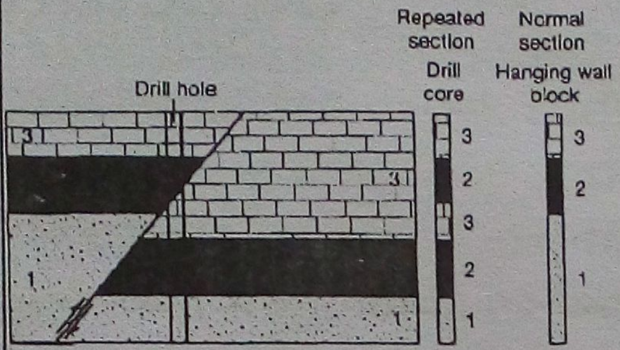
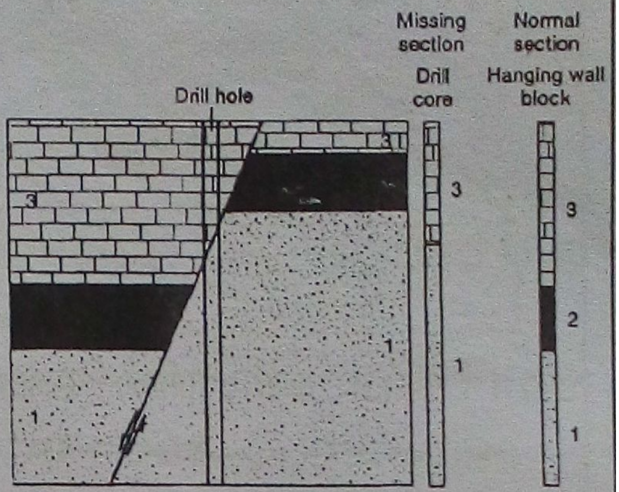
Drilling through a fault

Strata may be
repeated or omitted





Definitions related to Fault

A fault line is the surface trace of a fault, the line of intersection between the fault plane and the Earth's surface.

Faults do not usually consist of a single, clean fracture plane, they consist of fault zones where complex deformation takes place.

The two sides of a non-vertical fault are known as the hanging wall and footwall. The hanging wall occurs above the fault plane and the footwall below the fault.

Fault Zone Structure

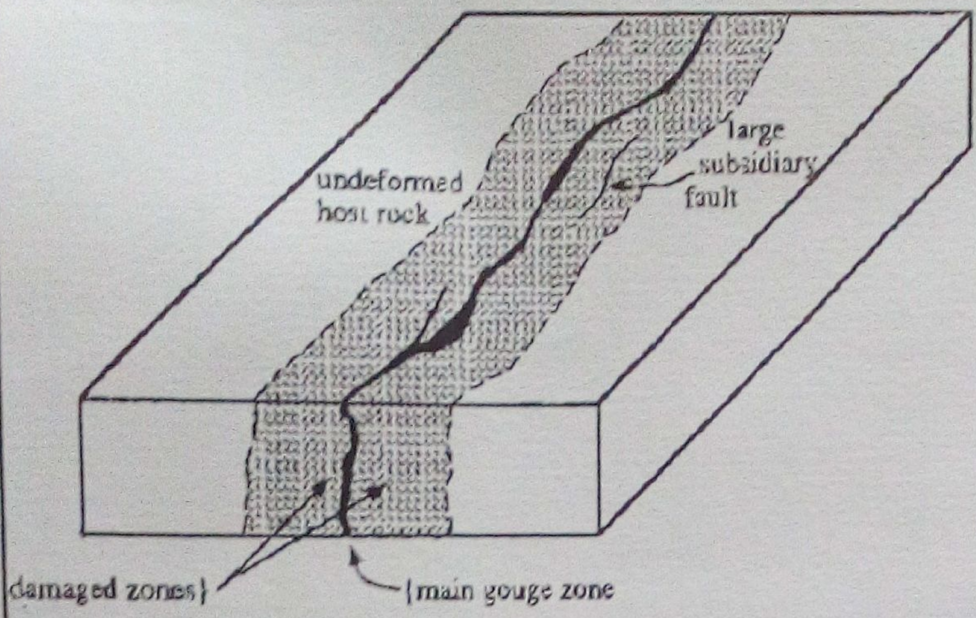


Fig. 1. Fault Zone Structure. Generalized fault zone structure showing main gouge zone along which most fault displacement occurs, surrounded by damaged zones, characterized by subsidiary deformational features (faults, fractures, cataclasis), and surrounding undeformed host rock (after Chester and Logan, 1986).

Recognition of fault

Faults are generally recognized in the field not by direct observations, but by drawing inference from lithological and other physiographical evidences available.

Lithological Evidences:

Slickenslides – rock surface may be polished but containing striations and grooves

Breccias and Gouge – rocks highly fractured into angular fragments called breccias. Sometimes very fine clay like material is present called gouge

Recognition of fault (contd.)

Lithological Evidences:

Shear Zones – presence of closely spaced fractures along which movements have been distributed. Weathering along such zone is more than adjacent rocks.

Dislocation of Strata – Abrupt termination (discontinuation) of bed, fold, dyke etc. along common line or zone. Repeatation or omission of strata. Offset of strata indicating slip.

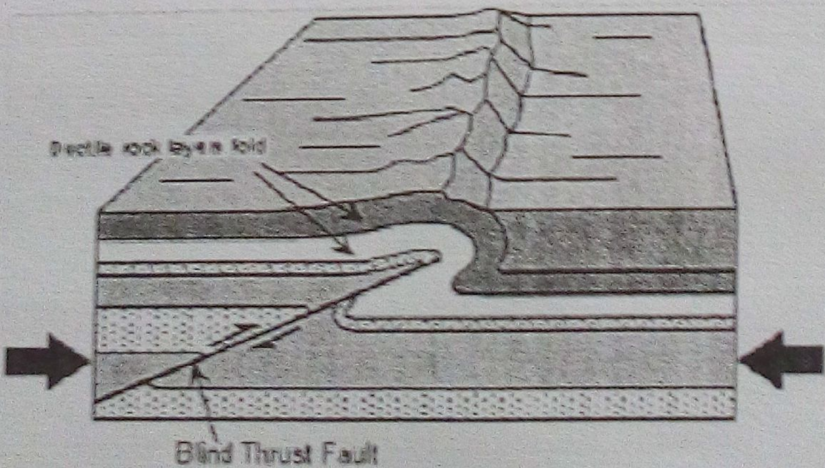
Recognition of fault (contd.)

Physiographical Evidences:

Escarpments – fault scarp, fault-line scarp.

Other topographical evidences– Number of springs arranged in a line. Local deviation of stream from its main course. Offsets of ridges.

Blind Fault



A blind thrust fault is a thrust fault that does not rupture all the way up to the surface so there is no evidence of it on the ground.

Active Fault

An active fault is a fault that is likely to have another earthquake sometime in the future. Faults are commonly considered to be active if they have moved one or more times in the last 10,000 years.

Practical engineering Aspects: Faults

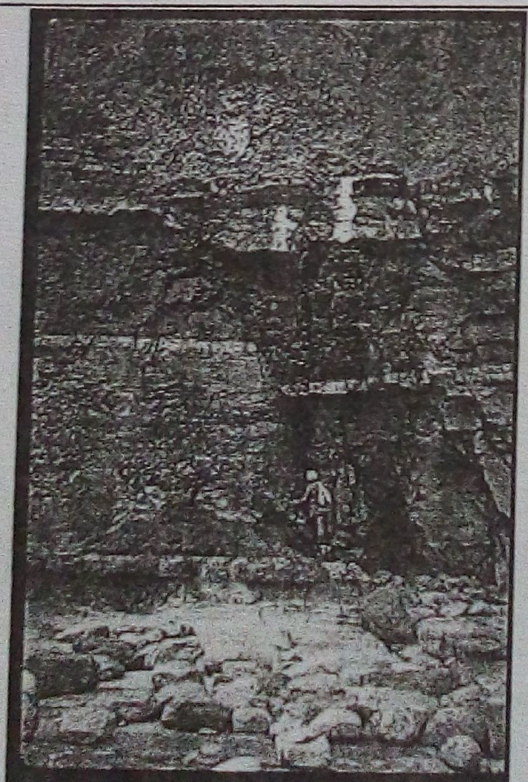
Faulted rocks generally offer unstable sites from engineering considerations, because further fresh movements may take place along the faults at any time in future. Thus, if a structure is constructed on faults, then any future movements along the fault planes may endanger the stability of the structure, and thus causing it to collapse.

Hence, an engineer, as a general rule, must try to avoid locating any major structures on fault. **Earthquake shaking is also very strong and has different characteristics in the vicinity of the fault.**

This is much more necessary to follow in the region where fault(s) have been active in the recent past.

Practical engineering Aspects: Faults

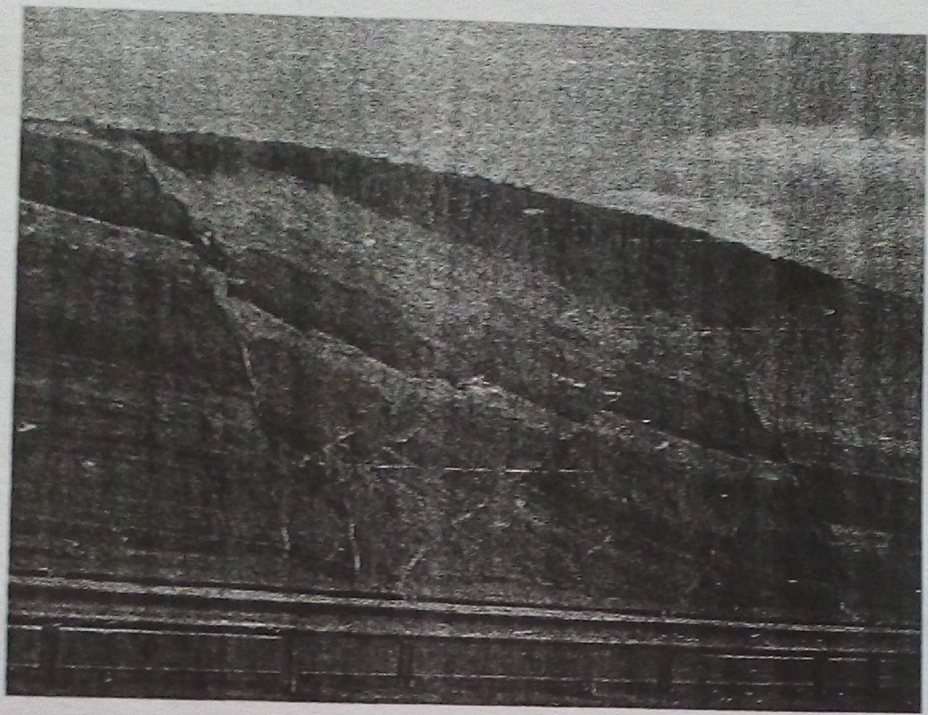
Nevertheless, sometimes, it becomes necessary for an engineer to design and construct even his major structures in moderately faulted regions. In such cases, precautions must be taken to avoid any major failures, either by seismic effects caused by movements along the faults, or due to heavy leakage that may take place through the faulted rocks. The improvement works in faulted rocks, such as excavation of weaker material from the fault zone and refilling or grouting it with cement concrete, etc. may therefore, become necessary. The additional safety factors in designs and constructions will have to be adopted.



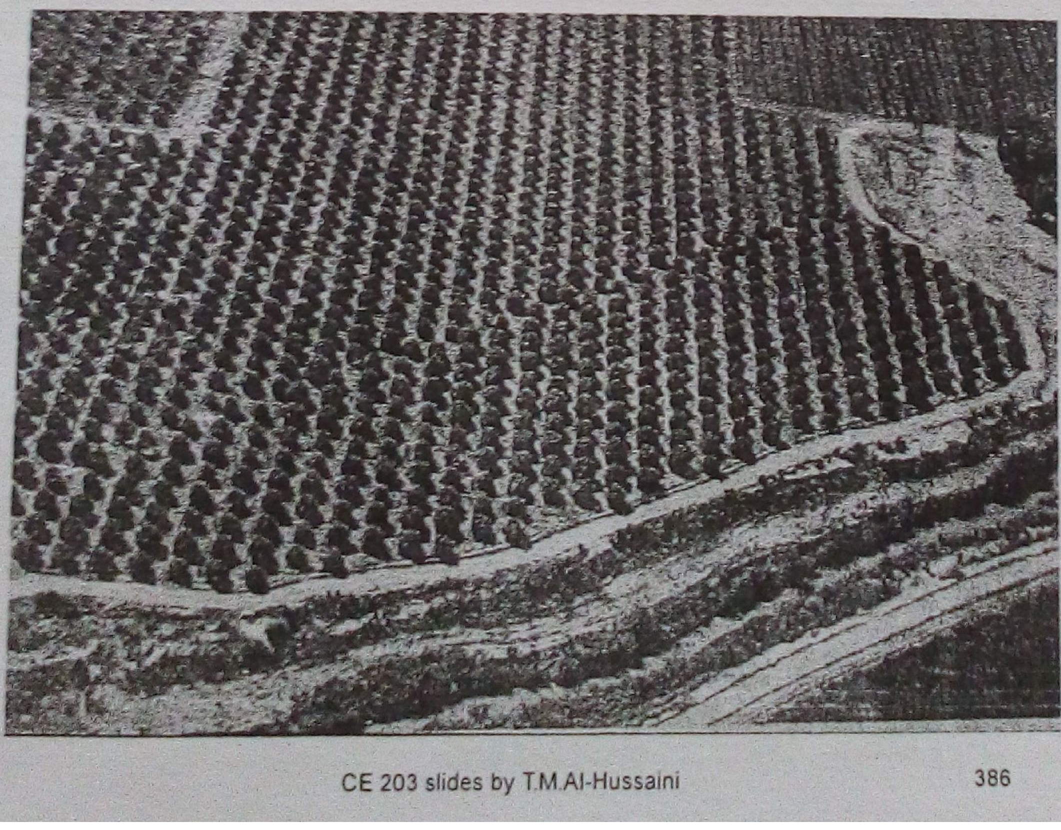
....

Fault ?

.... Fault in Iran



.... Fault ?



Joints

Difference between Fault and Joint

Joints are fractures, but which do not show clear movement of blocks across them.

Faults are also fractures but with movement of blocks (rock mass) across the fractures

Fractures and Joints

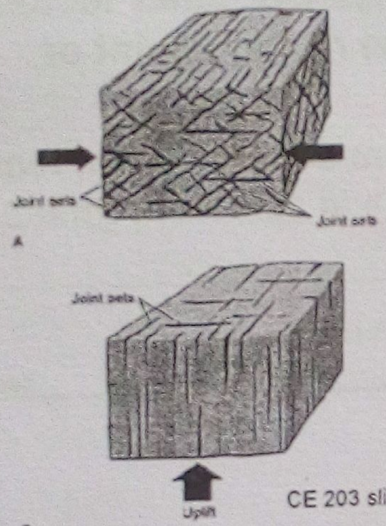
- Joints occur where a rock breaks but there is no displacement or faulting associated with the break. Joints are not singular features, but they occur in sets within a given type or area of a rock.
- Fractures are breaks in rocks that are often singular more random features and are not associated with a set of joints. Fractures often occur in association with faults or folds.
- Crustal movements, deformation, or other tectonic related movements can cause rocks to joint or fracture.
- Joints and fractures form from compression, tension, or shear stress and can range in size from millimeters to kilometers.

Fractures and Joints (contd.)

- Common forms of jointing are columnar, sheet jointing, and tensional joints.
  - Columnar jointing occurs when igneous rocks cool and develop shrinkage joints along pillar-like columns.
  - Sheeting joints occur when the layers of rock release pressure and exfoliate along parallel planes.
  - Brittle fractures and tensional joints are caused by regionally extensive compressional or elongated pressures along folds in the crustal rocks.
- Sometimes, jointing is obvious, but the processes that caused it may be unknown, or difficult to identify.
- Fractures and joints create a variety of pathways for water to flow through, which weaken the rock and facilitate chemical, biological, and mechanical weathering processes.

Brittle Strain → Joints

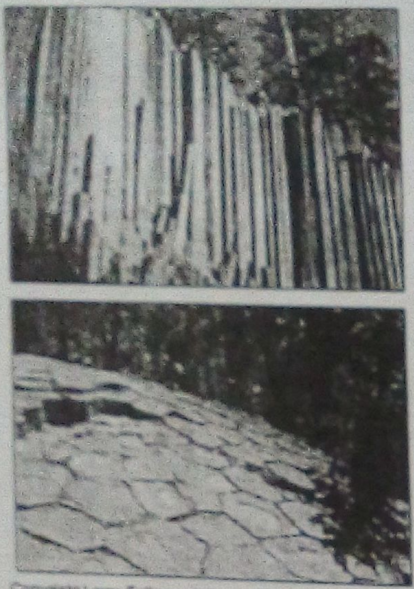
- When shallow crust is strained rocks tend to exhibit brittle strain



Joints: Fractures – with no movement

Standard 3-3.6, 3-3.8
Standard 8-3.7, 8-3.9

Jointing



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These two images are an example of columnar jointing. The image on the top is a side view and the image below is from the top. These hexagonal columns of rock formed from cooled basalt are part of Devil's Postpile National Monument in California.

The image below is of vertical jointed, bedded meta-sandstone in the Snake Range in Nevada.

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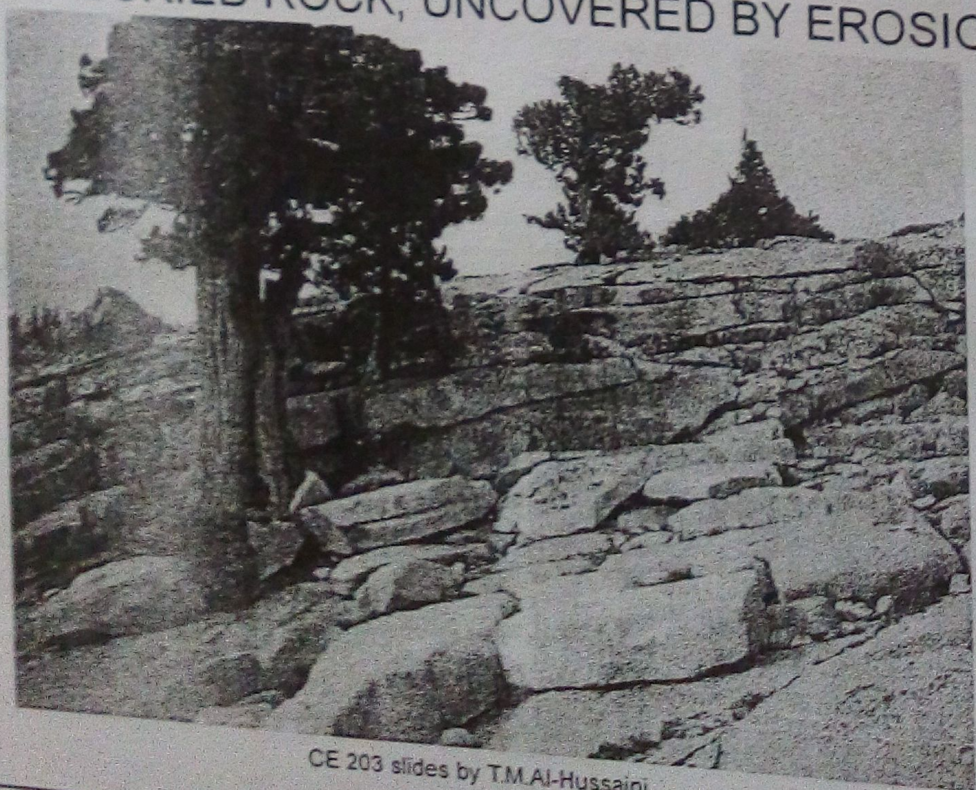
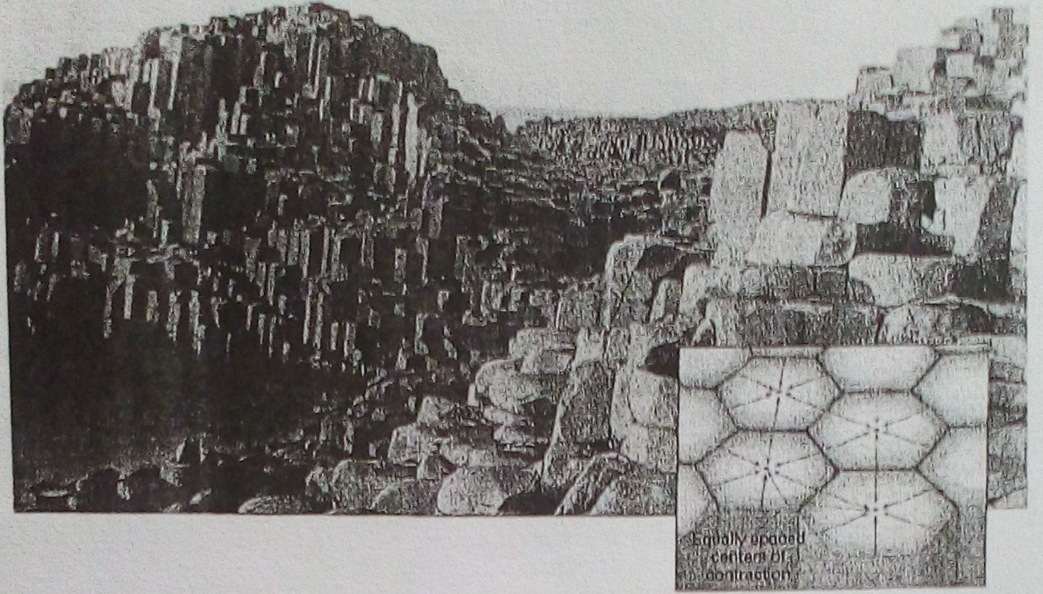
EXFOLIATION/UNLOADING JOINTS IN FORMERLY DEEPLY-BURIED ROCK, UNCOVERED BY EROSION.





CONTRACTION JOINTS IN VOLCANIC ROCK.
COOLING LAVA CONTRACTS AND FORMS
HEXAGONAL FRACTURES (COLUMNAR JOINTING)

Practical engineering Aspects: Joints

For construction of any major civil engineering structure in any area, it is absolutely necessary to investigate the rock joints thoroughly, mainly because joints act as sources of weakness for the rocks, and also as sources of leakage through the rocks.

Hence, if the proposed foundation rocks for a dam or a reservoir happens to be heavily jointed, and if the water-table of the region is low, then the leakage from the reservoir to the underground may be very heavy, finally resulting in abandoning the proposed site.

Practical engineering Aspects: Joints

Similarly, in construction of tunnels, if the roof or the side rocks, are highly fractured or jointed, the ground water may seep into the tunnel, thus creating acute water troubles, in addition to its becoming unstable or unsafe structurally.

The joints in rocks play a very important role in landslides in hilly regions, because they may serve as slip surfaces. For example, joints dipping towards the hill slope may allow the overlying, unsupported mass of rock to slide down, causing a landslide. Hence, the occurrence and orientation of joints, and their possibilities of lubrications, must be investigated, as they may lead to landslides from under the highway, or along the proposed engineering structure

Earthquake Magnitude

(Represents Earthquake Energy)

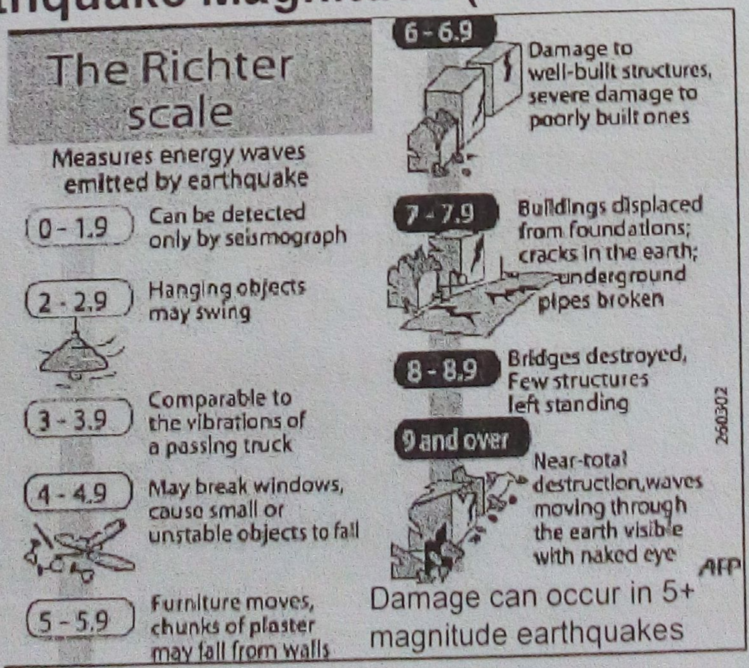
There are different magnitude scales

Earthquake Magnitude (M)

Reflects amount of energy released in an earthquake.

Description	Magnitude	Number of events per year
Great	8 and higher	1
Major	7 - 7.9	17
Strong	6 - 6.9	134
Moderate	5 - 5.9	1319
Light	4 - 4.9	13,000 (estimated)
Minor	3 - 3.9	130,000 (estimated)
Very Minor	2 - 2.9	1,300,000 (estimated)

Earthquake Magnitude (Richter Scale)



Damage can occur in 5+ magnitude earthquakes

Magnitude (M) of an earthquake is a measure of the size of an earthquake based on the total amount of the energy released by an earthquake, when the over-strained rocks suddenly rebound to cause the given earthquake. The released energy, infact, travels in the form of earthquake waves, which are recorded at the receiving station (seismograph station). The energy released (E) and the earthquake magnitude (M) are estimated with the help of the record of the surface waves, as discussed below:

A typical accelerogram of earthquake waves produced at a seismographic observatory is shown in Fig. 6.14. Such a graph will indicate the maximum acceleration (ex) reached during the earthquake (maximum ordinate recorded on Y-axis). This value of maximum ground acceleration (ex) is then empirically connected to estimate the value of E i.e. max. energy released, by the equation:

The magnitude (M) of an earthquake has also been connected by Richter with the max. displacement amplitude (A) of the recorded surface waves, by the equation :

$$M = \log_{10} A - \log_{10} A_0 \qquad ...(6.3)$$

where M = Magnitude in Richter

A = Max. Trace amplitude in mm (Fig. 6.8)

A_0 = Distance correction (Fig. 6.15) for the known (estimated) value of distance D of the observatory (recording station) from the epicentre of the earthquake.

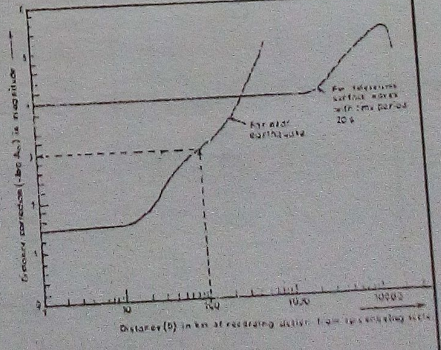


Fig. 6.15. Estimating Distance Correction (A_0).

Say for example, if the max. *trace amplitude* on the seismograph is measured to be 10 mm, and the distance of the epicentre from the seismographic station is estimated to be 100 km (say), then from Fig. 6.15, we read for 100 km, the value of (–) $\log_{10} A_0 = 3$

$$\therefore \quad M = \log_{10} 10 + 3$$
$$= 1 + 3 = 4.0 \text{ Richter.}$$

The Richter's scale of magnitude in fact, classifies the various shocks in magnitude varying from 1 to 10, and its every successive higher number represents a little over 30 fold *(i.e. $10^{1.5} \approx 30$) increase* in energy released (Please see Eq. 6.2). Thus, an earthquake of magnitude 9 has over 30 times more energy than an earthquake of magnitude 8, and 900 times more energy than an earthquake of magnitude 7, and 27000 times more energy than an earthquake of magnitude 6. The complete scale is given in table 6.4.

