Plate Tectonics Theory

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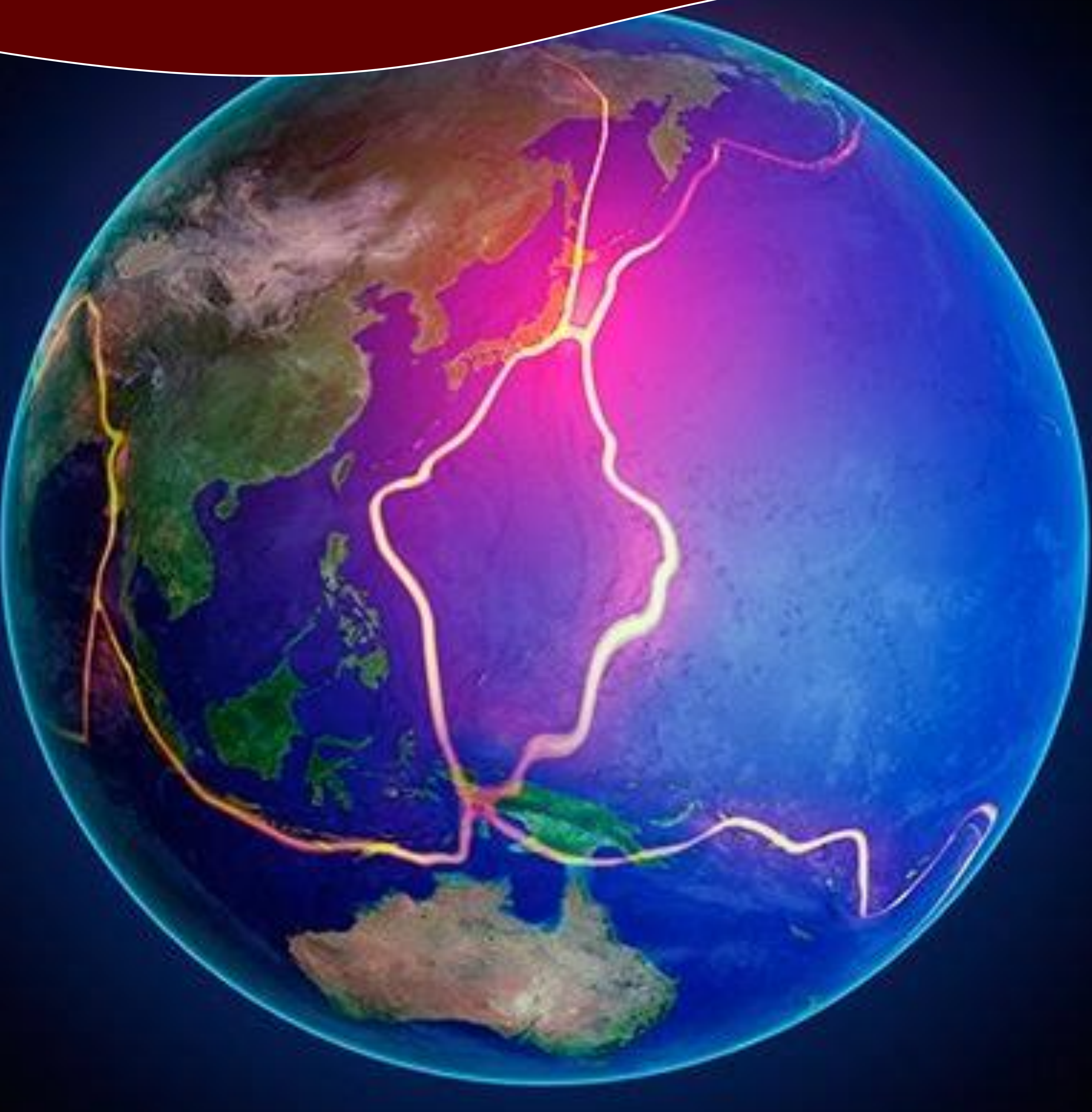
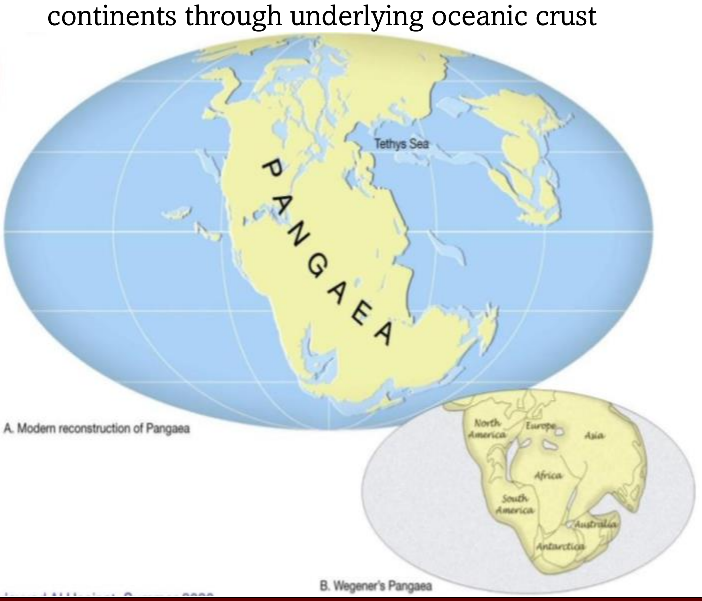


Chapter One

INTRODUCTION TO PLATE TECTONICS THEORY

PLATE TECTONICS

- **Plate Tectonics**: is the theory that state that Earth's outer shell is divided into several plates that glide over the mantle (rocky inner layer above core) The plates act like a hard & rigid shell compared to mantle & the continents gradually migrate across the globe
- **Pathymetry**: is a seafloor topography
- **Plate Tectonics Mechanisms:** a new ocean basins are created between diverging block where landmass split apart, & older portions of the seafloor are carried back into the mantle near oceanic trenches in deep ocean floor, & Earth's great mountain range are formed where blocks of continental crust collides
- A scientific revolution was began by Alfred Wegener hypothesis "**Continental Drift**" that Rejected after a heated debate for many years, but then Aspects of **Continental drift** & **Seafloor spreading** incorporated into **Plate Tectonics theory**
- **Continental Drift**: Wegener published *the Origin of Continents & Oceans*, state that Supercontinent (Pangaea) about 200Ma began breaking apart then drifted to the present conditions, & the movement of continents through underlying oceanic crust



Evidence used for continental drift hypothesis	
Fit of continents (shoreline)	e.g. S-America & Africa shorelines (وجد فيغنر تطابق بحدود القارات خاصة بين افريقيا وامريكا الجنوبية) • Few places where continents overlapped because stream deposites enlarging continental shelves
Fossil evidence	Identical fossil organisms were known from rocks in S-America & Africa, e.g. Mesosaurus • بعض المستحاثات متطابقة بحواف القارات مثل الموجودة في امريكا الجنوبية وافريقيا (Mesosaurus) وهي احافير برمائية لكنها لا تستطيع السباحة لمساحات طويلة • **Mesosaurus**: aquatic fish catching reptile found in black shale of Permian 260Ma
Rock structural similarity	Appalachian Mountains (America & Africa), & Mountains in Greenland & Scandinavia • وجد فيغنر انواع من الصخور بافريقيا وامريكا تعود لنفس الفترة الزمنية والسلاسل الجبلية في حدود الصفائح متطابقة
Paleo-climatic evidence	Glacial debris in what is now tropical regions • وجد فيغنر Glacial debris بمناطق حارة ما يدل انها كانت بمناطق متجمدة وبالتالي تغيرت اماكن القارات

- **Great Debate**: Wegener's hypothesis was rejected
  1. **Lack of a mechanism for moving continents**
  2. Assumption. the tidal **influences of the Moon** was strong enough to move the continents
     - ❖ Opponents. magnitude of tidal friction brings rotation to a halt in a matter of few years
  3. Assumption. **continents broke through the oceans**, much like ice breakers cut through ice
     - ❖ Opponents. no evidence that the ocean floor weak enough to breakup without deformation

  ➢ **Result:** hypothesis are correct in principle, but incorrect in details. a few scientists considered Wegener's ideas plausible & continued the search
- The New Paradigm Scientific developments led to the existence of ***Plate Tectonic theory***, the development that led to the foundation of Plate Tectonics are
  1. The discovery of a global oceanic ridge system
  2. Tectonic activity was occurring at great depths beneath deep-ocean trenches
  3. No oceanic crust older than 180Ma
  4. Sediment accumulations in the deep ocean basins were found to be thinner than expected
- **A major departure of tectonic theory from Wegener's hypothesis** الفرق بين فاغنر والصفائح التكتونية
  - ➢ continents moved through ocean floor, not with it
  - ➢ No plate is defined only by margins of a continent
- **Movement mechanism**: plates move as coherent units at a very slow rate (5cm/yr) & this movment drives from unequal distribution of heat & generate earthquake, volcanoes, mountain, deformed the rock
- **Proofs of Tectonic Theory:**
  1. The **geometric fit** of the displaced continents
  2. the **similarity of rock ages & Paleozoic fossils** in corresponding bands or zones
  3. **Ocean topography** (mid-oceanic ridges)
  4. the **existence of ophiolte suites** (slivers of oceanic floor with fossils) in upper mountain chains due to the uplift of crust in collision zones
  5. the **magnetic signatures or orientations** of rocks on either side of divergent boundaries

Earth Plates According to plate tectonics model	
Lithosphere	Is the crust & uppermost mantle, behaves as a strong & rigid layer, that broken into pieces called plates • Oceanic lithosphere (0-10Km) • Continental (100-150 — 250Km)
Asthenosphere	weaker region in mantle, the rocks near melting T that results in a very weak zone that permits lithosphere to be detached down ward

- **There are 7 (up to 13) major lithospheric plates:** N.American, S.American, Pacific (largest), Eurasian, Australian, Indian, & Antarctica, & **Most of plates include entire continent + area of oceanic floor**
- The interior of plates may experience deformation, all major interactions among individual plates occur along their boundaries, & **Boundaries were first established by plotting locations of earthquakes**

PLATE BOUNDARIES

Divergent (constructive margins)

located along the crests of oceanic ridges, new oceanic lithosphere is generated

- **Seafloor spreading (after Hess)**: seafloor is elevated forming oceanic ridge, the mechanism operates along the oceanic ridge system to create new seafloor, adds new materials to oceanic floor & bushing older rock away from ridge
- **Oceanic ridge**: longest topographic feature on the surface (Rift Valley is found along ridge axis)
- **Continental Rifting (Rift Valley):** Divergent plate boundary can develop within a continent as Wegener had proposed for the break of Pangaea
- **The Red Sea formed when the Arabian plate rifted from Africa 20Ma,** but not all rift valley develop to full-spreading centers

Convergent (destructive margins)

As plates move toward each other, one (denser) slide beneath other, called **destructive** because lithosphere is destroyed, & can also called **subduction zones**

- Angle of subduction ranged from 0-90° (Avg. 45°)
- **Ocean trench**: is the surface expression of the descending plate (e.g.Peru-Chile trench)
- The density of the descending (subducted) plate is denser than the asthenosphere

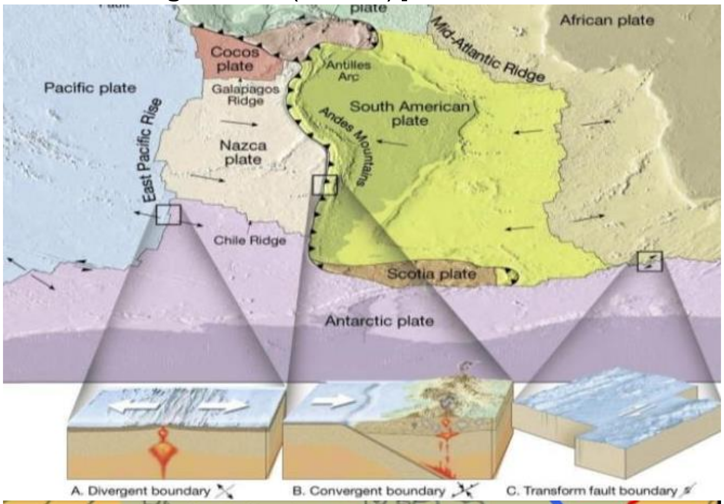
$$\rho_{\text{continental lithosphere}} < \rho_{\text{asthenosphere}} < \rho_{\text{oceanic lithosphere}}$$

