GENERAL GEOLOGY

1. Importants Part of Earth Interior:

Based on chemical properties	Depth km	Based on physical properties	Depth km
Crust	40	Lithosphere (cool, rigid)	100
Mantle	2883	Asthenosphere (hot, plastic)	350
		Mesosphere (hot but strong due to high pressure)	2883
Outer Core	6370	Liquid Outer Core (Liquid NiFe)	6370
Inner Core		Solid Inner Core (Solid NiFe)	

2. Major Features of the Earth:

- Shield Areas
- Stable Platforms
- Folded Mountains
- Ocean Floor
  a. The Oceanic Ridge
  b. The Abyssal Floor
  c. Seamounts or Volcanic Mounts
  d. Trenches
  e. Continental Margins

3. Percentage of the most abundant Element in Earth:

Elements	Symbol	Percentage
Oxygen	O	46.60
Silicon	Si	27.72
Aluminum	Al	8.13
Iron	Fe	5.00
Calcium	Ca	3.63
Sodium	Na	2.83
Potassium	K	2.59
Magnesium	Mg	2.09
Titanium	Ti	0.44
Hydrogen	H	0.14
Phosphorous	P	0.12
Manganese	Mn	0.10
Sulfur	S	0.05
Carbon	C	0.03

4. Mohos Scale of Hardness:

Hardness	Mineral	Scratched ability
1	Talc	Scratched by a Finger Nail
2	Gypsum	
3	Calcite	Scratched by a Copper Coin
4	Fluorite	
5	Apatite	Scratched by a Knife
6	Feldspar	Scratched by a Glass
7	Quartz	Steel File
8	Topaz	
9	Corundum	
10	Diamond	No Scratched

5. Rock forming Mineral:

S.No	Mineral Groups	Mineral
1	Oxides	Quartz, Hematite.
2	Carbonates	Calcite, Dolomite, Magnesite, Ankarite.
3	Sulfides	Pyrite, Galena
4	Sulfates	Gypsum, Anhydrite, Hexahydrite, Polyhalite.
5	Chlorites	Rock Salt, Sylvite, Bischoffite, Carnallite.
6	Silicates	Feldspars, Mica, Hornblende, Augite, Olivine

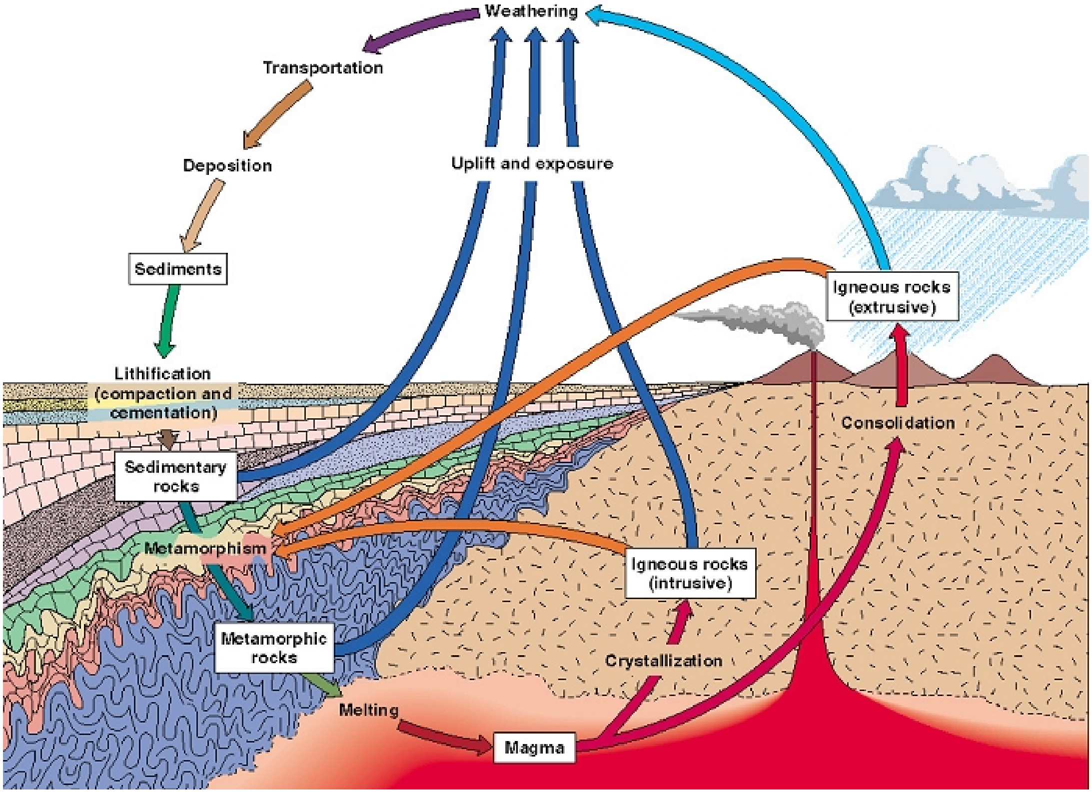
6. Crystal System:

System	Axes	Mineral Example
Isometric	3 axes, at 90	Garnet, Fluorite, Pyrite, Sphalerite, Halite
Tetragonal	3 axes at 90, 2 hori = but 2 ver is short or long	Zircon, Cassiterite
Hexagonal	4 axes, 3 = hori axes at 60, 1 axes vertical s l	Qurtz, Apatite, Calcite, Beryl
Orthorhombic	3 axes of differ length at 90	Olivine, Topaz
Monoclinic	3 unequal axes, 2 axes at 90 3 is inclined	Orthoclase, Mica, Augite, Gypsum
Triclinic	3 unequal axes, none at 90	Plagioclase, Axinite

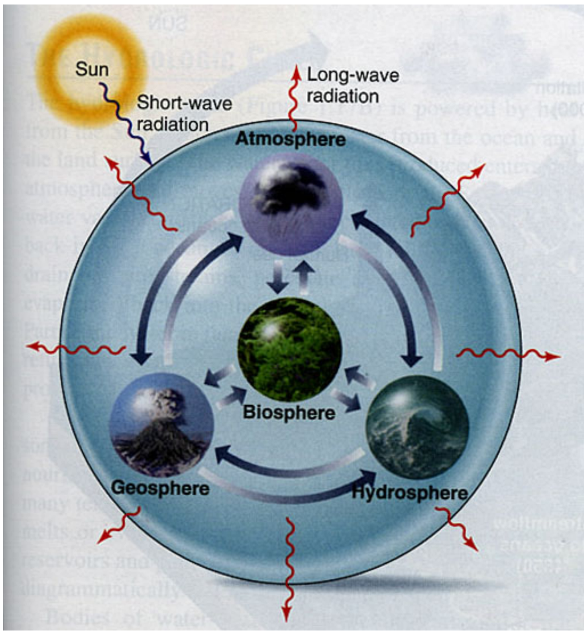
7. Geological Time Scale:

Era	Eon	Periods	Epoch	Well Known Names	Developments of Plants and animals	Duration in Ma	Ma ago
Phanerozoic	Cenozoic	Quaternary	Holocene	Human age	Human		0.01
			Pleistocene	Ice age	Modern Plants	1.6	1.6
		Tertiary: Neogene	Pliocene	Age of Mammals		3.7	5.3
			Miocene		Mammals	18.4	23.7
		Paleogene	Oligocene			12.9	36.6
			Eocene		Mollusks	21.2	57.8
			Paleocene	*Extinction of*		8.6	66.4
	Mesozoic	Cretaceous		*Dinosaurs and other species*	1st Flowering Plant	78	144
		Jurassic			First Bird	64	208
		Triassic		Age of Reptiles	Dinosaurs dominant *Extinction of*	37	245
	Paleozoic	Permian		Age of Amphibians	*Trilobites*	41	286
		Carboniferous	Pennsylvanian		1st Reptiles	34	320
			Mississipian		Large Coal swamps and amphibians abundunt	40	360
		Devonian		Age of Fishes	1st Insect fossils	48	408
		Silurian			1st Land Plants and Fishes dominant	30	438
		Ordovician		Age of Invertebrates	1st Fishes	67	505
		Cambrian			1st organisms with shells and Trilobites dominant	65	570
Precambrian	Proterozoic	Late			1st Multi celled Organisms	330	900
		Middle				700	1600
		Early				900	2500
	Archean	Late			1st One celled organism	500	3000
		Middle				400	3400
		Early			Age of Oldest Rock	400	3800
	Haden				Origin of Earth	1200+	4600

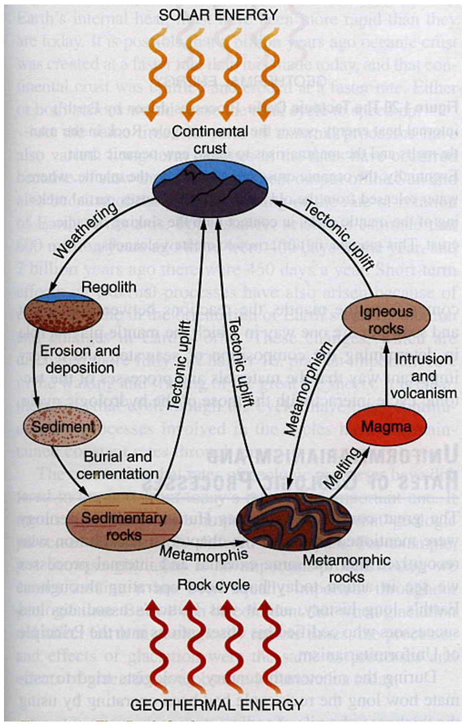
8. Rock Cycle:



The image shows how rocks are created and destroyed as part of a process called the “rock cycle”. All three types of rocks – igneous, sedimentary, and metamorphic – are created and destroyed as part of the earth’s various processes.



