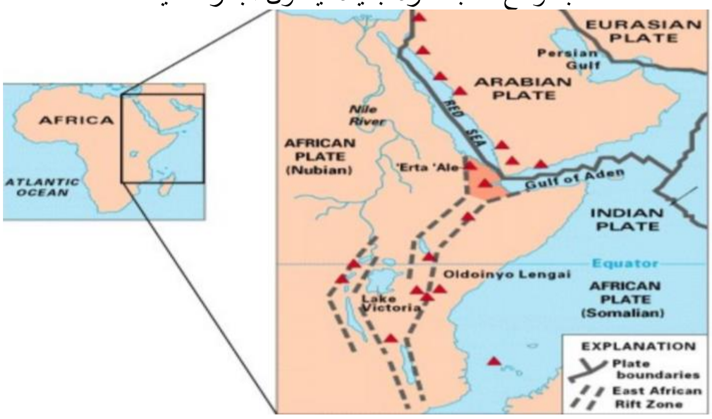
Mechanism Of The Continental Rift (الشق القاري)

Doming & Upwarping: تحت تتدفق الصهارة من باطن الارض الى اسفل القارة ما يؤدي لعملية شد للقارة في اتجاهين متعاكسين

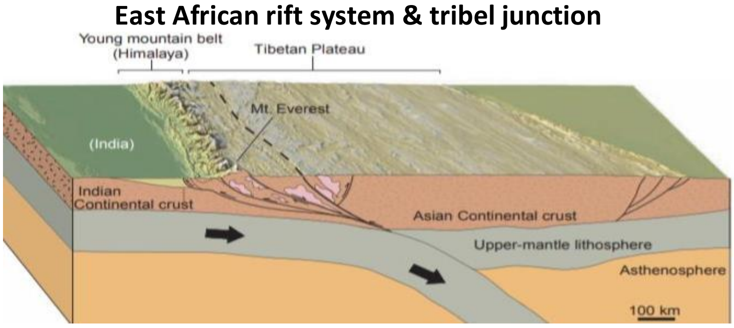
Continental rift (elongated depression): تستمر عملية الشد وبسبب حرارة الصهارة تصبح القشرة القارية ضعيفة ما يؤدي لتشققها وتصبح المنطقة منخفضة وهذا ما يسمى الشق القارة

Narrow Sea (Sea Linear): بعد حدوث الانخفاض تبدأ المياه بالتجمع في هذا المنخفض فيتكون بحر (ولا يكون يحتوي بعد على حزام المحيط)

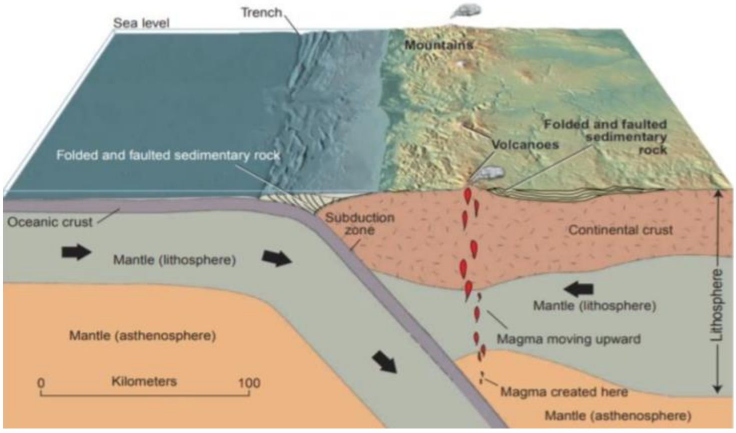
Mid Oceanic Ridges & Volcanic Activity: هذه في المرحلة تبدأ الصهارة بالتدفق الى السطح فينشأ الحزام المحيطي وتبدأ القشرة المحيطية بالتوسع منتجة قارة جديدة فيتحول البحر لمحيط



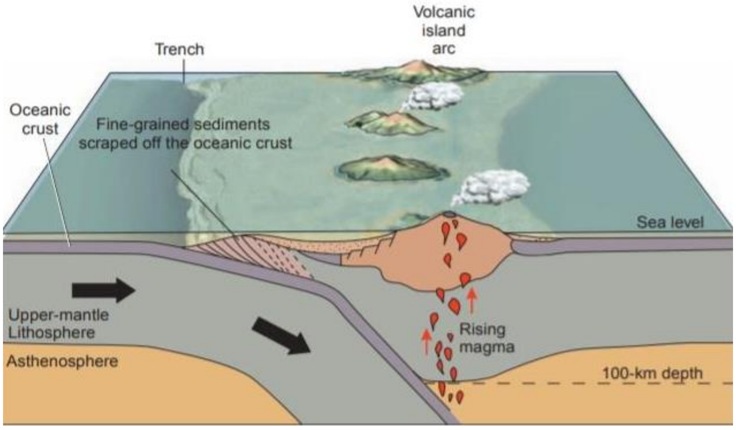
East African rift system & tribel junction