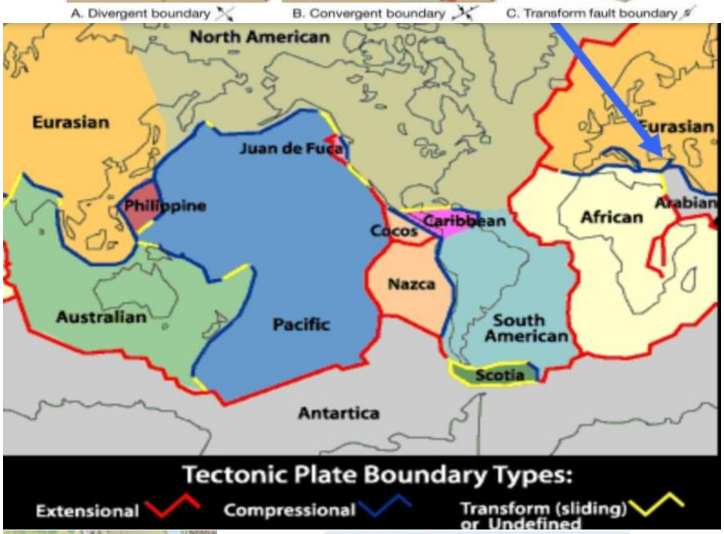
- **Oceanic-Continental:** Denser oceanic slab sinks into the asthenospher, Along the descending plate partial melting of mantle rock generates magma (100) & volatiles (water) act as salt does to melt ice
  - ➢ Molten magma (less denser than mantle) rises toward surface as a teardrop-shaped structure
  - ➢ **Continental volcanic arc** (***Andes***) volcanic mountain chain formed when magma ascend to surface & give rise to a volcanic eruption
  - ➢ **Partial melting:** Water squeezed by sub-ducting oceanic crust triggers some melting of hot wedge of mantle rocks lies above it (mixture of melted & unmelted mantle rocks)
- **Oceanic-Oceanic:** When 2 oceanic slabs converge, one descends beneath the other
  - ➢ Initiate volcanic activity by same mec-hanism in oceanic-continent boundary
  - ➢ Form chain of volcanoes on ocean floor
  - ➢ **Island arc**: arc shaped chain of small volcanic islands formed if subduction sustained &volcanoes emerge as island
- **Continental-Continental**: Resulting in collision between 2 continental blocks & produces mountains (e.g. Himalayas, Alps, Appalachians, Urals), less dense buoyant plate does not subduct
- Landmasses (continents) are separated by ocean basin → prior to continental collusion, oceanic crust is subducted beneath one of the plates → partial melting → volcanic arc or island arcs

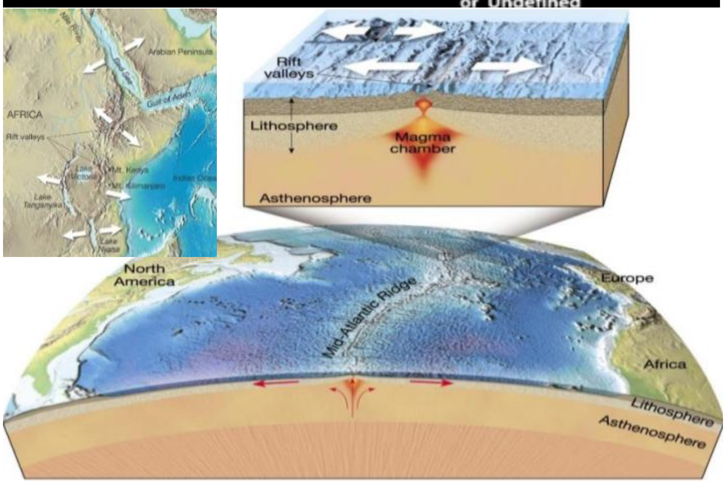
Transform fault

- **Conservative margin**: Plates slide horizontally past one another without production or destruction of each other
- **Fracture zones**: 2 segments of mid-oceanic ridges (MOR) along breaks in the oceanic crust
- Most transform faults are located within the ocean basins, a few (San Andreas, Alpine) cut through continental crust

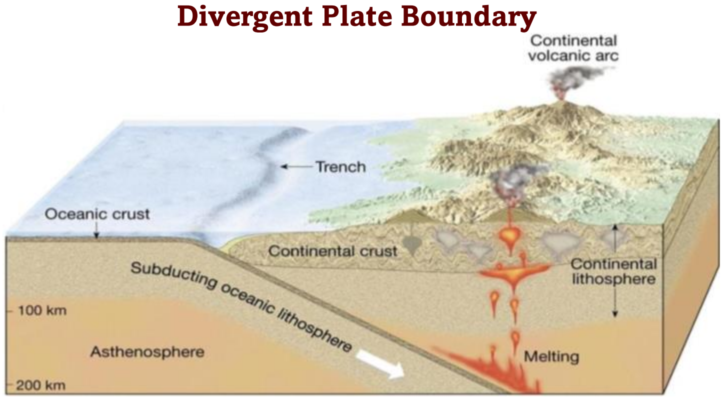
- **Seafloor are consumed prior to continental collusion:** Earth's total surface remain constant, The addition of newly created lithosphere is balanced by the descending of dense (oceanic) plates into the mantle



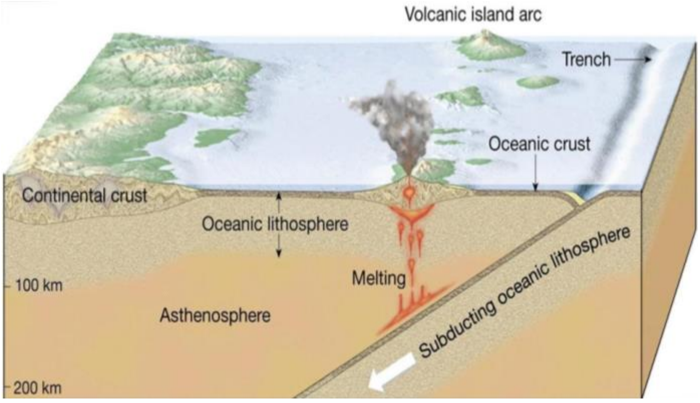




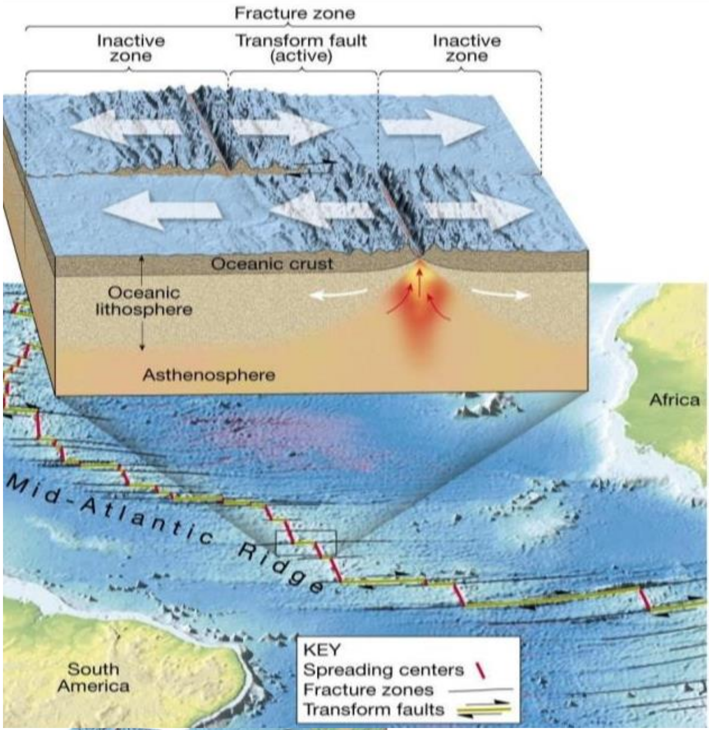
Divergent Plate Boundary

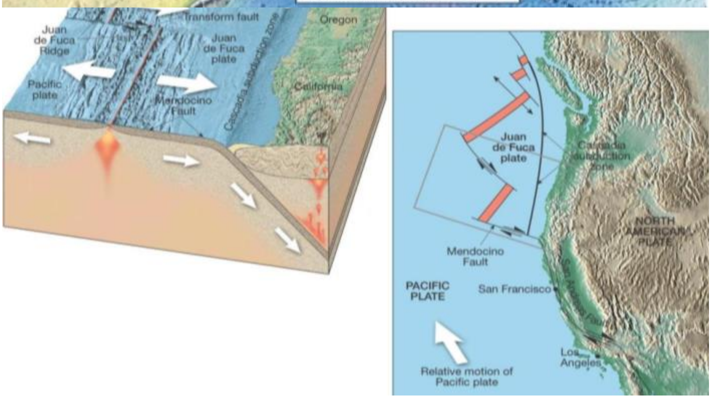


Oceanic-Continental Convergence

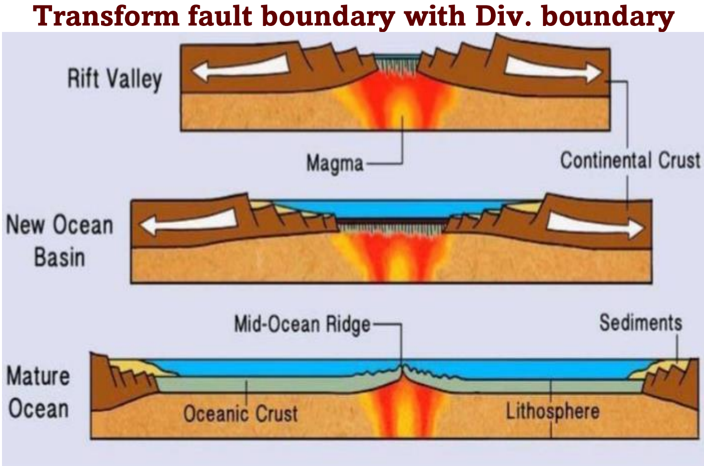


Oceanic-Oceanic Convergence

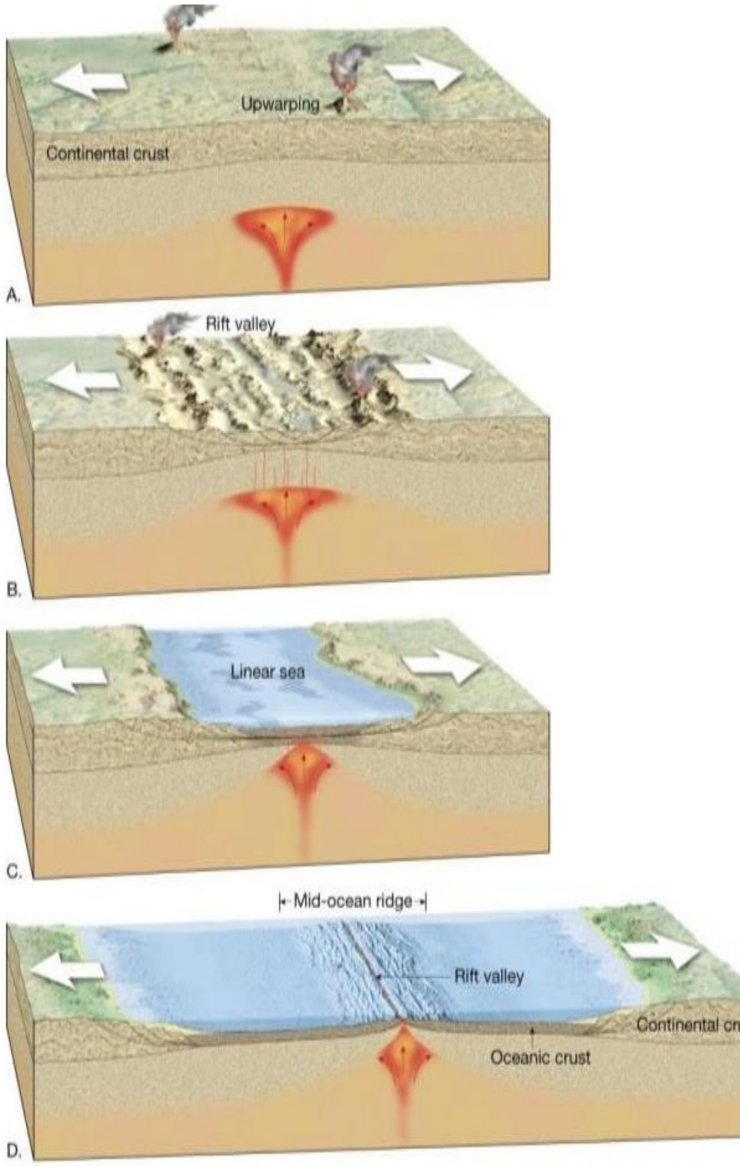




Transform fault boundary with Div. boundary



Continental Rift



Mechanism Of The Continental Rift (الشق القاري)