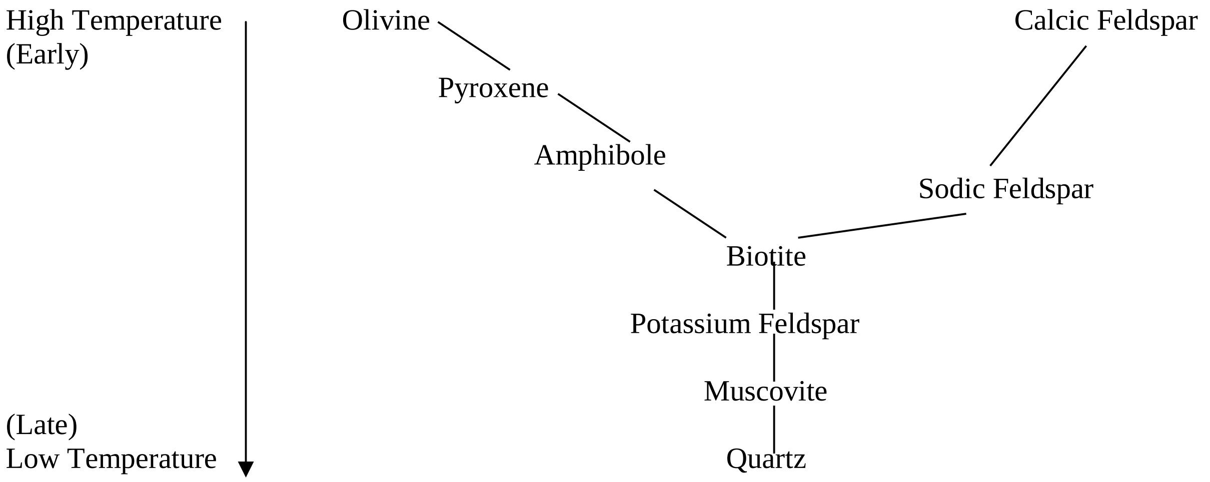
Pix show Energy reaches earth from an external source eventually returns to space as heat radiation. Smaller System within earth the atmosphere, biosphere, hydrosphere, and geosphere – are all open systems.



The rock cycle traces the processes whereby materials within and on top of earth’s crust are weathered, transported deposited, metamorphosed, and even melted.

9. Igneous Rock:

Bowen Reaction Series:



Igneous Rock Classification:

		“On the Basis of Silica Content”				
		Acidic Si >65% Light	**Intermediate Si 65-55% Medium** **Sub Acidic**	**Sub Basic**	**Basic Si 55-45% Dark**	**Ultrabasic Si <45% V.Dark**
“On the Basis of Texture and mode of occurrence”	PLUTONIC	Granodiorite	Syenite	Diorite	Gabbro	Peridotite
		Granite				Dunite
						Pyroxenite
	HYPABYSSAL	Andulite	Monzonite	Trachysite	Syeno Gabbro	
		Pegmatite Granite Porphry	Syenite Porphry	Diorite Porphry	Dolerite	
					Trachy Basalt	
	VOLCANIC	Rhyolite	Trachyte	Andesite	Alkali Gabbro	
		Obsidian			Alkali Basalt	
		Pitchstone			Basalt	
Min Comp		Quartz Orthoclase	Orthoclase >+-Plagio	Plagio >+- Orthoclase	Plagio +Augite	Olivine Pyroxene

Occurrence:

Sill => intrusive body parallel to strata
Dyke => intrusive body perpendicular to strata
Batholith => Large magmatic basin
Lapolith => Funnel shape
Laccolith => Umberalla shape (plano-convex)
Phacolith => crests and trough under folded strata
Stock => small batholith
Boss => Circular shape
Volcanic Neck or Plug => plug type intrusive body
Lawa flows

10. Metamorphic Rock:

Agents of Metamorphism:

- Temperature
- Pressure
- Chemical Fluids

Types of Metamorphism:

- Thermal Metamorphism
- Dynamothermal Metamorphism (Regional Metamorphism)
- Cataclastic Metamorphism
- Plutonic Metamorphism
- Metasomatism

Zones of Metamorphism:

Metamorphic Zones	Temperature	Pressure	Metamorphism Types	Example
Epizone or Upper Zone	Low (300)	High dp	Cataclastic	Phyllites
Mesozone or Intermediate Zone	300 – 500	High dp	Dynamothermal	Schists
Katazone or Lower Zone	500 – 800+	High up	Plutonic	Gneiss

Structures of Metamorphic Rocks:

- Schistose Structure
- Gneissose Structure
- Granulose Structure
- Slaty Structure

11. Sedimentary Rocks:

Terminologies of grains:

Sorting	Shapes	Sphericity	Angularity	Roundness	Transporting Agency
Very well sorted Well sorted Moderately sorted Poorly sorted Very poorly sorted	Equant Rod like Tabular Discoidal	High Low	Very Angular Angular Sab Angular	Sub rounded Rounded Well rounded	Glacier => Glacial deposites. Water => River = Alluvial deposites Lakes = Lacustrine deposites Sea = Marine deposites Wind => Aeolian/ Eolian deposites.

Classification of Sedimentary Rocks:

<table>
<tr><td rowspan="5">Clastic Rocks</td><td rowspan="3">Mechanically Formed (based on physical behaviour)</td><td>Rudaceous Rocks</td><td>Boulder deposit e.g, Conglomerate</td></tr>
<tr><td>Arenaceous Rocks</td><td>Sandy Rocks e.g, Sandstone</td></tr>
<tr><td>Argillaceous Rocks</td><td>Clayey Rocks e.g, Shale</td></tr>
<tr><td rowspan="2">Organically Formed (due to accumulation animals and plant remains)</td><td>Calcarious Rocks</td><td>Limestone</td></tr>
<tr><td>Carbonaceous Rocks</td><td>Coal Seams</td></tr>
<tr><td rowspan="3">Non Clastic Rocks</td><td rowspan="3">Chemically Formed (due to precipitation accumulation of soluble constituents)</td><td>Carbonate Rocks</td><td>Limestone, Dolostone</td></tr>
<tr><td>Sulfate Rocks</td><td>Gypsum rock</td></tr>
<tr><td>Chlorite Rocks</td><td>Rock Salt</td></tr>
</table>

Wentworth Scale of Grain:

<table>
<tr><th>Size F</th><th>Size mm</th><th>Grain size names</th><th>Rock group</th><th>Rock name</th><th>Texture</th></tr>
<tr><td></td><td>>256</td><td>Boulders</td><td rowspan="4">Gravel</td><td rowspan="4">Cnglemerate, Breccia</td><td rowspan="4">Epiclastic ruditic</td></tr>
<tr><td>-8</td><td>256</td><td>Cobbles</td></tr>
<tr><td>-6</td><td>64</td><td>Pebbles</td></tr>
<tr><td>-2</td><td>4</td><td>Granules</td></tr>
<tr><td>-1</td><td>2</td><td>Very Coarse Sand</td><td rowspan="5">Sand</td><td rowspan="5">Sandstone (Arenite, Wacke)</td><td rowspan="5">Epiclastic arenitic</td></tr>
<tr><td>0</td><td>1</td><td>Coarse Sand</td></tr>
<tr><td>1</td><td>1/2</td><td>Medium Sand</td></tr>
<tr><td>2</td><td>1/4</td><td>Fine Sand</td></tr>
<tr><td>3</td><td>1/8</td><td>Very Fine Sand</td></tr>
<tr><td>4</td><td>1/16</td><td>Silt</td><td rowspan="2">Mud</td><td rowspan="2">Siltstone, Shale, Mudstone, Claystone</td><td rowspan="2">Epiclastic lutitic</td></tr>
<tr><td>8</td><td>1/256</td><td>Clay</td></tr>
</table>