Table 6.4. Richter's Scale of Magnitude

Mag-nitude Number	*App. Energy released in Joules (Computed by Eq. 6.1)*	*Approximate Amount of TNT* explosive required to produce the same energy*	*Effects of energy released*
(1)	(2)	(3)	(4)
0	$10^{4.8}$	600 gm	A small explosion to uproot a stem of a tree.
1	$10^{6.3}$	20 kg	An explosive used in foundation excavation for construction
2	$10^{7.8}$	600 kg	A normal explosion in stone quarry
3	$10^{9.3}$	20,000 kg (i.e. 20 t)	A big explosion in an open cast mine
4	$10^{10.8}$	600 t	The first explosion of the experimental atom bomb

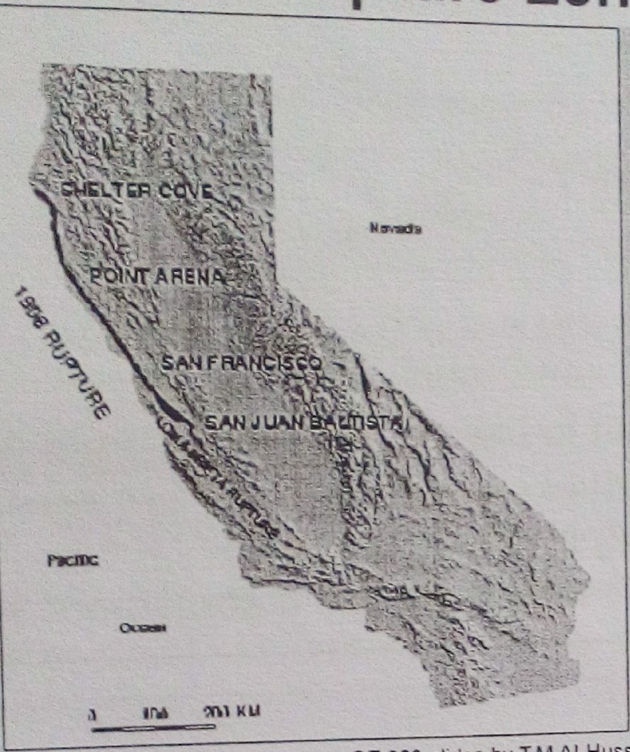
*producing about 100 kJ/kg

Magnitude Number	App. Energy released in Joules (Computed by Eq. 6.1)	Approximate Amount of TNT explosive required to produce the same energy	Effects of energy released
5	$10^{12.3} = x$	20,000 t	Atom bomb exploded at Hiroshima
6	$10^{13.8} = 30x$	600,000 t (0.6 Mt)	An explosion of hydrogen bomb
7	$10^{15.3} = 900x$	20 Mt	Simultaneous explosion of 30 hydrogen bombs
8	$10^{16.8} = 27000x$	600 Mt	About 1000 hydrogen bombs exploding simultaneously
9	$10^{18.3} = 810000x$	20,000 Mt	Simultaneous explosion of 30,000 hydrogen bombs. Energy equivalent of borning 5 yrs. production of coal and oil in the entire world.

Table 6.5. Overall Effects of Recorded Earthquakes of Different Magnitudes Over the World

Magnitude (M) in Richter	Height of generated surface waves on standard record in metres	Length of fault along which slippage occurs in km	Approximate Radius of felt area in km	Approximate Duration of Earthquake in secs	Energy Released per earthquake in Joules (Watt-sec)	No. of earthquakes of similar magnitude occurring per year in the whole world
(1)	(2)	(3)	(4)	(5)	(6)	(7)
< 2.5	—	—	—	—	—	9,00,000
3	0.001	0.5	15	< 5	20×10^{8}	1,50,000
4	0.01	1.3	80	< 5	6×10^{10}	15,000
5	0.1	3	150	5-10	20×10^{11}	1500
6	1.0	8	225	15	6×10^{13}	150
7	10.0	40	400	25-30	20×10^{14}	15
8	100.0	800	600	45-50	6×10^{16}	1.5
> 8						1 every 5 year

Rupture Length

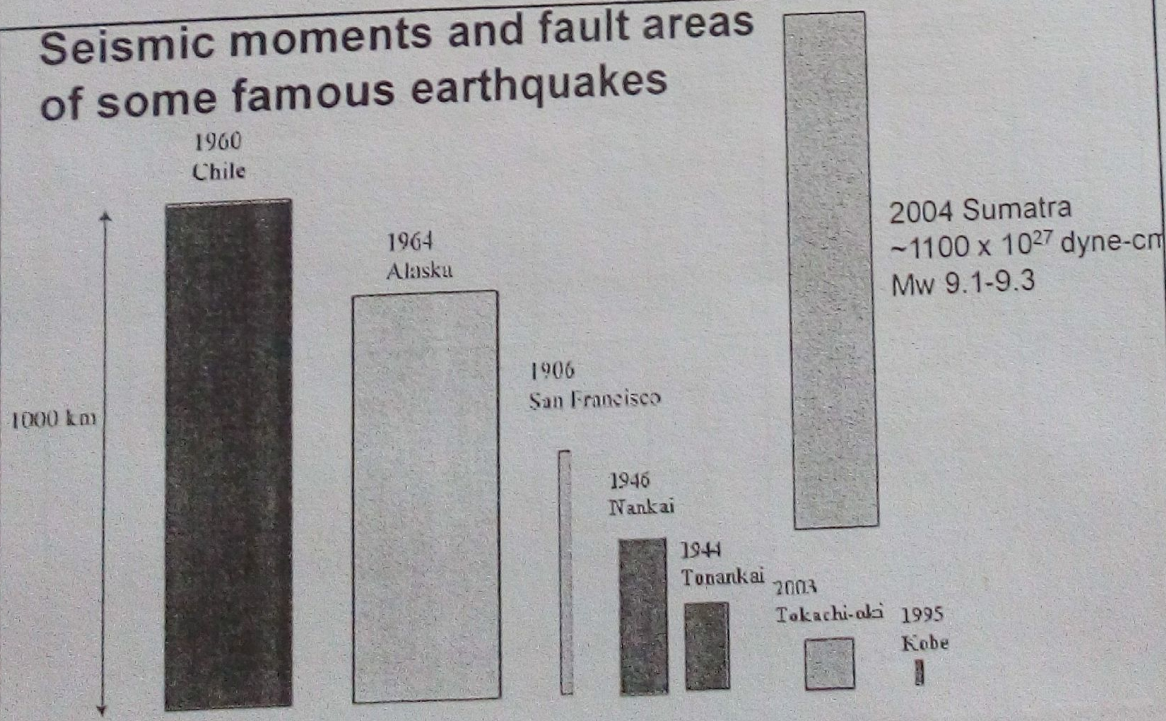


San Andreas fault

1906 San Francisco EQ
M7.7-7.9
Rupture L =470 km

1989 Loma Prieta EQ
M7.0
Rupture L = 40 km

Seismic moments and fault areas of some famous earthquakes



	1960 Chile	1964 Alaska	1906 San Francisco	1946 Nankai	1944 Tonankai	2003 Tokachi-oki	1995 Kobe
Moment (x10^{27}dyne-cm)	2000	800	10	15	15	9	0.3
Mw	9.5	9.2	7.9	8.1	8.1	7.9	6.9

Modified Mercalli Intensity Scale

It measures the impact of an earthquake at different places by sending out trained observers to look at the damage done to the built environment and the earth (landslides etc.) and at the reaction of people to the event.

EARTHQUAKE INTENSITY

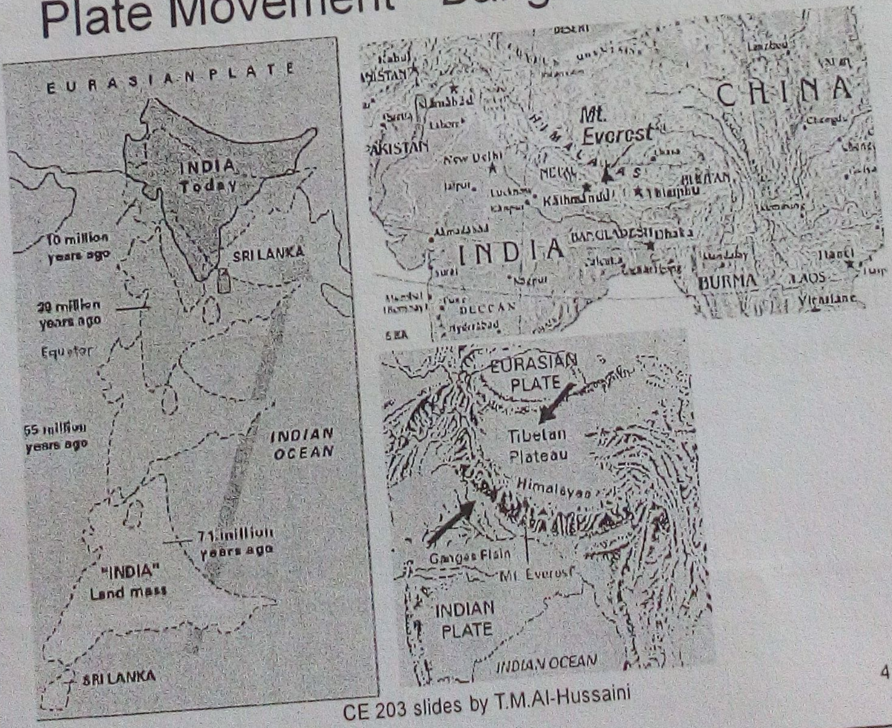
Intensity	Acceleration produced (mm/sec²)	Name of the shock and its effect
I	Less than 10	Instrumental- recorded only by the seismograph
II	Over 10	Feeble-felt only by some very sensitive people
III	Over 25	Slight-commonly felt by people
IV	Over 50	Moderate-commonly felt by people
V	Over 100	Fairly strong-considerable amount of vibration which wakes up people at sleep and causes ringing bells
VI	Over 250	Strong-minor damage to the buildings, particu- larly to their overhanging and projecting parts.
VII	Over 500	very strong-damage to the buildings, such as cracks in the walls etc.
VIII	Over 1000	Destructive-greater damage to the buildings involving over througing of overhanging and projecting portions like chimneys
IX	Over 2500	Ruinous- sever damage to the buildings, involving their over througing
X	Over 5000	Disasterous-with a sever, general destruction of buildings
XI	Over 7500	Very disasterous-sever destruction of buildings and cracking of the ground.
XII	Over 9800	Catastrohpc-large scale to complete destruction of the buildings and ground.

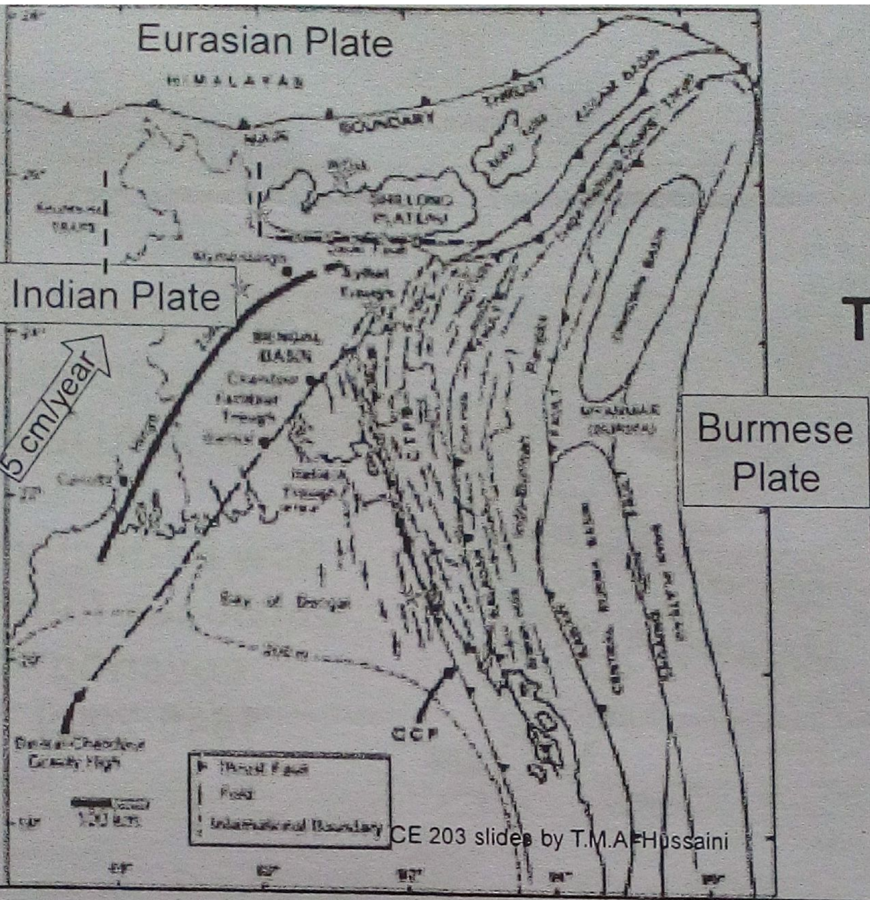
An earthquake has one magnitude, however it may vary by small amount depending on which magnitude scale you are using. Energy is a measure of magnitude.

On the other hand, the **earthquake has different intensities at different locations**, usually intensity decreases with distance. Ground acceleration is a measure of intensity at a particular place.

Seismicity in and around Bangladesh

Plate Movement - Bangladesh case



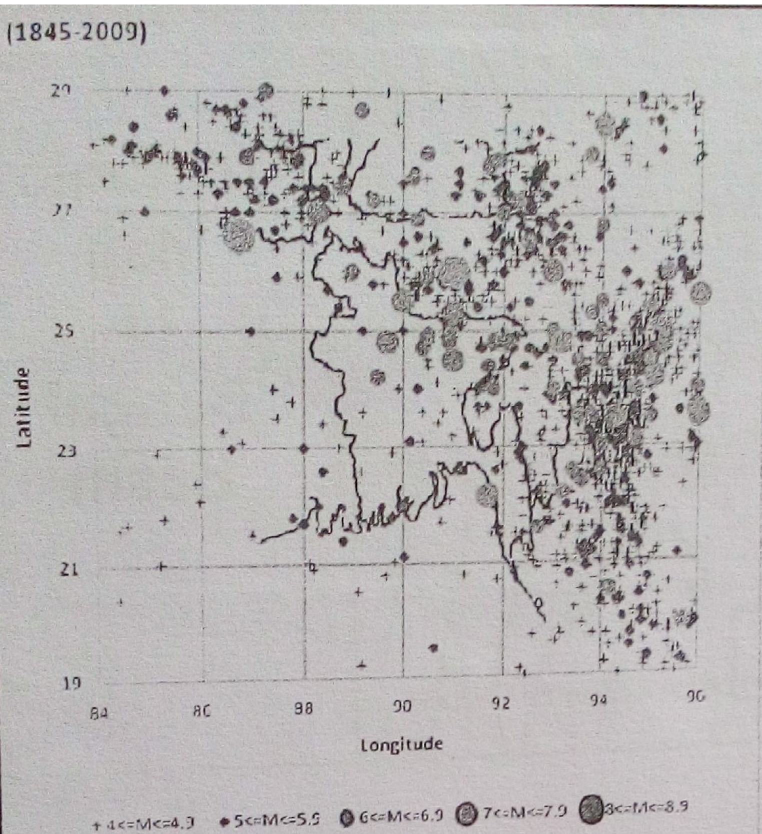


Tectonic Map of Bengal Basin

Strong Earthquakes affecting Bangladesh

Date	Earthquake	Magnitude	Distance (km) from Dhaka
2nd April, 1762	Chittagong Earthquake	7.5	260+
10 Jan, 1869	Cachar Earthquake	7.5	250
14 July, 1885	Bengal Earthquake	7.0	170
12 June, 1897	Great Indian Earthquake	8.1 (revised)	230
8 July, 1918	Srimongal Earthquake	7.6	150
3 July, 1930	Dhubri Earthquake	7.1	250

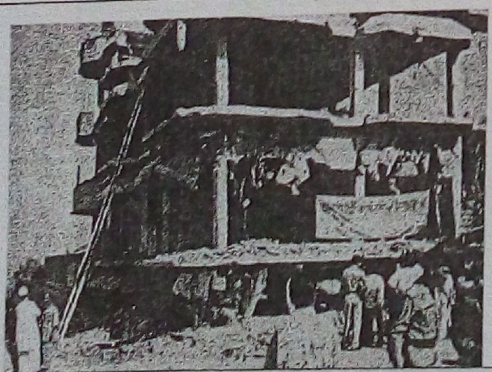
No large earthquake in last 80+ years!

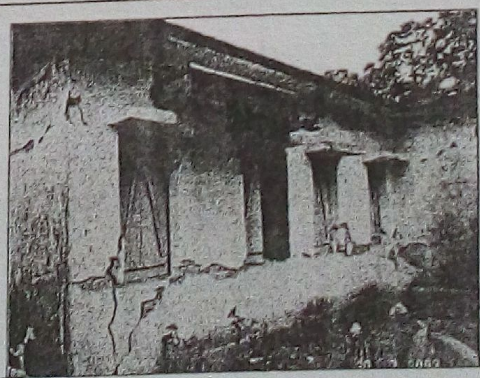


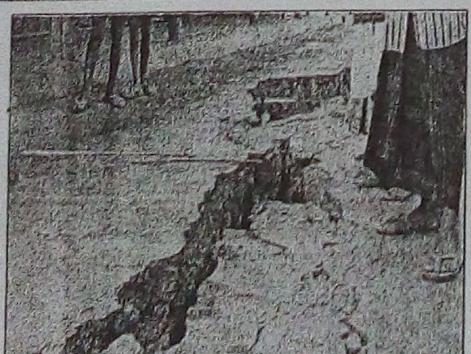
EARTHQUAKES IN & AROUND BANGLADESH

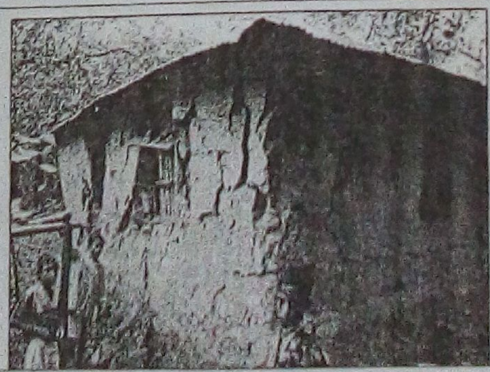
New Earthquake Catalogue formed covering 1845-2009

Damage due to Recent Earthquakes


1997: RC Frame Building, Chittagong


2003: Brick Masonry Building, Kolabunia


2003: Long crack along River, Kolabunia

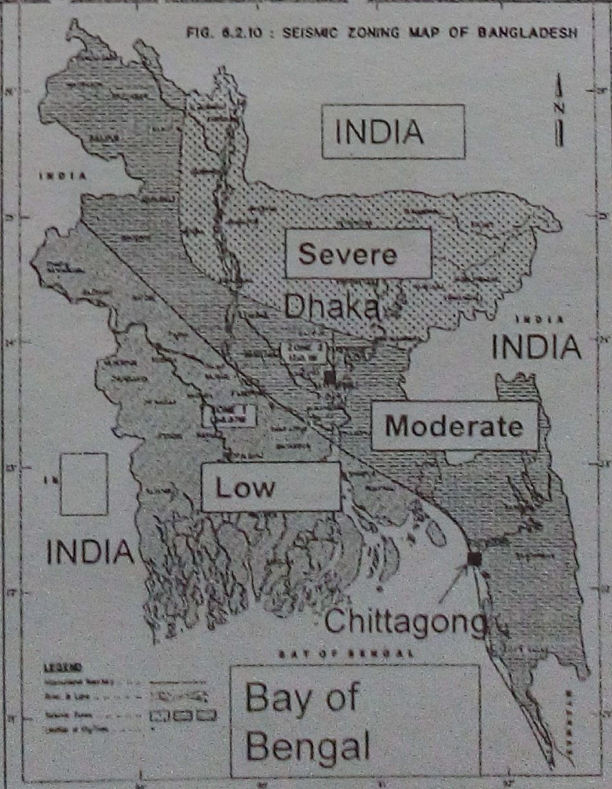

2003: Mud-walled House, Kolabunia

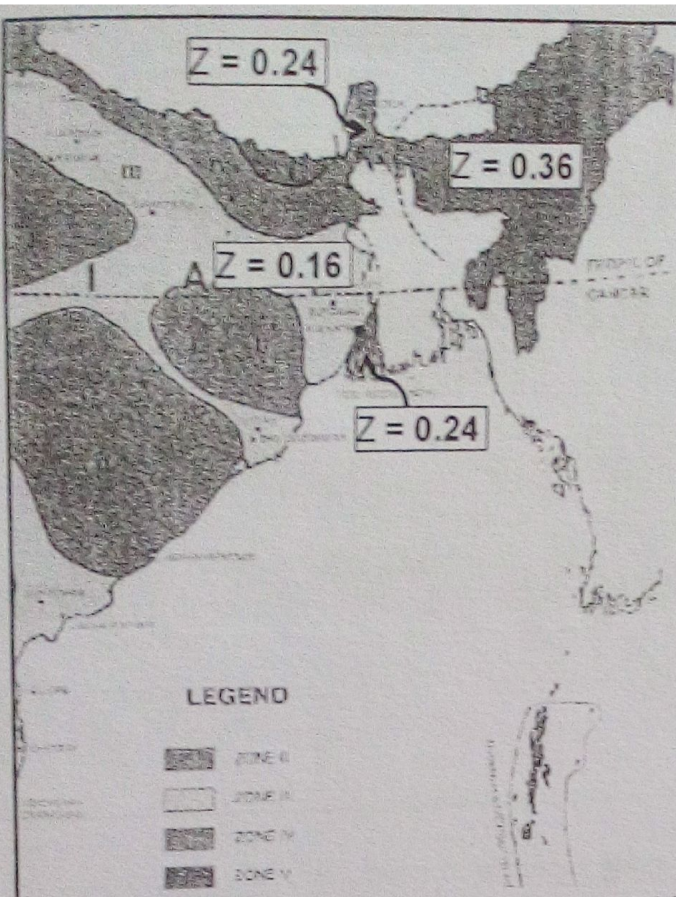
Seismicity Hazard Map of Bangladesh

Seismic Zoning Map of Bangladesh

Bangladesh National Building Code (1993)

Bangladesh is divided into 3 zones based on intensity of ground shaking:
(i) Severe
(ii) Moderate
(iii) Low

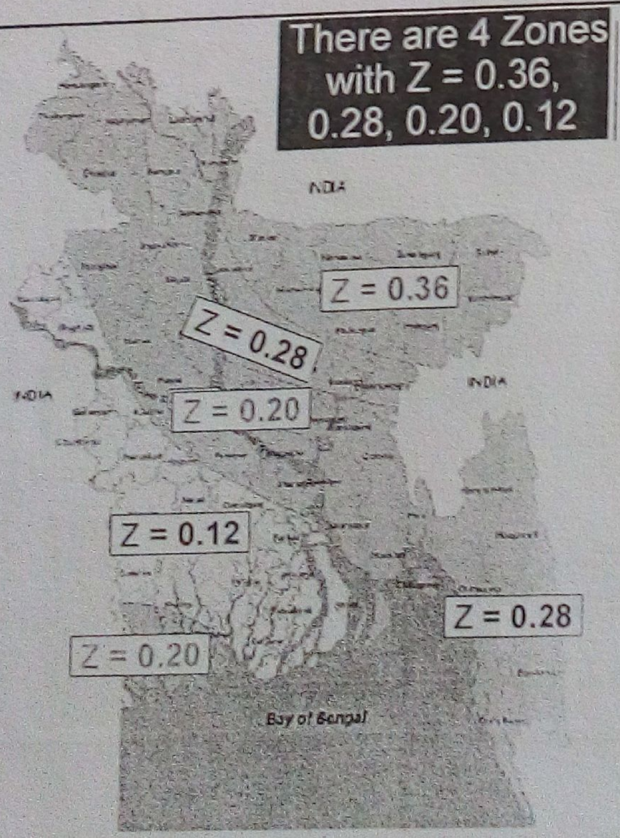




SEISMIC ZONING MAP OF INDIA, BUILDING CODE (2005)

Z represents the maximum considered earthquake (MCE) ground acceleration (g) in these zones.

Note that there are three zone factors surrounding Bangladesh:
0.36, 0.28 and 0.16.

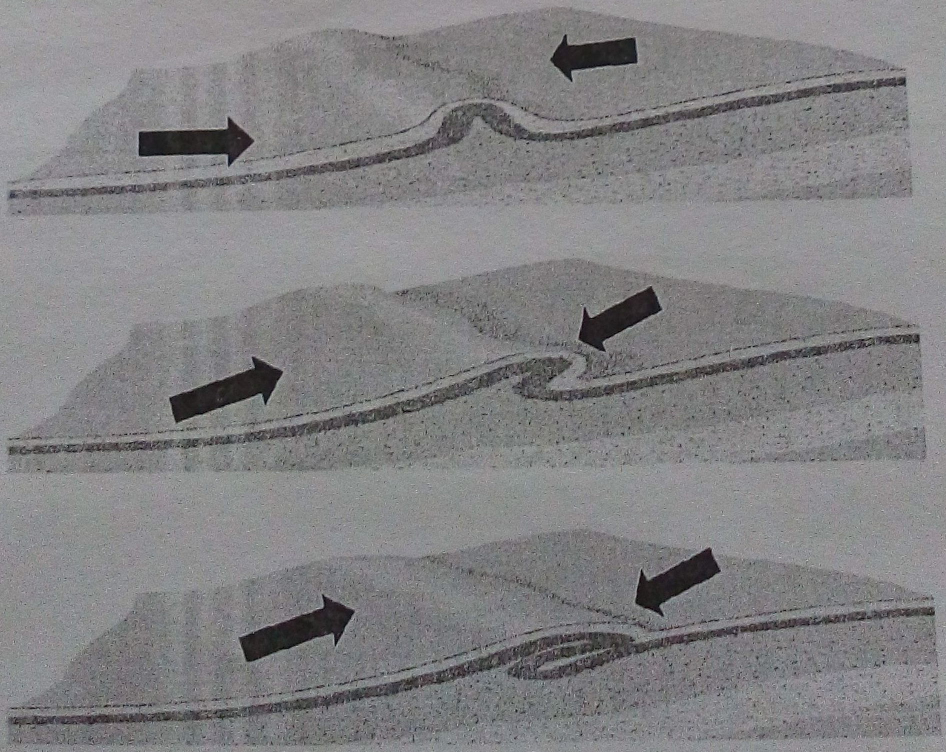


PROPOSED SEISMIC ZONING MAP (2010)

Al-Hussaini et al., 2012

Z represents the **maximum considered earthquake (MCE) ground acceleration** (g) in these zones.

Folds



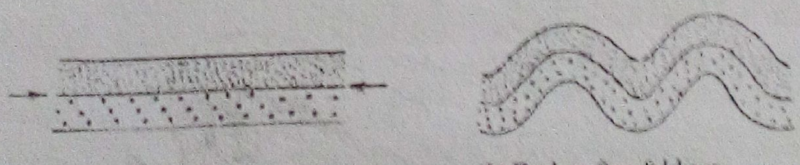
Causes of Folding

Tectonic Causes:

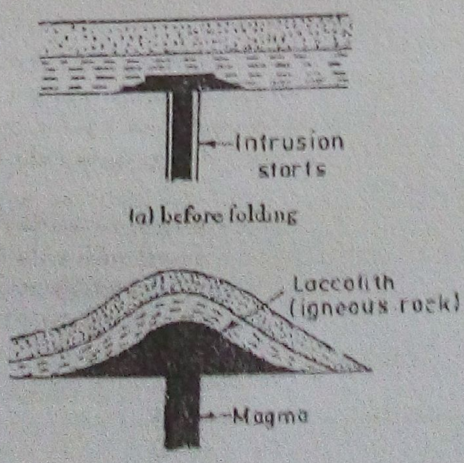
- Compressive stress developed in the earths crust
- Igneous intrusions – magma intrusion from beneath may result in folding of overlying strata.
- Salt intrusions

Non-Tectonic Causes (mainly due to gravitational forces):

- Landslide
- Creep – along hill slopes
- Isostatic setting – bending of wide basin due to increased sediment load in the middle.
- Subsidence into solution cavities
- Glacier movement induced stresses



(a) Rocks before folding (b) Rocks after folding
Fig. 8.34. Lateral compression resulting in folding.



(a) before folding
(b) after folding
Fig. 8.36. Folding due to intrusion of magma.

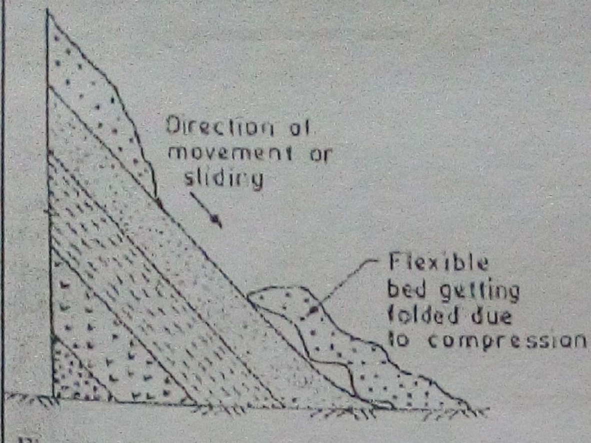


Fig. 8.38. Folding of a flexible bed by landsliding.