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

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

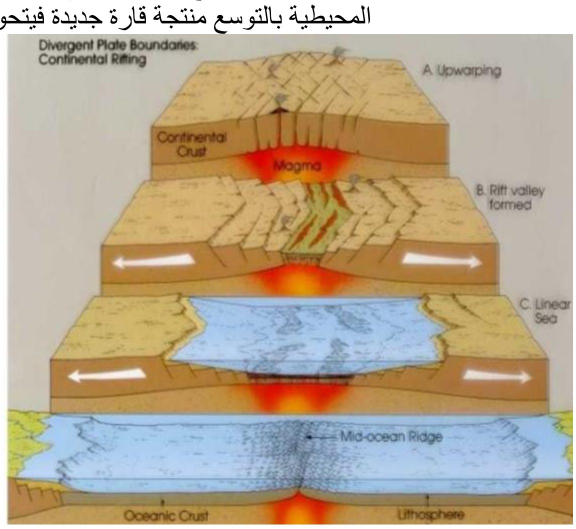
(C) Linear Sea (Narrow Sea): بعد حدوث الانخفاض تبدأ المياه بالتجمع في هذا المنخفض فيتكون البحر(لا يحتوي بعد على هدبة ظهر محيط)

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

Wilson Cycle

East Africa

Red Sea formation



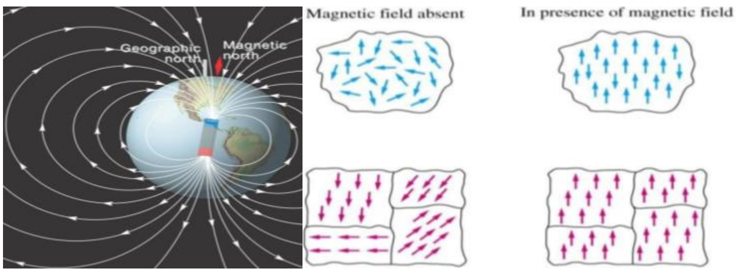
Continental Rift

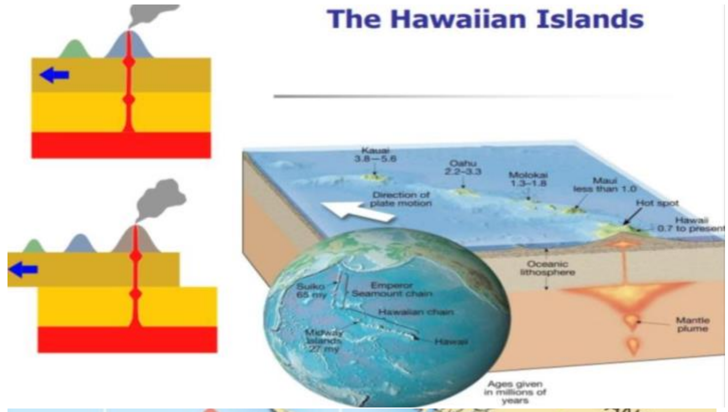
PLATE MODELS

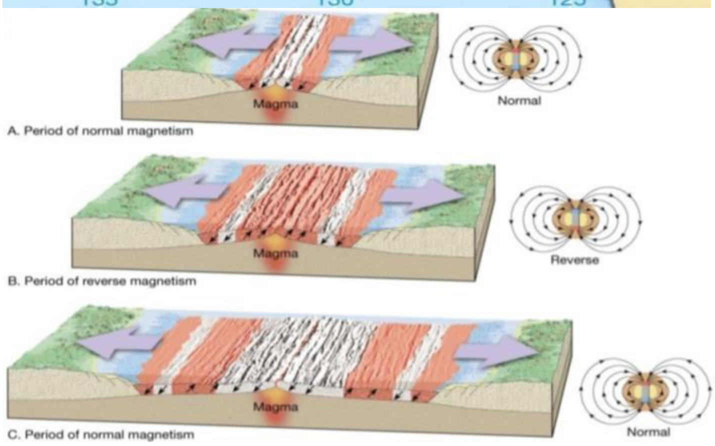
Testing the Plate Tectonics Model	
Ocean Drilling	Some of the most convincing evidence has come from drilling of the ocean-floor sediments, give information about ocean basins age & processes that formed them • **Result of oceanic drilling (Evedance):** 1. The age of sediment increased away from ridge 2. No seafloor >180Ma, & continental crust >4Ba 3. Thickness of ocean-floor sediments increases with increasing distance from the ridge
Hot spots & mantle plumes	• Mapped a chain of volcanic islands & seamounts • **Mantle plumes:** Long-lived structures originate at great depth (mantle-core), Maintain fixed positions within the mantle, however, recent evidence showed that some hot spots may slowly migrate • **Hot spot**: areas of volcanism, high heat flow, & crustal uplifting, such as the surface of hawaiian • **Hot spot tracks**: is the chain of volcanoes that trace the direction of plate motion • **Hawaiian Island** (Seamount) increase in age with increasing distance from Hawaii, Caused by rising plumes of mantle material located beneath Hawaii
Paleomagnetism	Magnetic-Geographic poles align closely (not exactly) with each other (Magnetic field → rotational axis), & Certain rock contain mineral serve as ***fossil compasses*** such as Fe-rich minerals (in basaltic lava flows) • As lava cool below Curie point (585°C) they become magnetized in the direction of magnetic force: when magma solidify or crystallize the magnetism will remain frozen in its position, & indicates the position of the magnetic poles at time of formation • **Fossil Magnetism or Paleomagnetism**: Rocks are contain a "record" of the direction of the magnetic poles at the time of their formation • Magnetic alignment in Fe-minerals indicated many different paleomagnetic poles, & this explained by: ➢ **Polar wandering**: magnetic poles migrate, polar wandering paths are explained by the theory of plate tectonics ➢ **Continents drifted**: lava flows moved ➢ **Plate tectonic**: magnetic poles move in erratic path, correspond to positions of geo-poles

- **Magnetic declination (variation)**: the difference between true geographic north & magnetic north
- **Magnetic reversals**: magnetic field periodically reverses polarity (N-pole become S-pole & vice versa)
  - ➢ **Evidence:** normally & reversely magnetized rocks of a given age in one location matched magnetism of rocks of the same age in other locations

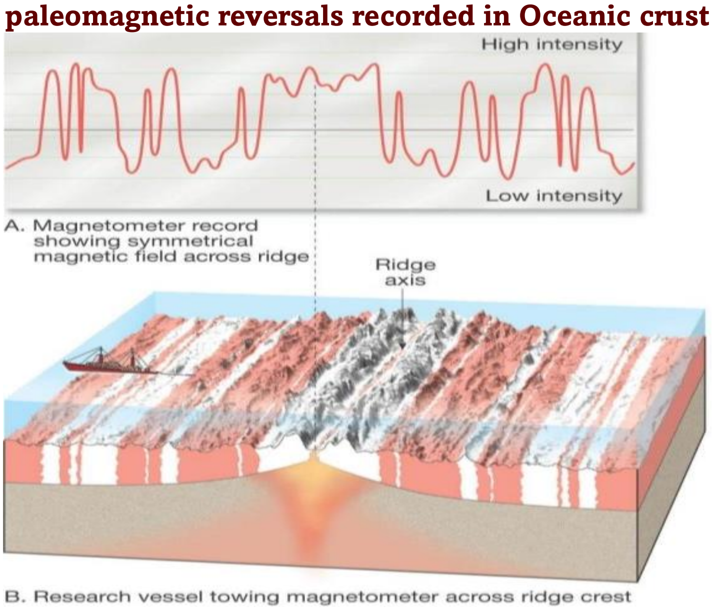
1. **Normal polarity**: rocks exhibit the same magnetism as the present magnetic field
2. **Reverse polarity**: rocks exhibiting the opposite magnetism to the present magnetic field







paleomagnetic reversals recorded in Oceanic crust



PANGAEA & MOTION

200Ma	Pangaea was began to breakup, & led to the creation of a new ocean basin "the Atlantic"
180-165Ma	N.America & Africa split (first split)
130Ma	S.Atlantic began open near tip of S.Africa & continued separation of Africa & Antarctica
90Ma	The formation of India
50Ma	Australia had separated from Antarctica & S.Atlantic ocean developed fully
45Ma	- India collided with Eurasia & created the Himalayas & the Tibetan Highlands - Greenland separated from Eurasia
20Ma	Arabian plate rifted from Africa → Red Sea

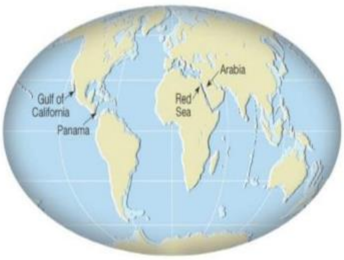
A. 200 Million Years Ago (Early Jurassic Period)

B. 150 Million Years Ago (Late Jurassic Period)

C. 90 Million Years Ago (Cretaceous Period)

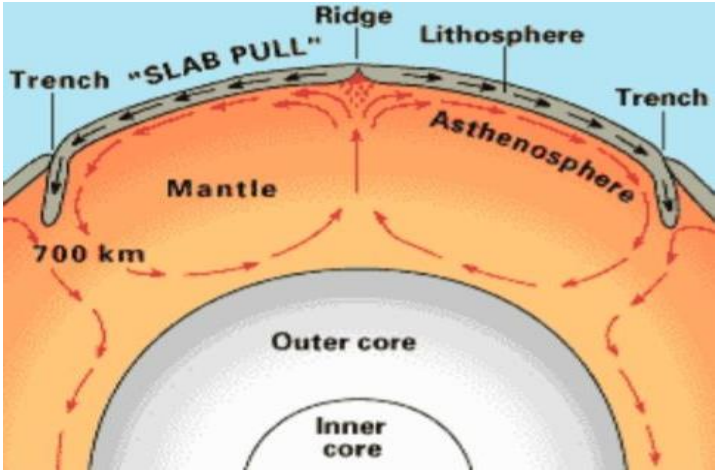
D. 50 Million Years Ago (Early Cenozoic)

E. 20 Million Years Ago (Late Cenozoic)



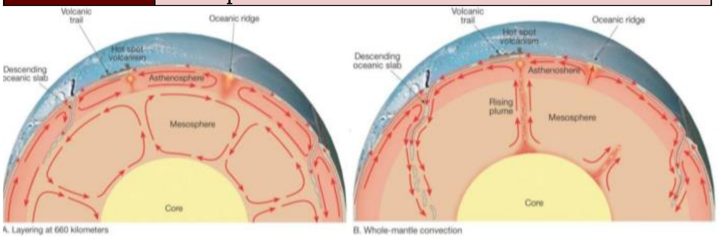
F. Present

- **What Drives Plate Motions:** Researchers agree on
  1. **Convective flow in the mantle**: basic driving force of plate movement, density variation (warm & buoyant rocks rises, cold & denser rocks sinks)
  2. **Mantle convection & plate tectonics are part of the same system:** subducting oceanic plates drive cold downward-move portion of convective flow, & Shallow upwelling of hot rock along oceanic ridge & buoyant mantle plumes are upward-moving portion of convective flow
  3. The slow movements of Earth's plates & mantle are ultimately driven by the unequal distribution of heat within Earth's interior
- **Convection Flow:** the horizontal movement of lithospheric plates away from the ridge causes mantle upwelling (convection), & As the plates moves they drag adjacent material along inducing flow in mantle
- This is the result of **differentiation**: a process driven by gravity, as a planet is young & hot to be semi-molten, denser materials sink & lighter float higher up



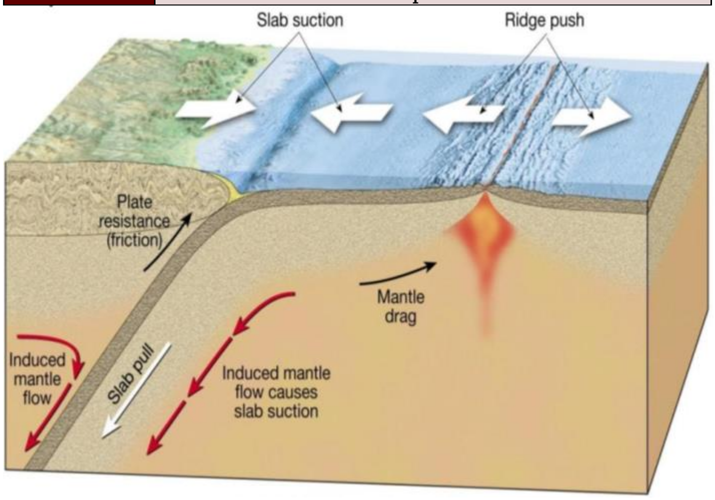
Convection Flow

Models of plate-mantle convection	
Layering at 660Km	• **2 zones of convection**: 1. *A thin convective layer* above 660km, MOR basalts come from upper layer 2. *A thick convective layer* located below, mantle plume resides in lower layer
Whole-mantle convection	Slabs of cold, oceanic lithosphere descend to great depths & stir the entire mantle, & hot mantle plumes near the mantle-core boundary transport heat & material toward the surface