Dunhan's (1962) Classification of Carbonate:

On the basis of texture and grains mud ratio

<table>
<tr><th colspan="3"></th><th>Terms</th><th>Predominantly calcite Cc>95%</th><th>Dominatly Clalcite 95%>Cc<50%</th><th>Dominantly Dolomite Do>50%</th></tr>
<tr><td rowspan="5">Depositional texture recognizeable</td><td rowspan="3">Contains Mud</td><td rowspan="2">Mud Supported</td><td>Mudstone
<10% grain</td><td>Lime Mudstone</td><td>Dolomitic Lime Mudstone</td><td>Dolomudstone</td></tr>
<tr><td>Wackstone
>10% grain</td><td>Wackstone</td><td>Dolomitic Wackstone</td><td>Dolowackstone</td></tr>
<tr><td rowspan="2">Grain Supported</td><td>Packstone
>10% Mud</td><td>Packstone</td><td>Dolomitic Packstone</td><td>Dolopackstone</td></tr>
<tr><td>Lacks Mud</td><td>Grainstone
<10% Mud</td><td>Grainstone</td><td>Dolomitic Grainstone</td><td>Dolograinstone</td></tr>
<tr><td colspan="2">Originally Compounds bound together</td><td>Boundstone</td><td>Boundstone</td><td>Dolomitic Boundstone</td><td>Doloboundstone</td></tr>
<tr><td colspan="3">Depositional texture not recognizeable</td><td>Crystalline Carbonate</td><td>Crystalline Limestone</td><td>Dolomitic Limestone</td><td>Crystalline Dolostone</td></tr>
</table>

Weathering Products of Common Minerals:

Common Minerals in Rocks	**Weathering Products**
Quartz	Quartz, dissolved Silica
Feldspars	Clays; Ca, Na, K ions; dissolved Silica
White Micas	Clays; Ca, Na, K ions; dissolved Silica; Gibbsite
Biotite	Clays; iron oxides; K, Mg, Fe ions; dissolved Silica
Amphiboles	Clays; iron oxides; Ca, Na, Mg, Fe ions; dissolved Silica
Pyroxene	Clays; iron oxides; Ca, Mn, Mg, Fe ions; dissolved Silica
Olivine	Clays; iron oxides; Mg, Fe ions; dissolved Silica
Garnets	Clays; iron oxides; Ca, Mg, Fe ions; dissolved Silica
Al-Silicates	Clay, Silica, Gibbsite
Magnetite	Hematite, Geothite, Limonite
Calcite	Ca ions, HCO3- ions
Dolomite	Ca, Mg ions, HCO3- ions
Iron Carbonates	Ca, Mg, Fe ions; iron oxide; HCO3-

Color of Mud Rocks:

- Black, Brown and Gray Color refers organic content is high i.e. sulfides quantity.
- Red color of Hematitic clay refers high oxidation zone.
- Red and brown shale contains iron oxide coatings.
- Green shale characterize by chlorite and illite.
- Olive and yellow shale contains mixtures of illite, chlorite, organic material and iron sulfides.

Sedimentary Environment:

Major Categories	General Environments	Specific Environments
Continental	Fluvial (River)	Channel and Bar
		Overbank, high energy (levee)
		Overbank, low energy (swamp)
		Alluvial Fan
	Desert	Playa
		Erg
	Glacial	Sub glacial
		Englacial
		Supraglacial
		Cryolacustrine
		Proglacial fluvial
		Proglacial Aeolian
	Lacustrine	Cryolacusrine
		Playa Lake (salina)
		Fresh water lacustrine
	Paludal (Swamp)	Intra Paludal
		Deltaic Paludal
Transitional	Coastal Deltaic	Channel Bar
		Overbank crevasse splay
		Deltaic paludal
		Deltaic lacustrine
		Prodelta
		Delta front
	Eustrine-Lagoon	Eustrine
		Lagoonal
		Slat marsh
	Littoral beach	Beach forshore
		Beach backshore
		Beach dune (bern)
		Tidal channel
		Tidal flat
Marine	Shelf shallow sea	Low energy open
		Low energy restricted
		High energy
	Reef	Glaciomarine
		Reefal
		Fore reef
		Rreef lagoon
	Submarine Canyon, Slope and Rise	Open Slope
		Open Rise
		Slope Basin
		Submarine Fans
	Pelagic	Basinal or Abbysal Plain
		Oceanic Plateau
	Trench	Trench Slope
		Trenc Slope Basin
		Trench Floor
		Submarine fan
	Rift Fracture Zone	

Sedimentary Structure:

Rock Type	**Depositional**	**Erosional**	**Deformational**	**Diegenatic**
Sandstone	Bedding	Channels	Soft-sediment folds	Concretions
	Cross Bedding	Tool marks	Slumps or slide scars	Stylolites
	Ripple Marks	Rip-up	Breccias	Sand crystals
	Salt crystal casts	Trails and tracks	Sandstone Dikes	Liesegang bands
	Laminations	Flute cast	Sandstone Sills	Liesegang rings
	Cross Laminations	Load cast	Flame Structures	
	Graded bedding	Burrows	Fluid Escape channels	
			Ice wedge casts	
			Ball and pillow structure	
			Panecontemporanous faults	
			Slump or Slide cast	
			Sand volcanoes	
			Convolute Laminations	
			Dish structures	
			Organic escape structures	
			Root cast and molds	
Carbonates	Bedding	Channels	Soft-sediment folds	Concretions
	Cross Bedding	Tool marks	Desiccation cracks	Viens
	Ripple Marks	Burrows	Breccias	Stylolites
	Stromatolites	Trails and tracks	Tepees	Breccias
	Laminations	Flute cast	Load cast	Liesegang bands
	Cross Laminations		Flame Structures	Liesegang rings
	Graded bedding		Panecontemporanous faults	Nodules
	Pellets		Convolute Laminations	Vugs
	Reefs			Stromatactis
	Oncolites			Hardgrounds
	Grapestones			Fenestrae
	Mounds			Pisolites
	Fensetrae			
Mud Rocks	Bedding (II, ~, I~)	Mud cracks	Mud volcanoes	Concretions
	Lamination (II, ~, I~)	Tool marks	Flame Structures	Escape structure
	Parallel stratification	Burrows	Load cast	
	Ripple Marks	Trails and tracks	Crystal casts	
	Salt crystal casts	Flute cast	Color banding	
	Laminations	Rain prints	Bioturbatted bedding	
	Cross Laminations		Convolute bedding	
	Graded bedding		Soft-sediment folds	
	Sole Marks		Soft-sediment faults	
			Slickenside	

Lime Mud: G < ssp	**Micrite:** G < 0.004mm
Sparite: G > 0.004 mm	**Microsparite:** G b/w 0.004 – 0.06mm
	Macrosparite: G < 0.06mm
Allochems: **Transport Fragements of Precipetated material**	**Intraclast:** fragments of preexist rock **Oids:** (oolith, oolites) c = p (G b/w 0.25-0.02mm) **Pellets:** G < 0.25mm ,**Grapestones, Skeletal Fragment** **Oncolites:** G < 10cm
Biolithic Elements: **By precipitation by organisms**	**Stramatolites:** by Organic precipitation **Test, Skeleton**

STRUCTURUL GEOLOGY

- It is the Geometry of the rocks or Architecture of the rock.