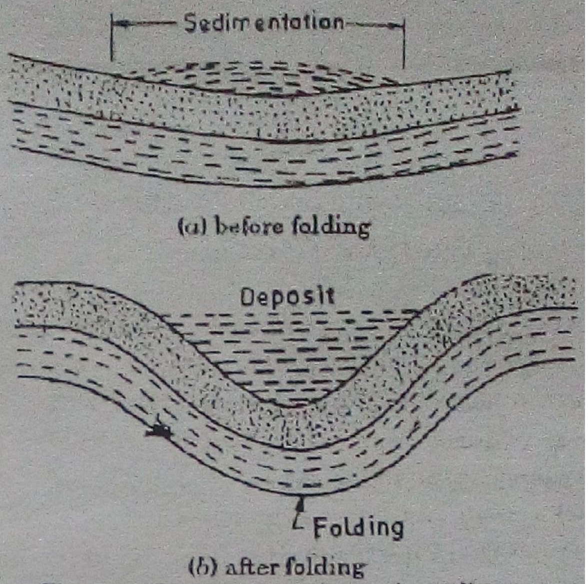
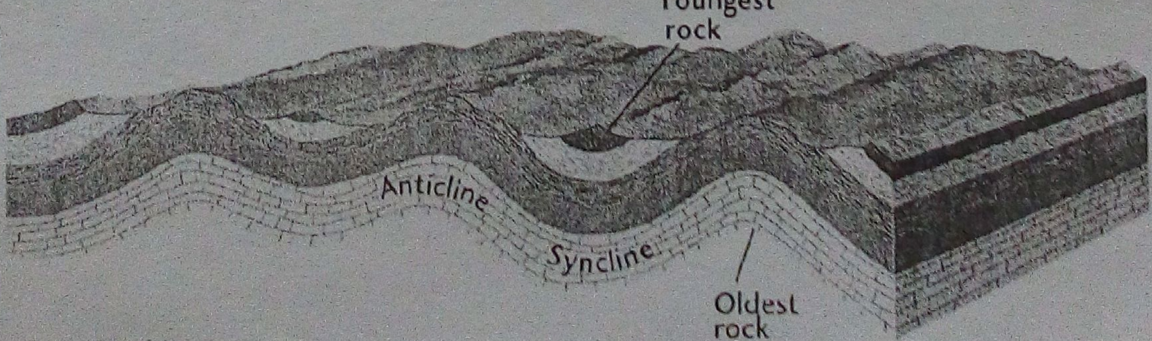


Fig. 8.41. Folding due to isostatic settling.

Folding of Rocks

- Produced by compressive forces

ROCK FOLDING IS INFLUENCED BY THE TYPE OF ROCK AND THE COMPRESSIVE FORCES



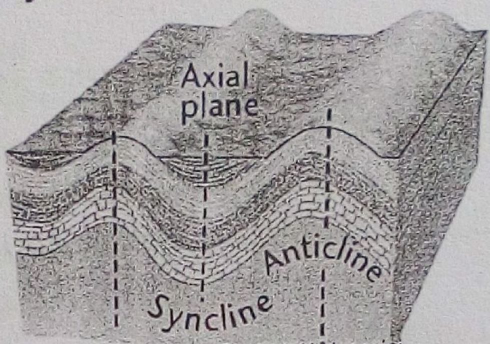
Scanned by CamScanner

syncline: a sequence of folded rocks with the youngest rocks on the inside of the fold

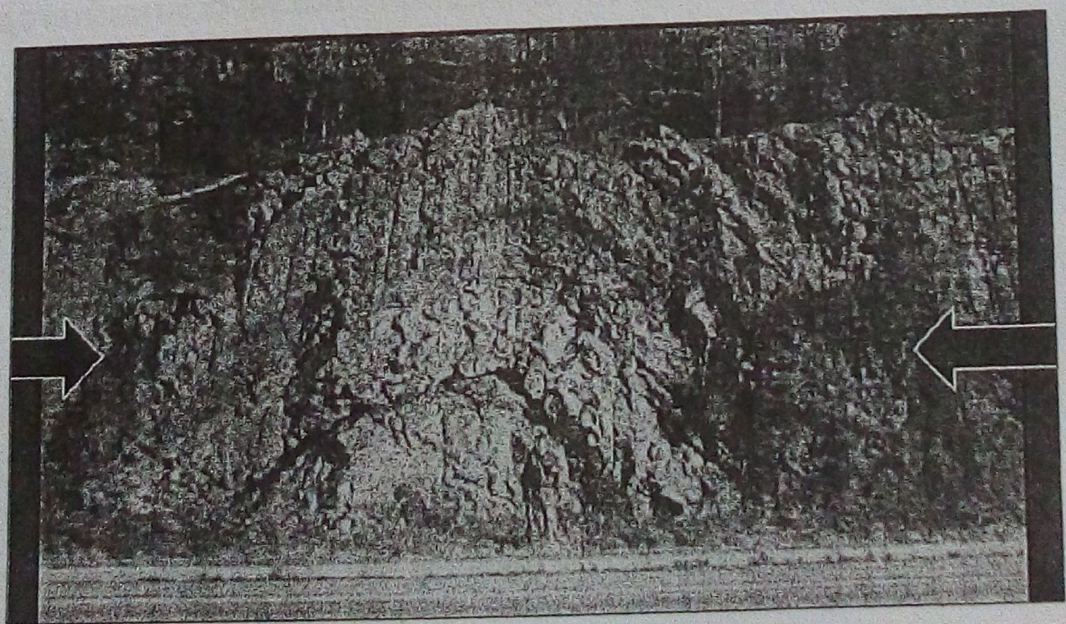
anticline: a sequence of folded rocks with the oldest rocks on the inside of the fold

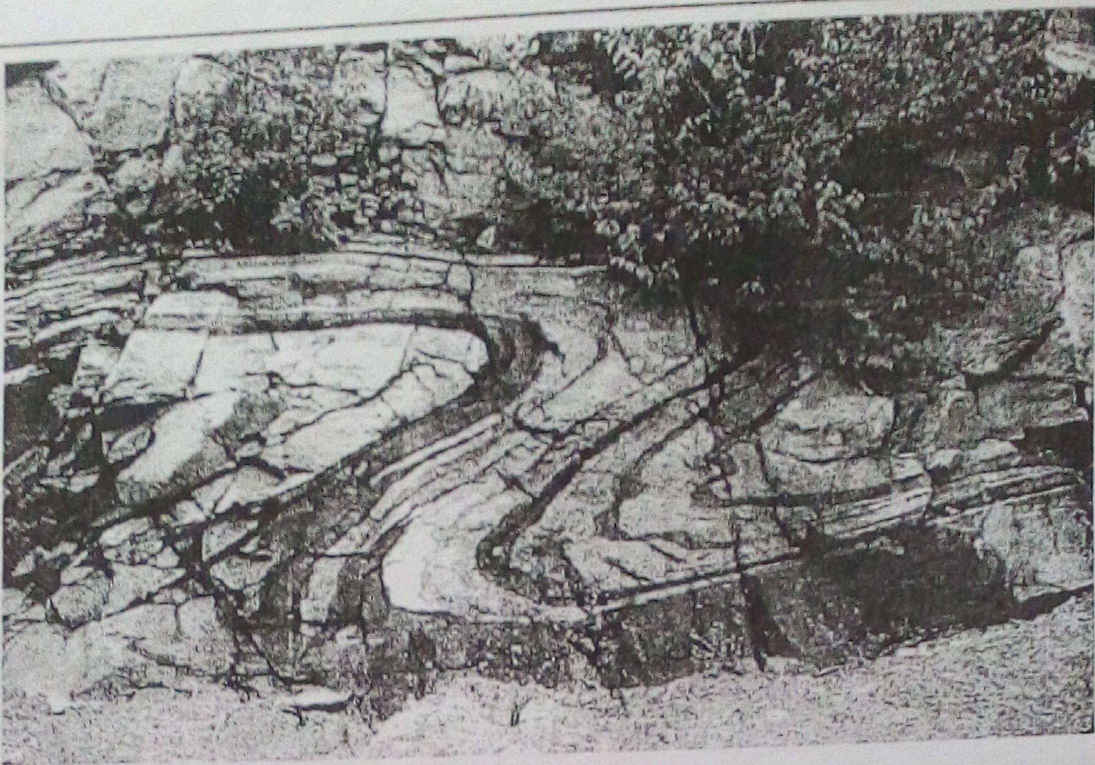
axial plane: the plane of mirror symmetry dividing the fold into two limbs

Symmetrical folds



FOLDING CAUSED BY COMPRESSION





CE 203 slides by T.M.Al-Hussaini

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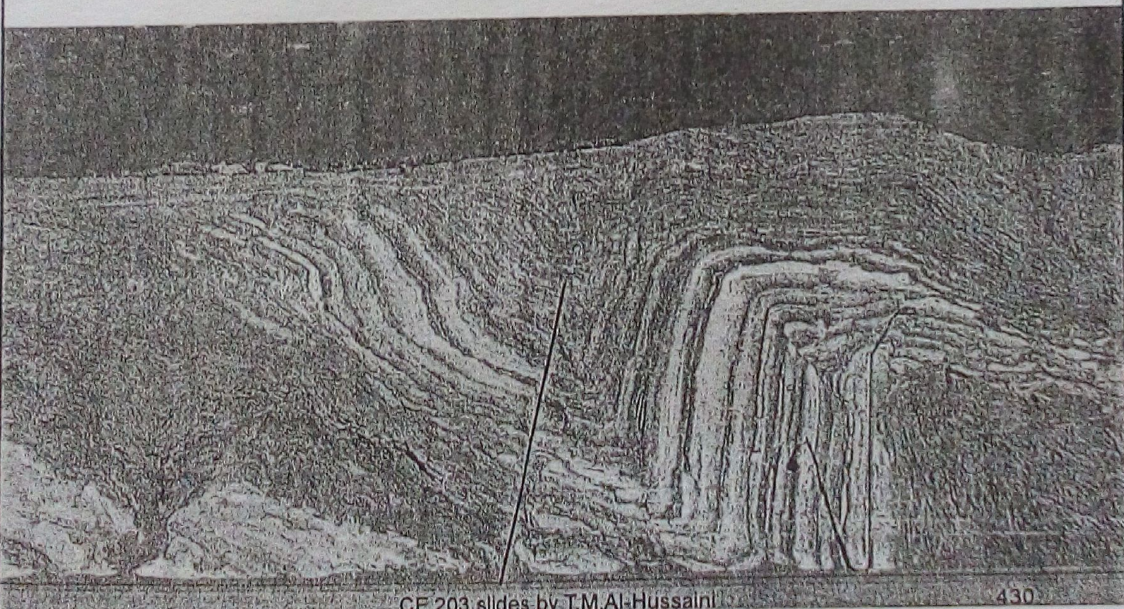
Fig. 10-CO, p. 216

Folds and Faults (Palmdale, Ca)



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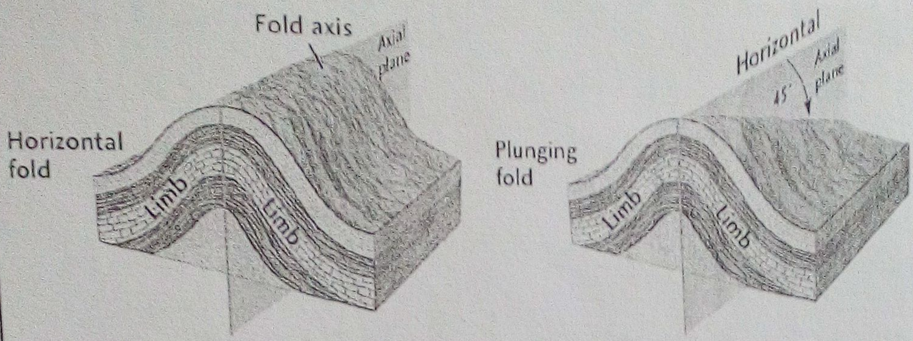
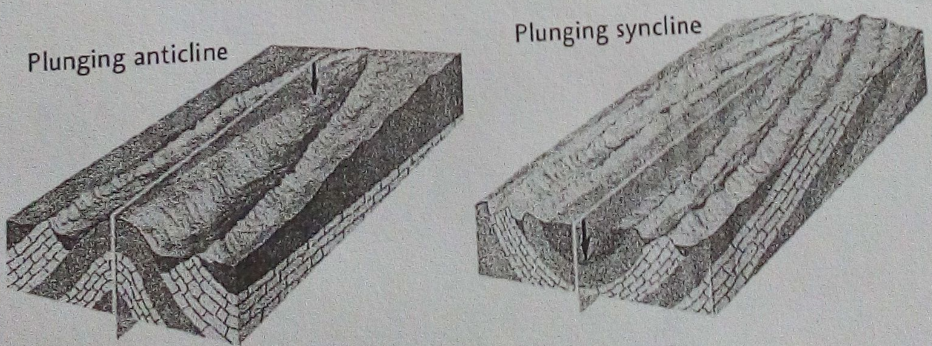
See Fig. 10-2a, p. 219



axis: the line formed by the intersection of the axial plane and a bedding plane

horizontal fold: axis is horizontal

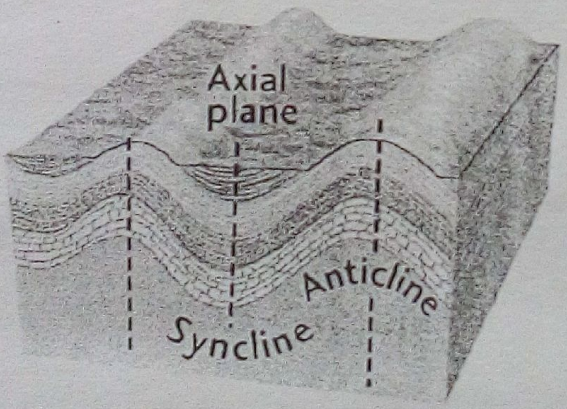
plunging fold: axis is not horizontal



Types of Folds
(based on geometry)

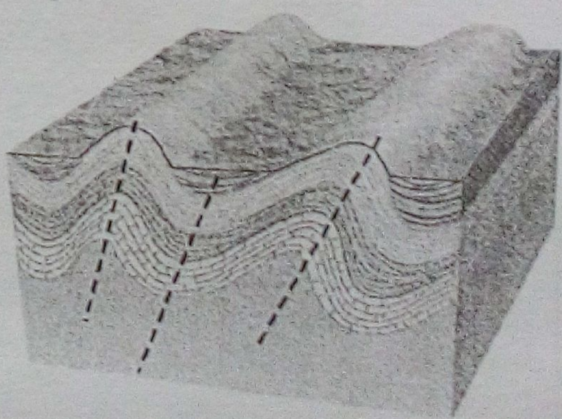
- Symmetrical folds
- Asymmetrical folds
- Overturned folds
- Recumbent folds

Symmetrical folds



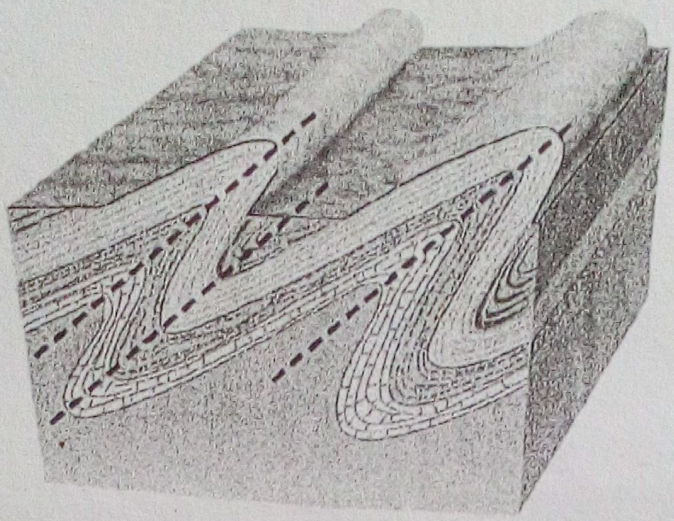
Beds dip away symmetrically from the axial plane

Asymmetrical folds



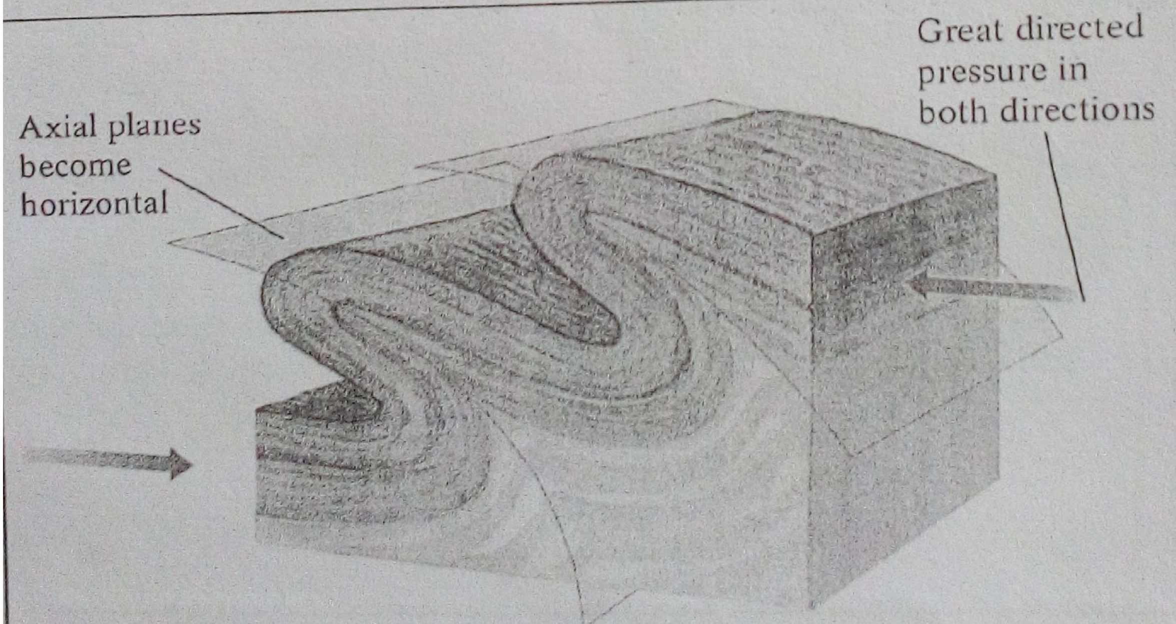
Beds on one side of the axial plane dip steeper than those on the other side

Overturned folds



Both limbs dip in the same direction

Recumbent Fold



Types of Fold (Contd.)

- **Symmetrical folds:** Limbs dipping symmetrically on each side of axial plane. Axial plane is vertical.
- **Asymmetrical folds:** have the bed on one side of fold dipping more steeply than other. Axial plane is not vertical.
- **Overturned folds:** Both limbs dipping in the same direction.
- **Recumbent folds:** Overturned fold where the axial plane is almost horizontal.

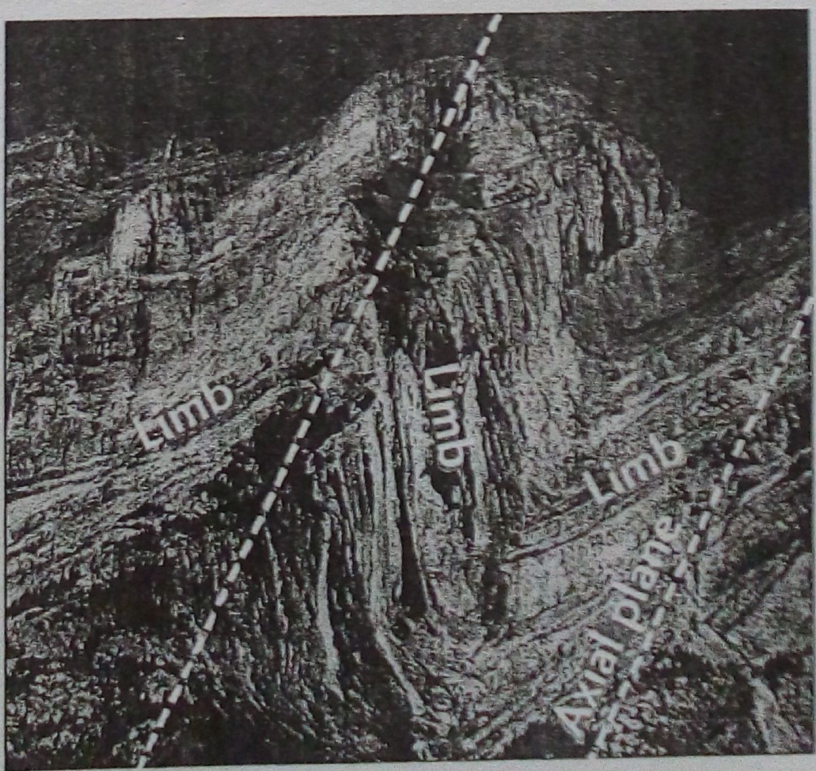
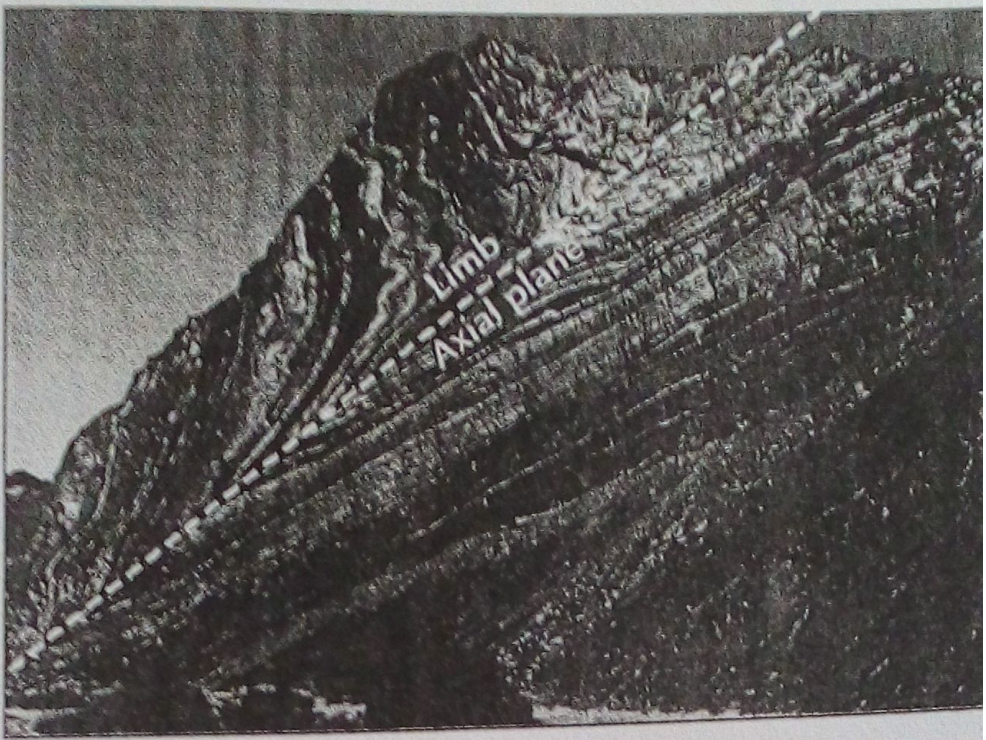
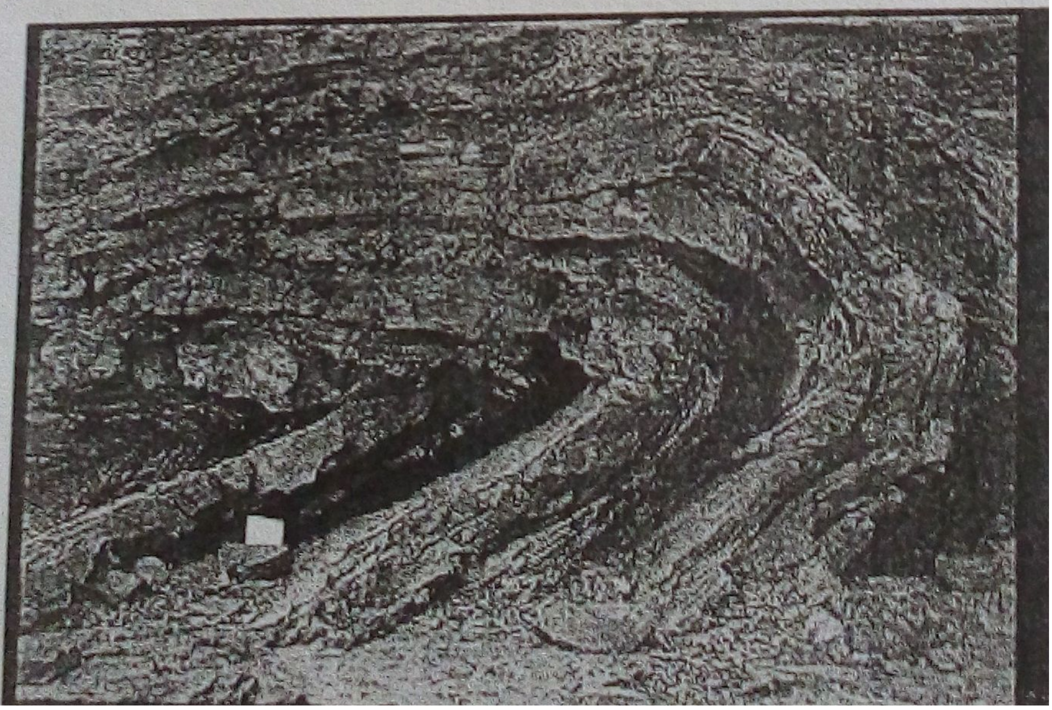
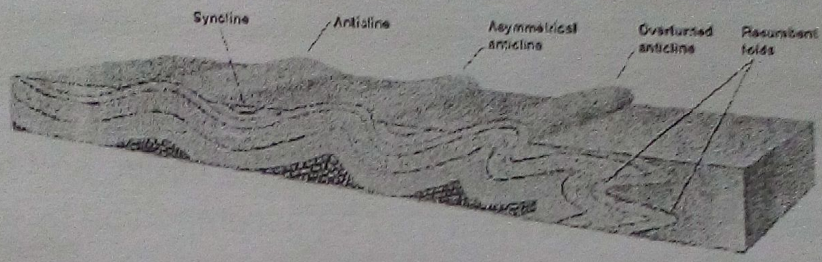


Fig. Story 11.16


Limb
Axial plane



Thompson and Turk: Earth Science and the Environment, 2/e
Figure 8.5



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Practical engineering Aspects: Folds

A civil engineer has to be very cautious, while he is handling or excavating through the folded rocks, because whenever, the folds are disturbed, they release the stored energy and may damage the site in various ways. Moreover, folded rocks are generally highly fractured, particularly along the axial parts. These fractures, not only make the rocks weak, but also act as channel-ways for the surface waters to percolate through them. Hence, for all major projects, like construction of tunnels, site selection for dams and reservoirs,
construction of highways, etc. due consideration must be given to the presence of folds.

Practical engineering Aspects: Folds

(i) Synclinal folded rocks may yield hard and tough quality stones; whereas, anticlinal folded rocks will yield weaker stones.

(ii) Folded rocks are under considerable strain, and hence, excavations through them may be accompanied by slips and rock bursts.

(iii) Folded rocks are generally shattered and weak, particularly in the axial regions; and hence, they are unsafe to be trusted as roofs or floors of tunnels, or as foundations for dams. Such regions should therefore, be avoided for such purposes, or must be thoroughly investigated, and remedial measures taken, if at all adopted for such uses.