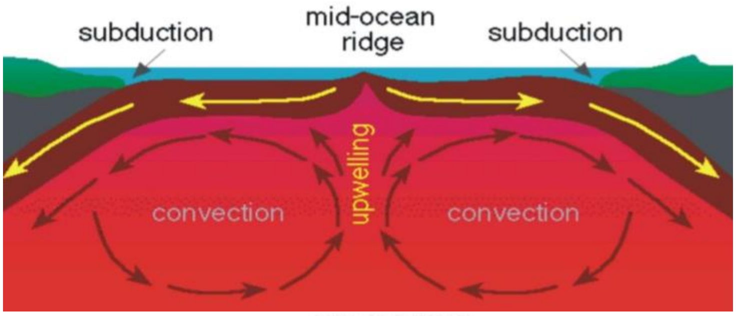
Continental-Continental Convergence

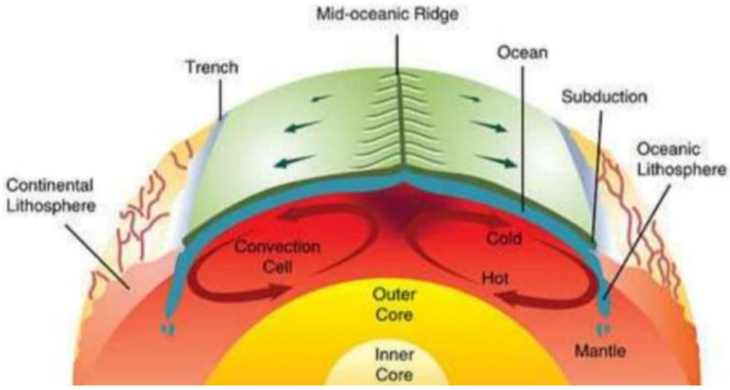


Continental-Oceanic Convergence

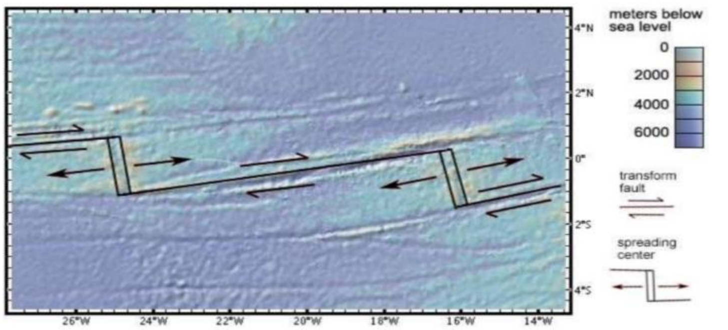


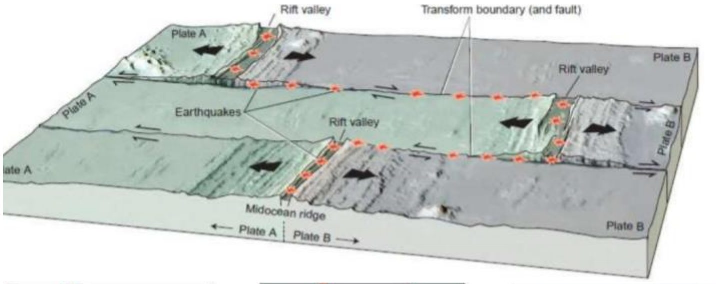
Oceanic-Oceanic Convergence

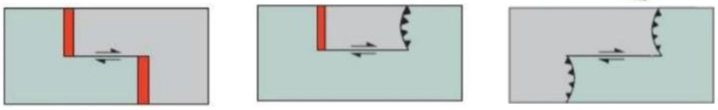




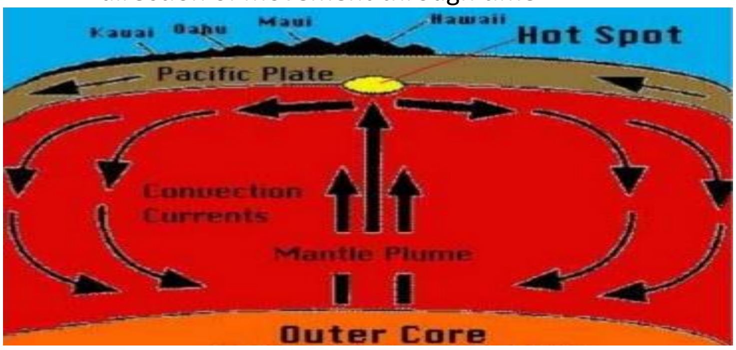
Convection Flows

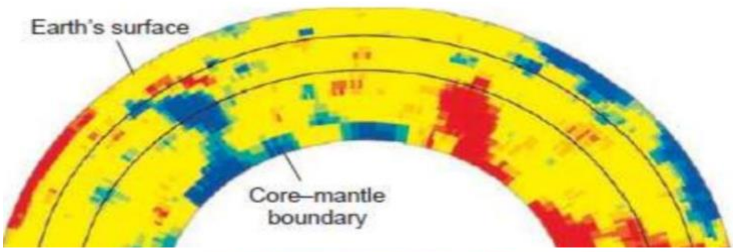


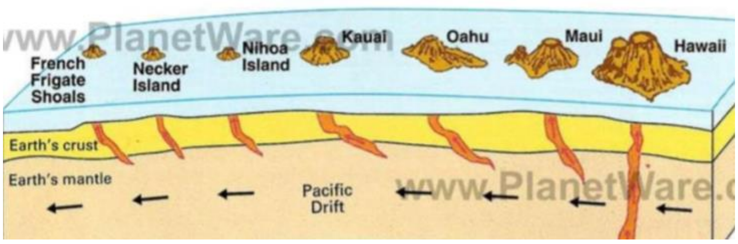




- **Rates & directions of plate movement determined by**
  1. Polar-wander curves from continental rocks
  2. Seafloor spreading away from the ridge
  3. Mantle plumes & hot spots
- **Rates of seafloor spreading** found by dating rocks at different distance & dividing the distance by rock's age
  - ➢ e.g. For 10Ma sea floor is collected at 100Km, the average rate of movement 100km/10Ma (1cm/yr)
- **Hot Spots**: areas of volcanic activity, not associated with plate boundaries but attributed to rising warm mantle material (plumes), originating at the base of the mantle
  - ➢ Reduction in P as plume rises lead to partial melting
  - ➢ If hot spots remain fixed in position & lithospher move over them, the result should be a volcanoes of differing ages with the youngest closest to the hot spot & oldest away from hotspot (e.g. Hawaiian)