Models Of Plate-Mantle Convection

Forces that drive plate motion	
Slab-pull	Cold dense slabs of oceanic lithosphere sink into asthenosphere pull the trailing plate along
Slab suction	The subduction of the lithosphere result in a mantle circulation that pulls both subducting & overriding plates toward the trench, & the mantle flow tends to suck in nearby plates
Ridge-push	Elevated position of the oceanic ridge causes slabs of lithosphere to slide down ridge flank by gravity • contributes far less to plate motions than does slab pull, & steep ridges spread less than the less steep ones



Forces That Drive Plate Motions

Chapter Two

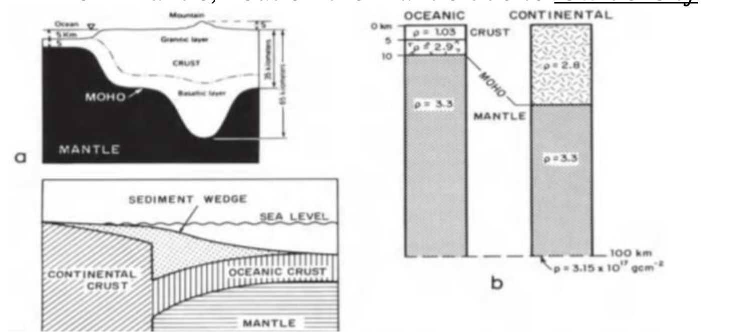
ORIGIN & MORPHOLOGY OF OCEANIC MARGINS

CONTINENTAL MARGIN

- **Continental margin (or Ocean margin):** transition area between continents & deep oceans (seafloor). include part of the continents, part of oceanic crust, & light continental mass above sea floor
  - **OR** edge of the landmasses below ocean surface & steep slopes that descend to the sea floor
  - **Sediment Traps:** dumping sites of continental debris (terrigenous sediments) & the most fertile parts of the ocean where productivity is high. much organic matter becomes buried within the debris & develops petroleum if condition are right
- **Light-weight continental mass above sea floor**: is a thick sediment mass accumulate at the boundary between continents & oceans, & build actual margin. may be well-layered or deformed based on tectonics

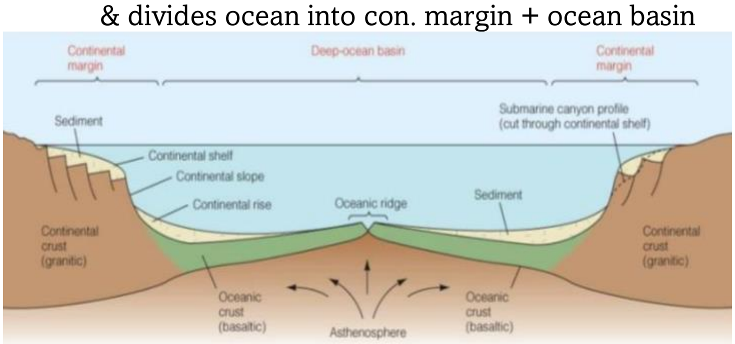
Margins	Continents	Oceans
Age	Older	Younger
Composition	Granitic	Basaltic(close to mantle)
Derived from	Mantle	Mantle
Density	Less dense	Denser(high Fe content)
Thickness	Thick	Thin

- **Continental crust derived from** mantle of crystal rocks by fractionation processes such as orogenesis (mountain building) & erosion that originally derived from mantle, float on the mantle due to low density



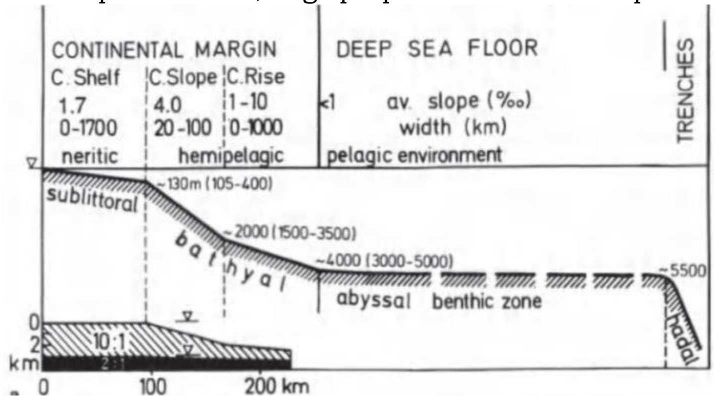
Isostatic block for continent-ocean-transition
a) Cross-section through continent "floating" on mantle
b) Density profiles. c) Nature of continental margin

- **The transition between continents & sea floor:**
  - **Near shore**: features of oceanic floor are similar to continents (share the same granitic basement)
  - **Transition to basalt** mark edge of the continent & divides ocean into con. margin + ocean basin



- **Efficiency of exogenic & endogenic process provide balance between extent of continents & ocean basins,** This balance is produced by:
  1. **Rock cycle**: Erosion of highlands & Deposition
  2. **Orogenesis**: Mountain building processes

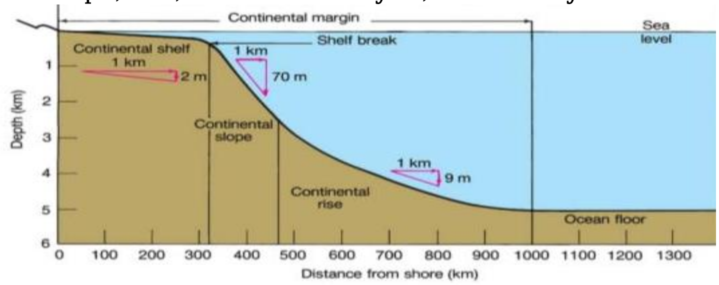
- Large parts of the low-lying portions of continents are covered with marine deposits (part of shelf) which is normally submerged in the course of geologic history
  - present time, large proportion of shelf is exposed

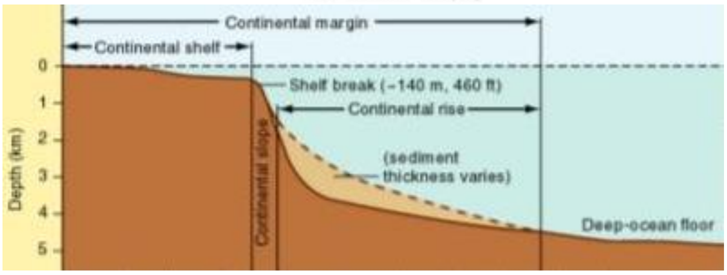


- **Atlantic margin** have thick wedge of sediments (10km) because ocean basin draining a large land area, & the largest proportion of slope & rise areas
  - The reason for this: the margins are old "trailing edges" & have not been disturbed by tectonic processes, other than sinking, for a long time

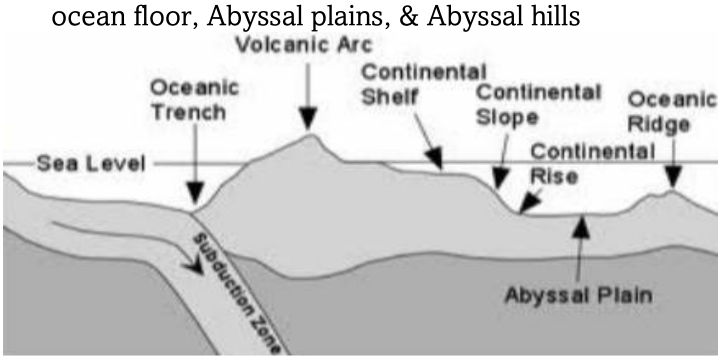
Ocean	Atlantic	Indian	Pacific
Shelf	**6.1Km²**	2.6Km²	2.7Km²
Cont. Slope	6.6Km²	3.5Km²	**8.6Km²**
Con. rise	**5.4Km²**	4.2Km²	2.7Km²
Tranches	0.5Km²	0.3Km²	**4.8Km²**

- The continental shelf width is usually determined by its proximity to a plate boundary
- **Features of continental margins:** shelf, break, slope, rise, Submarine canyon, & Turbidity Current





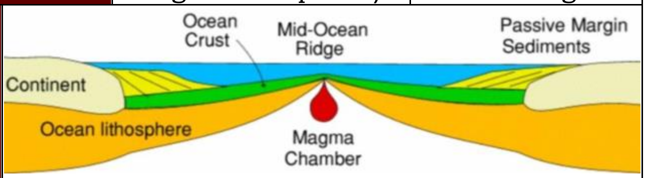
- **Main Features of Deep oceanic Basins:** MOR, Trenches, Seamounts (guyots), Island arcs, deep ocean floor, Abyssal plains, & Abyssal hills



TYPES OF MARGINS

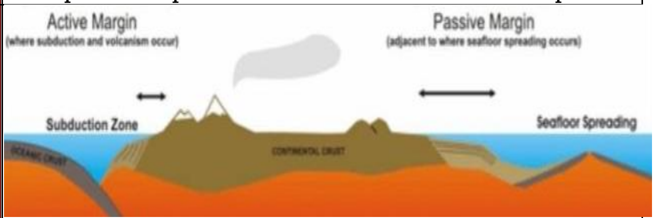
Continental margins are differ by tectonic style, earthquakes, & volcanoes activities		
Margins	**Passive (Atlantic)**	**Active(Pacific)**
Plate Boundaries	Not associated (near MOR)	Convergent (nean tranche)
Region description	Conservative, & Sinking region	Destructive, & rising region
Con. Shelf	Broad (Wide)	Narrow
Con. Slope	Gentler	Steeper
Tectonics	Inactive	Active
Associated with	Thick sequences of sediment in layer-cake fashion (facing edge of Div. plates)	Volcanism, folding, faulting, & mountain-building

Passive (Atlantic) Margins

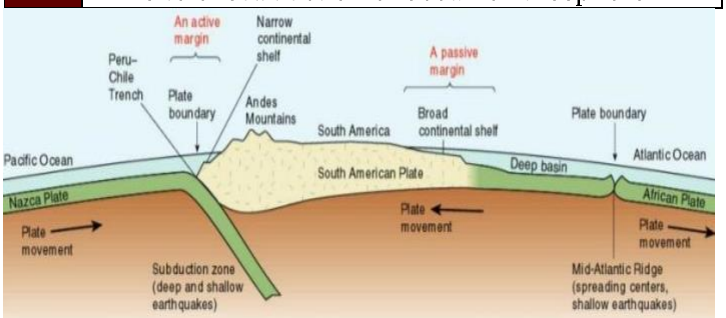


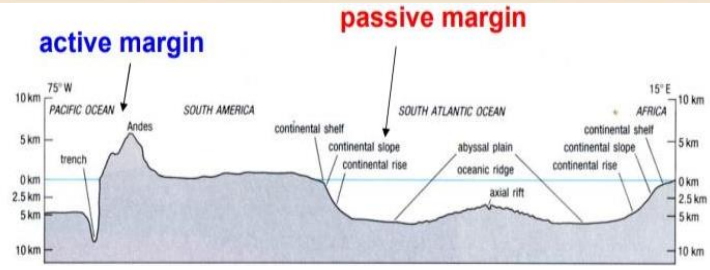
- **Originated by** a tearing apart of an ancient continents along a line of weakness or great stress, **Evolved by** sinking & loading of sed.
- **Formed after** continents are rifted apart, creating new ocean basin between them
- **Involve** the transition from continental crust to oceanic crust in the same lithospheric plate
- **Red Sea is passive margin**: mantle material pushes up & tears Arabian from African plates

Active (Pacific) Margins

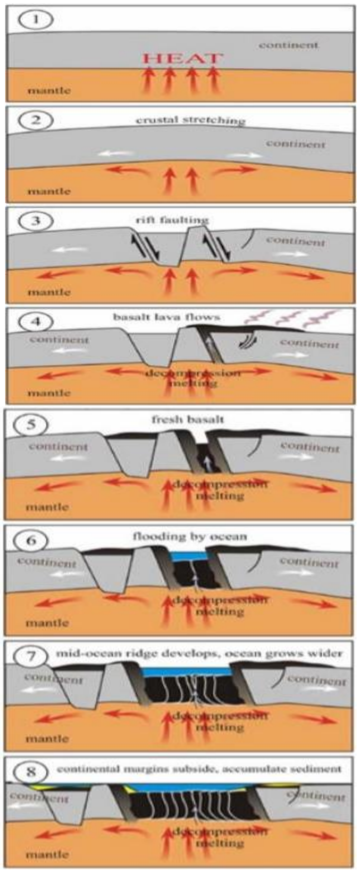


- *Destructive plate margin* associated with *trench*
- **Active margins are sediment traps:** sediments are piled up into chaotic mixtures
- **Oceanic trench:** Rising region, marking the site of subduction of oceanic lithosphere