Practical engineering Aspects: Folds

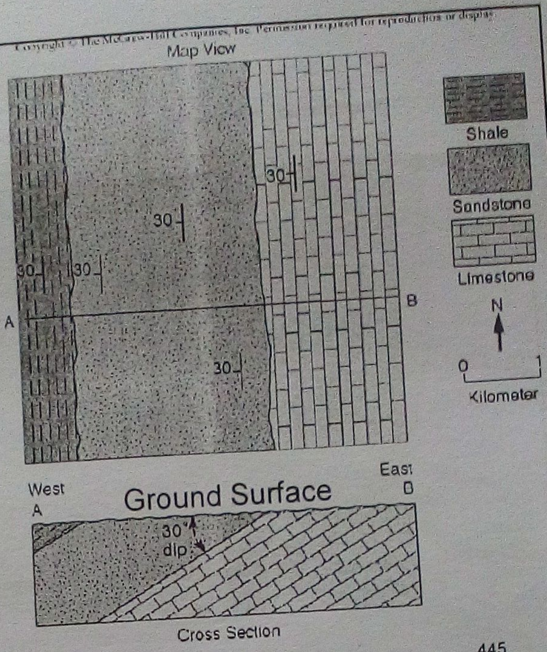
(iv) Fractured folded rocks are highly permeable, and as such may pose numerous problems. Say for example, while excavating tunnels through such regions, ground water may rush into the excavation. Similarly, in dam construction in such areas, heavy leakage from beneath the dam may take place.

(v) Since the folded rocks offer great prospects for ground water, they become quite important for engineers searching for water supplies. Infact, artesian conditions are developed only when aquifers are folded (or inclined) as synclines, and are enclosed between top and bottom impervious layers.

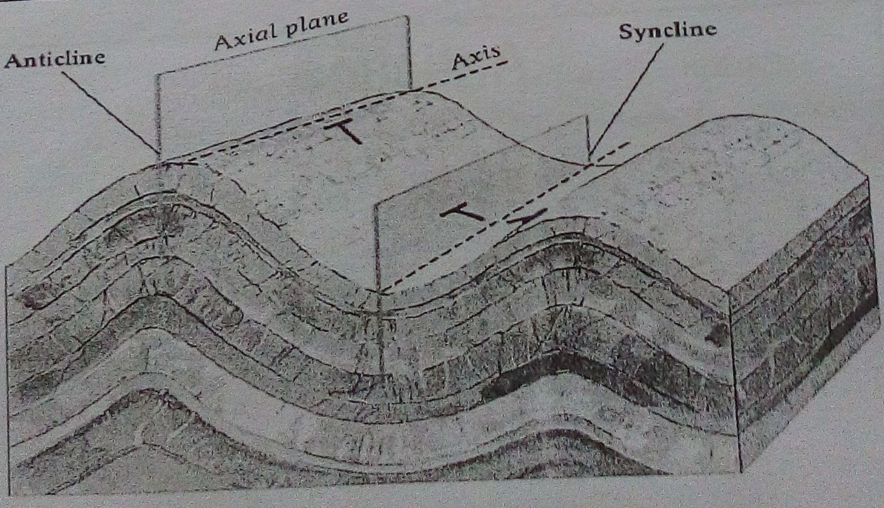
(vi) The anticlinal folds provide good prospects for stored petroleum.

Rock Outcrop

Outcrops are places where bedrock is exposed at the ground surface

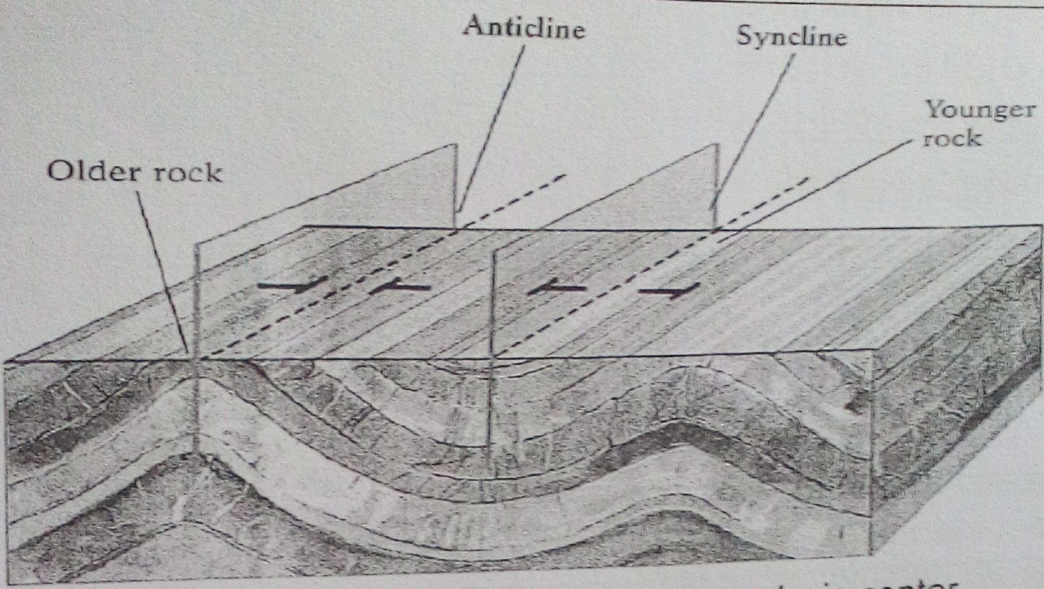


Folded Rock Before Erosion



1 Folded rocks before erosion

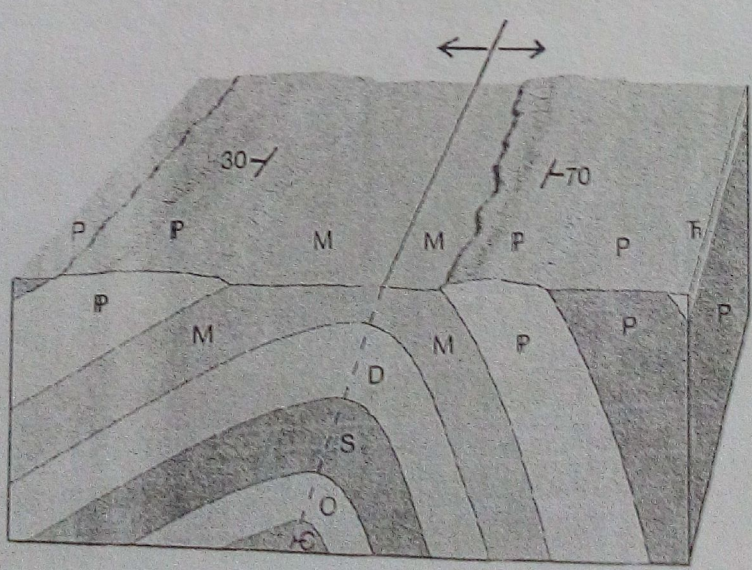
Folded Rock After Erosion



2 After erosion

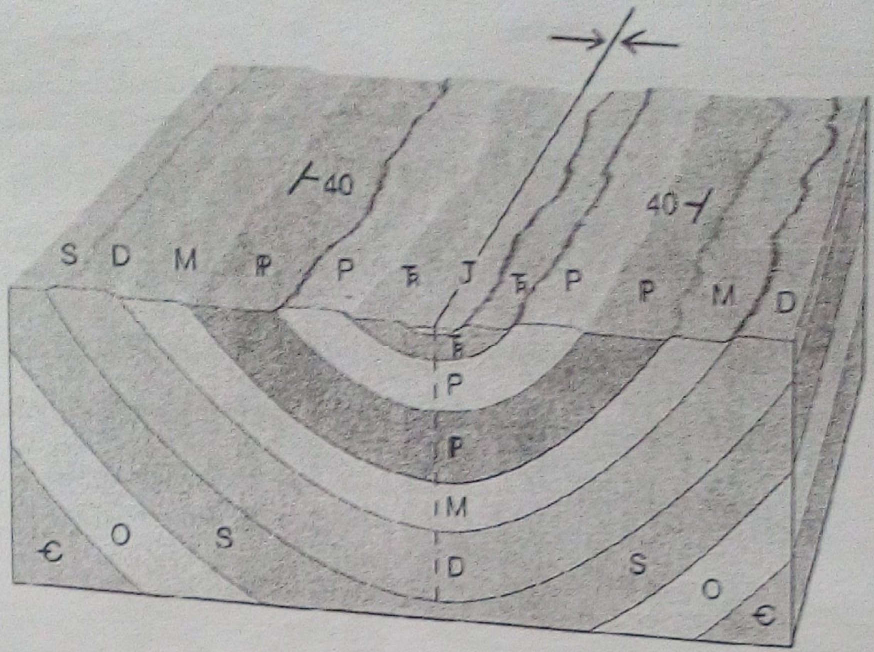
Eroded Anticline, older rocks in center.
Syncline is opposite.

Anticline



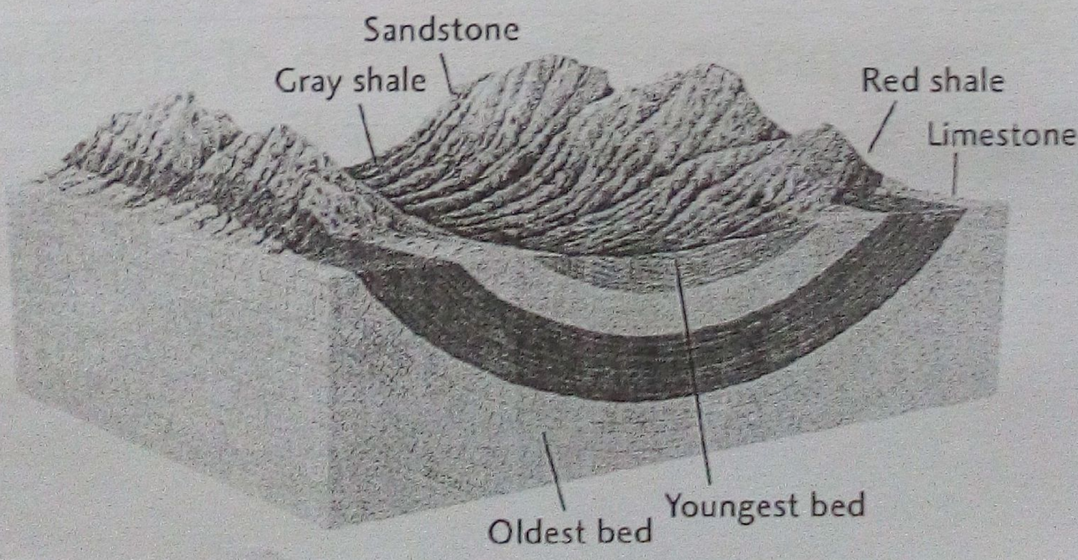
A. Anticline (asymmetrical): oldest rocks (€) occur in the center of the fold

Syncline

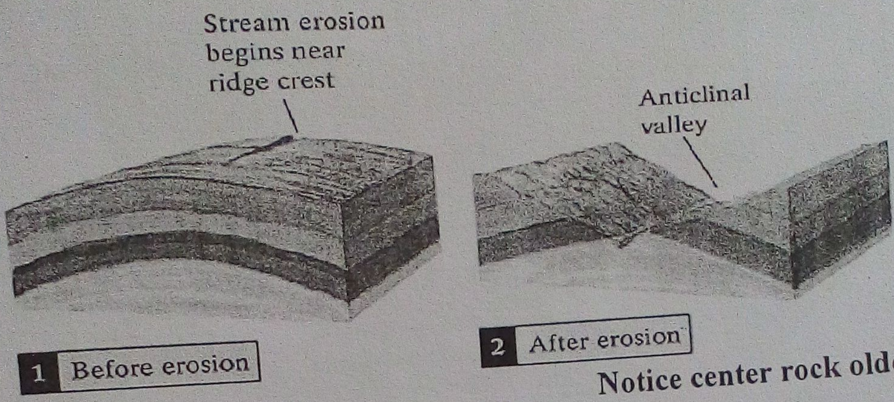


B. Syncline (symmetrical): youngest rocks (J) occur in the center of the fold

Syncline



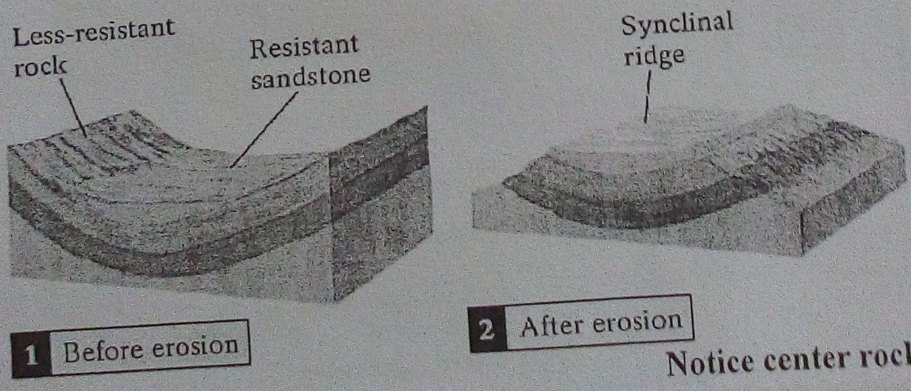
Topography may be opposite of Structure Anticline Before/After Erosion



Notice center rock oldest

(a) Anticline with highly erodible surface

Topography may be opposite of Structure Syncline Before/After Erosion

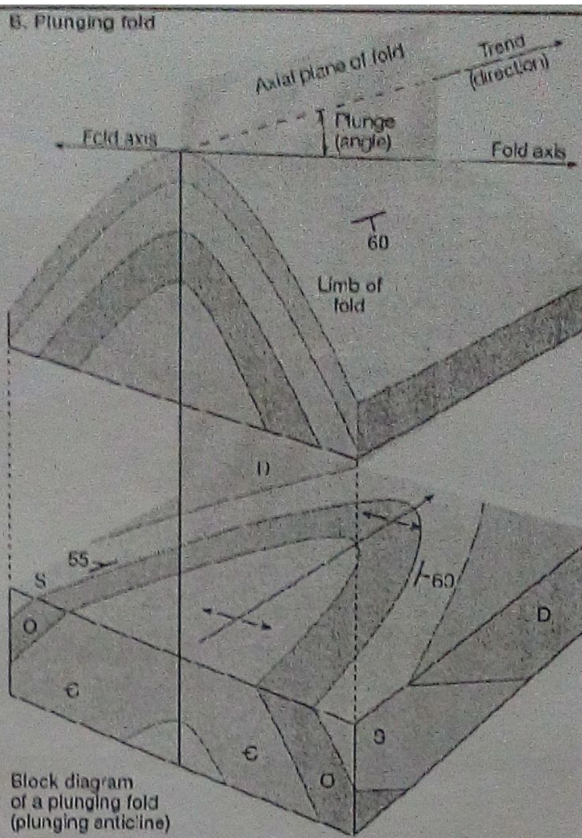


Notice center rock youngest

(b) Syncline with resistant rock at axis

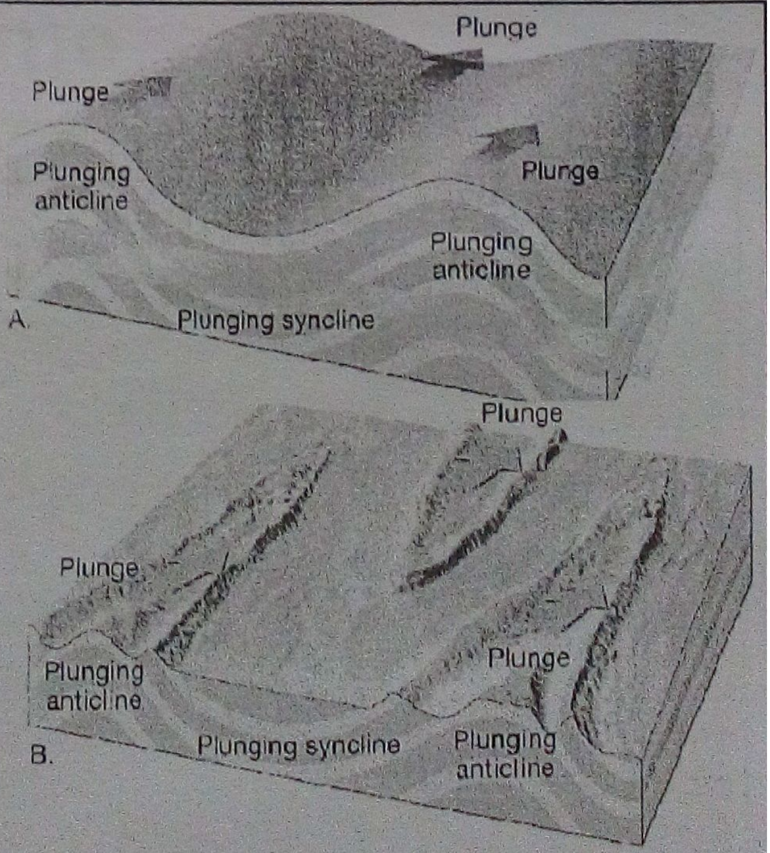
Plunging Anticline

Where surfaces have been leveled by erosion, plunging folds form V- or horseshoe-shaped patterns of exposed rock layers (beds).

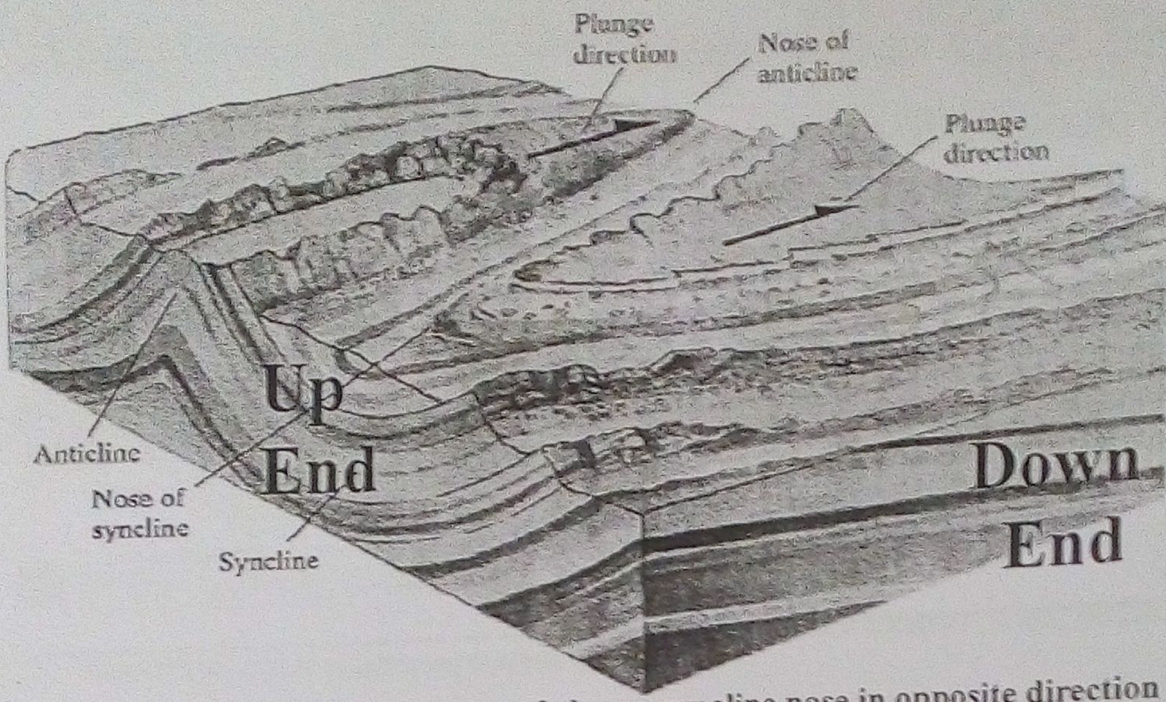


"the law of v's" gives the direction of dip and some indication of the dip angle (the longer the V, the lower the angle of dip).

For anticline, the direction of V coincides with direction of plunge. For syncline the opposite occurs.

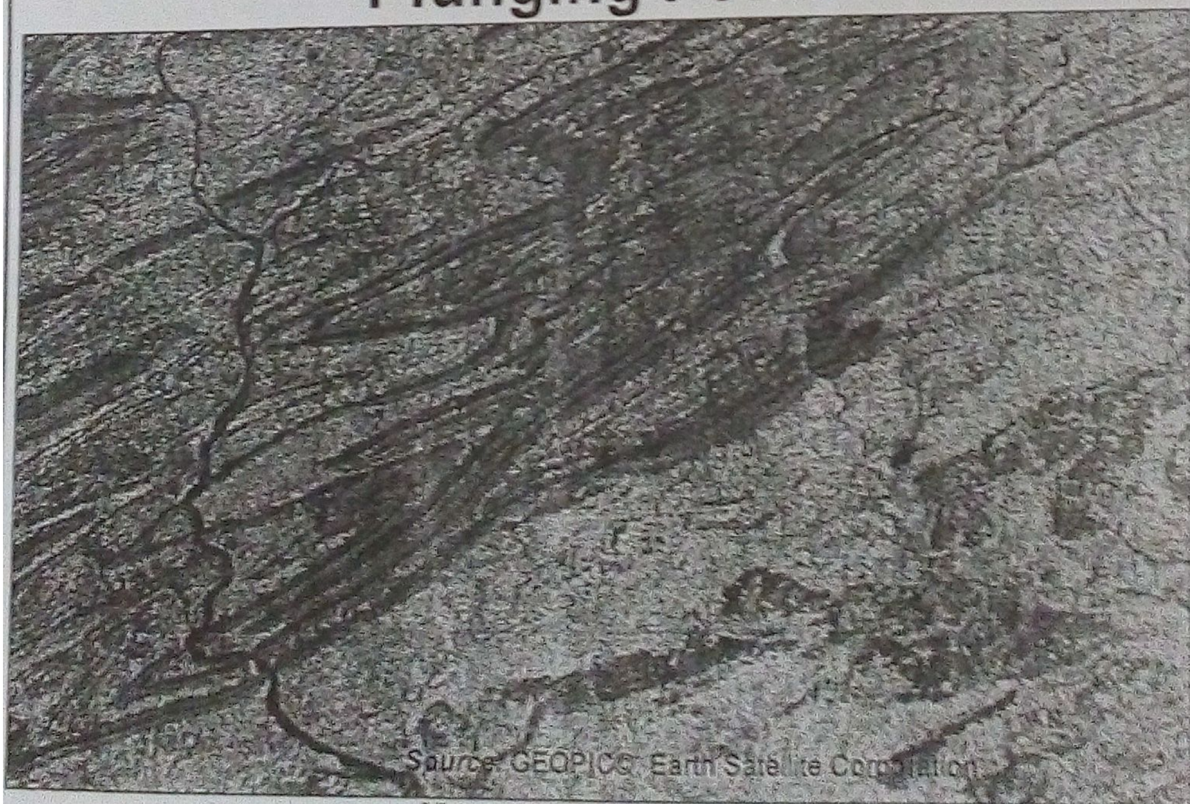


Plunging Folds

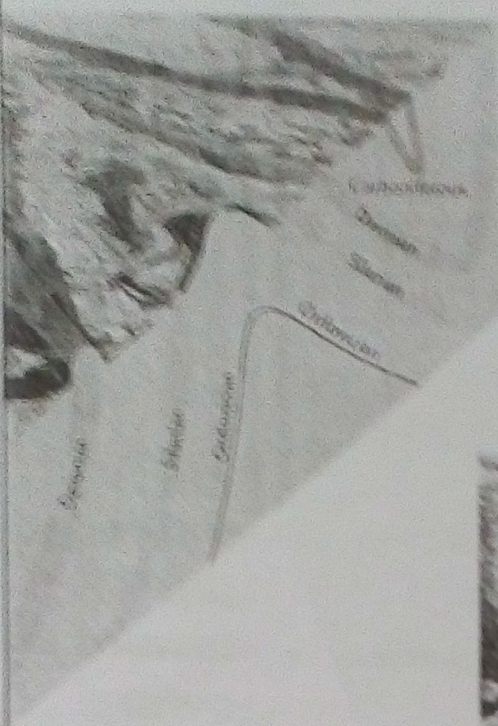


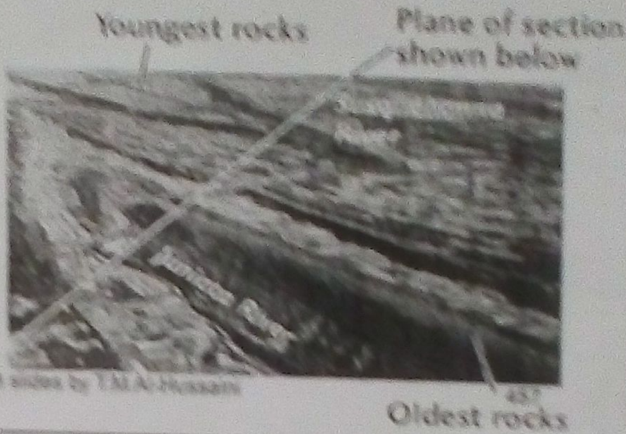
Nose of anticline points direction of plunge, syncline nose in opposite direction

Plunging Folds

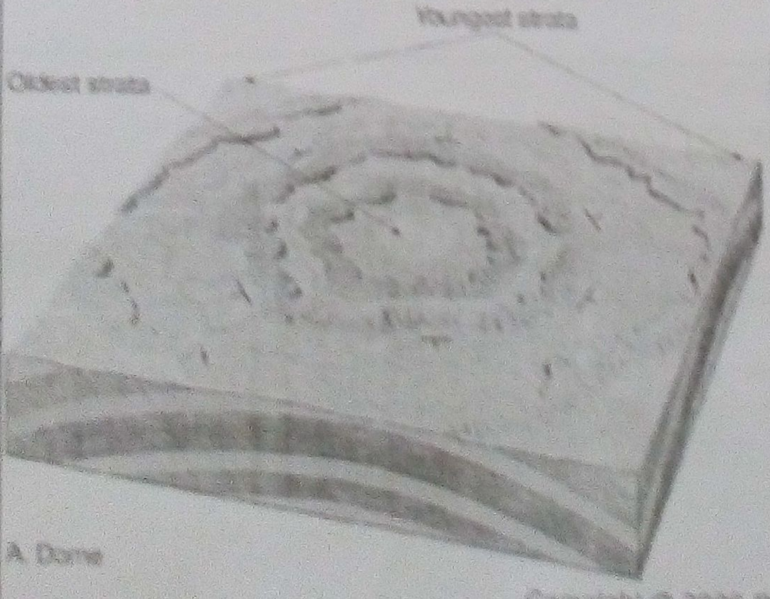


Source: GEOPIC© Earth Satellite Compilation





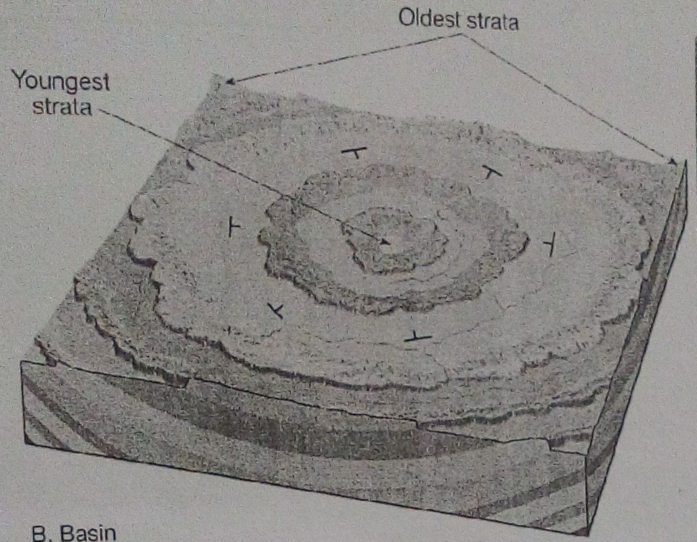
Dome



Domes are structures in which the beds dip away in all directions from a central point.

Scanned by CamScanner

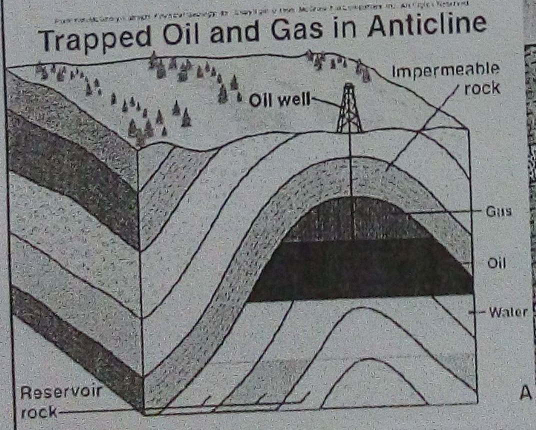
Basin

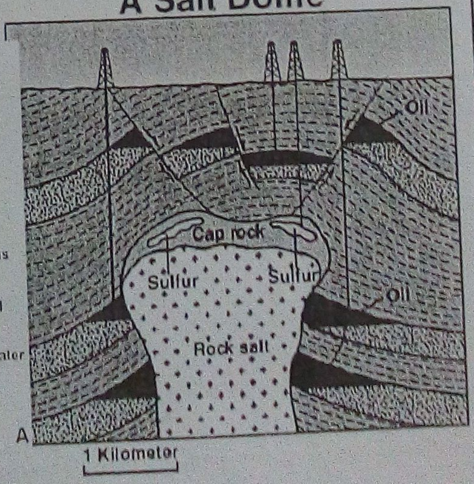


Basins are structures in which the beds dip toward a central point.