  - ➢ Orientation of islands indicates direction of plate movement, & the kink indicates thae changes in the direction of movement through time





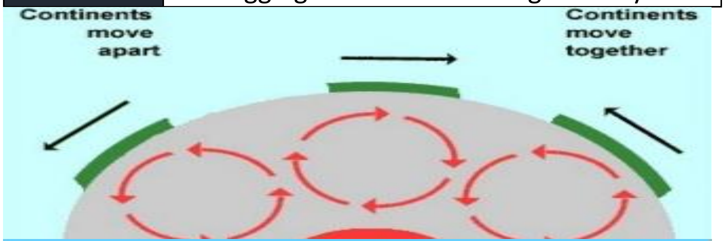


- **Past plate motion can quantified using other methods:**
  1. Widths of strips of sea floor or Points of known age
  2. Position along a continent's polar wandering curve
  3. Satellite-technology for modern plate movement
- The Avg rate of plate motion = 2-3cm/yr (up to 10cm/yr)

WHY DO PLATES MOVE?

- The plates move by **convection cells in asthenosphere:**
  - ➢ **At spreading ridges**: hot material rises upward to form new lithosphere, & the rest of magma spreads beneath lithosphere (slowly cooling & open ridges)
  - ➢ **Under subduction zones**: colder material sink back deeper into the asthenosphere

	Models of Forces
Slab-pull	The weight of downgoing slab of lithosphere pulls the rest of the trailing plate along with it, opening up the ridges so magma can ooze upward, Mantle convection might then result from lithospheric drag, not the reverse
Ridge push	Slabs (Sliding) of plates, the topographic highs at ridges & rift by rising warm mantle, & dragging some mantle along laterally