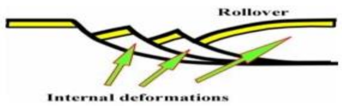
PASSIVE MARGINS



- **Evolution of passive continental margins:**

1. **Heat released** by mantle make CC weak enough to Uplift & Spelt apart
2. **Uplift** of mantle material led to expand CC cause graben & volcanism
3. CC thins, subsides, & **splits apart**
4. Terrigenous sediments, volcano-deposits, & may salt start to accumulate
5. **Rifting** followed by drift cause further subsidence
6. **New OC form** (Red Sea)
7. **Spreading** widens OC
8. **Sediment** cover parts of sea floor, build margin

- **E-African Rift Valley is a good example of initial phase of the continental margin**
- **Listric faults**: curved normal faults (the fault surface concave upward)



- **The Graben receives large amount of sediment** forms by erosion of mountain that uplifted by magma
- **Central valley** (started as gap) sinks under sed., as it widen by cooling, sea invade & magmatic accretion assert itself morphologically as MOR with axial valley
- Magma intrudes between blocks of CC, partly re-melts it & may be reaches the surface to producing large outpourings of basalt (e.g. Afar desert/Ethiopia)
- **The Red Sea:** the Submerged margins are sinking on the cooling lithosphere. Thick reefs structures can grow on these sinking blocks, building up a carbonate shelf, & further depressing the crust with their weight.
  - ➢ The receding margins sink & a rampart of reef carbonate may build up, & salt deposits may form in the early phase of rifting, in low latitudes
  - ➢ Large petroleum reserves may be associated with these salt deposits, because S-Atlantic was site for deposition of organic-rich sediments (Mid-Cret)

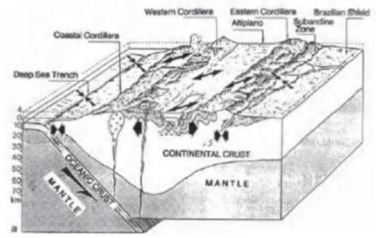
The materials accumulating on passive margins depends on the geologic setting of the region	
Reef carbonates	Grow in the tropics & where no large rivers bring sediment or freshwater
Hemipelagic mud & shell	where mixtures of lagoonal & riverine sediment buried by offshore **Shells** of planktonic (floating) or benthic (bottom-living) organism:
Thick sed. stacks	On sinking blocks of continental edge & adjacent oceanic crust due to rifting

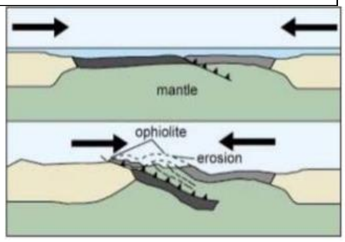
ACTIVE MARGINS

There are 3 types of collision margins	
Continent-Continent	As the Himalaya
Continent-Ocean margins	As Peru-Chile-Trench ***Shallow dip subduction***
Ocean-Ocean margins	As along the Marianas ***Deep dip subduction*** Place: along **island arcs**

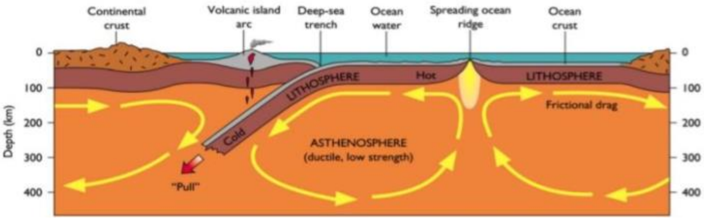
- **The most important characteristic of collision :**
  1. The Folding & Shearing of sediments
  2. Addition of volcanic & plutonic material by mobilizing matter from downgoing lithosphere

Types of rock characterize continental margins next to subduction zones are extremely varied	
Mafic & Ultramafic rocks	Basalt, Serpentinite, Gabbro, Peridotite Derived from mantle & altered by hydrothermal reaction
Pelagic sediments	such as deep-sea clay, shell carbonates, & biogenous silica
Ophiolites	part of mantle & crust rising up due to uplifting near tranche, Mapped to finding ancient subduction zones

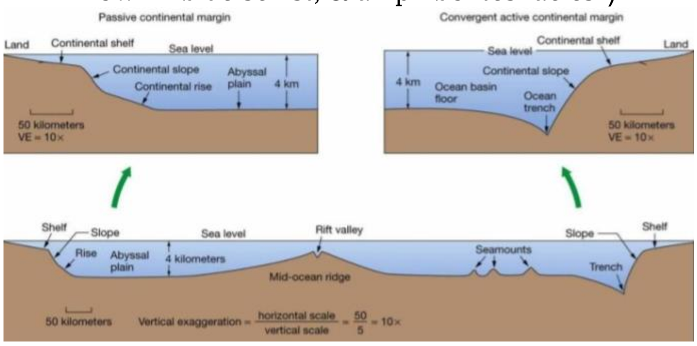




- **Trenches may occur next to:**
  1. **Continental margin with volcanic mountain ranges** where the oceanic lithosphere is subducted beneath continental crust
  2. **Island arcs** where oceanic lithosphere is subducted beneath oceanic lithosphere

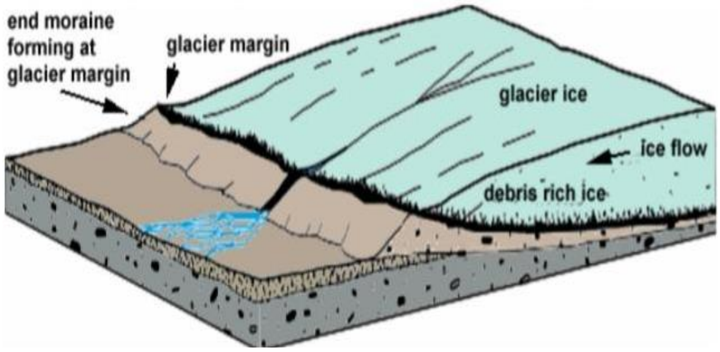


- Sediments carried by **turbidity currents** are trapped by trenche at foot of continental slopes (rise)
  - ➢ Steep slope favorable for large-scale gravitational transport & accumulation of rock masses in rises
  - ➢ **Jumbled mass** (**melange**) are sheared & metamorphosed (baked & cooked under high P & low T "blue schist, & amphibolites facies")



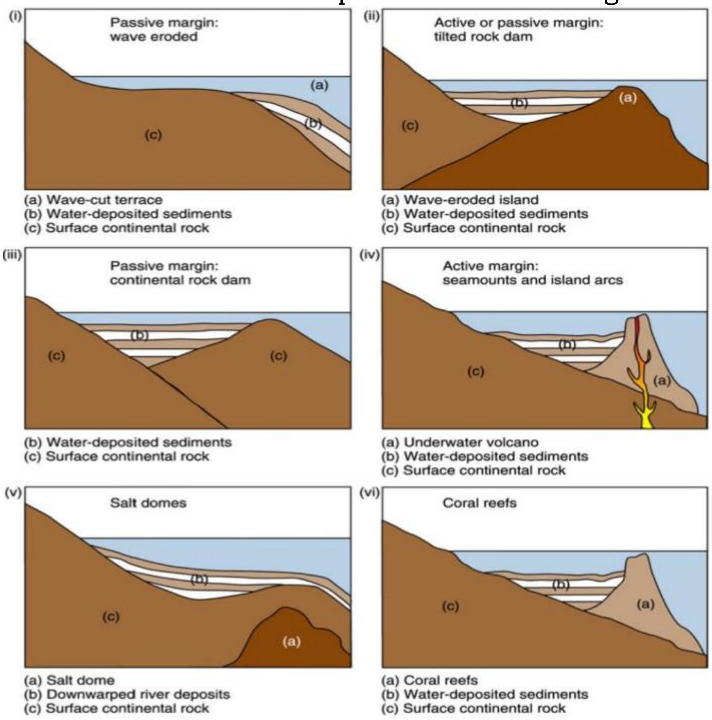
CONTINENTAL SHELF

- **Shelf**: is the submerged part of a margins, flat borders that slope gently toward oceanic basins (Avg 65Km)
  - ➢ *Geologically* continental shelf is part of continental crust, submerged seaward edges of continents
- **Width of shelf** is related to slope of the adjacent land (wide along low-laying land "S.America" & narrow along mountainous coasts "N.America")
- Some shelves extend deep into continents, & harbor shelf seas (e.g. Hudson Bay, Baltic Sea, Arabian Gulf)
- Most of the **Marine Sediments** found on land were originally deposited in a shelf seas
- **Shelf environment & sediments show a variety over short distances due to:**
  1. <u>*Sea level stood lower (15Ka)*</u> due to ice sheets that make the ocean go down by 130m (Atlantic shelf)
  2. <u>*Conditions of precipitation*</u> some portions reflect those conditions in topography & sediments
- **The nature of shelves reflects:**
  1. Erosional processes effect the shaping of shelf
  2. Tectonics setting (Active—Passive margins)
  3. Rise of the sea level (Transgression—Regression)
  4. Climatic & Sediment supply (in a regional scale)
  5. Buildup by reef forming organism (in low latitude)
  6. Ice is important agents (in high latitudes)
  - ➢ e.g. **Ice sheets in N.Atlantic shelves** leds to exposure of the shelf, & dumped debris in places
- **The moraines**: is any glacially formed accumulation of unconsolidated glacial debris (soil & rock)



- **Shape of shelves are affected by environmens**
  1. ***Very flat & Monotonous:*** large deltas off river (Amazon, Mississippi), fine sediment associated with delta redistribution & smoothing by waves
  2. ***The rugged shelves***: ice-carved shelf
  3. ***the irregular shelves***: coral reef shelf
- **The shelves have been covered & uncovered by fluctuations in sea level (sea level affects)**
  - ➢ ***During glacial age***: sea level sinks down, erosion deepened valleys, waves eroded submerged land, & rivers transported sediments away
  - ➢ ***When the glacial ice melted*** the areas flooded, & the sediments accumulated in the new shore
  - ➢ ***At present time*** some sediments still reflects the scars of old riverbeds & glaciers
  - ➢ ***Today*** some continental shelves are covered with thick deposits of silt, sand, & mud sediments derived from the land (by erosion)

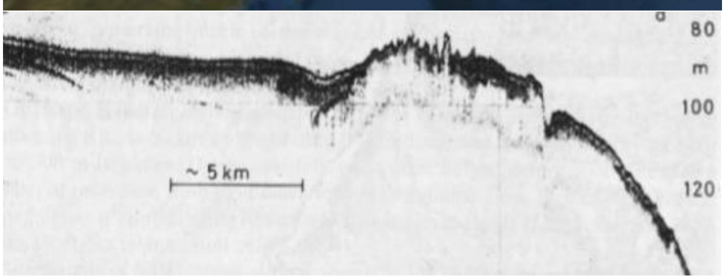
- **Processes contribute in formation of shelves:**
  1. Coral reefs, or salt domes
  2. Seamounts & Island arcs in active margins
  3. Continental rock dam in passive margins
  4. Waves eroded sediments in passive margins
  5. Titled rock dam in passive or active margins



- **Tsunamis**: very long waves produced in trenches rimming Pacific & low in the open sea. At a shelf area the wave slows down & builds up, & cause damages on coasts of shelves & influence shelf morphology

CONTINENTAL BREAKS

- **Break:** is the boundary of shelf on the oceanic side, & determined or represented by abrupt change in continental slope (rapid or distinct increase in depth)
- **Marks the depth** below which influence of sea level on erosion & deposition wanes (decreases) rapidly
- ***Distinct increase in slope marks the lowstand of glacial sea level*** in the Antarctic & Greenland it is very deep & mark the depression by the ice load & the maximum depth of carving by ice



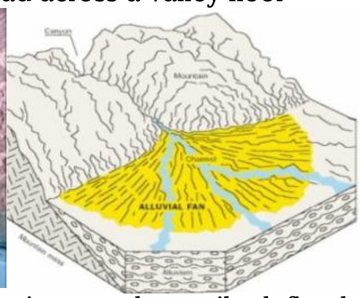
Shelf break at the entrance of the Persian Gulf