Fold:

- It is the Flexure in rock series by compressional forces.
- **Classification of Fold:**

Younging Direction and Convergence	**Cylindericity**	**Shape of Axial Surface**	**Fold Symmetry**	**Orientation of Axial Surface and Hinge**	**Dip Isogons or Geometrical or Ramsay's**	**Interlimb Angle**	**Shape of Fold Hinge**	**Misc. Fold**
Antiformal Anticline	Cylinderical	Plane	Symmetry	Horizontal Normal	Convergent: • Strongly • Parallel • Weakly	Gentle 180-120	Smooth Hinge	Overturned
Synformal Syncline	Non Cylinderical	Non Plane	Asymmetry	Plunging Normal		Open 120-70	Box	Monocline
Synformal Anticline				Horizontal Inclined	Parallel	Closed 70-30	Chevron	Drag
Antiformal Syncline				Plunging Inclined	Divergent	Tight 0-30	Kink Bands	Dome
				Neutral: • Vertical • Recumbent • Reclined		Isoclinal 0		Basin
						Negative, Mastroom -ve		En-Echelon

Faults:

- It is the fracture in rock which there has been an observable amount of displacement.
- **Classification of Fault:**

	Geometrical Classification			
Genetic Classification	**Rake or Pitch of net slip**	**Att. Of Fault related to Att. Of adjacent Bed**	**Fault Pattern or Cross Section**	**Amount of Dip of Fault**
Thrust Fault: • Reverse >45 • Thrust 10-45 • Overthrust <10	Strike Slip Fault	Strike Fault	Parallel Fault	High Angle Fault > 45
	Dip Slip Fault	Bedding Fault	En-Echelon Fault	Low Angle Fault > 45
Normal Fault: • Horst • Graben or Rift Valley • Rollover Antiforms • Antithetic Faults	Oblique Slip Fault	Dip Fault	Peripheral Fault	
		Oblique or Diagonal	Radial Fault	
		Longitudinal		
		Transverse		
Strikeslip Faults: • Sinstral or Left Lateral Faults • Dextral or Right Lateral Faults				

Unconformity:

Angular Unconformity, Disconformity, Nonconformity, Paraconformity.

Some Fold Concepts:

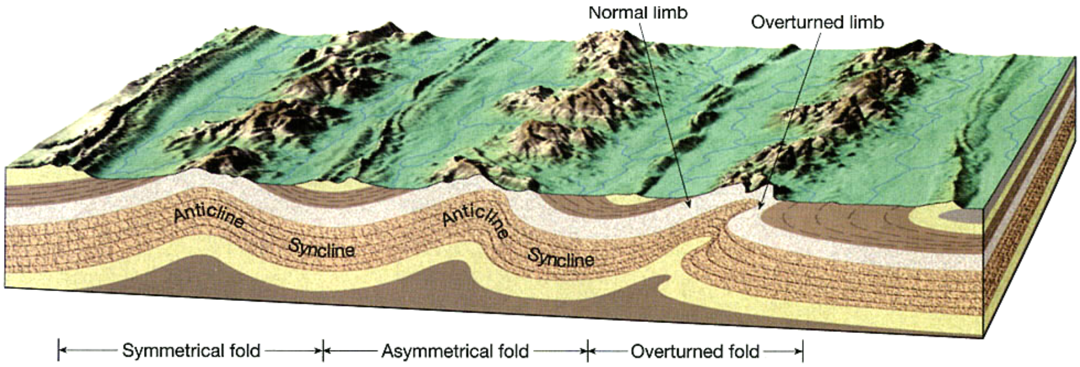


Figure 15.10 Block diagram of principal types of folded strata. The upfolded or arched structures are anticlines. The downfolds or troughs are synclines. Notice that the limb of an anticline is also the limb of the adjacent syncline.

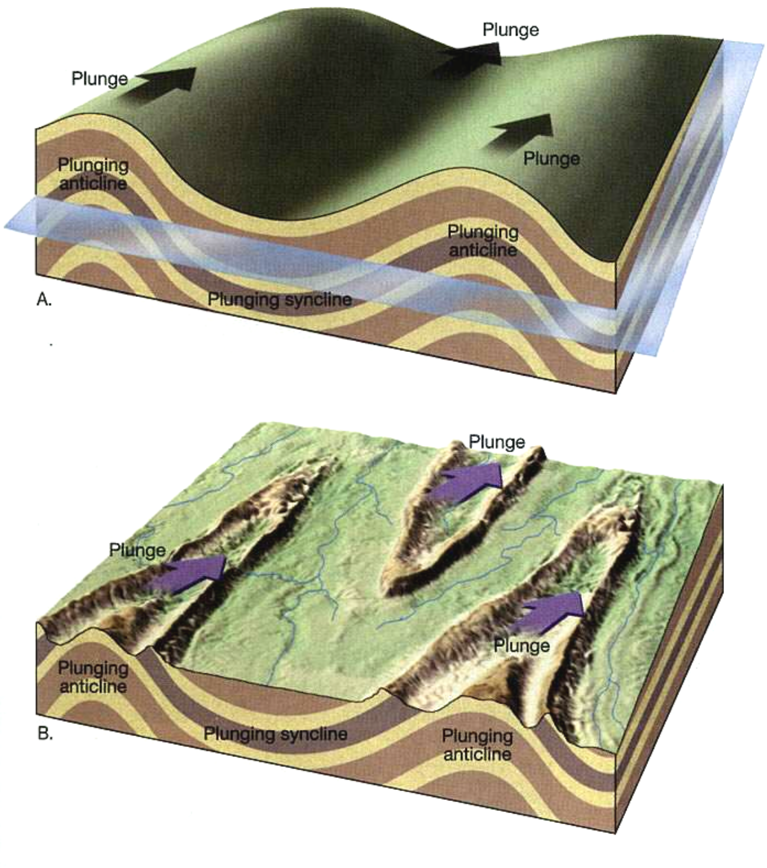


Figure 15.12 Plunging folds. **A.** Idealized view of plunging folds in which a horizontal surface has been added. **B.** View of plunging folds as they might appear after extensive erosion. Notice that in a plunging anticline the outcrop pattern "points" in the direction of the plunge, while the opposite is true of plunging synclines.

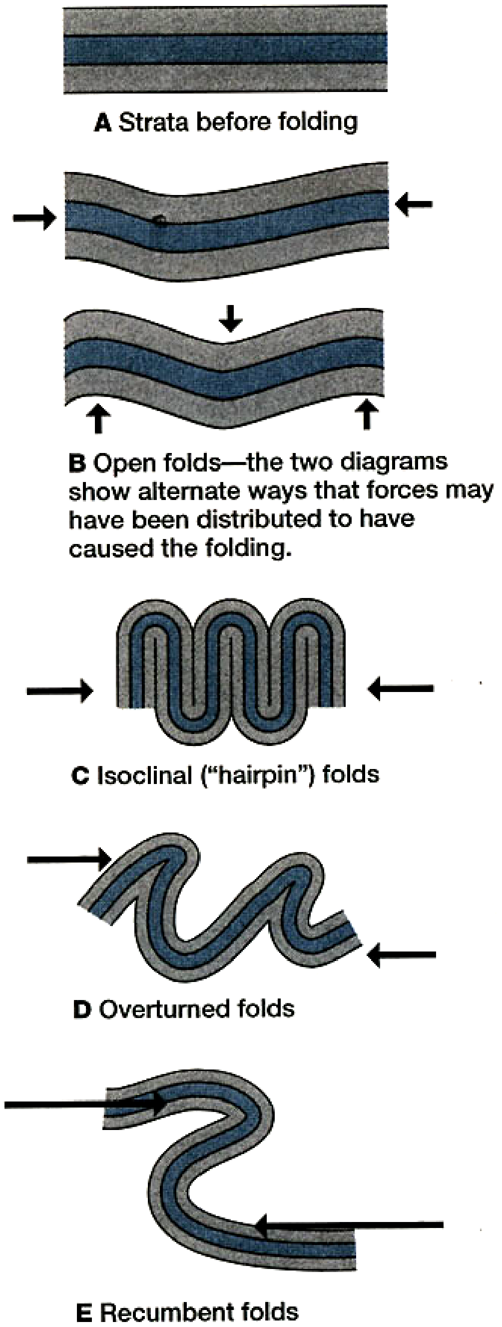


Figure 15.19
Cross sections of some types of folds and possible directions of movement implied by each. The length of the arrows in A through E is proportional to the intensity of the forces involved and to movement of the earth's crust.