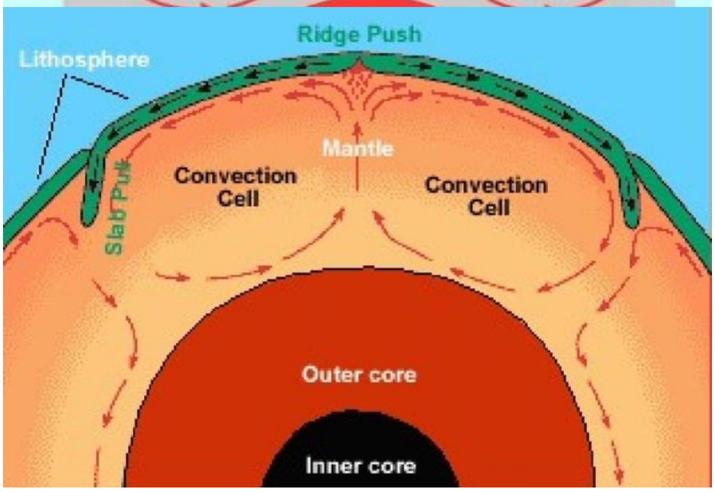


PLATE TECTONICS & ROCKS

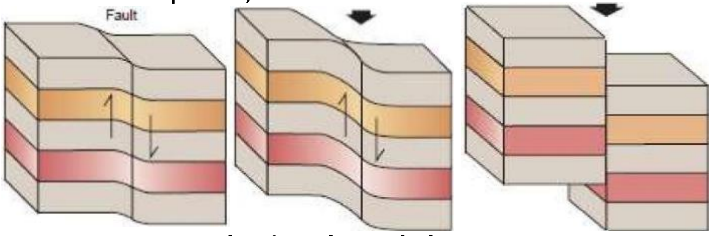
- New igneous rocks form from magmas rising at spreading ridges or in subduction zones
- **Metamorphism**: can causes by the following processes
  - ➢ Heat radiated by cooling magmas: contact metamorphesim due to heat released by magma
  - ➢ The pressure of plate collision at convergent plates
  - ➢ Sedimentary rocks may be metamorphosed by the stresses & the igneous activity at the plate margins
- **Igneous rock formation**: sediments, sedimentary rocks, igneous rocks, or metamorphic materials may be carried down with subducted oceanic lithosphere, to be melted & eventually recycled as igneous rock
- **Sedimentary rock formation:**
  - ➢ Weathering & erosion on the continents wear down preexisting rocks of all kinds into sediment
  - ➢ Much of sediment is transported to the edges of the continents, & deposited in deep basins or trenches
  - ➢ Through burial under more layers of sediment, it may become solidified into sedimentary rock

CHAPTER FOUR

EARTHQUAKES

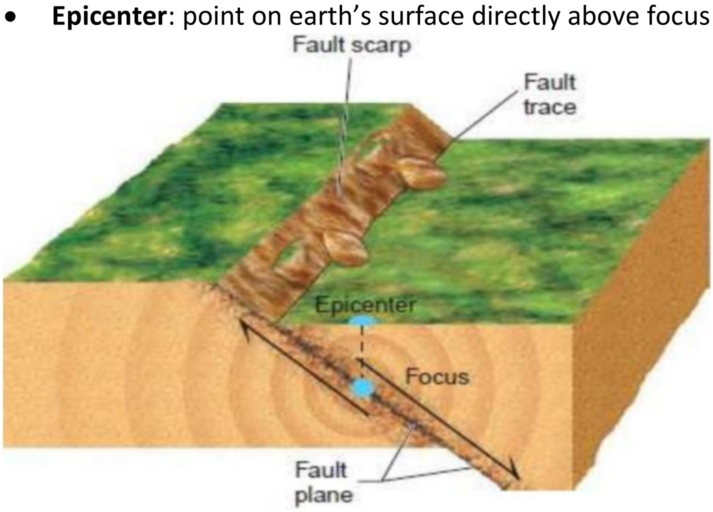
BASICS & PRINCIPLES

- **Earthquakes (EQ)** represent a release of built-up stress in the lithosphere along faults & plate boundaries
- The stress may produces new faults or breaks, & slipping along old faults
- **Creep (seismic slip)**: gradual & smooth movement along faults, or fault displacement without significant EQs
- **In term of deformation:**
  - ➢ If friction between rock prevents rock from slipping, some ***elastic deformation*** occur before ***failure***
  - ➢ If the stress exceeds the ***rupture strength*** of the rock, a sudden movement occurs to release the stress (an earthquake , or seismic slip)
  - ➢ After removing of applied stress, the rocks back elastically to their previous dimensions causing earthquakes; this behavior is called ***elastic rebound***

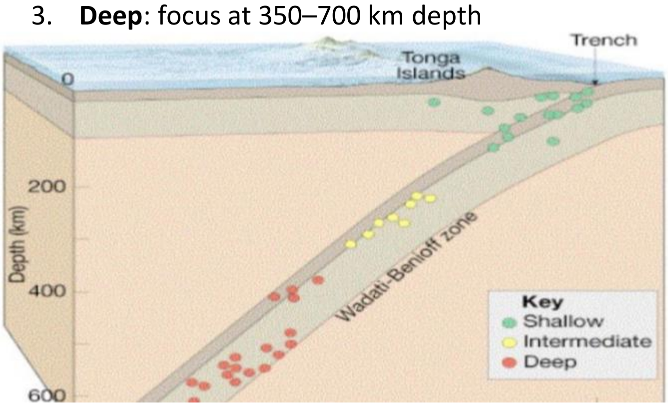


Elastic Rebound Theory

- Faults come in all sizes, so earthquakes come in all sizes (from tremors to massive shocks that can level cities)
- **Earthquakes damage** is a function of energy released
- **Focus (hypocenter):** The point on a fault at which the first movement or break occurs
- **Epicenter**: point on earth's surface directly above focus