CONTINENTAL SLOPES

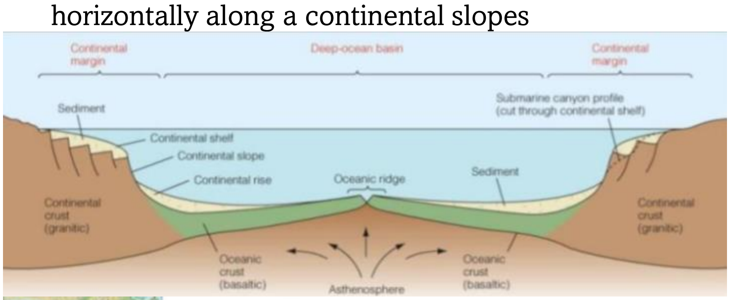
- **Continental Slope**: is a short & steep part of the continental margins below the shelf break (where depth increase rapidly from 200 to 3000m)
- ***Slopes are surface of accumulations*** of continental sediments that mixed with biologic marine materials
- ***High rate of accumulation*** on slopes can leads to a precarious (unstable) balance in places such as deltas which can cause landslides
- ***The slope show rocky outcroppings & relatively bare of sediments because of*** its steepness, tectonic activity, & a low supply of sediment from land
- The collision margins off Peru & Chile characterized by steep slope, without a rise the trench swallows material which normally build rise

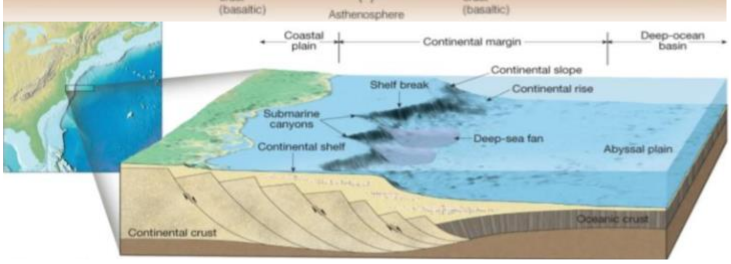
CONTINENTAL RISES

- **Rise:** is a portion of seafloor, gentle slope at the base of the continental slope, marks areas of accumulation of sediments, & may be compared to the *alluvial fans*
- **Alluvial fans**: is a landforms found where sediments from steep canyons spread across a valley floor



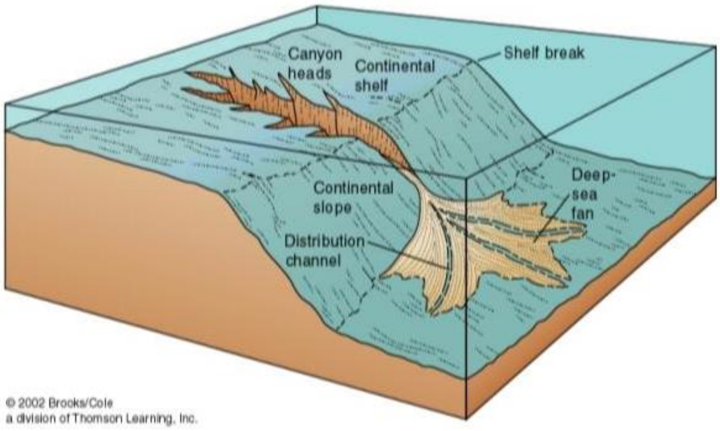
- In **Passive margins** the rises can be easily defined, but in **Active** trenches located at base of a slope
- **Formed by**: accumulation of sediments by any process that carry sediments (sands, muds, & silts) down the continental slope, such as the following
  1. ***Turbidity currents***: Much of sediment on rises
  2. ***Landslides***: result from small disturbances in slopes when there is no time to dewatering & solidification of sediments (even in gentle slope)
- Slides of sediments starting near continental breaks, & subsequently redistributed by ***contour current***
- **Contour currents**: are strong deep currents flowing horizontally along a continental slopes





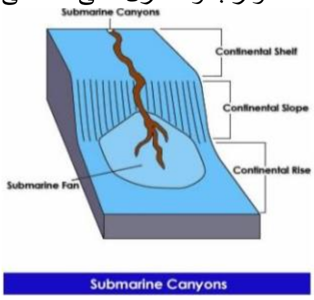
SUBMARINE CANYONS

- **Canyons**: incision, ravine, or valley cut continental slopes, may extend up into & across continental shelf



- Many large canyons is steep with V-shaped & have tributaries similar to those of land river-cut canyons
  - ➢ **Tributary system**: upper part with meandering
  - ➢ **Steep sides:** in places (20°-25°, even 45°)
  - ➢ **Overhanging walls:** wall that consist hard rocks
- Many of canyons associated with land rivers, were cut into shelf during glaciers periods (low sea level)
- Ancient fishing villages are sometimes located at the heads of canyons: the greater water depth disperses high waves away from the coast & provides some safety for boats & houses on shore

تقع قرى الصيد القديمة اعلى ال canyons لان عمق المياه الكبير يبدد الموجات العالية بعيدا عن الساحل ما يوفر بعض السلامة للقوارب والمنازل على الشاطئ



- The submarine canyons seem to be absent due to gentle slopes or low sediment supply (insufficient for producing downhill currents)
- The canyons seem to be ***formed by Turbidity currents*** & the evidences for turbidity currents are
  1. ***Ripple marks*** on floor of the submerged canyons
  2. ***Sediments*** fanning out at the ends of the canyon

TURBIDITY CURRENTS

- **Turbidity Currents**: fast sediment-laden currents (90km/hr), OR fast avalanches of mud, sand, & water that flow down slope that can erodes & picking up the sediments, & when reaches the bottom, it slows, spreads, & settling the sediments
- ***Turbidity Current can carrying*** suspension up to 300kg of mixed size from sand to pebbles & boulders, & able to erode, deepen, & widen canyons by erosion
- Turbidity Currents leeds to the formation of:
  1. **Graded Bedding**: the current power decreases downslope (course size deposited first then finer)
  2. **Deep-sea fans:** huge semi-conal sediment body
- ***Turbidity Currents can caused by*** earthquake & overloading of sediment (Mudslides)
- **Agents for mudslides** (muddy flow, & turbidity currents): Flood, hurricanes, wave action, earthquake
- Sediment on the outer shelf & upper slope could be resuspended due to storms, providing for mud-laden, heavy water bodies, which could move downslope & initiate powerful turbidity currents
- Stir mud into water start in soft sediments deposited off river mouths (canyons associated with the mouths of large rivers: the Congo, Indus, Ganges, & Hudson)
- **Turbidity currents play important role in:**
  1. Marine processes
  2. Geologic record: because these are rare events
- Most turbidites are thin & are soon destroyed through reworking by bottom living organisms & by bottom currents. Thick layers can survive this process & are then recognizable in the sediment sequence.
- Turbidity currents run along floor over long distances (3000 km, the distribution of abyssal plains)
- For such currents, trenches would form an absolute obstacle, & no abyssal plains found beyond them. Once a trench is filled, plains develop on other side
- As supply of turbidity deposits runs out, far in the deep sea, abyssal ocean floor starts showing its typical bumpy morphology: abyssal hills, which are covered by pelagic oozes & clay

DEEP-SEA FANS

- The muddy waters drop their load within a short time as graded layers. Such layers are found within the fan deposits of continental slopes & in the sediments building the abyssal plains
- Deep-sea fans consist of overlapping tongues of sediment, dissected by channels, which are re-filled when abandoned, Meanders of several km width
- Fans are of interest from an economic point of view, as potential reservoirs for hydrocarbons, with their huge dimensions, & their many meters-thick sand bodies offering high porosity & permeability
- **Build op of deep-sea fans:**
  1. Canyon & slope traps sediment to the fan
  2. Upper fan valley, wall with slump feature, bottom with debris flows & graded coarse grained beds
  3. Levees with thin-bedded turbidity may breached
  4. Active suprafan with distributary channel, filled with pebbly or massive sands
  5. Outer fan with classical turbidites
  6. Abyssal hill beyond fan, Valleys between hills
- Most of the sediment in deep-sea fans consists of turbidites (the deposits of turbidity currents)
- Turbidites are also common both within slope sediments & in abyssal plains. Depending on magnitude, turbidity currents rushing down a fan valley leave the distributary channels at various points, & build up turbidites as their velocity slows

Compilation of exogenic processes shaping (passive) continental margins

Chapter Three

SEA LEVEL PROCESSES & CHANGES

SEA LEVEL POSITION

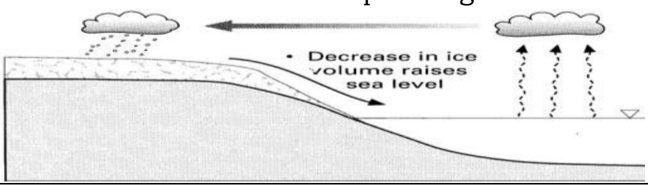
- **Position of sea level controls**
  1. The rates of erosion of the continents
  2. The sites of deposition in the ocean
  3. Transportation of sediments
- **The depth of deposition (sea level) dominates**:
  1. The facies patterns of material accumulating on it
  2. The size distributions if clastic sediments
  3. The chemistry of biogenous & authigenic matter
  4. The distribution of benthic organisms
- **Sea level fluctuations:** trans. & reg. on the shaves

Types of the sea level fluctuations

Global or Eustatic

transgressions & regressions on the shelves of the all continents (**Eustatic**: changes in sea level)

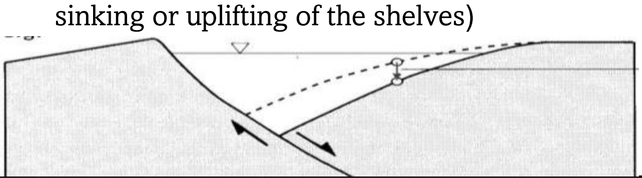
- **Produced by** volume changes of ocean water or Avg depth of the ocean basin by changes in ice volume or sea floor spreading rate



Regional,

Transgressions & regressions on a particular shelf

- **Caused by** tectonic processes (regional sinking or uplifting of the shelves)



Effects of sea level fluctuations

On small scale

Physical, chemical, & biological process tack place where sea-level intersects with margin (Max. activity are found on Waves, Tides, & Currents)

***Higher Productivity* is in** sediments associated with nutrient cycling, gas exchange, life process

Sea-level line of erosion & deposition exposed areas are eroded & submerged build up coastal morphology (used as indicators & paleo-record)

On large scale

The position of sea level controls the degree to which shelves are submerged: Flooded (submerged) shelf absorb more light than exposed shelf (adding heat to global budget)

Sealevel are tied to paleoclimatic evolution: CO_2 rise (warm climate) during global sealevel rise because submerged land experiences no chemical weathering that keep down CO_2 in atm

Transgression	**Mild & Warm Climate**
Regression	**Harsh & Cold Climate**

Controls production of hydrocarbons & coal

Transgression	**Hydrocarbons** (oil & gas)
Regression	**Coal** (vigitation in swamp)

Controla sediments transport to ocean: during highstand sediment transported by turbidity currents reduced (depend on mud-supply to shelf)

Transgression	**Low turbidity currents**
Regression	**High turbidity currents**

SEA LEVEL PROCESSES

Sea-Level Processes & Indicators

Wave Action (wave-cut terrace)

Most conspicuous indicators of sea level because leaves erosional & depositional marks in record, Waves transport & sediments reworking changing sediments texture & structure by sorting

Steep escarpment (cliff): result of regional uplift & wave attack on the land-sea coastline (1m/yr)

- Growth rate of escarpment platform depends
  1. The force of the waves
  2. The resistance of the cliff material
  3. The time available for cutting

Ripple Marks: Thick enrichments of heavy minerals (called placers) on a beach

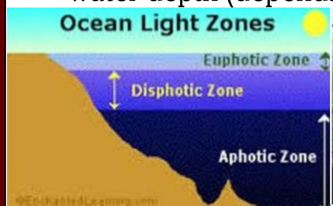
Coquina: shell pavements, formed when wave influence seafloor down to 10-20m

Polished beach shingles & Calcareous oolites

Photosynthesis Action

Benthic organism (Sessile plants such as algal mats & calcareous algae, <100m depth) & animals living with algae (foraminifera, stone corals, & mollusks) indicate shallow water (by Photosynthesis)

- Surface light intensity drops 1% in 10-20m water depth (depends on water clearness)



Tides & Storm Action

The tides raise & lower sea level by cm's-m's/day, & amplitudes of the waves are highest near coast