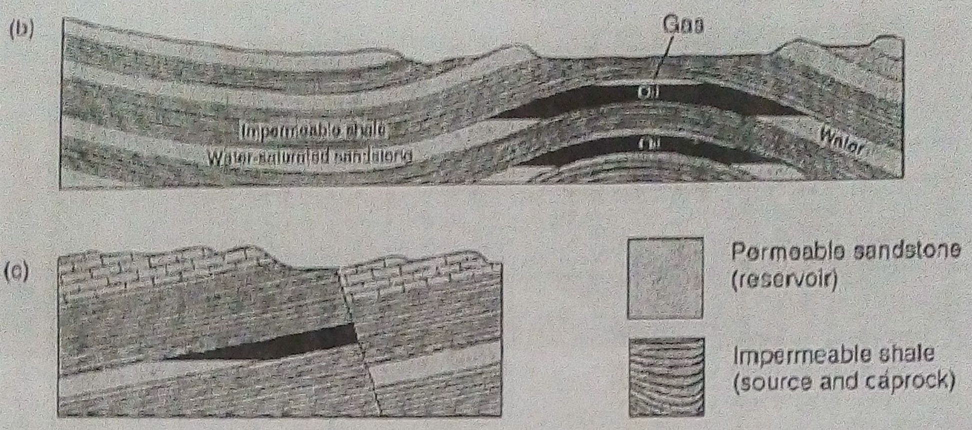
B. Basin

Oil Reservoirs



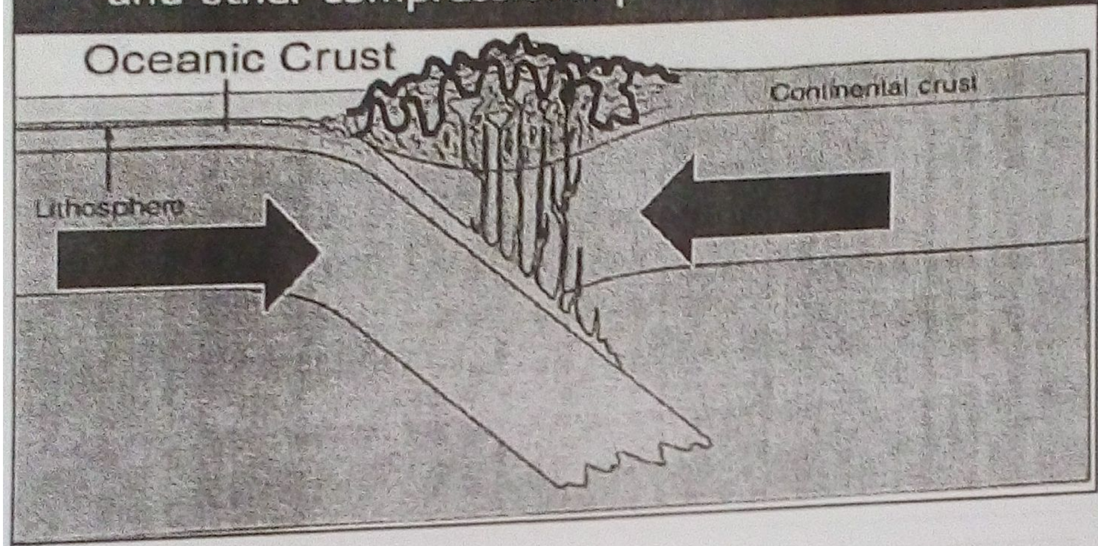


Oil Reservoirs (contd.)

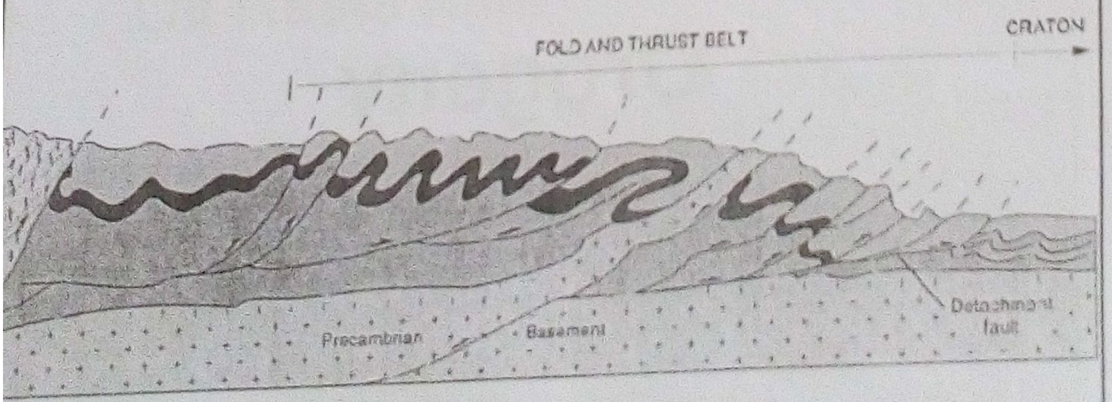


Orogeny

- Orogeny: The formation of mountain ranges by intense upward displacement of the earth's crust.
  - Usually associated with folding, thrust faulting, and other compressional processes.

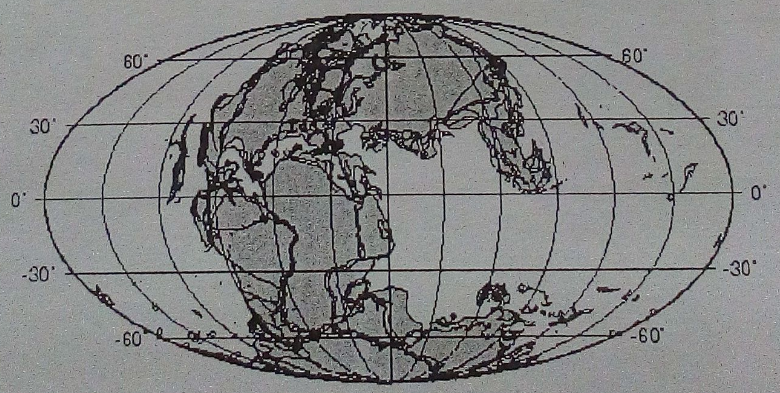


Folds & Thrust Faults



Orogeny (contd.)

The processes of orogeny can take tens of millions of years and build mountains from plains or the ocean floor. Frequently, rock formations that undergo orogeny are severely deformed and undergo metamorphism. During orogeny, deeply buried rocks may be pushed to the surface. Sea bottom and near shore material may cover some or all of the orogenic area.

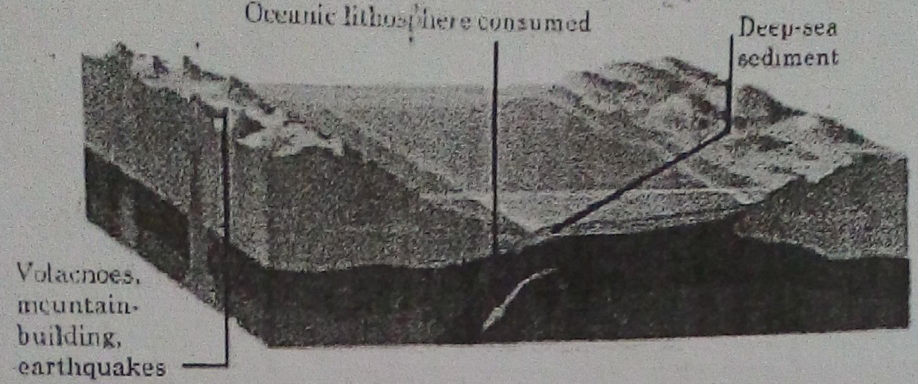


150 My Reconstruction

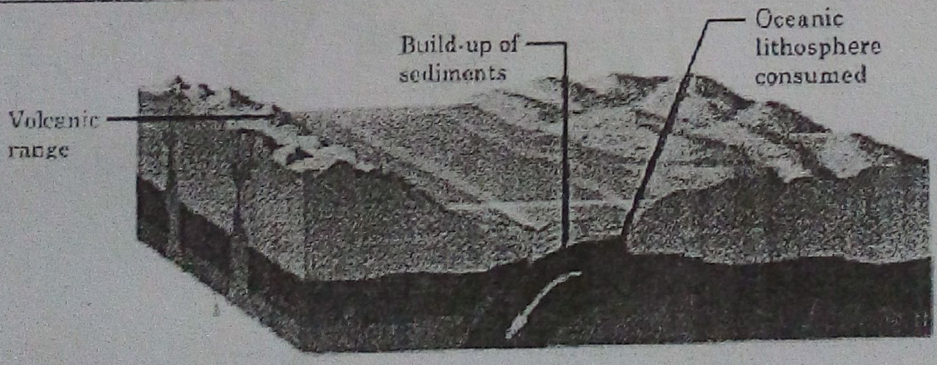
http://www.faithfreedom.org/debates/NaikCampbellp5.htm

Continent-Continent Collision

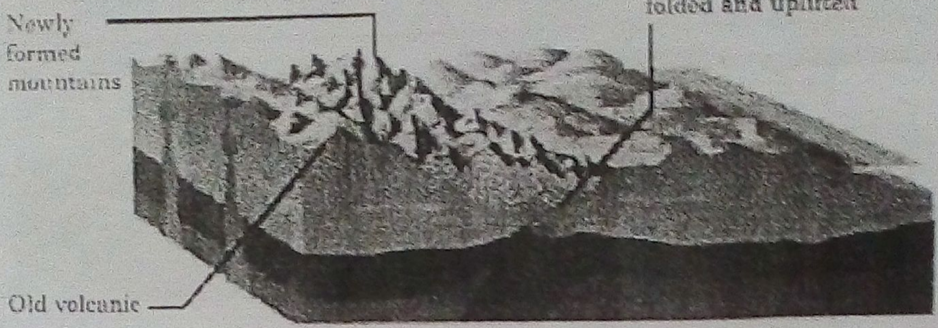
Colour Photo Fig. 6.8. When Continents Collide



When continental blocks move together ocean plate between is destroyed as it slides beneath the continental plate to form a trench. Earthquakes, volcanoes and mountain-building occur on the land.



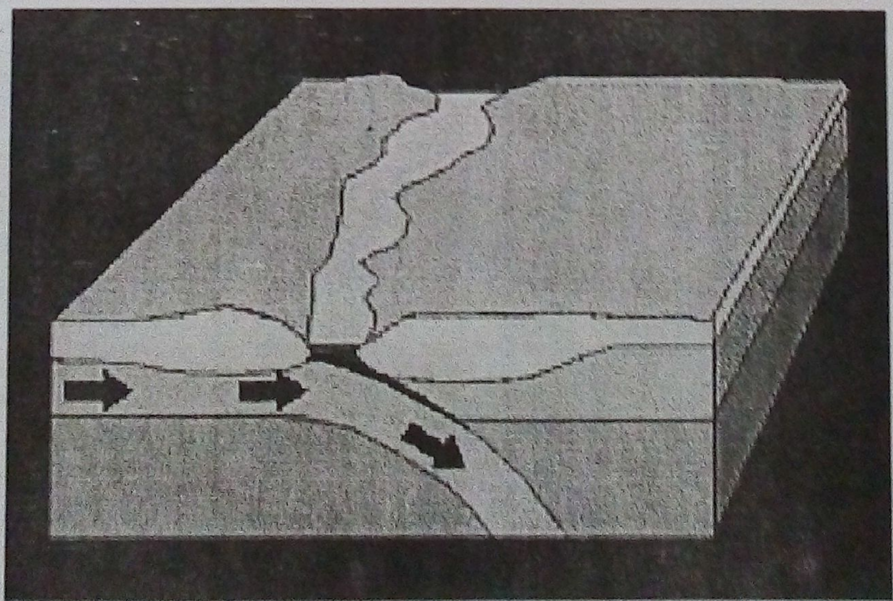
Sediments are scrapped off the ocean floor by the continental plate and build-up thickly. Sediments on the continental margin are also compressed and raised. Oceanic plate continues to be consumed.



When the ocean floor has been completely consumed, the landmasses collide. Accumulated sediments are compressed, folded and uplifted to form mountain ranges. Older volcanic ranges are also compressed and raised.

Fig. showing Collision of Continents, leading to Earthquakes, Volcanoes, and Building of Mountains.

Continent-Continent Collision

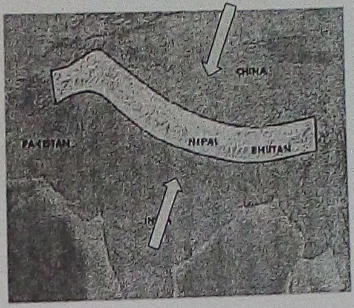


http://www.faithfreedom.org/debates/NaikCampbellp5.htm

Formation of Himalayas

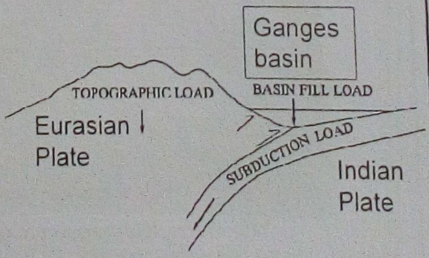
If the orogeny is due to two continents colliding, the resulting mountains can be very high (Himalayas).

Lifted by the collision of the Indian tectonic plate with the Eurasian Plate, the Himalayan range runs, west-northwest to east-southeast, in an arc 2,400 kilometres (1,500 mi) long.

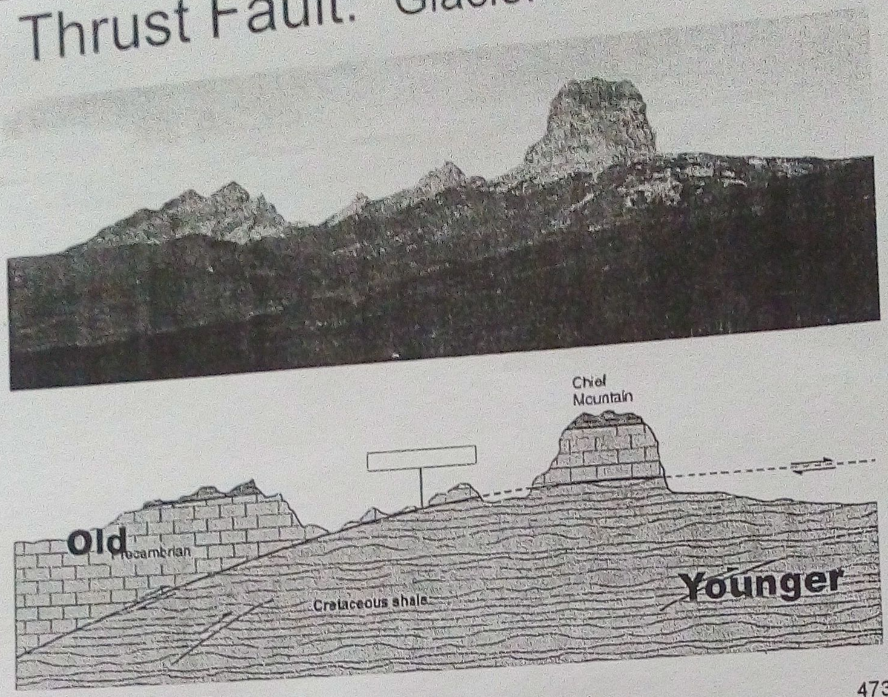


Formation of Ganges Basin

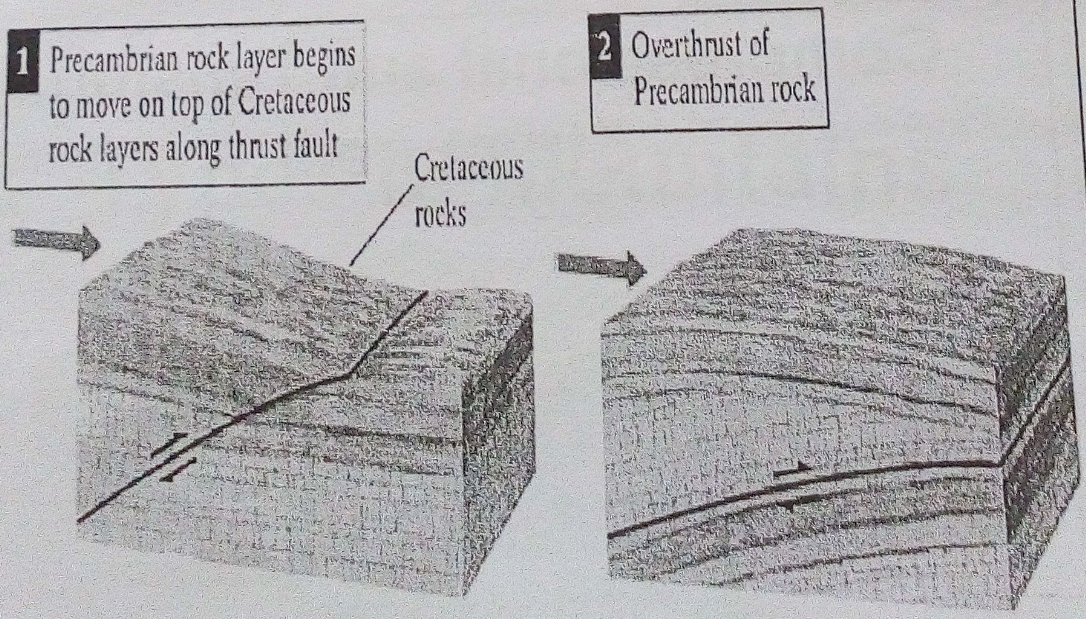
Basin (such as Ganges basin) may develop adjacent and parallel to a mountain belt, on the plate that is subducted or underthrust during plate collision. Basin receives sediment that is eroded off the adjacent mountain belt, filling with thick sedimentary successions.



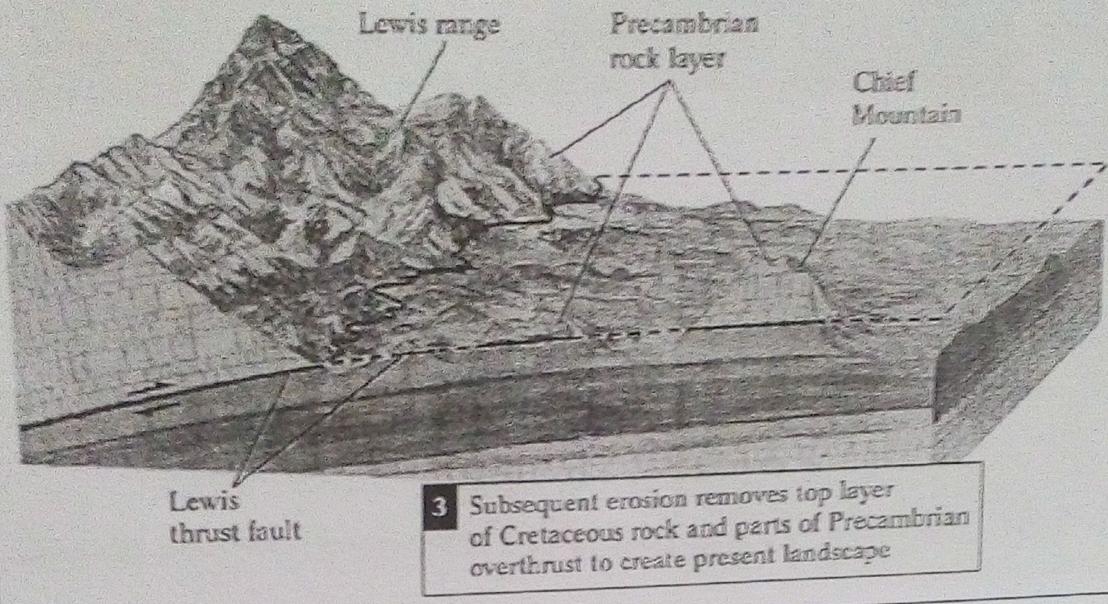
Thrust Fault: Glacier NP, Montana



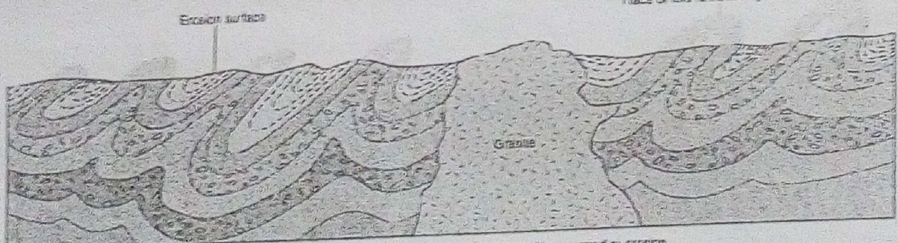
Lewis Thrust Fault



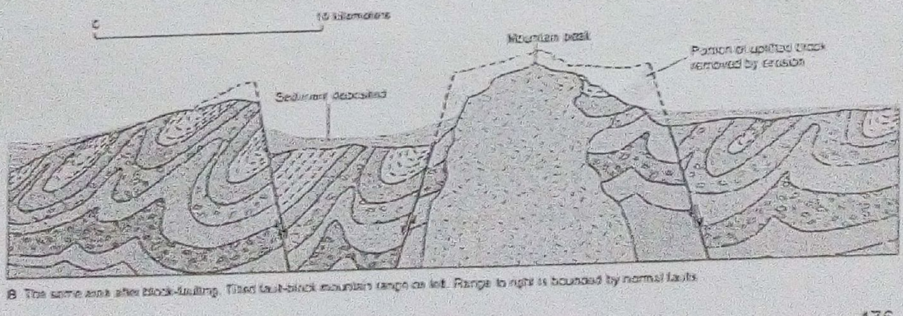
Lewis Thrust Fault (cont'd)



Compressional and Tensional Structures



A Before block faulting. Folding and intrusion of a pluton during an orogeny has been followed by a period of erosion.



B The same area after block-faulting. Tilted fault-block mountain range on left. Range to right is bounded by normal faults.

- *Geologic structures* are dynamically-produced patterns or arrangements of rock or sediment that result from forces within the Earth. Such structures are produced as rocks change shape and orientation in response to applied stress. These structures give information about forces within the Earth. Tilted beds, rock outcrops, folds, faults, joints are example of geologic structures.

- *Structural geology* is the study of the shapes, arrangement, and interrelationships of rock units and the forces that cause them. It studies crustal deformation.

Types of Mountains

6.21.1. Volcanic Mountains. As we know by now, volcanoes at various places, throw lavas, which get deposited and solidified in the form of huge conical heaps of solid material around the point of erruption. These huge dome-shaped heaps, when become quite prominent in comparison to the level of the surrounding land, may be called as *volcanic mountains*. Volcanic mountains are generally small or medium sized mountains.

'Mount Vesuvius', 'Agung', and 'Etna' are a few examples of this type of mountains.

Mt. Fuji, Japan

6.21.2. Residual Mountains. The mountains which are formed by the prolonged action of differential-erosion (caused by various erosion agents) acting on the pre-existing plateaus or plains, are called *residual mountains.* Infact, due to differential erosion, the weaker and the less resistant rocks are worn down and lowered, while hard and more resistant rocks remain standing above the ground surface, making hills and hillocks, called residual mountains.

Most of the medium-sized Indian mountains including the 'Vindhyas', the 'Satpuras', the Eastern and the Western 'Ghats', but excluding the 'Himalayas' and the 'Aravallis' all belong to this category.

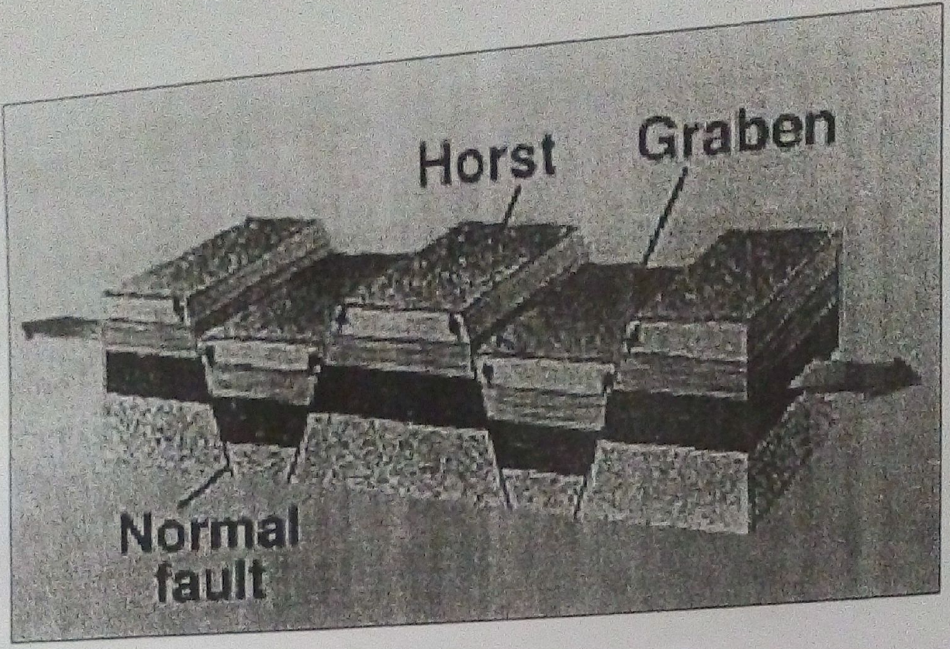
6.21.3. Fault Mountains or Block Mountains. *Faulting* in crustal rocks always result in displacement of the blocks along the rupture plane. Sometimes, this displacement is *lateral*, and at other times, it is *vertical* or *oblique*. During such vertical or oblique motions along fault planes, sometimes, a central block of considerable area may be *thrown up* with respect to the side blocks. This happens when the rock-block, in consideration, has a fault plane on either side, as shown in Fig. 6.22. Such upthrown blocks are termed as *Horsts* ; and when they are of considerable height and size, may be called as *fault mountains.*

Fault-block mountains

- **Rift Valleys, Mid Ocean Ridges**
- Normal Fault Blocks as in East Africa or Western USA

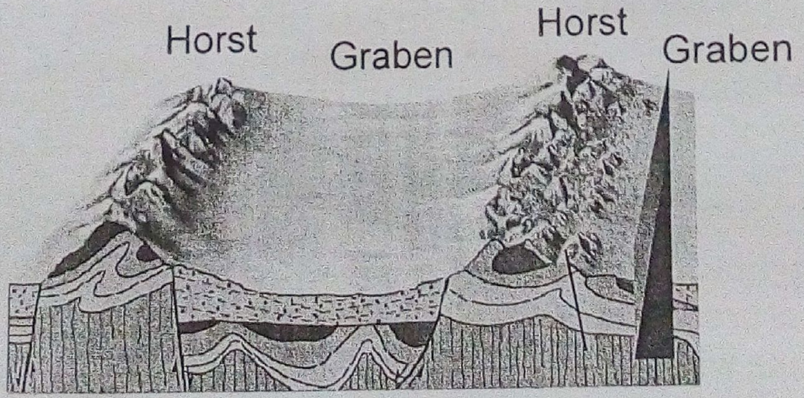
Horst & Grabens (Nevada, USA)

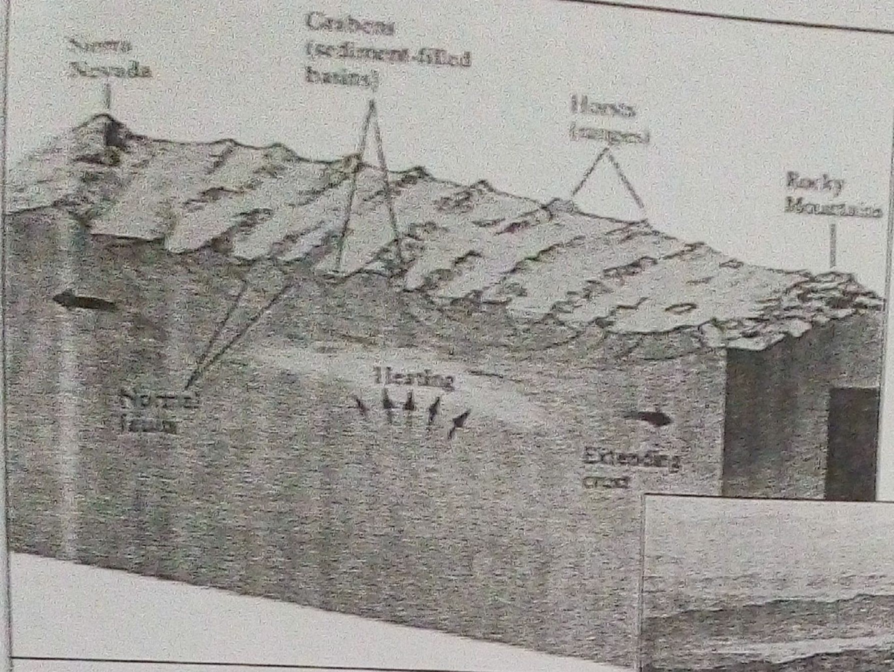
- Horst and graben topography is generated by normal faulting associated with crustal extension.
- The central block termed graben is bounded by normal faults and the graben drops as the crust separates.
- The graben forms an elongated valley that is bound by uplifted ridge-like mountainous structures referred to as horsts.
- Some horsts may tilt slightly producing asymmetric, tilted terrane or mountain ranges.
- In Western USA, horst and graben fault sequences are described as "Basin and Range" topography.