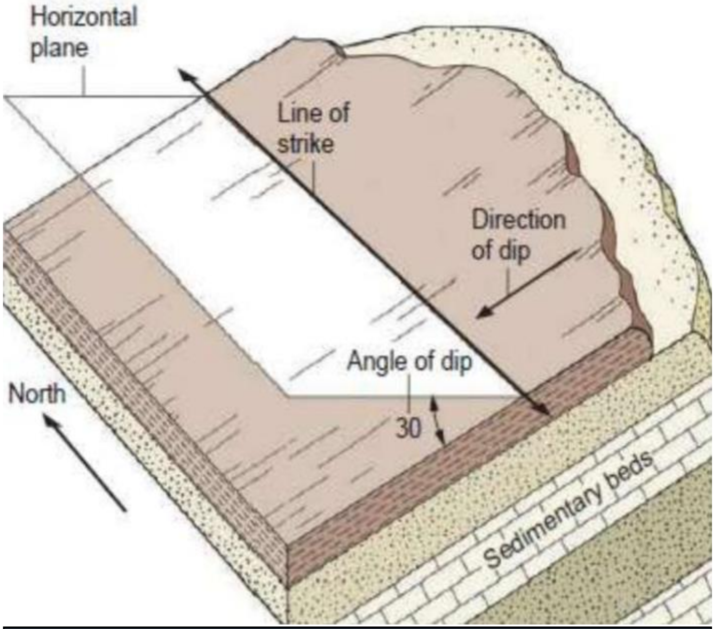


- **Earthquakes types:**
  1. **Shallow**: focus at 0–70 km depth
  2. **Intermediate**: focus at 70–350 km depth
  3. **Deep**: focus at 350–700 km depth

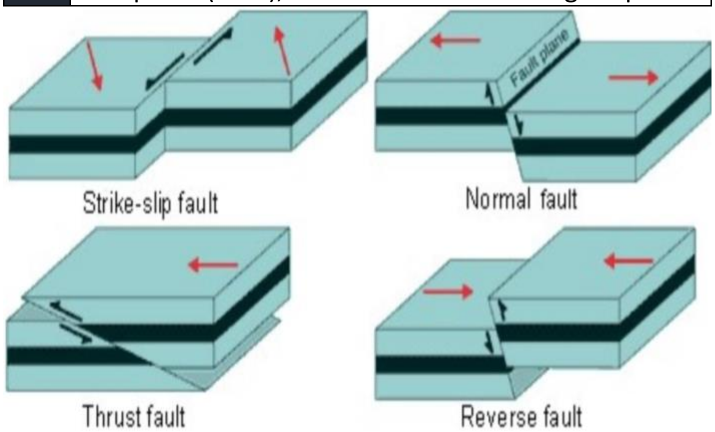


FAULTS

- **Faults**: planar breaks in rock along which there is displacement of one side relative to the other, described in terms of the nature of the displacement
- **The strike**: is the compass orientation of the line of intersection of the plane of interest with earth's surface
- **The dip**: is the angle the plane makes with the horizontal (the steepness of slope of the plane)



Types of faults	
Strike-slip	**If the displacement is parallel to strike (horizontal)** • **A transform fault:** is a type of strike-slip fault & reflects stresses acting horizontally • **Example**: San Andreas fault, & Dead Sea Transform Fault System
Dip-slip	**If the displacement is vertical (up or down of dip)** • **Normal fault:** block above moves down relative to the block below (tensional stress or gravity) • **Reverse fault:** block above move up relative to the block below (ndicates compressional stress) • **Thrust faults:** reverse with shallow dip fault plane (<45°), associated with convergent plates

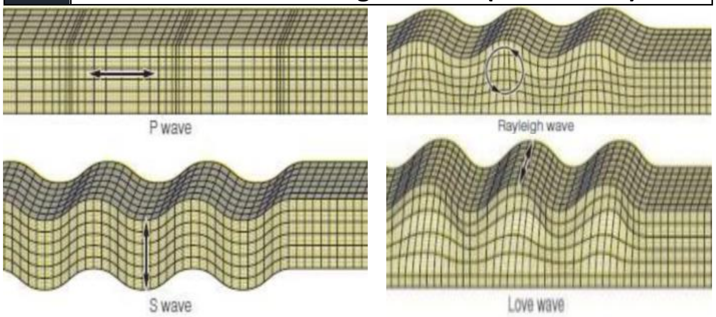


- **The locations of major earthquake epicenters** are concentrated in linear belts (plate boundaries), plate movements may build up very large stresses, where major faults or breaks already exist, but intraplate earthquakes certainly occur, & may be quite severe near intraplate faults

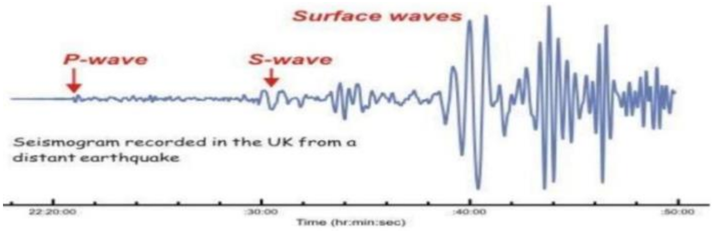
SEISMIC WAVES

- When an earthquake occurs, it releases the stored-up energy in seismic waves that travel away from the focus