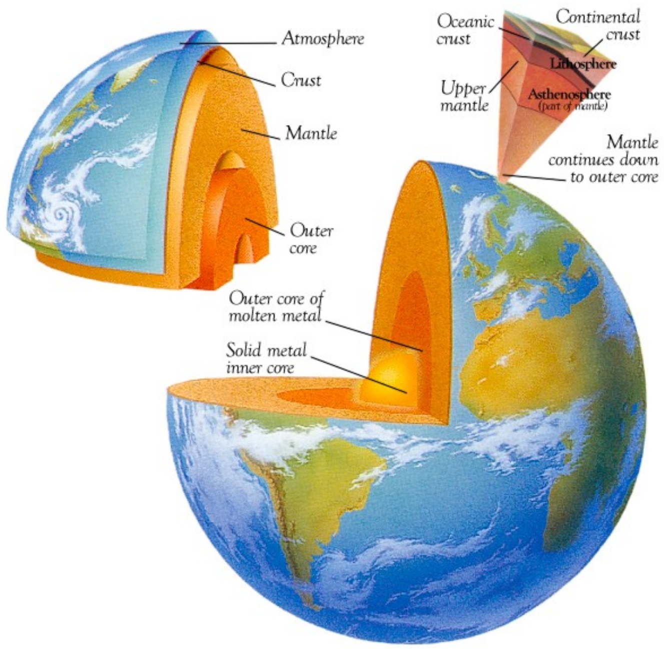
Recognition of Unconfirmity:

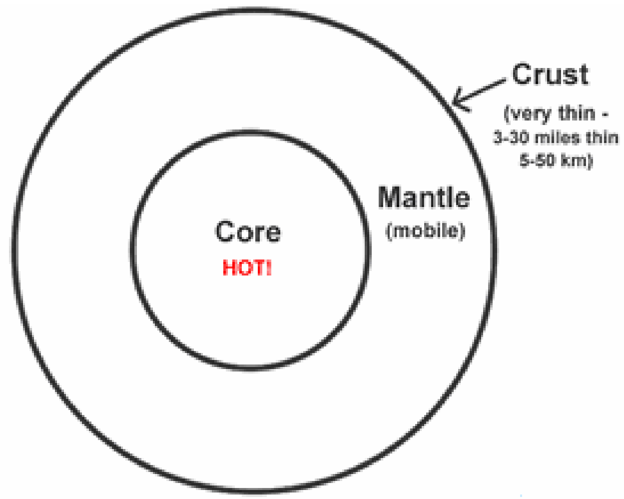
- Difference in structure.
- Fossil record.
- Fossil soil.
- Enviornament or time change.
- Rock type change.

TECTONICS

Earth's structure:

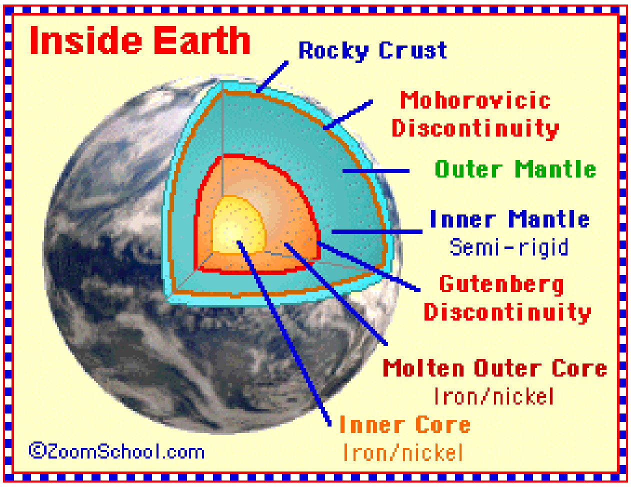
- The earth consists of several different and distinct layers.
- The three main layers are the core, the mantle and the crust.
- The core is the inner part of the earth, the crust is the outer part and between them is the mantle.
- Knowledge of earth's interior is essential for understanding plate tectonics.
- The Earth is made of many layers. The deeper layers are composed of heavier materials; they are hotter, denser and under much greater pressure than the outer layers.
- The Earth's surface is composed mostly of water, basalt and granite. Oceans cover about 70% of Earth's surface. These oceans are up to 3.7 km deep.





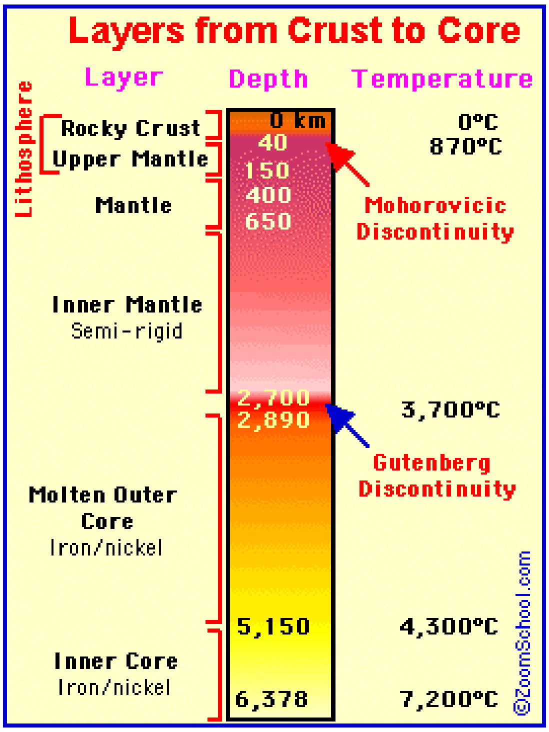
The Earth's Interior:

1. **Core**
2. **Mantle**
3. **Crust**



Earths Layers with

- **Mohorovicic Discontinuity**
- **Gutenberg Discontinuity**

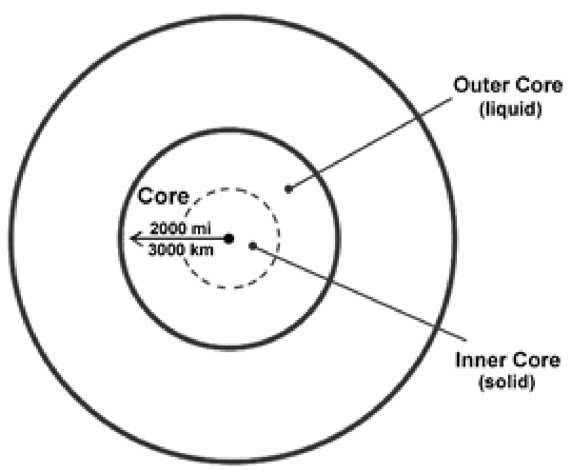


The Core:

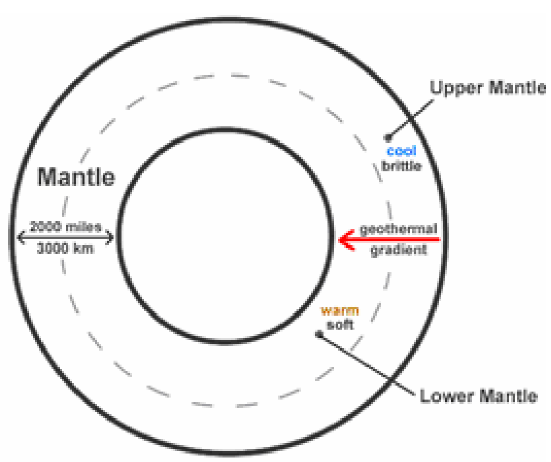
- The Core of the earth is about 1,800 miles (2,900 km) below the earth's surface.
- The core is a dense ball of the elements iron and nickel.
- It is divided into two layers, the inner core and the outer core.
- The inner core - the centre of earth - is solid and about 780 miles (1,250 km) thick. The inner core may have a temperature up to about 13,000°F (7,200°C = 7,500 K), which is hotter than the surface of the Sun. The inner core (which has a radius of about 750 miles (1,228 km) is solid.
- The outer core is so hot that the metal is always molten. The outer core is about 1370 miles (2,200 km) thick. Because the earth rotates, the outer core spins around the inner core and that causes the earth's magnetism. The outer core is in a liquid state and is about 1,400 miles (2,260 km) thick.
- The Earth has an iron-nickel core that is about 2,100 miles in radius.
- The core is earth's source of internal heat because it contains radioactive materials which release heat as they break down into more stable substances.

The Mantle:

- The layer above the core is the mantle which is about 1,800 miles (2,900 km) thick and makes up nearly 80 percent of the Earth's total volume.
- It begins about 6 miles (10 km) below the oceanic crust and about 19 miles (30 km) below the continental crust.
- It is composed of olivine-rich rock mainly silicon, oxygen, magnesium, iron, aluminum, and calcium.
- The mantle is to divide into the lower mantle and the upper mantle.
- The upper mantle is rigid and is part of the **lithosphere** (together with the crust).
- The lower mantle flows slowly, at a rate of a few centimeters per year. The **asthenosphere** is a part of the upper mantle that exhibits plastic properties. It is located below the lithosphere (the crust and upper mantle), between about 100 and 250 kilometers deep.
- Convection (heat) currents carry heat from the hot inner mantle to the cooler outer mantle. The mantle gets warmer with depth, the highest temperatures occur where the mantle material is in contact with the heat-producing core and is about 4,000-6,700° F (2,200-3,700° C) while the top of the mantle is about 1,600° F (870° C).
- The Gutenberg discontinuity separates the outer core and the mantle.
- The steady increase of temperature with depth is known as the geothermal gradient. The geothermal gradient is responsible for different rock behaviors and the different rock behaviors are used to divide the mantle into two different zones. Rocks in the upper mantle are cool and brittle, while rocks in the lower mantle are hot and soft (but not molten).