Horsts and Grabens

- Older Rocks are exposed along the ridges formed by the horsts
- Younger rocks lie beneath the grabens
- Sediment fills in the linear valleys





Horst & Grabens (Nevada, USA)

6.21.4. Fold Mountains. Fold mountains are the important mountains of the world, and include the Himalayas and the Alps. They are the most complex in character, possessing all sorts of structural complications in their constitution. These mountains are thus made of rocks, which are generally *jointed, folded* and *faulted*. The formation of these mountains is not very well understood. It is thought that these mountains are formed as a result of certain forces which originate within the Earths' crust, and are called *orogenic** forces ; the process of formation being termed as *orogeny*. The Earth movements, which involve folding, faulting and thrusting, are called *orogenic movements*, and involve both horizontal as well as vertical crustal movements. Their formation and alteration over time is reflected in Coloured Fig. 6.5.

This *orogeny* or *mountain building activity* is a very complex and a time consuming process. Its completion may take millions of years.

Fold-and-thrust mountains

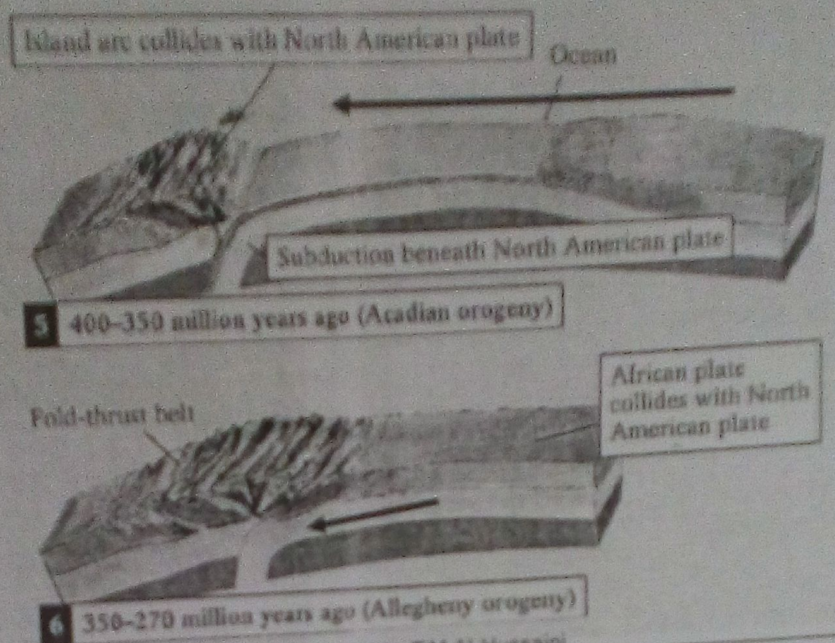
– Formed by **Continent-Continent** Collisions

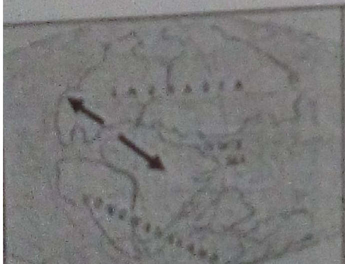
Appalachian Mountains

- The Appalachian Mountains extend along the eastern margin of North America from Alabama to Maine in the United States, and through the southeastern provinces of Canada to Newfoundland.
- The Appalachian Mountains were formed during the Paleozoic Era from several orogenic episodes, the Taconic Orogeny (Ordovician ~480 mya), followed by the Acadian Orogeny (Devonian ~400 mya), and lastly the Alleghany Orogeny (Permian ~ 300 mya).
- Each of these major orogenic episodes involved multiple events of folding, faulting, metamorphism, emplacements of igneous intrusions, and uplift.

Model for the Evolution of the Southern Appalachians

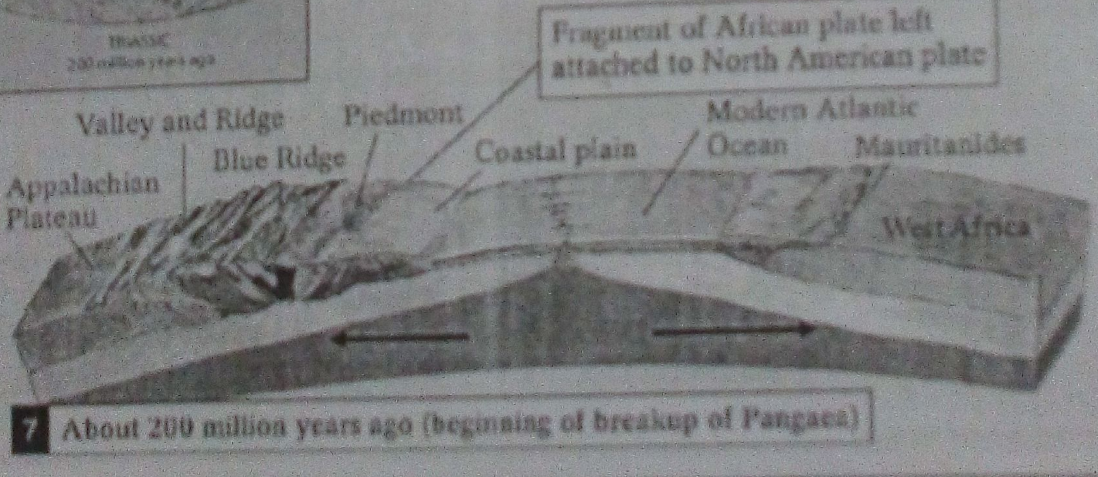
African Plate subducts (westward) underneath North American Plate

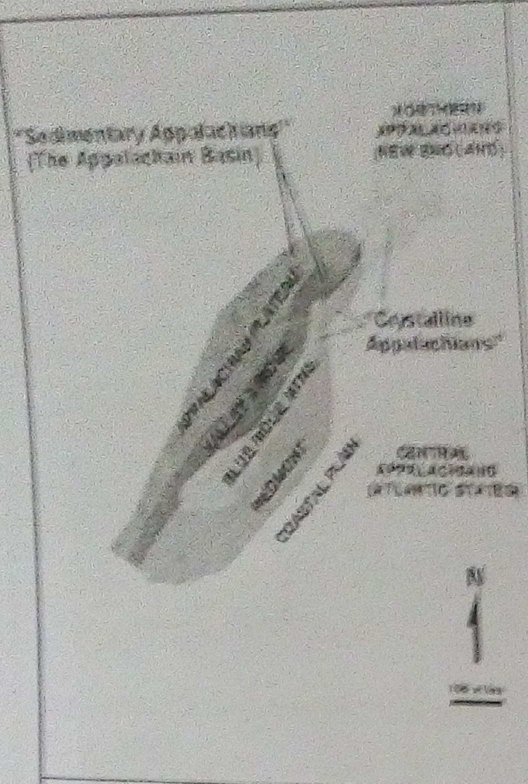




Evolution of the Southern Appalachians (cont'd)

Rifting starts (North American Plate moves away from African Plate)





The Appalachian Mountains are divided into four major provinces: Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau.

Photo courtesy of SCGS, SCDNR

Upwarped mountains

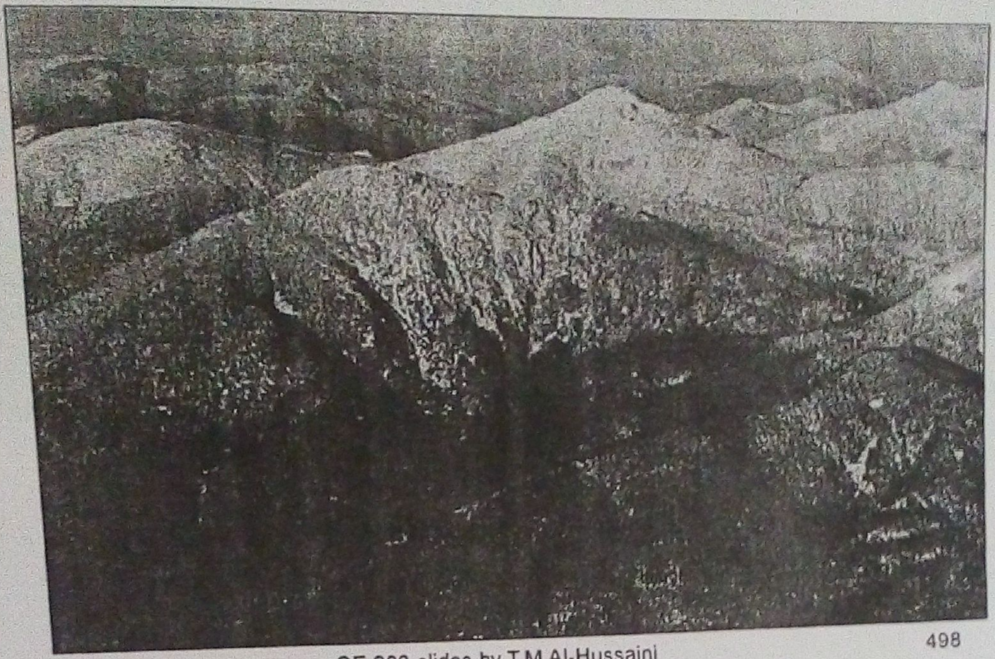
a) Gently bent without much deformation

b) Ascent of buoyant mantle material

c) Far from plate boundaries

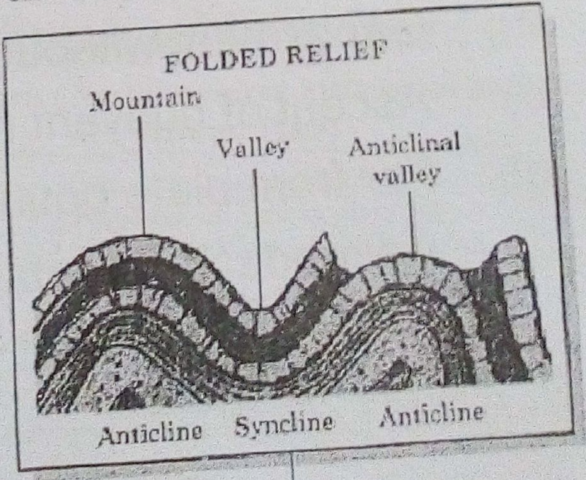
d) Adirondack Mountains: Uplift of deep PreCambrian Igneous and Metamorphic rocks

The Adirondack Mountains of Northern New York

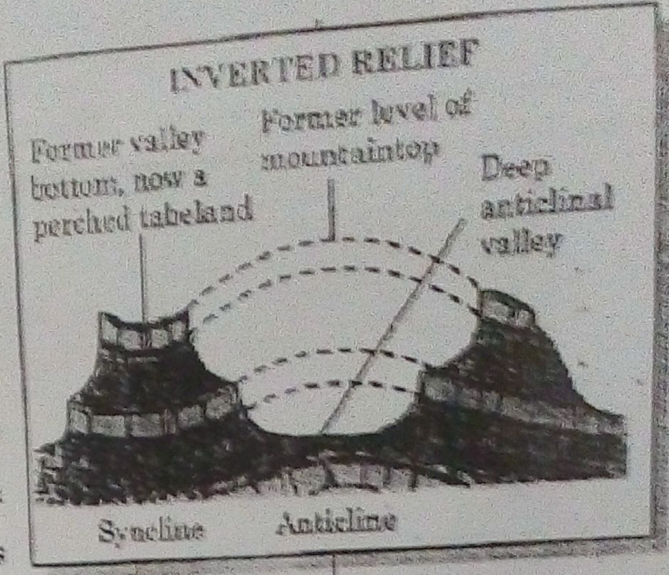


How Folded Mountains are Formed and then Altered Over the Course of Time

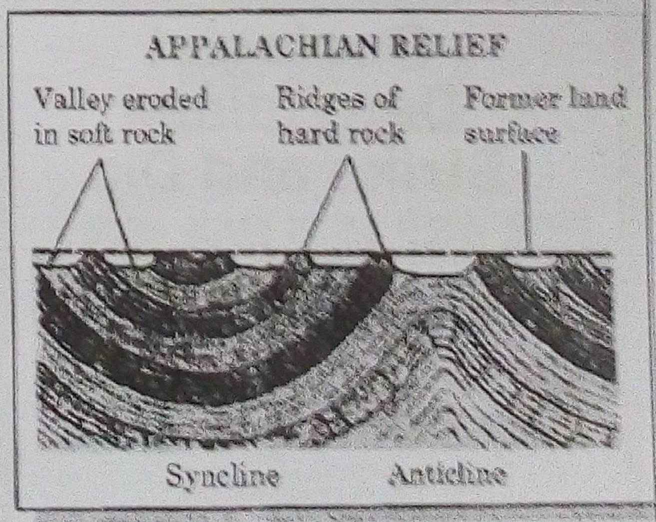
Rigid though rock is, great horizontal pressure can cause it to bend into wavelike folds. The folds usually occur in long parallel rows of mountain ridges separated by valleys, such as are found in the Zagros. The upward folds are termed **anticlines**; the intervening downwarped troughs are called synclines.



Erosion in time can mask the basic structure of the folds. The top of a fold may be worn away to form an anticlinal valley (*left*). Severe erosion can completely wear away the anticline, resulting in inverted relief (*center*). In this case the synclines-once the bottoms of valleys-are left standing high above their



surroundings. In the case of so-called Appalachian relief (*right*), the folds are first eroded down to a flat surface. Renewed erosion then wears away the areas of soft rock to produce valleys separated by ridges of more resistant rock.



Scanned by CamScanner

Truncated Dome

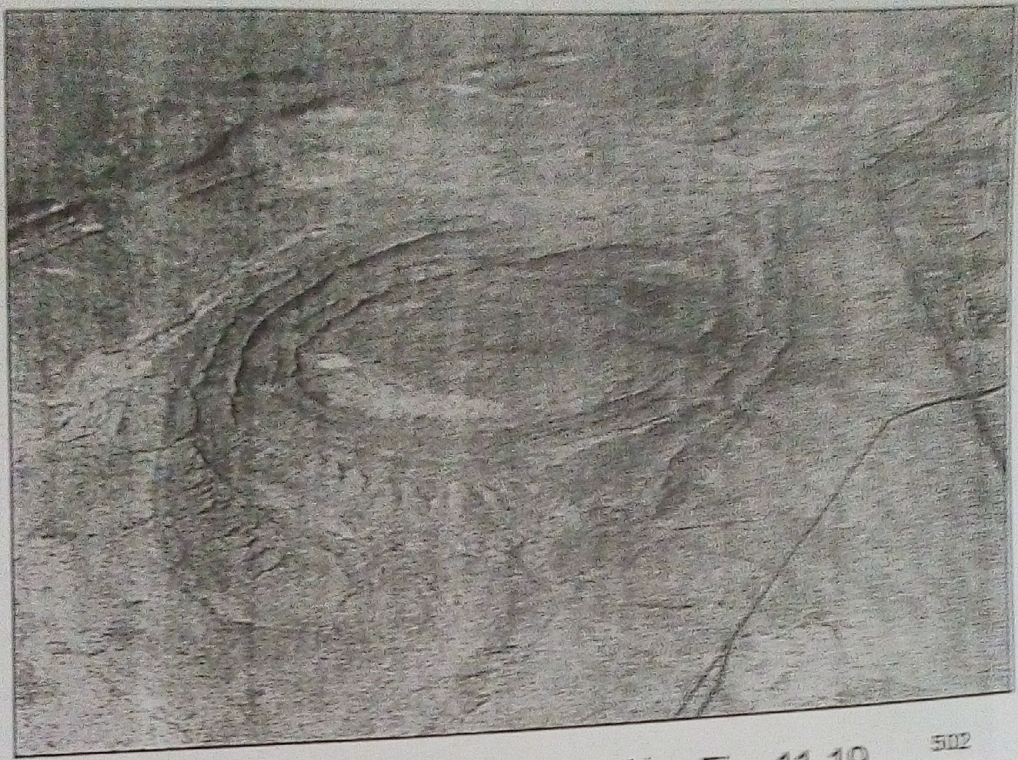
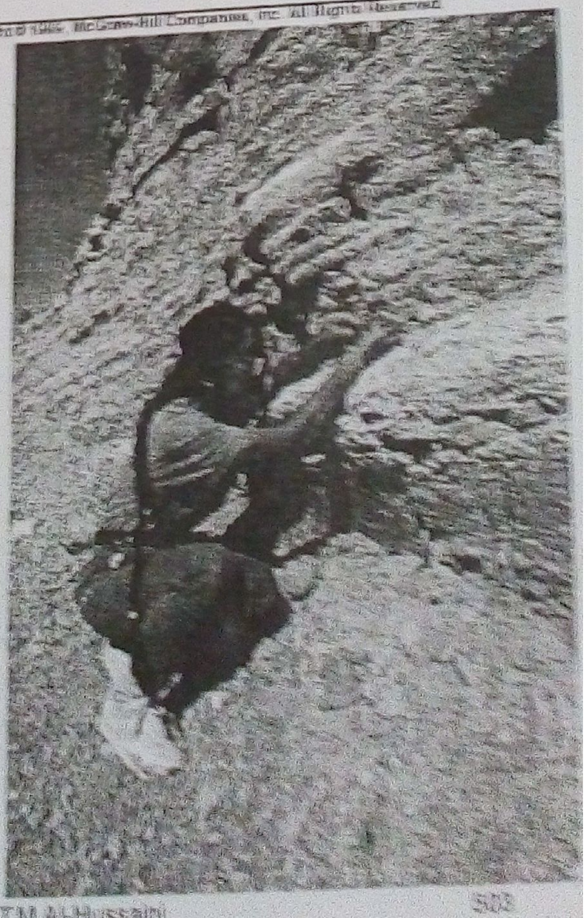
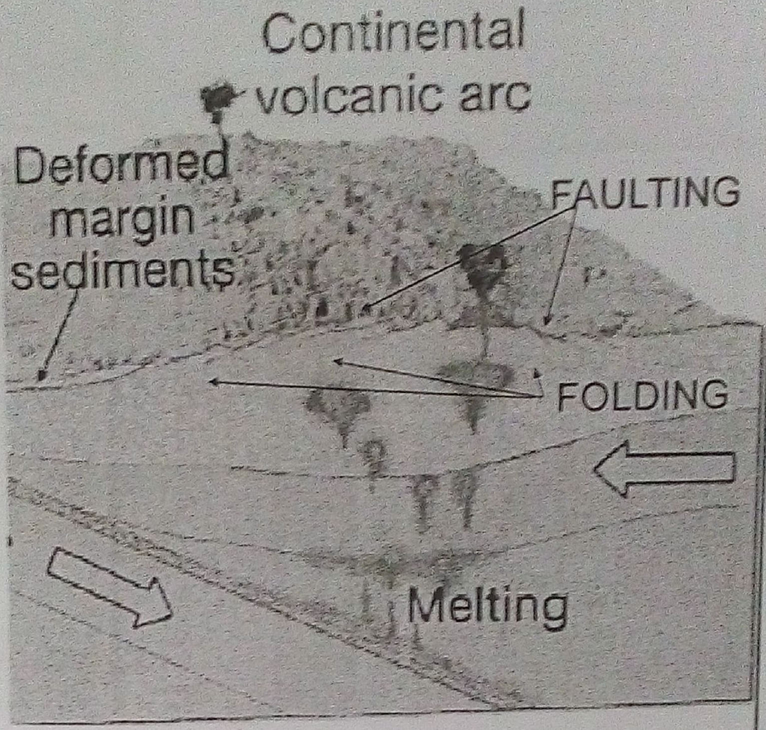


 Fig. 11.19

Geologist Determines Strike and Dip



Many folds in orogenic belts have in fact formed at depth and later been exposed at the surface by erosion of overlying rocks. On the other hand, rocks at or near the surface of the earth are under low confining pressure and low temperature, and tend to be BRITTLE and fracture when subjected to stress.



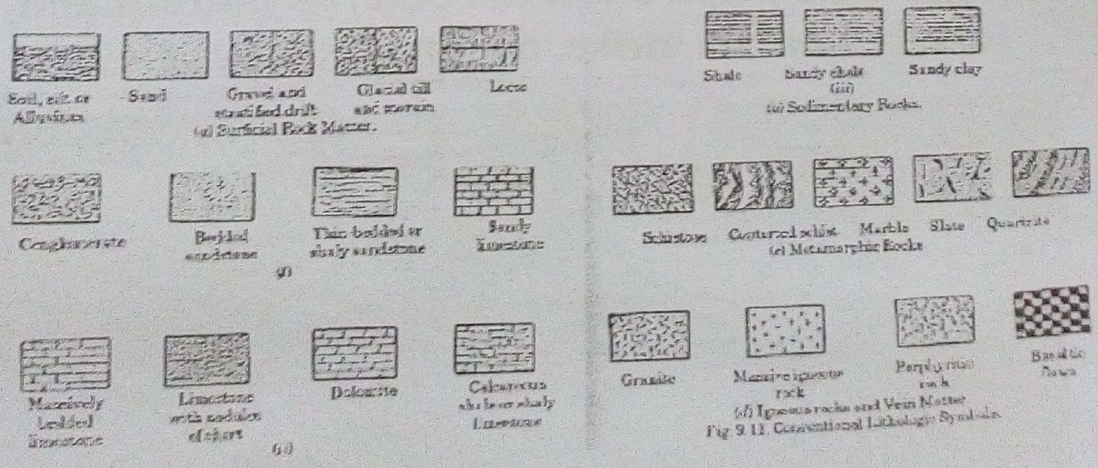
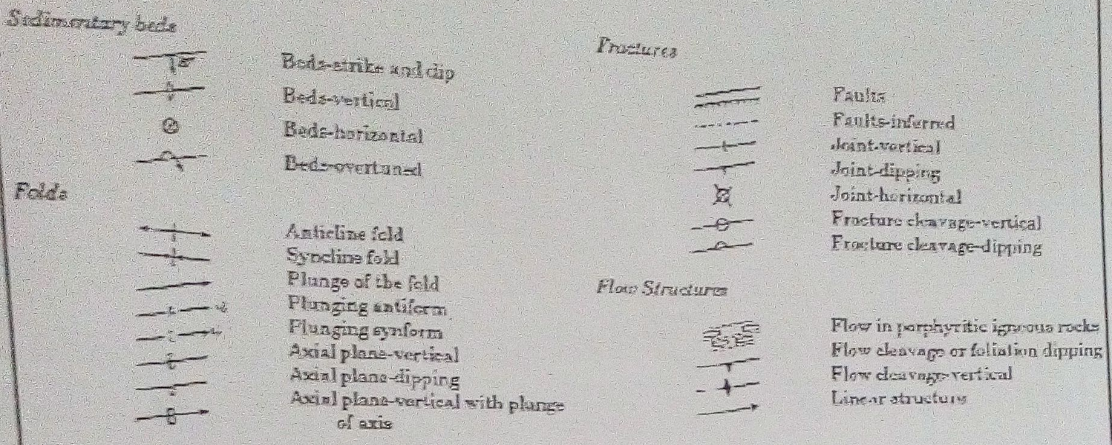
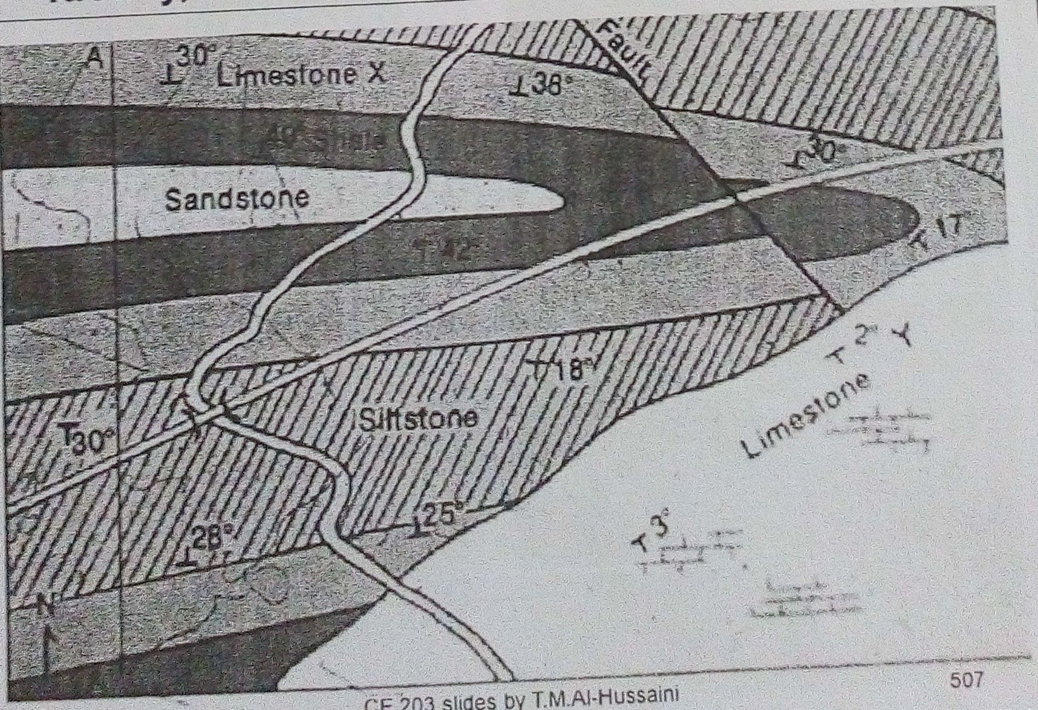
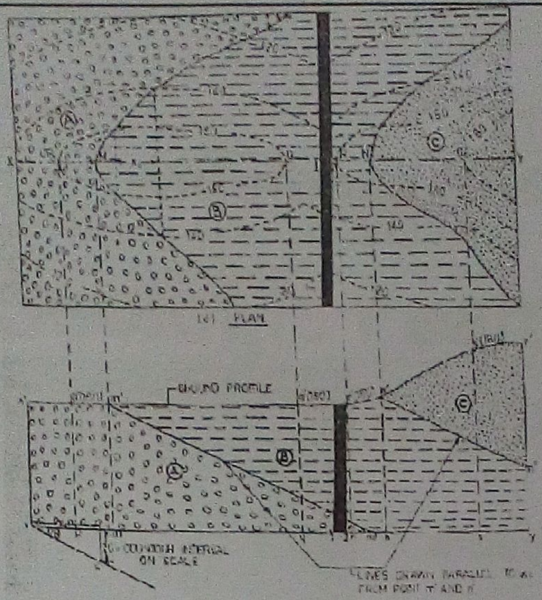


Fig. 9.11. Conventional Lithologic Symbols



2-D geologic maps show the outcrop pattern and, ideally, contain strike, dip and fault symbols:





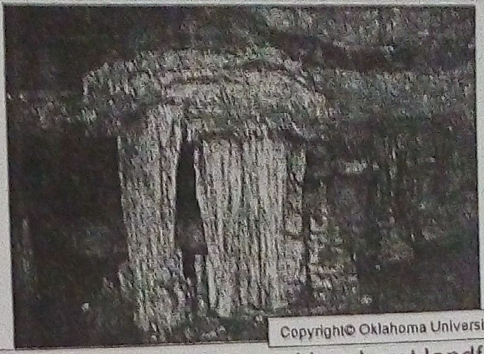
(a) Plan i.e. geological map.
(b) Section of the geological map along the line XY.
Fig. 9.25

Karst Landform

Karst Landforms

Karst is a term used to describe landscapes that are formed by chemical weathering process controlled by groundwater activity. Karst landscapes are predominantly composed of limestone rock that contains ≥ 70 percent calcium carbonate.