- Distribution of tides frequencies & amplitudes used to obtain information about changes in the Earth-Moon system & basinal morphology
- Tides ***shaped by*** basin morphology, ***related to*** astronomical forcing (***generated by*** attraction of moon & sun in opposite direction)

Tidal flats can associated with river deltas or estuaries, & produce the following features

1. *Changes in sea level & type of sediments*
2. *lenticular-bedding, cross-bedding, & bioturbation*
3. *Peat, Salt-Marsh, Marine-Muds, & Sand-Shell*
4. *Muddy intertidal flats* of the subtropics
5. *High evaporation rate*: Mud-Cracks, Rain-Drop, Animal-Tracks, Halite, & Gypsum

RECENT SEALEVEL RISE

- ***Coast of uplifted margins*** are shaped by interplay of tectonic forces & marine processes (wave erosion)
- ***Coastal morphology of slowly sinking margin*** is dominated by the processes associated with sea level
- **Raise marine terrace**: uplifted marging morphology
- **Sea level rise today** *in response to* melting of glacial ice (of Laurentian & Scandinavian, but Antarctica released minor amount!), by 1-2mm/yr due to thermal expansion of ocean water layers (by global warming)
- ***Recent rapid*** sea-level rise are began ***15Ka***, & lasted until 7Ka (*Max. Level 15-9Ka by 120-130m*) & Sea level is rising right now after ***stability during Holocene***
- **Sea level rise during deglaciation** *(15-9Ka):* Dating by radiocarbon determination that suggest 2 major pulses of sea level rise (14-11Ka & 10-12Ka)
- The effects of deglacial transgression on coastal morphology & sediments were varied & profound
  1. ***Rise in humid regions:*** peat grew, flooded by salt & covered by sediment, approaching surf erode dunes
  2. Resistant matter left from the erosional process collected as a transgression ***basal conglomerate***
- **Sea level rise reflected in** rapid changes in δ18O of oceans relative to foraminifera, or U/Th of corals

Effects of Recent Sea Level Rise

River Mouths

River mouths: run across coastline, when inter canyon slowed because released it's load forming estuary-delta

Sealevel	Sequence	Forms	Marine facies
Regression	Regg.	Delta	Retreats
Transgression	Trans.	estuary	

The regressive (shallow deposits over deeper) & transgressive sequences cannot be seen on the surface, but by studying sediment within delta

Why a delta forms & not estuary in regression areas? Low tidal activity in exposed shelf, High erosion rate & sediment load in high seasonal rains

Delta is economically interesting: site of high productivity & accumulation form source rocks

The best harbors are with a canyon & where strong tidal keeps outer river channel open (tidal action keeps channels open, building deltas on both sides)

Lagoons & Barriers

low-lying coasts show **facies zonation** parallel to coast

Barrier islands: occur with a sand beach, rivers emptying into lagoons cut channels via barriers & separate them into series of islands

Overwash fans: forms as storm waves break a barrier

Beach-dune complex: beach that backed by dunes (the wind piled up by sand from beach)

Barrier & lagoon morphology reflect changes in sea level (sealevel & sediments supply balance)

Mangrove Swamps

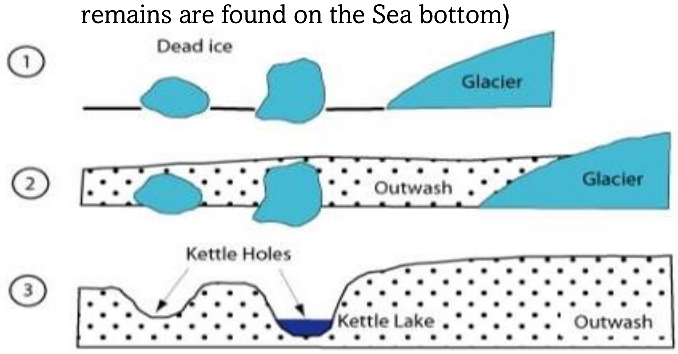
During the recent rise of sea level, the facies zones paralleling coast migrated landward forming ***Mangrove swamps*** in intertidal tropical zones & equator (≥20°C)

Mangrove swamps buried during deglaciation produce organic-rich layer (peat) on tropical zones

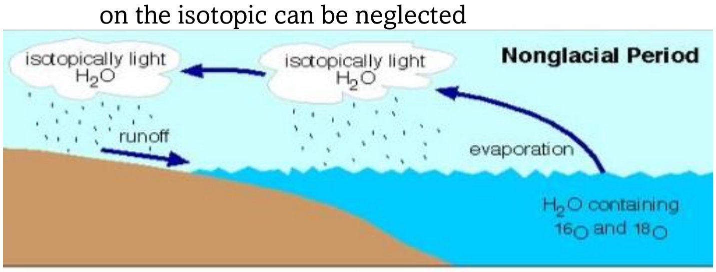
Mangrove swamps are sensitive to human activities, ***Changes in the coastal environment*** can be monitored using remote sensing, from satellites

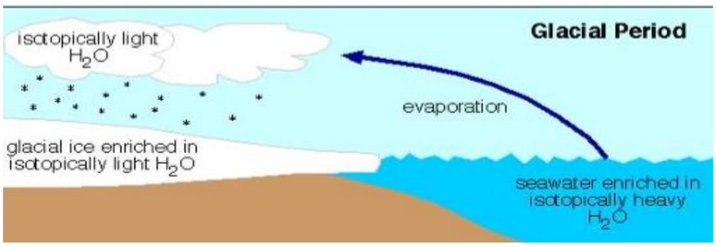
ICE-DRIVEN FLUCTUATION

- Sea level has been constantly changing over the last several 100Ka as a result of the waxing & waning of large continental ice masses
- The rise of the last deglaciation (15-7Ka), was one of the biggest & fastest sea level changes, result of a maximum change of climate (from a peak cold period to a peak warm)
- **Würm (in Europe), or Wisconsin (in N-America) age:** the last major ice age (17Ka)
  1. Sea level depressed by 130m
  2. a large shelf areas fell dry as a result of regression
  3. Rivers cutting shelf, & entered the sea, dropped their load in slope (led to turbidity flow)
  4. Outwash plains developed on the exposed shelf
  5. Dune field evolved on shelf as climate favorable
  6. Land animals spread over the emerged shelves
  7. Mammoths travel over the North Sea today (their remains are found on the Sea bottom)



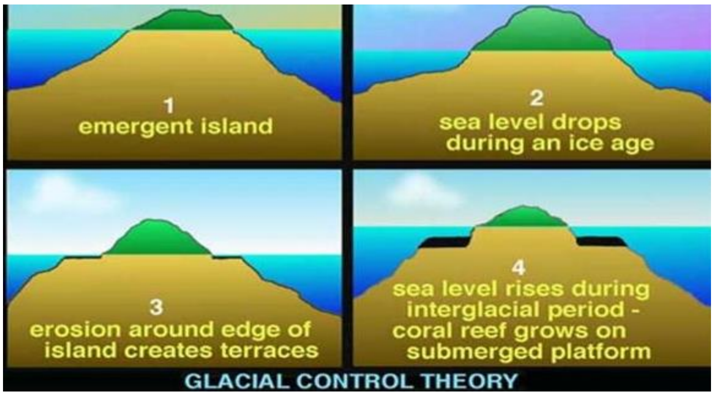
- ***Pleistocene Fluctuation*** *(126-11.7Ka):* major transgression were much more rapid than any of the regressions
  - ➢ The buildup of ice occur at a slower rate than melting (evidence from 18O/16O isotope from foraminifera)
- **Oxygen Isotopes**: There are 3 kinds of O, the normal one is 16O, the rare one is 18O, & 17O is very rare
- **Measured sea level changes from foraminifera**: after Emiliani, using mass spectrometry we can determine 16O/18O ratio (from $CaCO_3$ & H_2O in formanefra) relative to 16O/18O ratio in the water in which the shells grew, & if the ratio in the water changes, it will change in the shell
  - ➢ ***As sea level drops*** 18O/16O increases, because the glacial ice is impoverished in 18O & seawater is enriched in 18O during glacials
  - ➢ The 18O/16O ratio of the carbonate shells reflects this change in seawater chemistry, & Temperature also influences 18O/16O ratio of the shells
  - ➢ The long sediment core on which the measurements were made comes from an area where the effect of T on the isotopic can be neglected



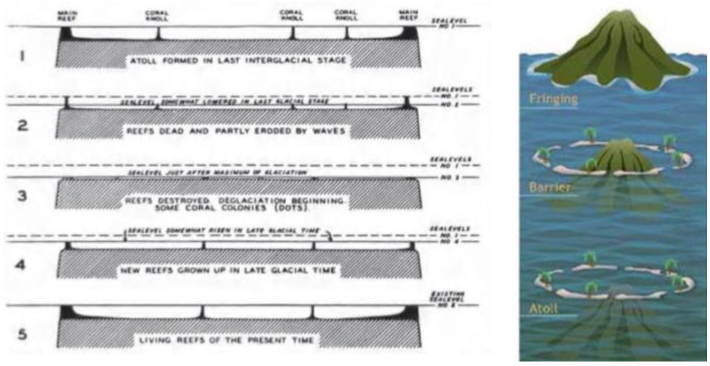


EFFECTS ON CORAL REEFS

- Pleistocene fluctuations left their imprint also in shallow water carbonates (in the tropical reefs)
- **Highstand** resulted in a *buildup of reef carbonates*, while the **lowstands** resulted in *erosion*



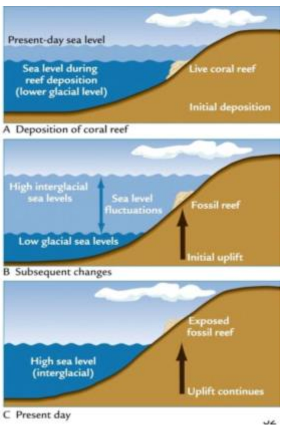
The origin of atolls, ring-shaped islands dotting the central Pacific, has been contemplated under this aspect



Daly's Glacial Control Theory of reefs(124Ka-now)

The ring shape of atolls is due to the more favorable situation for coral growth at the edges of the island (due to cleanness of water, & high food supply). The knolls in lagoon grow up on slightly elevated, mud-free ground

- On rising shores with reef belts the fluctuating sea level translates into raised reef terraces
- The terraces correspond to high stands in sea level
- Dated by measuring the concentration of U within individual coral heads, & the product of U decay. & at the time of growth of the coral there is no Th present, one can tell how much decay of U took place from the ratio of these radioactive isotopes



Corals for paleo-sea level reconstruction

A. Some corals live within a few meters sea level

B. Lower sea level will result in deeper corals

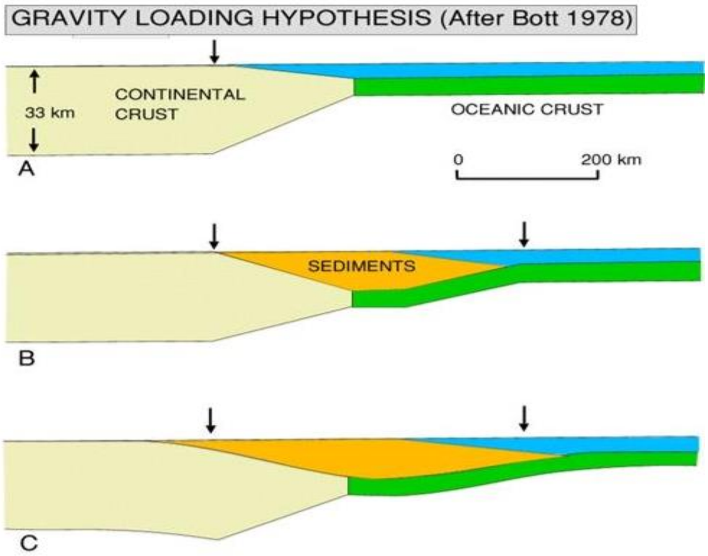
C. Have to correct for tectonic & isostaric uplift

From corals we know that LGM sea level was 125m

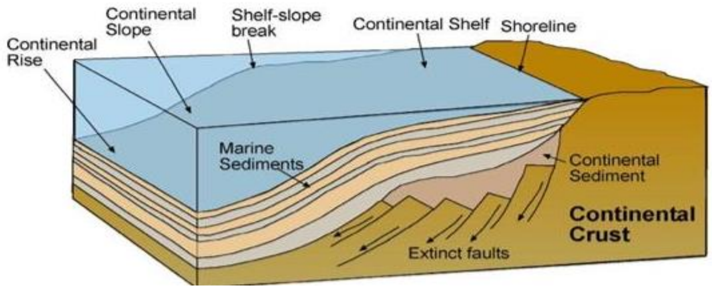
- Results: the uplifted corals grew during several high sea level stands, very much as expected from the O isotope curve shown. Ice-driven sea level fluctuations seem to have been less pronounced in the earlier Pleistocene than in the later part of the period