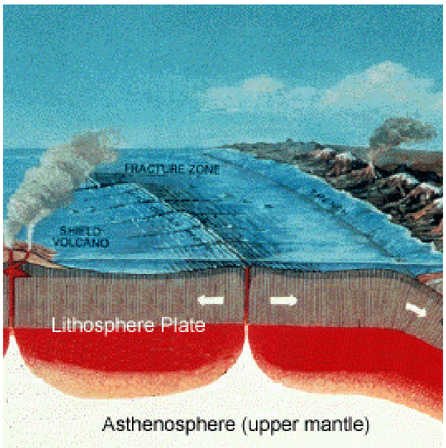
The Core

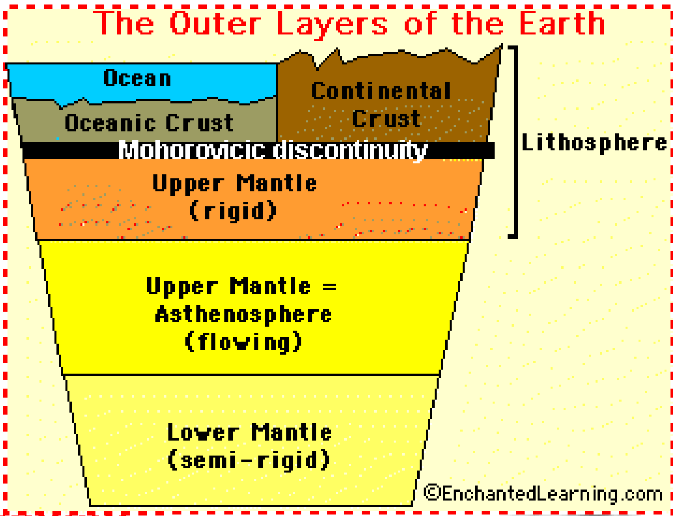


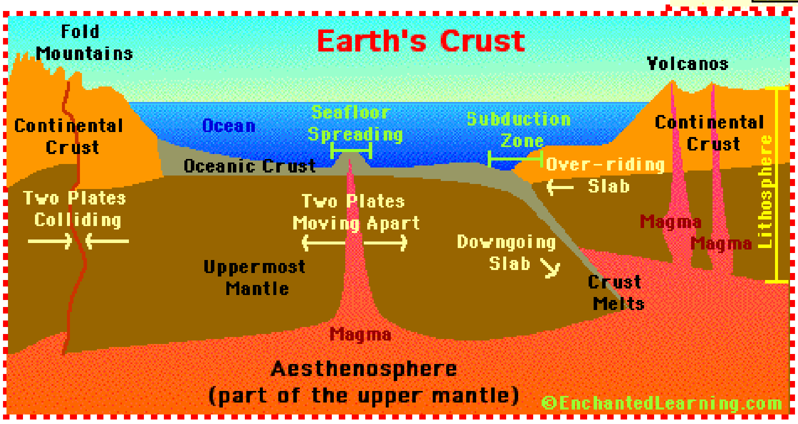
The Mantle

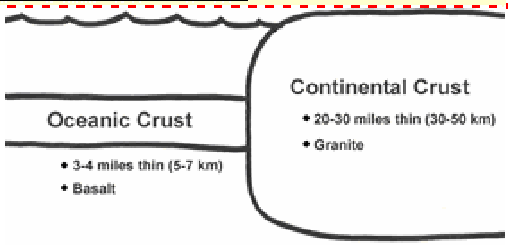
The Crust:

- The Crust lies above the mantle and is the earth's hard outer shell which is composed of silicon, aluminum, calcium, sodium and potassium.
- The crust is divided into continental plates which drift slowly (only a few centimeters each year) atop the less rigid mantle.
- There are two different types of crust. The Oceanic crust underlies the ocean basins and is thin (6-11 km thick); this is where new crust is formed. The Continental crust is about 25-90 km thick. The lithosphere is defined as the crust and the upper mantle, a rigid layer about 100-200 km thick.
- The thin oceanic crust is composed of primarily of basalt and the thicker continental crust is composed primarily of granite. The low density of the think continental crust allows it to "float" in high relief on the much higher density mantle below.
- The Mohorovicic discontinuity is the separation between the crust and the upper mantle.









Crust Type:

1. **Oceanic Crust**
2. **Continental Crust**

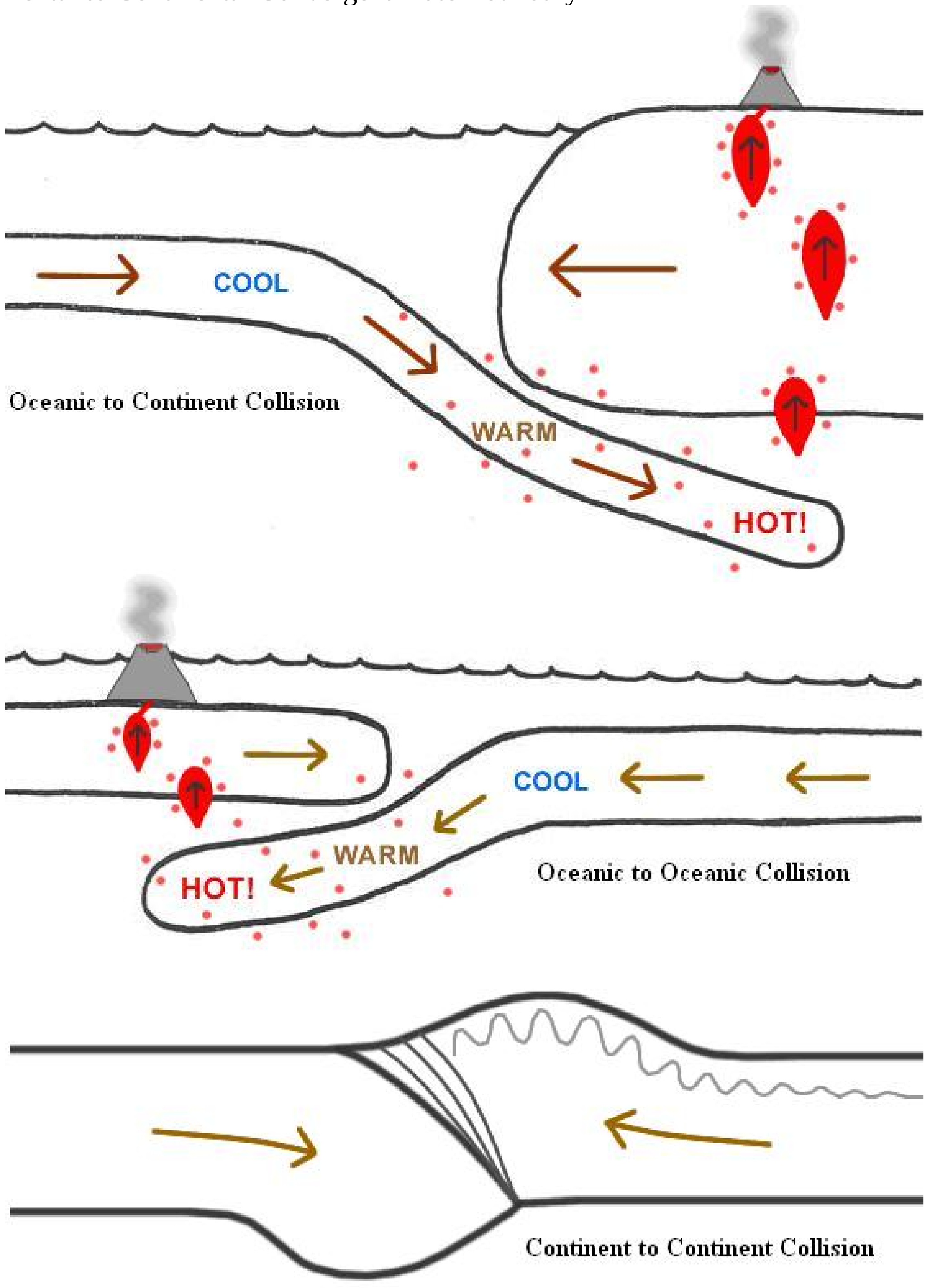
The Atmosphere

- It is the all kind of gaseous layer which is covered the earth.
- It is the essential part on earth for life, without this atmosphere life on earth isn't possible.
- It gives us air, water, warmth and is protecting us against harmful rays of the sun and against meteorites.
- This layer around the earth is a colourless, odourless, tasteless 'sea' of gases, water and fine dust.
- The atmosphere is made up of different layers with different qualities. It consists of 78% nitrogen, 21% oxygen, 0.93% argon, 0.03% carbon dioxide and 0.04% of other gases.
- The Troposphere is the layer where the weather happens; above this layer is the Stratosphere. Within the Stratosphere is the Ozone layer that absorbs the Sun's harmful ultraviolet rays. Above the Stratosphere is the Mesosphere, the Thermosphere - in which the Ionosphere - and the Exosphere. The atmosphere is about 500 miles (800 km) thick.