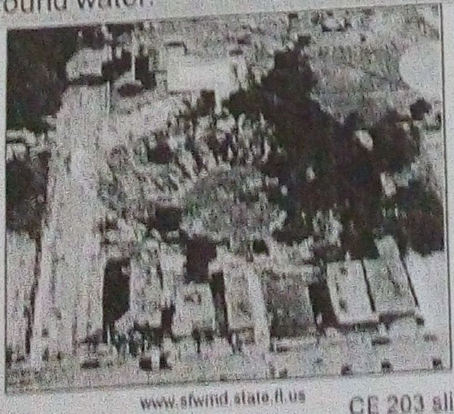
- Caverns (Caves)
- Sinkholes
- Disappearing Streams
- Springs
- Towers



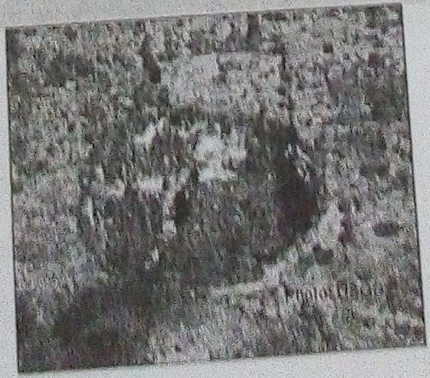
Onondaga Cave in Missouri is a karst landform formed by chemical solution in carbonate limestone rocks. Features within Onondaga Cave include stalagmites, stalactites, dripstones and active flowstone deposits.

Sinkholes

- Sinkholes are collapsed limestone features that develop in karst landscapes. Sinkholes form when the limestone bedrock is chemically weathered by naturally occurring chemicals in the ground water. The ground water slowly dissolves the limestone rock below the surface until it eventually becomes unstable and collapses creating local depressional features.
- Sinkholes pose a threat to developed areas, because if they occur beneath houses or other infrastructure they may collapse with the sinkhole.
- Increased pressure on water resources and depleted ground water tables can trigger sinkholes to collapse under the pressure of gravity or the void formed by the depleted ground water.

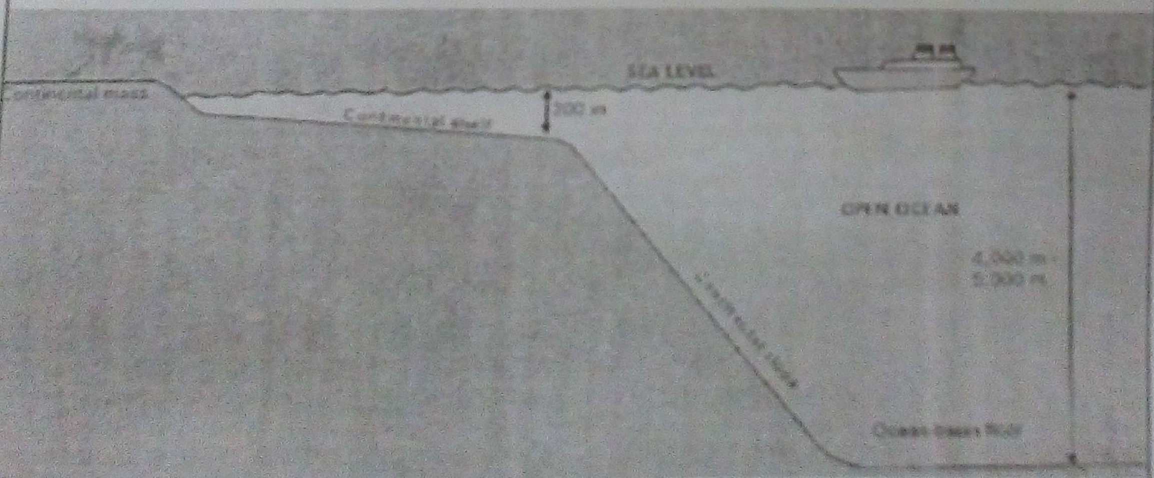


www.sfwmd.state.fl.us



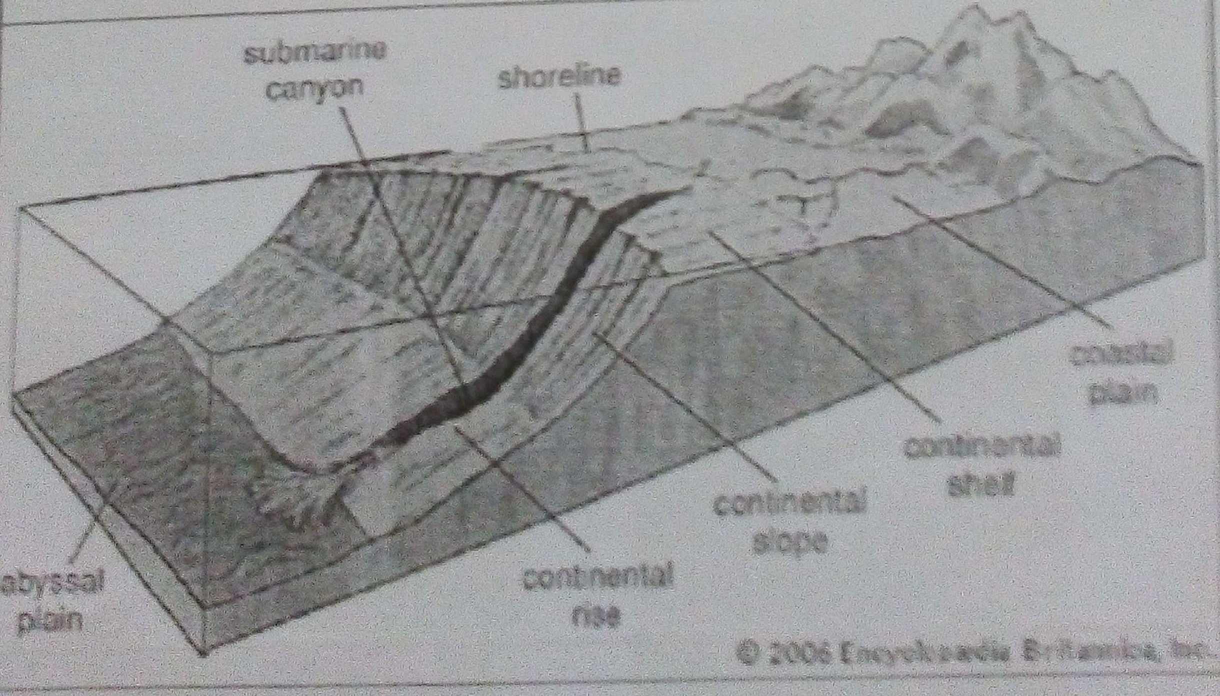
Geologic Features in the Ocean

Continental Shelf & Continental Slope



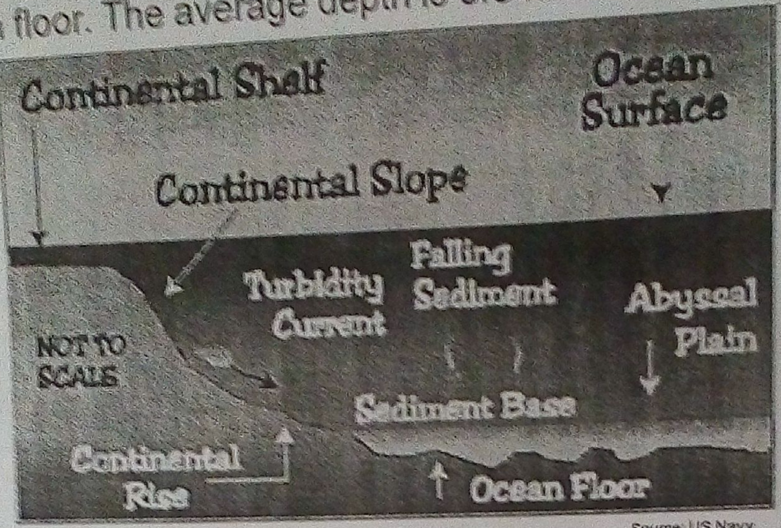
Continental Shelf

- The continental shelf is a submerged extension of the continental crust that slopes gently outward from the modern shoreline to the deep ocean basin.
- The continental shelf varies in width from being almost non-existent along some continental margins to extending outward for nearly 1500 kilometers (930 miles) in other places. On average it extends outward for about 80 kilometers (50 miles) and has an average slope of about 1 degree (2 meters/kilometer or 10 feet/mile).



Deep-Ocean Basin (covers 30% surface)

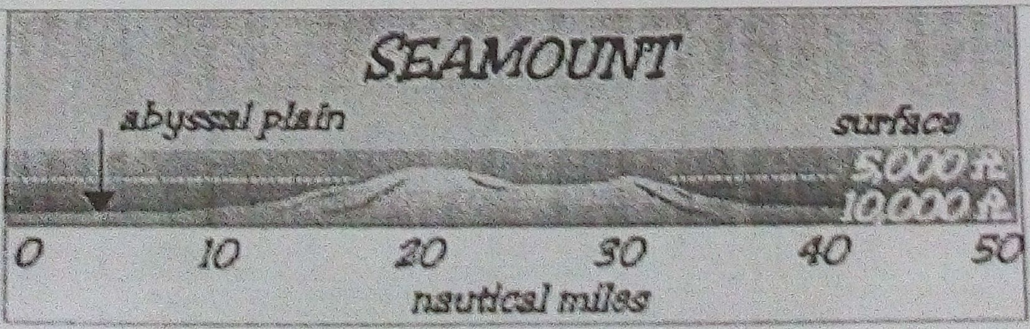
- Abyssal plains are nearly flat feature-less surfaces and may be the most level areas on Earth. They are very flat and consist of massive accumulations of sediment, deposited over the ocean floor. The average depth is 3.8 km.



Source: US Navy

Seamounts

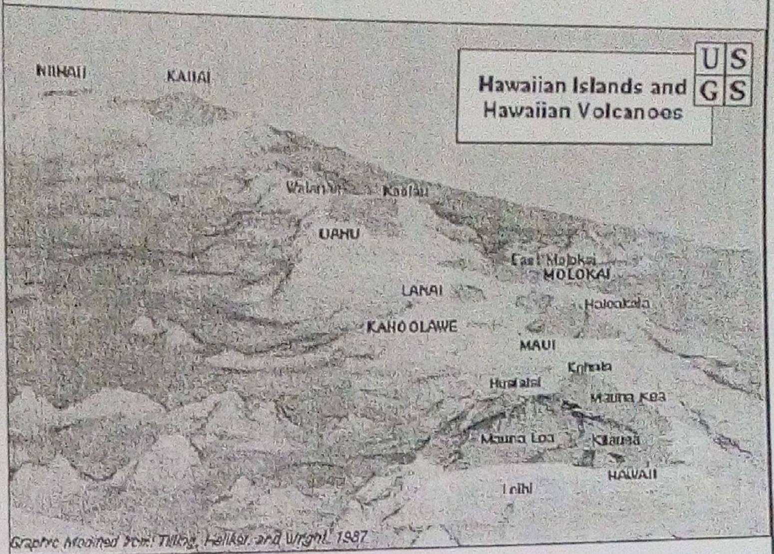
- Seamounts are steep-sided isolated submerged volcanic mountains (active or inactive) on the sea floor.
- Seamounts often occur far from mid-ocean ridges and trenches.



Source: US Navy

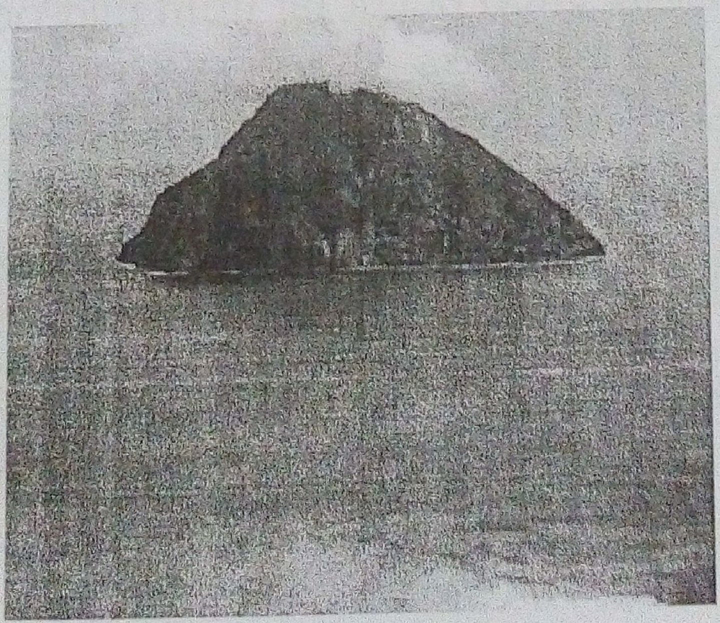
Seamounts often occur in long groups or "chains". Where seamounts poke above the sea surface, they form islands. Examples are Hawaiian Islands and Tahiti Islands.

Seamounts rising above sea surface



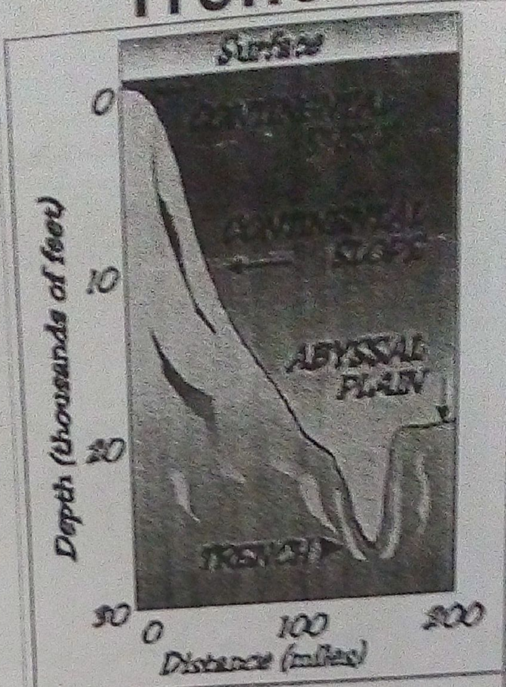
Source: US Navy

Seamounts rising above sea surface



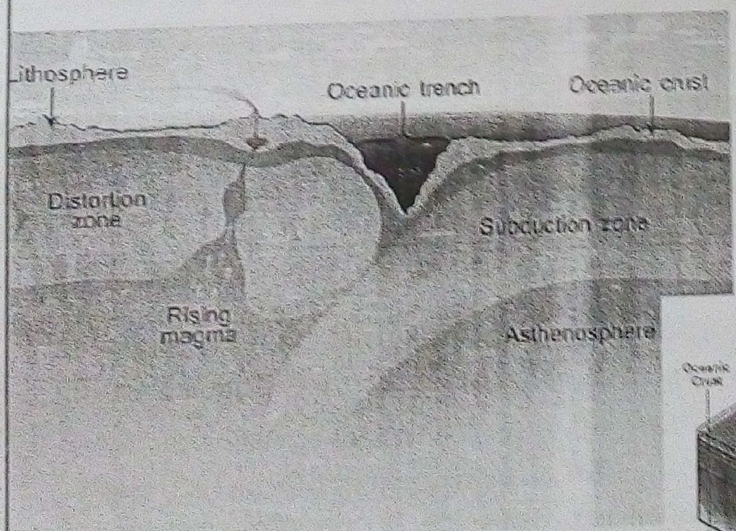
Trench

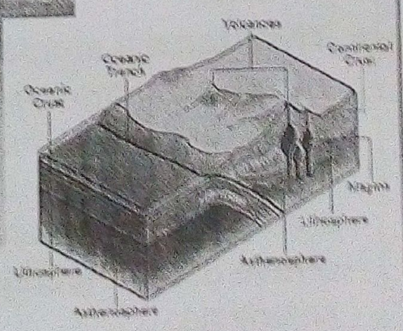
Ocean trenches may be defined as narrow V-shaped depressions formed over long distances were oceanic plate is subducting below another plate. Trenches are associated with volcanic island arcs and areas of intense earthquake activity. Marianas Trench in the South Pacific Ocean is the deepest (>10.6 km) trench.



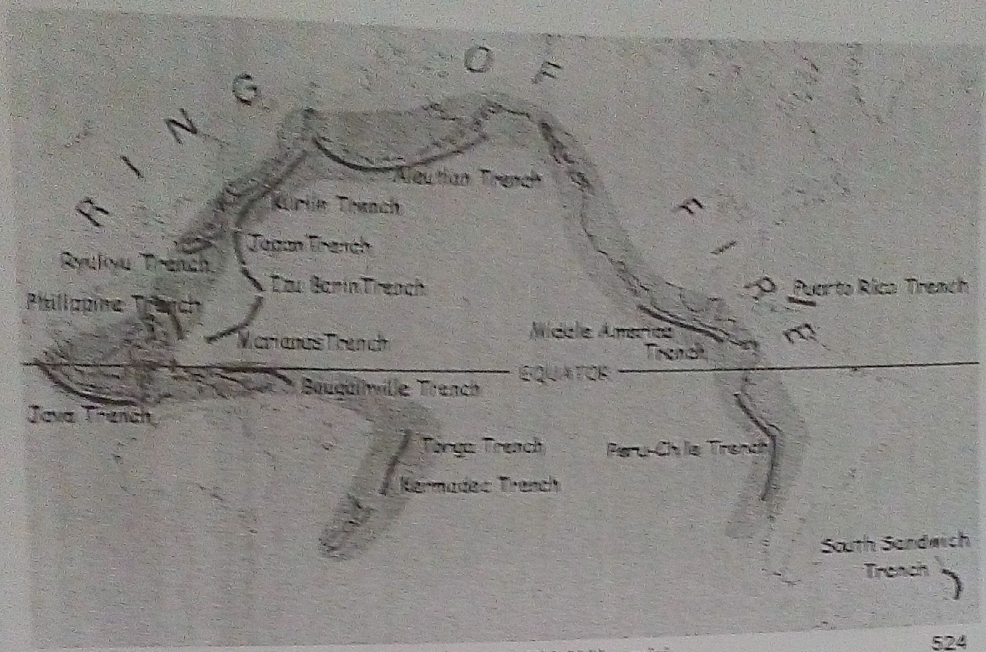
Source: US Navy

Formation of Oceanic Trench





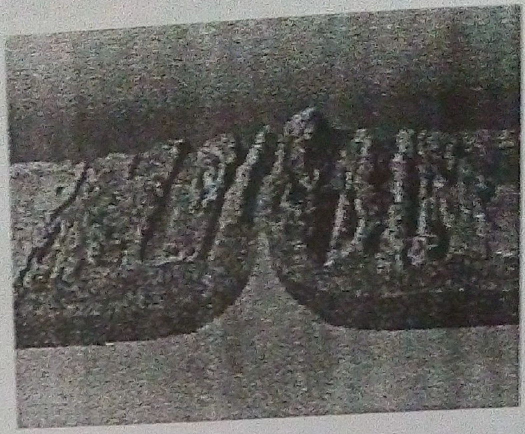
Most of Earth's deep-sea trenches are around the edges of the Pacific Ocean. This map shows the locations of these deep-sea trenches.



Mid-Ocean Ridges

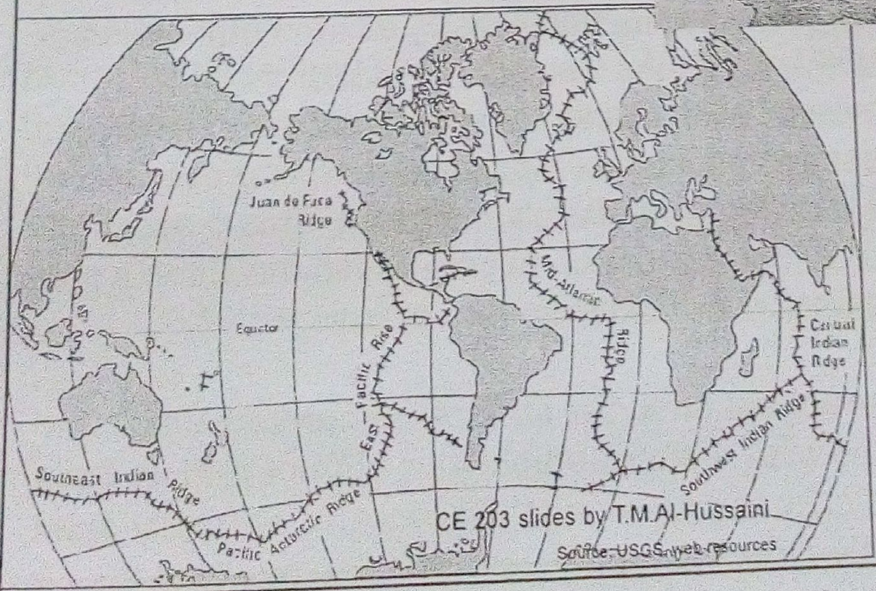
- **Mid-ocean ridges are formed by rising magma along divergent plate boundaries.** New oceanic crust is formed along the narrow ridge crest, where magma rises and solidifies.
- **They form a single, connected, volcanic mountain range over thousands of km in length.** The Mid-Atlantic Ridge extends almost the entire length of the North and South Atlantic Ocean and is one of the most prominent subterranean ocean floor features. It rises 3000 meters above the ocean basin floor and is closely monitored by scientists.
- The Mid-Indian Ridge is another prominent feature, and it is actually a continuance of the Mid-Atlantic Ridge system, stretching from below South Africa up to India and Egypt.

Formation of Mid-Ocean Ridges



Mid-Ocean Ridges

USGS created this "baseball" graphic to illustrate the locations of the major mid-ocean ridge systems. The continuous line marks the location and orientation of the ridge, and the cross-stitching represents potential fault patterns along the ridges. Because the ridges mark plate boundaries they are more or less continuous, but are differentiated by name relative to ocean basin or continental proximity.



Source: USGS web resources

Volcano

Volcanic Eruption

Due to the intense pressure inside the crust, the magma remains in a viscous state. But whenever, this pressure is released, because of the presence of fractures, fissures, and other weaker planes in the Earth's crust, the viscous hot matter melts, and injects along these weak surfaces. When the cracks extend up to the surface, the magmatic matter also starts erupting over toe ground, when it is called lava after its extrusion. This process of level intrusions (i.e., movement of magma within the Earth's crust) and eruptions is known as volcanism or volcanic activity.

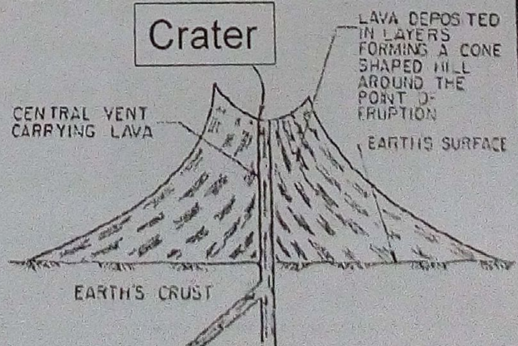
The lavas may erupt out on to the surface, either from long fissures extending over a considerable part of the Earth, or from centrally located chimney type vents. The former, normally quiet eruptions, are called fissure type eruptions (also called mass type eruptions) ; and the latter, generally violent explosive eruptions, are called central type eruptions.

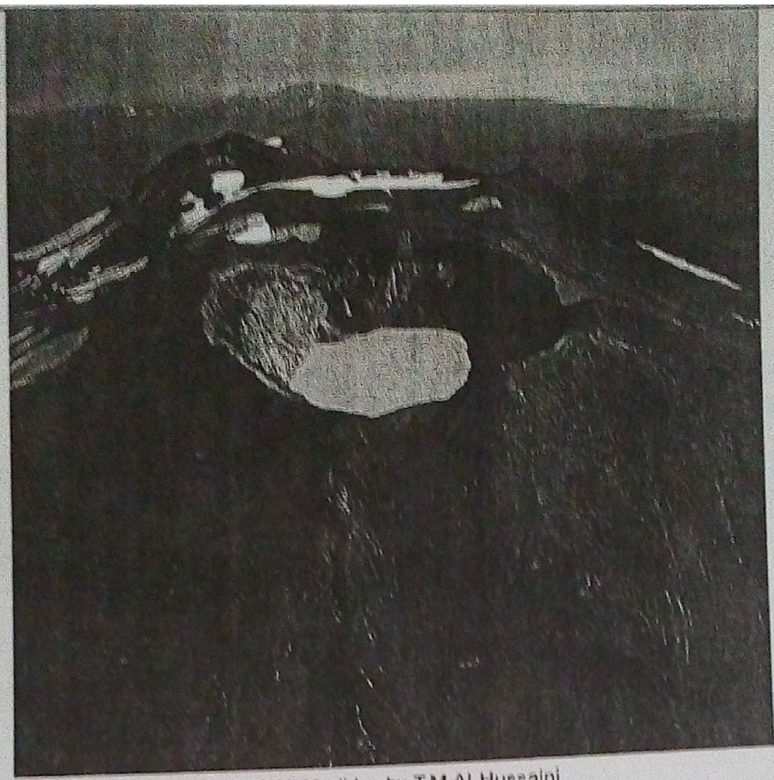
Volcano

Violent naturally occurring central type eruptions where hot lava comes out **through a central vent** regularly or occasionally, are called volcanoes. A frequently erupting volcano is known as **active volcano** ; one with rare eruptions is called **a dormant volcano**; while the volcanoes which have stopped their eruptions since a long geological time, are called extinct or **dead volcano**.

Volcanoes, thus, throw out molten material on the ground surface, which get accumulated around the central opening or vent, forming a cone shaped mountain. Such mountains may largely vary in their height, ranging from a few hundred metres to thousands of metres. For example, the Cotopaxi (Ecuador), the highest active volcano of the world, has a height of 5974 m.; and the Aconcagua (Chile) an extinct volcano, is 6900 m in height.

A typical volcano is, thus, a conical or roughly conical hill or mountain, formed by the accumulation of lava and blasted rocks. With the continuing accumulation of such materials, this cone shaped hill grows in height and expands in lateral directions. The erupted products spread in such a way that a typical circular depression or pit, known as crater, is formed at the top of the hill. The size of the crater grows with the size of the volcano, and may range up to several km in diameter. At the end of lava eruption, the molten lava congeals, and pluggs the vent also.





In general, volcanoes have been found concentrated along mountain regions, where earth movements take place frequently (*i.e.* they occur in the regions of crustal unrest). They are also found in the marine areas near seas.

The **factors which are responsible for the origin of a volcano** include :

(*i*) *The presence of molten material below the Earth's crust* ;

(*ii*) *The presence of fissures or vents* (through which the molten material may erupt) which may occur along definite tracts or belts, and

(*iii*) *the factors which may cause the upward movement of magma*, such as orogenic movements.

Considering all such factors, two causes have been attributed to the origin of volcanoes. They are explained below :

(1) It is assumed that the molten material exists locally beneath many regions of the Earth's crust. This molten mass is under high pressure and hence is in a viscous state. Whenever, curstal movements like those of mountain building activities (*i.e.* orogenic movements) take place in these local areas, the crust will develope fractures, thus releasing the pressure of the molten mass locally. The viscous hot matter will thus melt, and inject in these fractures, resulting in volcanism.

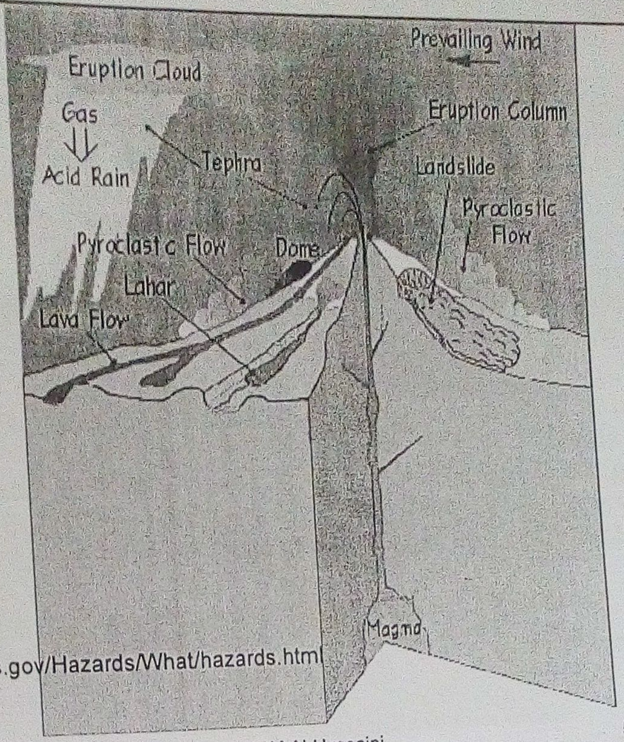
(2) It is possible that when water percolates through the Earth's crust, it may go deep and come in contact with molten rocks which are already at very high temperature (about 1000 to 1200°C). This will suddenly change the water into steam ; and this sudden change may result in creating an enormous pressure, sufficient to push up the molten matter up, through the points of least resistance (*i.e.* through the fractured zones). This possibility is supported by the facts that all volcanic eruptions are generally accompanied by huge quantities of steam, and also because many of the volcanoes of the world are situated near the seas.