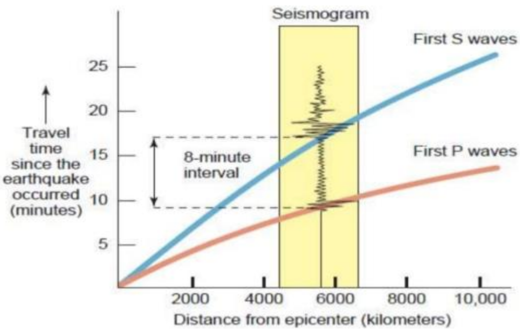
Types of seismic waves		
Body waves	**Travel through earth interior** (Smaller in amplitude, cause less structure damage, & faster than surface)	
	P-Waves	**Called:** Primary or Compressional waves **Affect:**Compress & expand matter like Slinky toy **Speed:** Fastest Waves (First Recorded Wave) **Intensity & Amplitudes:** Weakest wave **Travel through**: Liquid, Solid, or Gas
	S-Waves	**Called:** secondary or shear waves **Affect:** involving a side-to-side movement **Speed:** Faster than surface wave, slower than P **Intensity/Amplitude:** weaker than surface wave **Travel through**: Solid only
Surface	Larger in amplitude, cause more structure damage, & Slower than body waves. Cause rocks & soil to be displaced in such a way that the ground surface ripples or undulates, & similar to waves on water • **Vertical motions (rhyleigh):** like ripples on pond • **Horizontal shearing motions (love waves)**	



Types of seismic waves



- **The epicenters can be located using the body waves:** seismograph record P & S wave, the difference in arrival times is a function of distance to earthquake's epicenter
  - ➢ The farther receiving seismograph from epicenter, the greater the time lag between P & S waves
  - ➢ **Triangulation method**: at least 3 recording stations needed to determined the distances from the epicenter, the epicenter can be located on a map
  - ➢ **Complicating factors** (inhomogeneities in the crust) make epicenter location somewhat more difficult



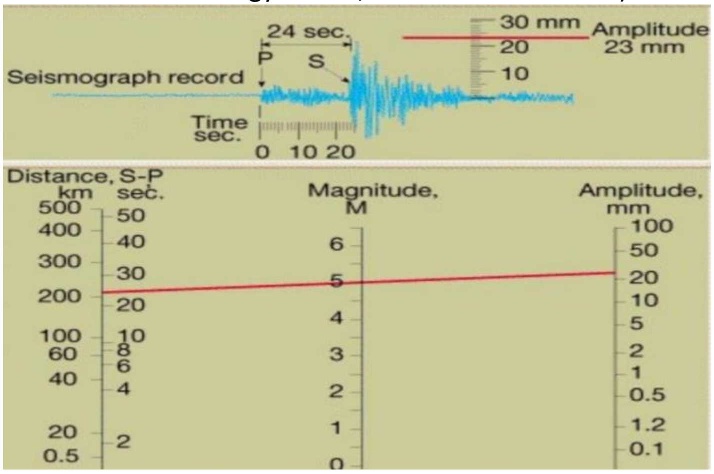
Difference in times of first arrivals of P & S waves is a function of the distance from the earthquake focus

MAGNITUDE & INTENSITY

- **Seismic waves:** acoustic waves that represents energy release & transmission & cause the ground shaking
- **Amplitude**: is the amount of ground displacement
- **Magnitude**: is the amount of ground motion, reported using Richter magnitude scale
- **Richter magnitude scale**: measured the magnitude of earthquakes depends on amount of ground motion or shaking near the epicenter (logarithmic scale)

e.g. 4 magnitude causes 10 times ground movement than 3, & 100 times than 2…)

- **The amount of energy released** increase 30times with increased magnitude by 1, (e.g. 4 magnitude releases 30 times more energy than 3, & 900 times than 2…)



- The amount of ground motion is measured by a seismograph (the size of highest-amplitude), & tends to decrease with increasing distance from the earthquake
- Different measuring stations in different places will arrive at the same estimate of the ground displacement.
- There is NO upper limit of the Richter scale: the largest recorded earthquakes have had magnitudes of 8.9

Descriptor	Magnitude	Per yr	Avg. Energy
Great	≥ 8.0	1 – 2	>$5.8x10^{23}$
Major	7.0 – 7.9	18	$23x10^{22}$
Strong	6.0 – 6.9	120	$79x10^{20}$
Moderate	5.0 – 5.9	800	$29x10^{19}$
Light	4.0 – 4.9	6,200	$10.5x10^{18}$
Minor	3.0 – 3.9	50,000	$38x10^{16}$
Very minor	< 3.0	> 50,000	< $4x10^{16}$

- **Limitations of Richter magnitude scale:**
  1. **Type of earthquakes**: the scale was developed in USA, where EQs are shallow-focus (result of strike-slip fault) & other area have different focal depth
  2. **A single earthquake can produce different effects**
- A better measure for very large EQs of energy release is **moment magnitude scale (MW)** that takes into account
  1. The area of break on the fault surface
  2. The displacement along the fault during the EQs
  3. The strength of the rock (force needed to rupture)
- **Intensity**: is the EQs effect on human & surface feature, more direct indication than magnitude, in which the extent of damage is related to the maximum ground velocity & acceleration (**Modified Mercalli Scale**)