Plate Boundaries:

Convergent Plate Boundaries:

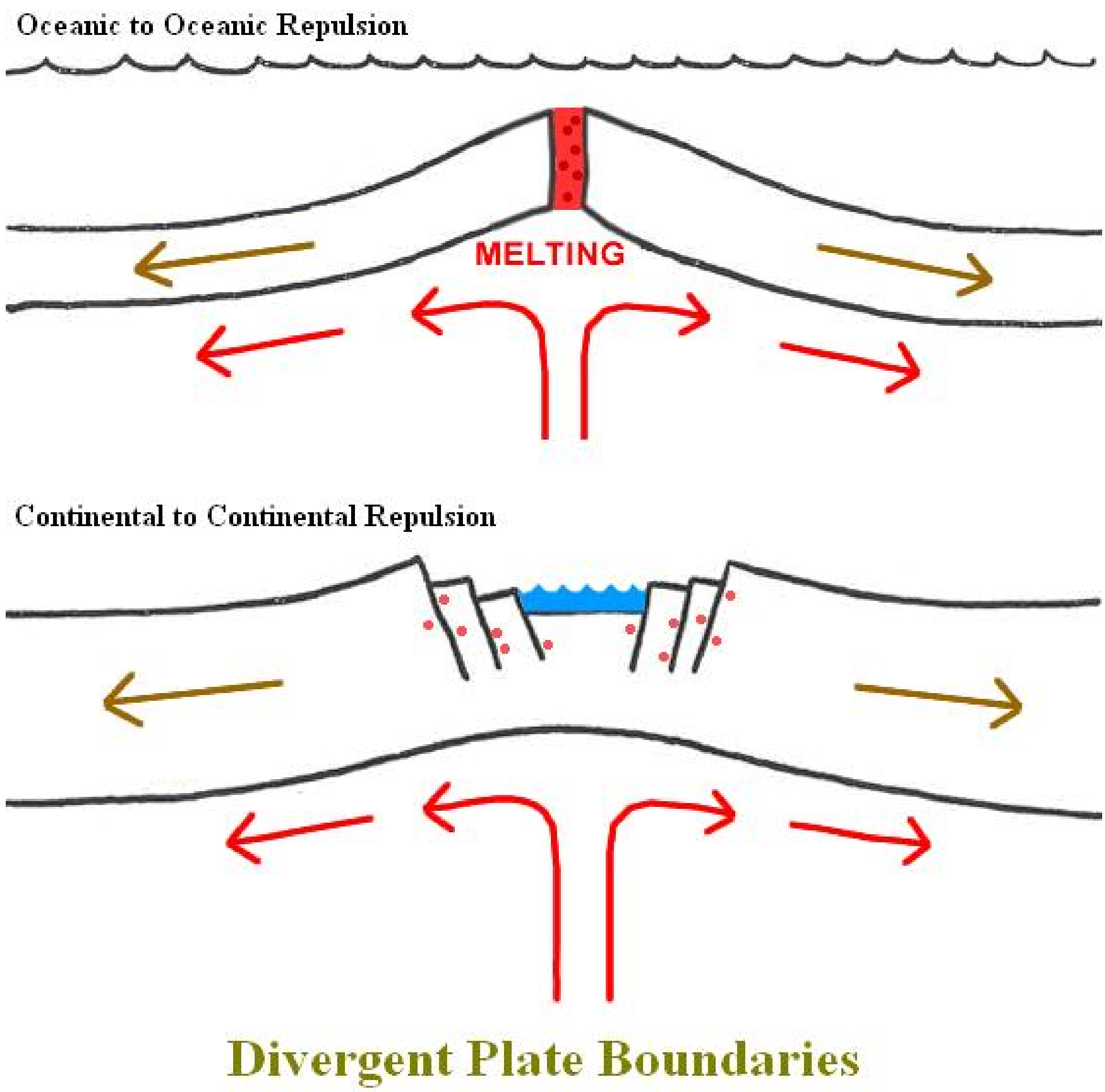
- Convergent plate boundaries are locations where lithospheric plates are moving towards one another.
- The plate collisions that occur in these areas can produce earthquakes, volcanic activity and crustal deformation.
- Three types of Convergent Plate Boundaries are:
  1. Oceanic to Continental Convergent Plate Boundary
  2. Oceanic to Oceanic Convergent Plate Boundary
  3. Continental to Continental Convergent Plate Boundary



Convergent Plate Boundaries

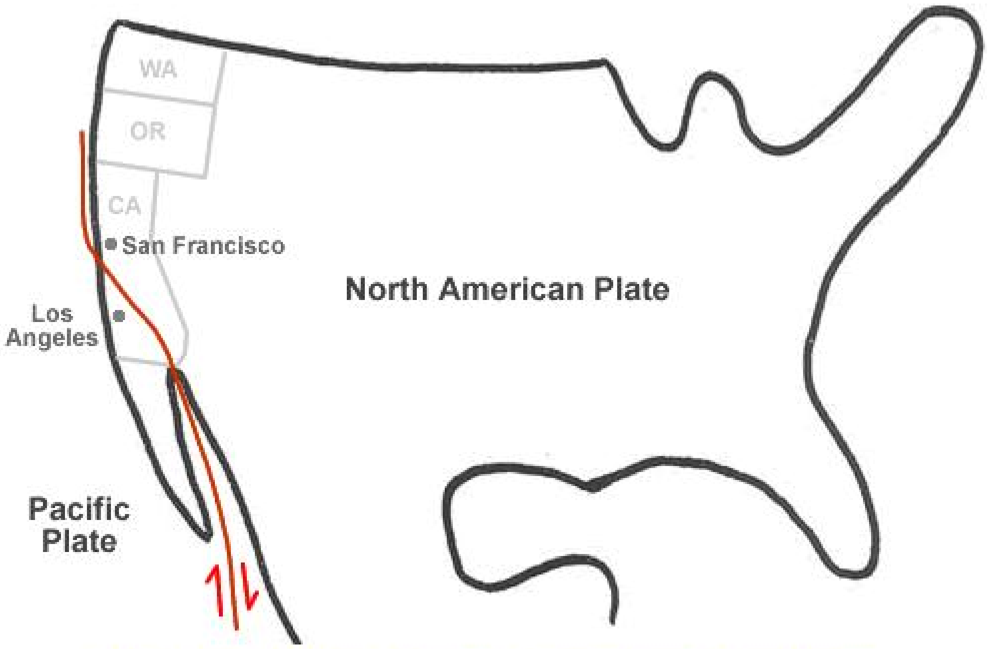
Divergent Plate Boundaries:

- Divergent plate boundaries are locations where plates are moving away from one another. This occurs above rising convection currents.
- The rising current pushes up on the bottom of the lithosphere, lifting it and flowing laterally beneath it. This lateral flow causes the plate material above to be dragged along in the direction of flow.
- At the crest of the uplift, the overlying plate is stretched thin, breaks and pulls apart.
- Two Types are as:
  1. Oceanic to Oceanic Divergent Plate Boundary
  2. Continental to Continental Divergent Plate Boundary

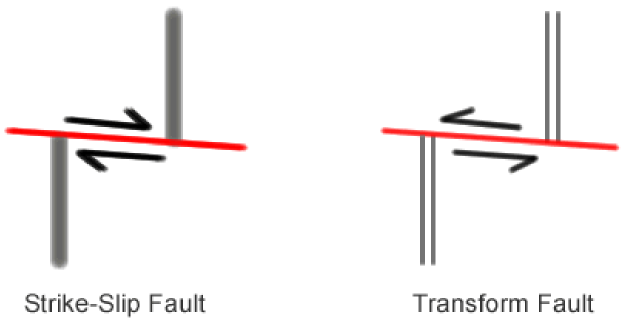


Transform Boundary:

- Transform Plate Boundaries are locations where two plates slide past one another.
- The fracture zone that forms a transform plate boundary is known as a transform fault.
- Most transform faults are found in the ocean basin and connect offsets in the mid-ocean ridges.