Volcanic hazards

- >1300 volcanoes known to have erupted in Holocene (last 10 000 years)
- ~500 classified as 'active' (i.e. known to have erupted in recorded history)
- Remainder classified as 'dormant' (may become active again) or 'extinct' (not expected to erupt again), but Vesuvius was thought to be extinct before AD 79!

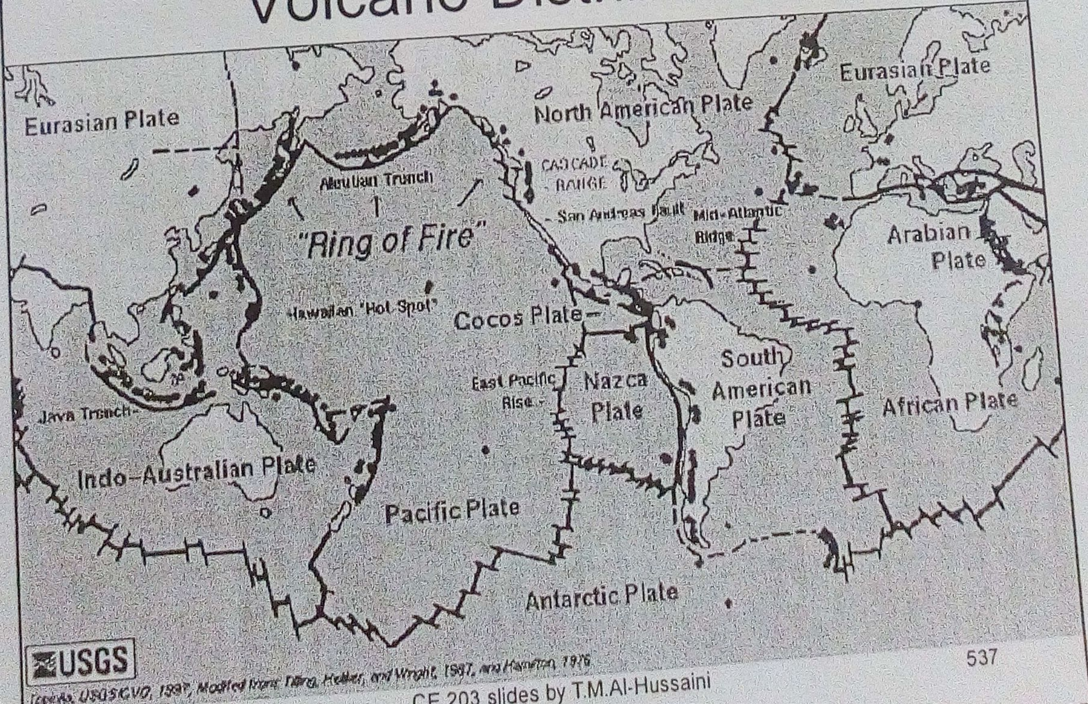
Plus new vents: e.g. Paricutin (Michoacan, Mexico) shown erupting in 1943 (graphic by Diego Rivera)

Types of volcanic hazard



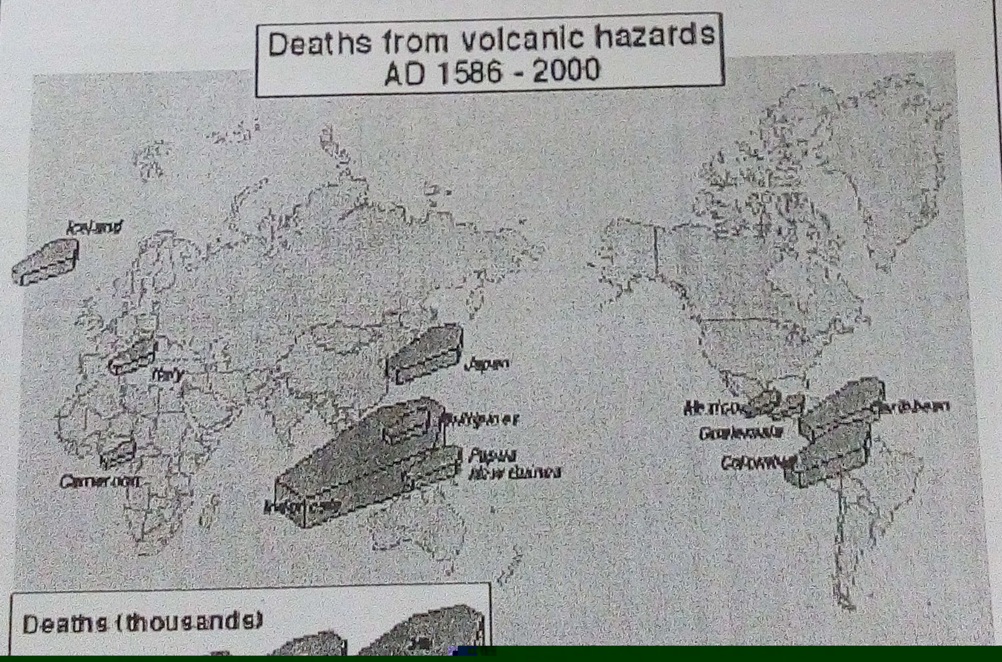
http://volcanoes.usgs.gov/Hazards/What/hazards.html

Volcano Distribution



Major volcanic eruptions since AD1600 (>8000 deaths)

Event	Date	Deaths	Hazard type
Laki, Iceland	1783	9000	Starvation
Unzen, Japan	1792	14300	70% by cone collapse; 30% by tsunami
Tambora, Indonesia	1815	92000	90% by starvation
Krakatoa, Indonesia	1883	36000	90% by starvation; <10% pyro. flows and tephra
Mt. Pel□e, Martinique	1902	29000	Pyroclastic flows
Nevada del Ruiz, Colombia	1985	25000	Lahars



Cinder cone

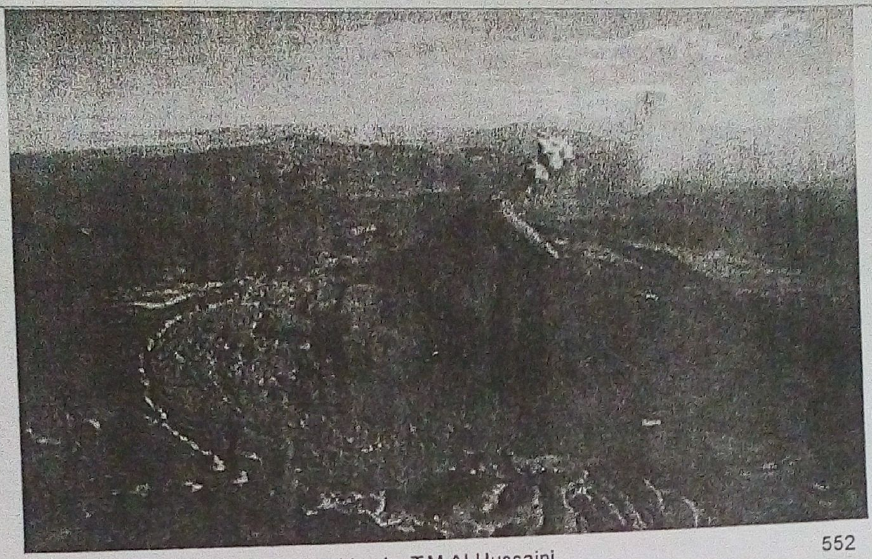
In a cinder cone, lava erupts from a small vent in the crust and 'sprays' melted rock fragments into the air where they then fall back to earth in a pile. These rock fragments are glassy, gas-filled chunks of lava called cinders that cool rapidly as they sail through the air and land next to the vent opening, slowly accumulating in the geometric shape of a cone. Cinder cones tend to be small, hill-sized volcanoes that range in height from tens to hundreds of meters high. Cinder cones are characterized by their steep sides and conical shape.

Cinder cones may appear as single volcanoes or as secondary volcanoes on larger existing stratovolcanoes or shieldvolcanoes. Mauna Kea, a volcano on the American island of Hawaii, and Mount Etna, a volcano on the Italian island of Sicily, are both covered with hundreds of cinder cones.

Cinder cone in Utah, USA

Shield Volcano

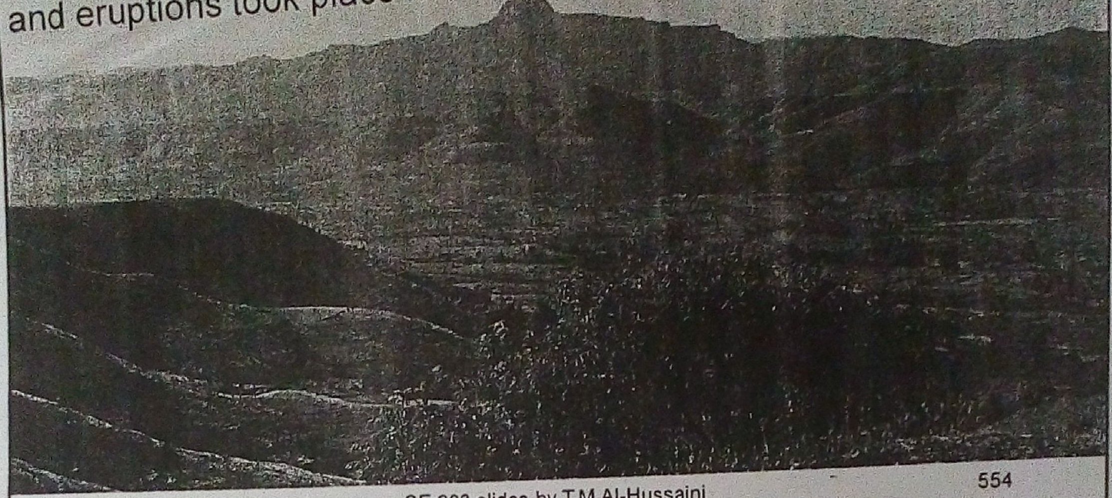
Slow and gradual accumulation of thin layers of lava build up over long periods of time, forming a long, shield-shaped volcano. Gentle sloping sides.



B) Flood basalts

- A flood basalt is the result of a giant volcanic eruption or series of eruptions that coats large stretches of land or the ocean floor with basalt lava. Eleven distinct flood basalt episodes occurred in the past 250 million years, resulting in large volcanic provinces, creating plateaus and mountain ranges on earth.
- They are formed by flow of very low viscosity magma, which is why they 'flood' rather than form taller volcanoes.
- The Deccan Traps of central India, the Siberian Traps, and the Columbia River Plateau of western North America are three regions covered by prehistoric flood basalts.

Deccan Traps located in west-central India are one of the largest volcanic features on Earth. They consist of multiple layers of solidified flood basalt that together are more than 2 km thick, today covering an area of 500,000 km^2. Deccan Traps began forming 66 million years ago, at the end of the Cretaceous period and eruptions took place less than 30,000 years.



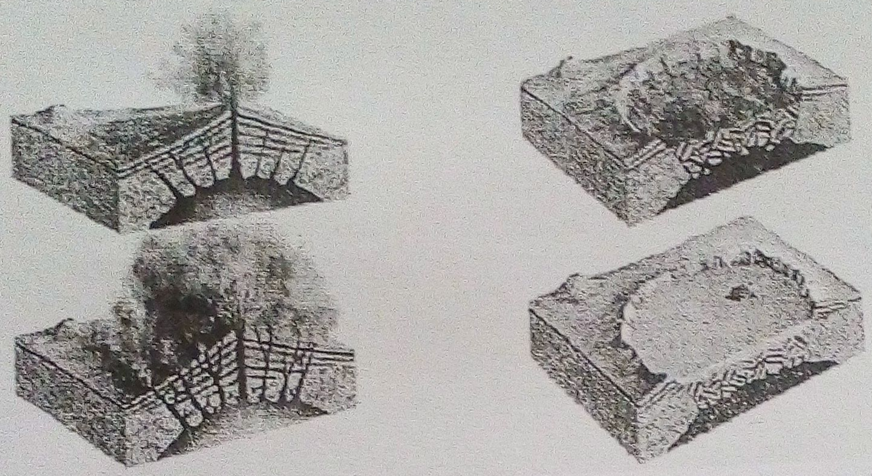
C) Calderas

- Large depressions (> 1km) from violent eruptions
- Ugashik Caldera, AK

Formation of Calderas

Volcano rapidly empties its magma chamber, and support is lost

Overlying material collapses into magma chamber and Caldera forms



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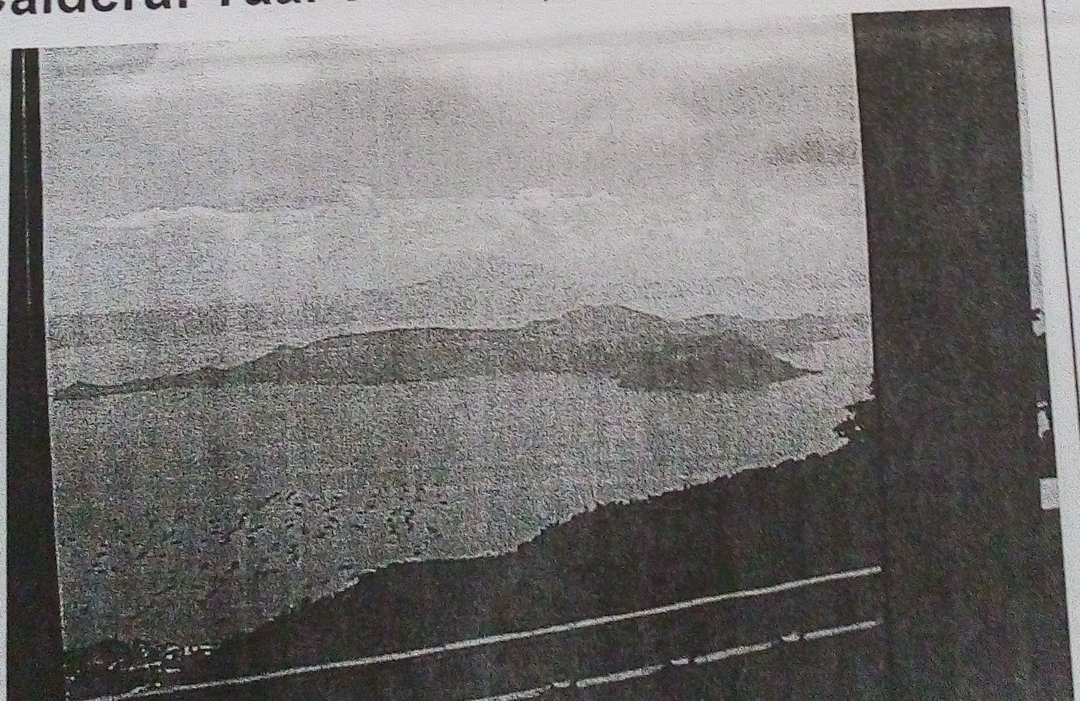
Caldera: Taal Volcano, Phillipines 2014



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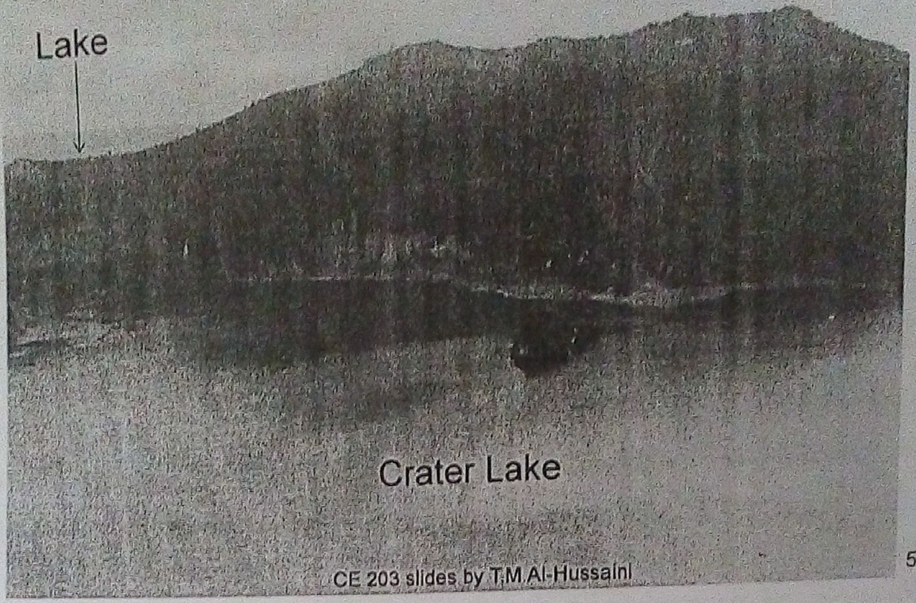
Lake within a Volcano within Lake within a Volcano, Phillipines 2014



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Smoke coming out from crater wall, Phillipines 2014

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Various Types of Lakes and their formation

A lake may be defined as water-filled depression of a fairly large size, existing on the Earth's surface. The size of a lake is somewhere between a pond and a sea. The water of the lake is generally semi-stagnant, as it has got a definite source of supply, and generally an outlet.

Depending upon the manner in which a *basin (depression)* gets filled up with water to form a lake, there can be nine types of lakes:

(1) Tectonic Lakes or Crustal Lakes. The depressions formed in the Earth's crust by tectonic movements *(displacements)* like folding, faulting etc, may result in the formation of basins for such lakes. This type of lakes are generally quite permanent.

(2) Barrier Lakes: These lakes are formed along river valleys by natural obstructions created across their courses. The lakes so formed on the upstream side of the obstruction may be called as a *barrier lake. The obstruction may be caused by rock slides, or by alluvial or glacial barriers. The alluvial barriers might be deposited* by excessive deposition caused by extinct glaciers or river flows, during the past history. There are many such lakes located in the higher ranges of Himalayas in India and Tibet.

(3) Rock-Basins: These may be defined as the hollows or depressions scooped out by glaciers on the rocky floors of the river valleys during the past geological times. These depressions or lake basins may get their water supply from the melting of glaciers of the upper regions or from rivers and rains. There are many fresh water lakes located in the higher ranges of Himalayas, and particularly in the Tibetan Himalayas, which are believed to be of such an origin.

(4) Volcanic Lakes or Crater Lakes. The crater or caldera of an extinct volcano may get filled up with water, and thus acting as a lake basin, called volcanic lake or crater lake. The Gohana lake of Garhwal (India) is believed to have been formed in this manner.

(5) Meteoric Lakes. Sometimes, the meteorites hit the earth surface with great impact, and as a result, may produce large hollows or depressions on the crust. The lakes formed in such basins may be called as meteoric lakes. Such lakes are generally very rare.

(6) Desert Lakes. In arid regions (deserts), sometimes, the winds may erode down the land surface to such an extent that the water table is exposed to form an *oasis (as discussed earlier). The lake so* formed at the site of the depression may be called as an oasis lake. The Quattara depression of Western Egypt provides an excellent example of such a type of lake basin. It is 300 km long, 140 km wide, and 125 m deep. The Sambar and other salt lakes of Rajasthan (India), which provide common salt on a large scale, are of *aeolian origin ;* formed by the rain water getting deposited in the depressions amongst the sand dunes.

(7) Deltaic Lakes. Sometimes, the inland *off-shoots of a sea may* get separated from the main body of the sea by deposition of spits, bars, etc.; forming a *deltaic lake on the land margin. The Chilka* lake in Orissa is only a few feet deep.

(8) Ox-bow Lakes. *Ox-bow lakes* are bodies of water standing in the deserted loops of a meandering river. Certain geologists believe that some of the lakes of Kashmere-Himalayas are ox-bow lakes instead of rock basins.

(9) Artifical Lakes. The lake formed on the upstream side of an artificial dam constructed across a river may be called as an *artificial lake*. Example is Kaptai Lake.

Geoogical work of Lakes

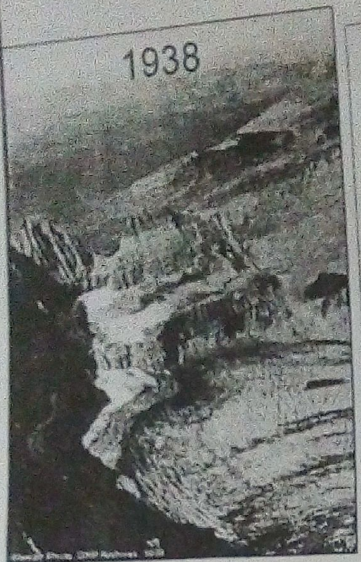
The lakes, because of their smaller size (compared to sea or ocean) are not the active agents of geological work. But, large sized lakes can perform the geological work of erosion and deposition just like a sea, although the work will be of much less magnitude. Only in such big sized lakes, the waves, capable of performing erosive work on shore rocks, are generated. Their most important work is, however, deposition. Most of the lake basins are bodies of standing water, like reservoirs, and they go on receiving sediments from time to time from the feeding rivers, glaciers, or the winds passing over them. They may also absorb some of the sediments eroded from their shores by waves.

The sediments brought into a lake, are generally very well sorted and screened, particularly in deep lakes. The rate of flow and the amount of sediment brought into a lake are also responsible for the quality of screening. Shallow lakes and lakes filled up rapidly by large quantities of rock-waste, may show poor sorting. In any case, the lake basins get gradually filled up with sediments; and thus, get vanished over a passage of time, leaving behind ponds, swamps and marshes.

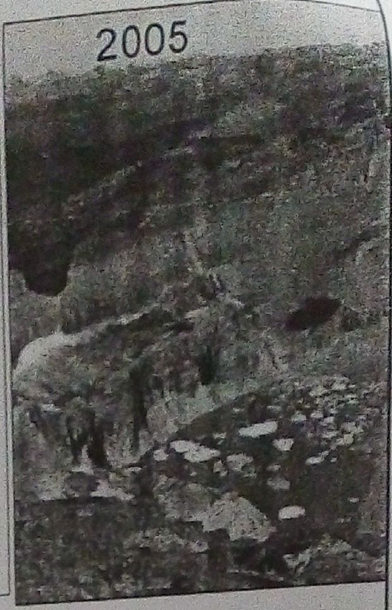
Lacustrine Deposits

- Lake - a land locked body of standing non-marine water.
- In Geological time scale, lakes are temporary features.
- They form in a basin and become sedimentary traps that eventually fill up.
- Ancient lake deposits are important source for oil-shale, uranium, and coal.

Effect of Global Warming – Glacier National Park, USA

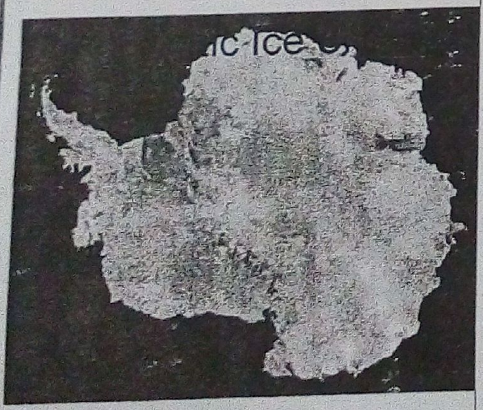


Glacier National Park in the United States has been sculpted by alpine glacial processes over thousands of years. Today, Glacier NP's landscape contains vestiges of past glaciation, with only a few active, high elevation alpine glaciers. Recent temperature increases are melting glaciers at an alarming rate. **Scientists predict that by 2030 there may not be any more glaciers in Glacier National Park!**



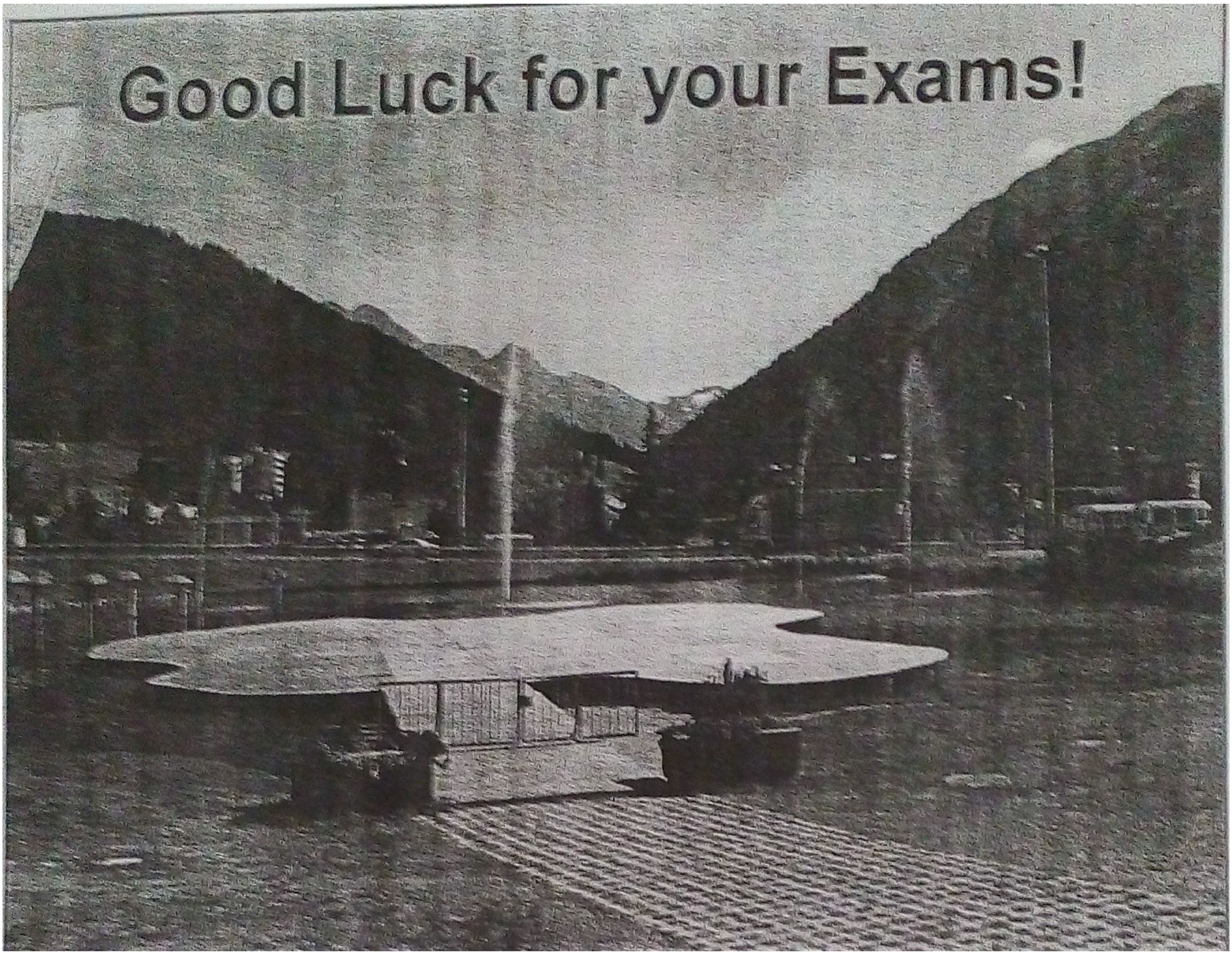
Source: USGS

Ice Sheet



Ice sheets are high latitude polar glaciers that cover extensive areas of continental landmasses. Ice sheet formation requires long periods of extremely low temperatures, which allows snow to collect over vast areas covering the underlying terrain. It is estimated that 90 percent of Antarctica and nearly 80 percent of Greenland are covered by ice sheets. Both of these ice sheets are so thick, that portions the Earth's crust below them are isostatically depressed, placing the actual landmass thousands of feet below sea-level. As the ice melts and the weight is removed, the landmass will slowly rebound and rise back up to sea-level. Both the Antarctic Ice Sheet and Greenland Ice Sheet are over 9800 feet thick in some places, and the only landmasses exposed are the highest elevation mountain peaks.

Source: USGS


Good Luck for your Exams!