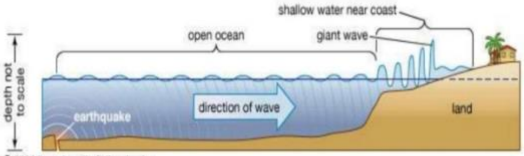
- **Intensity is subjective measure:**
  1. Observations of individuals
  2. Observers in same spot assign different intensity

Modified Mercalli Intensity Scale	
Intensity	**Distribution**
i (1)	Not Fell
ii (2)	Felt by persons at rest on upper floors
iii (3)	Felt indoors (hanging objects swing)
iv (4)	Widows, Dishes, & Doors rattle, Wales may creak
v (5)	Felt outdoors, small opjects move
vi (6)	Felt by all people, windows broken, trees shaken
vii (7)	Difficult to stand, Damage to weak materials
viii (8)	Steering automobile & Houses affected, & Collapse
ix (9)	Panic, Structures shifted, underground pipes broken
x (10)	Rails bent slightly, large landslides, dams & dikes damage, structures destroyed with their foundation
xi (11)	Rails bent greatly, Underground pipeline stops
xii (12)	Total Damage, rock shifted, objects thrown to the air

- **The surface effects are vary as a result of the following:**
  1. Local geologic conditions
  2. Nature of local geology: the area affected is near the coast?, Whether the terrain is steep or flat?
  3. Quality of construction
  4. Distance from the epicenter

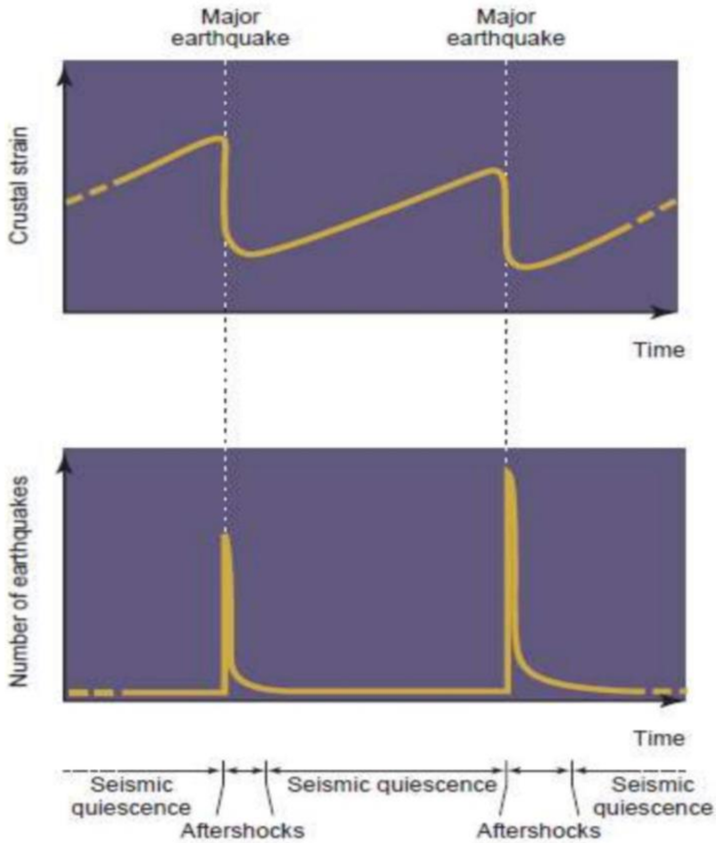
EQ-HAZARDS & REDUCTION

Earthquakes Hazards & Reduction	
Ground Motion (obvious hazard)	**Caused by movement along the fault that can break the offset between rocks** (power lines, pipelines, buildings, roads, bridges…) • The solution: 1. NOT to build near fault zones! 2. Enhance the building codes 3. Planning design: pipelines can be built with extra slack, or designed allow some "give"
Ground Failure (secondary hazard)	**Landslides:** occur on unstable slopes during EQs • *The solution:* NOT to build in such areas! **Liquefaction:** occur when the wet soil is shaken (water seep between particle, reducing friction) • *Affect:* Buildings sink into the liquefied soil • *Telltale signs:* sand boils as soil bubbles • Improved underground drainage system
Fire (secondary hazard)	**May be most devastating hazard than ground movement in cities** • 70% of damage in San Francisco EQs • Occur because: power & water lines broken • Solution: putting valves in pipeline systems
Tsunamis (secondary hazard)	**Tsunamis**: seismic sea waves affect coastal areas (especially around the Pacific Ocean) • During EQs, sudden movement of sea floor set up waves traveling away from that spot forming tsunami & water come ashore as a fast & high moving wall of water • In the open sea, tsunamis are broad swells & travel rapidly over long distances • **Solution:** Tsunami Early Warning System