TECTONICALLY-DRIVEN SEALEVEL FLUCTUATIONS

- Sea level fluctuated all through the Phanerozoic, even during periods when apparently no ice was present.
- The thick sediment stacks in the passive margins have been much studied for economic reasons.
- When a margin sinks more or less, coastal sediment bodies must reach great thickness, provided the sediment supply keeps pace with subsidence, & deposition remains locked in to the sea level



- The significance of sand bodies in economic geology lies in their porosity & permeability, & can retain (& deliver) great quantities of water, petroleum, or gas

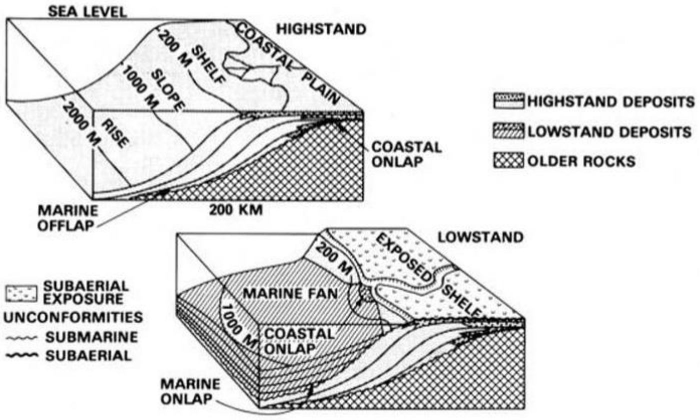


- To interpret the sequences of marine sediments (on land, margin, & sea floor), we would like to know how sea level fluctuated over the last 150Ma, in as much as the sea level variations within this geologic period were not driven by the growth & decay of ice caps, they were not reflected in the isotopic composition of seawater, so We cannot find them in the isotopic composition of the foraminifera

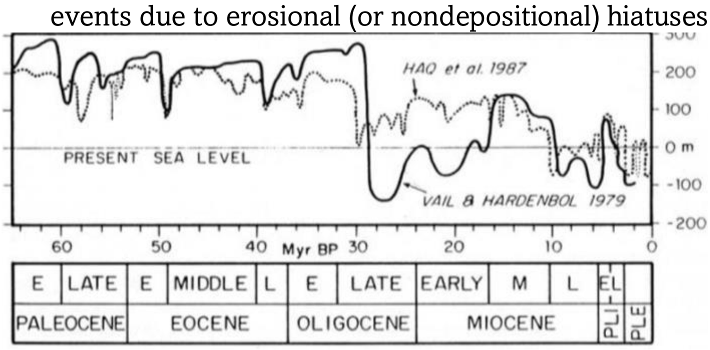
Reconstruction of Sea Level Changes

- Sediment-stacking patterns in margins of different ocean basins quite similar (based on seismic profiling of cont. margins) due to global sea level variation
- Vail & Mitchum developed a method to derive sea level fluctuations from the geometry of sediment layers, as recognized on seismic reflection records
- For the time since the beginning of the Triassic they have found >100 global sea-level changes (1/2Ma).
- **During rise of sea level** (**transgression**) sediment expand to shallower water, become wider as build up

- **During a fall of sea level (regression)** the reverse occurs, & erosion sets in on the shelf producing hiatus
- **Hiatus**: a surface which joins older & younger sediments in a discontinuous way.



- **During the lowstand**: the sediment pile moves into deeper waters, & its geometry changes, & The construction of the apparent sea level cycles is based on this changing geometry of sediment stacks
- **The falls in sea level** appear as instantaneous events due to erosional (or nondepositional) hiatuses

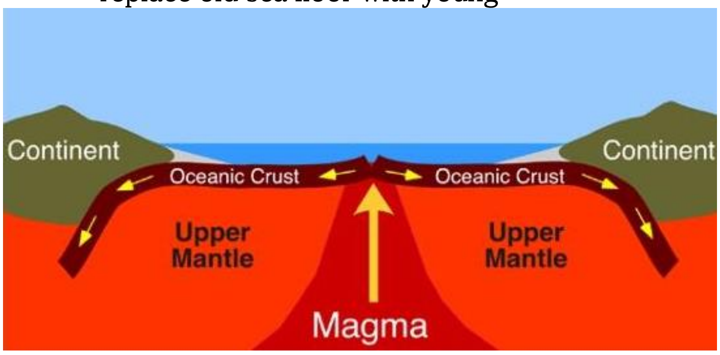


Relative changes of sea level as deduced from the geometry of margin sediment bodies

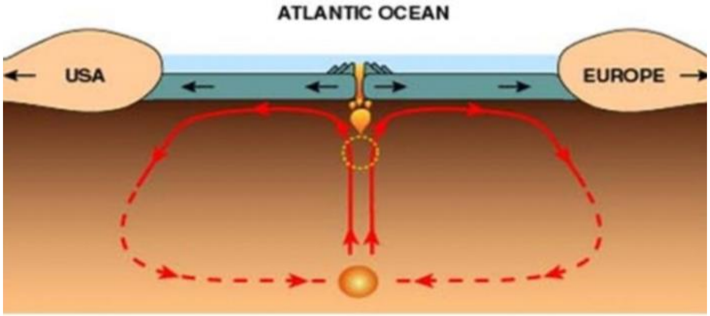
- **The Vail sea level curve:** is a tool for the correlation of seismic stratigraphies of margin sediments, is the curve reflects the true global sea level variations is not known (showing major cycles of sea level changes)
- **Problems of Vail sea level curve**
  A. The rate of sediment supply play an important role in controlling the geometry of the sediments
  B. The rate of sinking of margins must be considered

The Cause of Changes

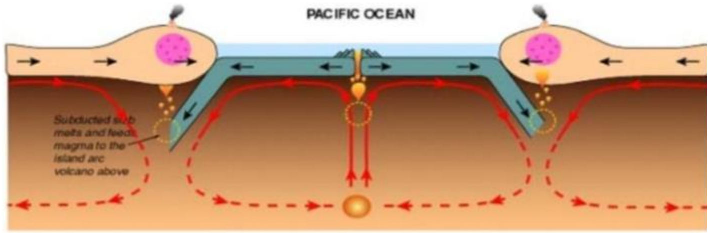
- The way to change sea level:
  A. by ice
  B. change the average depth of the sea floor: in shallow floor the sea level rises; & in deep it falls
  C. The depth of the sea floor is tied to its age: to decrease the age (cause a transgression), we must replace old sea floor with young



- This can be done by increasing the total mass of new lithosphere formed per year by increasing sea-floor spreading rates or length of the MOR & trenches
- Global tectonic events that led to changes average age of the sea floor & its depth, happened in the past
- **Opening of Atlantic** young sea floor was generated by the new spreading center in the Atlantic, while old floor was subducted elsewhere in the Pacific
  - ➢ As the Atlantic grows, the average age of its sea floor increases, at some point it becomes older than the average age in the Indo-Pacific & starts increasing the global average, & Further growth of the Atlantic results in a drop of sea level



The Atlantic ocean formed through rifting of a continent known as Pangaea about 180 million years ago. The USA and Europe are still moving apart today. The margins of the Atlantic ocean are known as passive margins because there is no plate boundary here - the continental crust is joined to the oceanic crust.



All around the edge of the Pacific, ocean crust is being subducted beneath continental crust. As a result, the Pacific is surrounded by a chain of volcanoes - known as the Ring of Fire

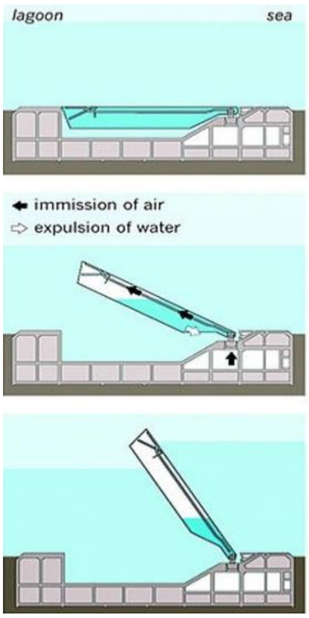
- The magnetic stripes on the sea floor indicate that global spreading rates in Late Cretaceous have been much higher than now. So the high sea level stands were caused by such a fast spreading rate
  - ➢ The changes which can be produced by replacing old sea floor with young, are large but gradual
- **Rapid changes in sea level** caused by Mountain-building with shallow ocean- or continental crust
  - ➢ Shallow crust (stacked up in mountain ranges) is removed & replaced by deeper sea floor which will cover itself with a thicker layer of water, drawing down the general sea level
  - ➢ If the Tibetan Plateau represents "doubled" continental crust (e.g. the corresponding sea level fall) is about 40m
  - ➢ The quickest way to change sea level is to fill or to empty an isolated ocean basin
  - ➢ The Mediterranean dried up intermittently between 5-6Ma
  - ➢ The water had to go elsewhere: global sea level was raised by about 10m whenever the Mediterranean dried up
  - ➢ When ocean water rushed in to fill the empty basin, global sea level must have dropped by the same amount

THE FATE OF VENICE

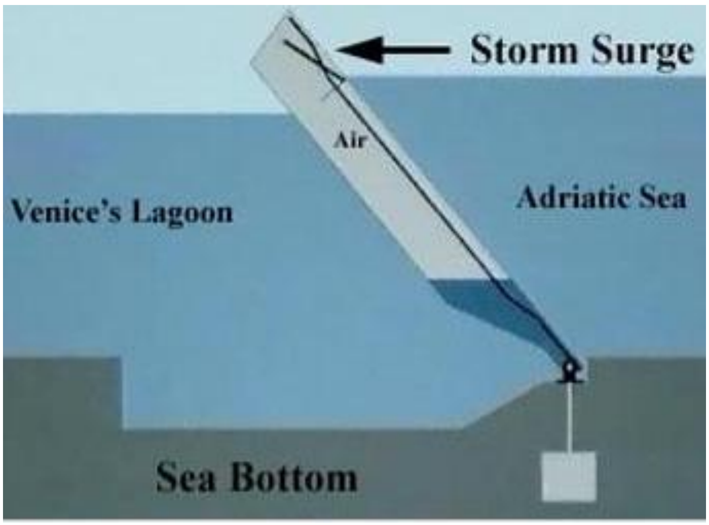
- Venice slowly sinking below sea level, & lies at the Po delta, in lagoon protected by a Lido barrier island
- Sinking extent determined by geodetic measurement
- **The Causes for the Subsidence**
  1. *The sinking of the Po Delta*: due to quaternary sediment (1.8Ma) below the central delta
  2. *The Quaternary sediments underlying the region are marine + continental* (indicating fluctuations)
  3. *Compaction of the sediments adds a component to subsidence*: by building & infilling of lagoon areas
  4. *The sand layers of the underlying sediment are groundwater reservoir (aquifer)*
  5. *Sea level rising by 1m/yr (standard 1-2 mm/*yr)
- **Summary**: the pumping of groundwater must be regulated. & the effects of filling lagoon, deepening the channels & changing the shapes of the inlets (providing ready access for storm tides)

What Can Be Done About It

- Building & maintaining gates that are up to 300m long & 15m high, & exposed to the sea while anchored in soft sediment, is a great technical challenge
- Nothing can be done about the regional sinking. We cannot control such geologic factors; we must live with them.



Schematic drawing of the MOSE gate in the inflated (closed) position. Normally, the gate lies flat on the ocean bottom. When a storm surge threatens, the hollow top of the gate will be filled with air, and the hinged gate will rise to the surface, blocking any incoming storm surges



NEOTECTONICS

- **Neotectonics**: is a branch of Earth Sciences that studies the present-day motions of tectonics plates
- When motions reach a certain level, cause sudden ground shaking (earthquakes), SO Neotectonics studies important to provide evidence for locations of major earthquakes along active fault zones, such as the San Andreas
- Neotectonics & earthquake prediction are intimately associated subjects, important for scientists & the people living in areas where earthquakes have occurred in the past & likely to occur in the future
- Neotectonics are related to subsurface structure, & topography
- **General term used in neotectonics**
  1. Subsurface: deep الجليديات تحت الارض يكون عمرها كبير ويصل الى اكثر من 10 الاف عام
  2. Near surfaces: shallow, الجليديات قرب السطح يكون عمرها اقل من 10 الاف عام
- تراكم الجليد فوق القارة يؤدي الى ضغط القشرة القارية تحته وتجويفها (اي يؤدي الجليد الى خفض المنطقة اسفله)