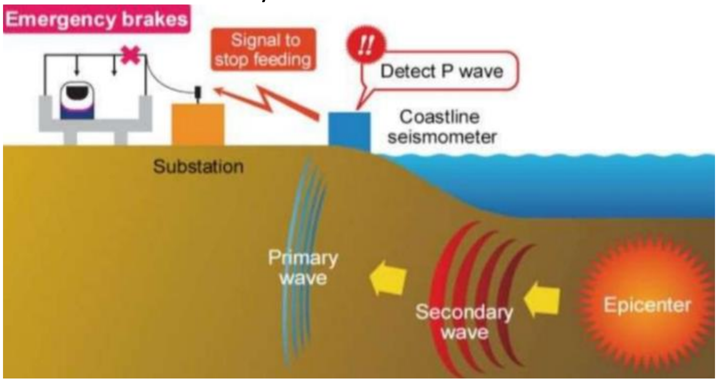


PREDICTION & FORECASTING

- **Seismic Gaps:** stretches along faults with little seismic activity, & represent locked section of active faults along which friction is preventing slip & accumulates energy & when fault slip, cause a very large earthquake
  - ➢ Recognition of seismic gaps makes it possible to identify areas in which large EQs may be occur
- **Things that happen or rock properties that change prior to earthquake (possibilities prior the earthquake)**
  1. Uplifting or tilting of the ground surface
  2. Change of seismic-wave velocity in rocks near fault
  3. Change electrical resistivity & water levels in wells
  4. Changes in the content of radon gas
  5. Anomalous behavior of animals
- Only 4 nations (Japan, Russia, China, USA) have had government sponsored EQ prediction programs, involve
  1. intensified monitoring of active fault zones
  2. observational data base
  3. laboratory experiments designed to increase understanding the behavior of rocks under stress
- **Earthquake cycle:** dates of large historic EQs along fault zones have suggested that they may be periodic
  1. A period of stress buildup
  2. Sudden fault rupture in a major earthquake
  3. Eqs followed by a brief interval of aftershocks
  4. Another extended period of stress buildup
- The rough periodicity understood by 2 considerations (suggest that periodicity is a reasonable expectation)
  1. Stress is associated with the slow, heavy, & nonstop movements (moves at constant rates), might expect constant rate of build of stress (elastic strain)
  2. Rocks along fault will accumulate energy before failure or rupture, that are constant from EQ to EQ



- **Estimation**: If the pattern for a fault zone is established (with strain accumulation) the time window during which the next EQ can be estimated, & if a fault can store only a certain amount of energy before failure, the maximum size of EQ can be estimated
- **Early Warning System**: based on the travel times of seismic waves in which surface waves travel more slowly than P & S waves, so earthquakes can be located seconds after they occur



- To decide when warnings should issued & automated-response systems activated, EQs magnitude should be known (not to react to every small EQs), but It is difficult to get accurate measure of magnitude in seconds
- **EQs early warnings issued a few seconds before an EQ strikes, the good would that do:**
  1. Trains could be slowed & stopped
  2. Traffic lights adjusted to get people off bridges
  3. Elevators stopped at the nearest floor
  4. Automated emergency systems for valves in fuel & chemical pipelines & nuclear power plants
  5. People in homes or offices could quickly take cover under sturdy desks & tables

EARTHQUAKE CONTROL

- **To reduce the risk of earthquakes:**
  1. Changes in land use, & Construction practices
  2. Siting comprehensive disaster-response plans for Earthquake-prone areas
  3. Improving public response by education
  4. Enhance the building codes
  5. Use of fluid enjection techniques in the area of seismic gaps
- **Challenges of building codes:**
  1. Experiments may not simulate real EQs
  2. Same building codes cannot be applied everywhere due to the different ground motion patterns
  3. Considering not only how structures are built, but what they are built on: built on solid rock (bedrock) less damage than built on deep soil
  4. Shaking amplified in unconsolidated materials
  5. **Aftershocks** should be considered
  6. The duration affects how well a building survives

FLUID ENJECTION

- Human efforts to stop earthquakes from occurring would seem to be futile, there has been speculation about the possibility of moderating some of earthquakes' most severe effects
- If locked faults, or seismic gaps, areas of accumulating energy, perhaps enough to cause a major earthquake, then releasing that energy before too much has built up might prevent a major catastrophe
- The increased fluid pressure in the cracks & pore spaces in the rocks resulting from the pumping-in of fluid decreased the shear strength, or resistance to shearing stress, along the fault zone
- Fluids in fault zones may facilitate movement along a fault. Such observations at one time prompted speculation that fluid injection might be used along locked sections of major faults to allow the release of built-up stress. Geologists are far from sure of the results to be expected from injecting fluid (probably water) along large, locked faults.
- There is certainly NO guarantee that only small earthquakes would be produced. Indeed, in long time locked faults, injecting fluid along that fault could lead to the release of all the stress at once (damaging earthquake). Therefore, this technique might Be more safely used in:
  1. major fault zones that have not been seismically quiet for long, where less stress has built up
  2. in areas of low population density to minimize the potential danger