Map View of San Andreas Transform Boundary between North American Plate and Pacific Plate.



- Transform faults can be distinguished from the typical strike-slip faults because the sense of movement is in the opposite direction.
- A strike-slip fault is a simple offset; however, a transform fault is formed between two different plates, each moving away from the spreading center of a divergent plate boundary.
- A smaller number of transform faults cut continental lithosphere. The most famous example of this is the San Andreas Fault Zone of western North America. The San Andreas connects a divergent boundary in the Gulf of California with the Cascadia subduction zone. Another example of a transform boundary on land is the Alpine Fault of New Zealand.
- Transform faults are locations of recurring earthquake activity and faulting. The earthquakes are usually shallow because they occur within and between plates that are not involved in subduction. Volcanic activity is normally not present because the typical magma sources of an upwelling convection current or a melting subducting plate are not present.

Major Continental Plates:

1. African Plate
2. Antarctic Plate
3. Arabian Plate
4. Indian Plate
5. Australian Plate
6. Caribbean Plate
7. Cocos Plate
8. Eurasian Plate
9. Juan de Fuca Plate
10. Nazca Plate
11. North American Plate
12. Pacific Plate
13. Philippines Plate
14. Scotia Plate
15. Somali Plate
16. South American Plate

Geological Evidences for Continental Drift:

- The continuity of Paleozoic Fold Belts.
- The correlation of the patterns of age provinces.
- Correspondence matching of coastlines of South America and Africa.
- Reconstruction of the continents.
- Distinctive Igneous rocks can be traced between continents.
- Distinctive Stratigraphic sequence can also be correlated between adjacent continents.
- Regions containing metallogenic provinces (Manganese, Iron ore, Gold, Tin etc.) can be matched across adjacent coastlines on such reconstructions.
- Climatic indicators are also play an important evidence for continental drift.
- Distinctive fossils can also be correlated between adjascent continents.
- Paleomagnetism can also be helped to understand continental drift.

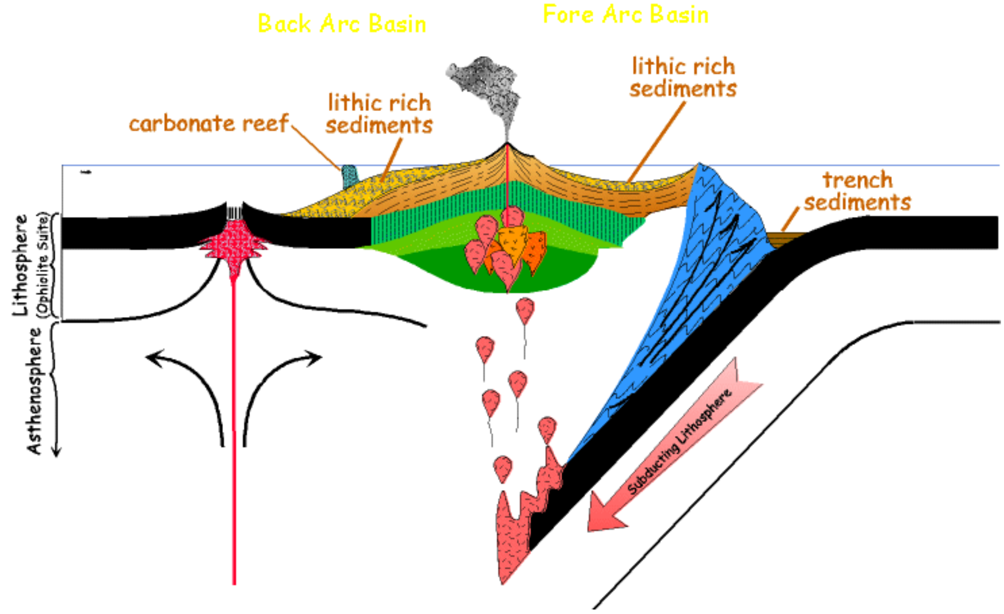
Earthquake Classification

On the basis of focal depth:

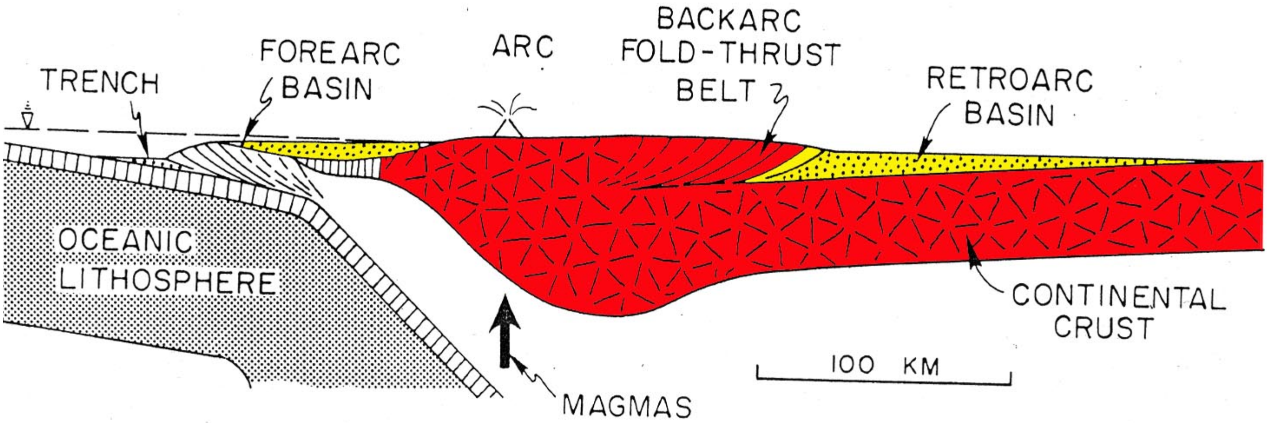
1. Shallow Earthquake, 0 – 70 km
2. Intermediate Earthquake 70 – 300 km
3. Deep Earthquake >300km

Morphology of Subduction zone:

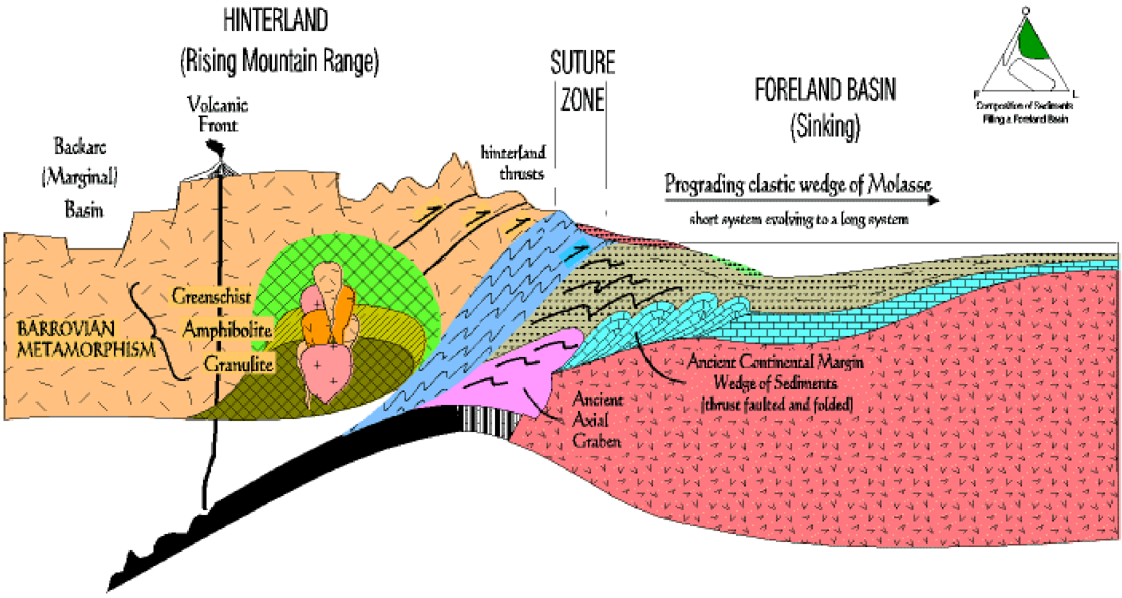
1. Island Arc system
2. A Bulge
3. Trench
4. Forearc Region
5. The Subduction complex/Accretionary Prism/1st Arc/Accretionary Wedge
6. The Forearc Basin
7. The Island Arc
8. The Remnant Arc
9. Marginal Sea/Backarc basin



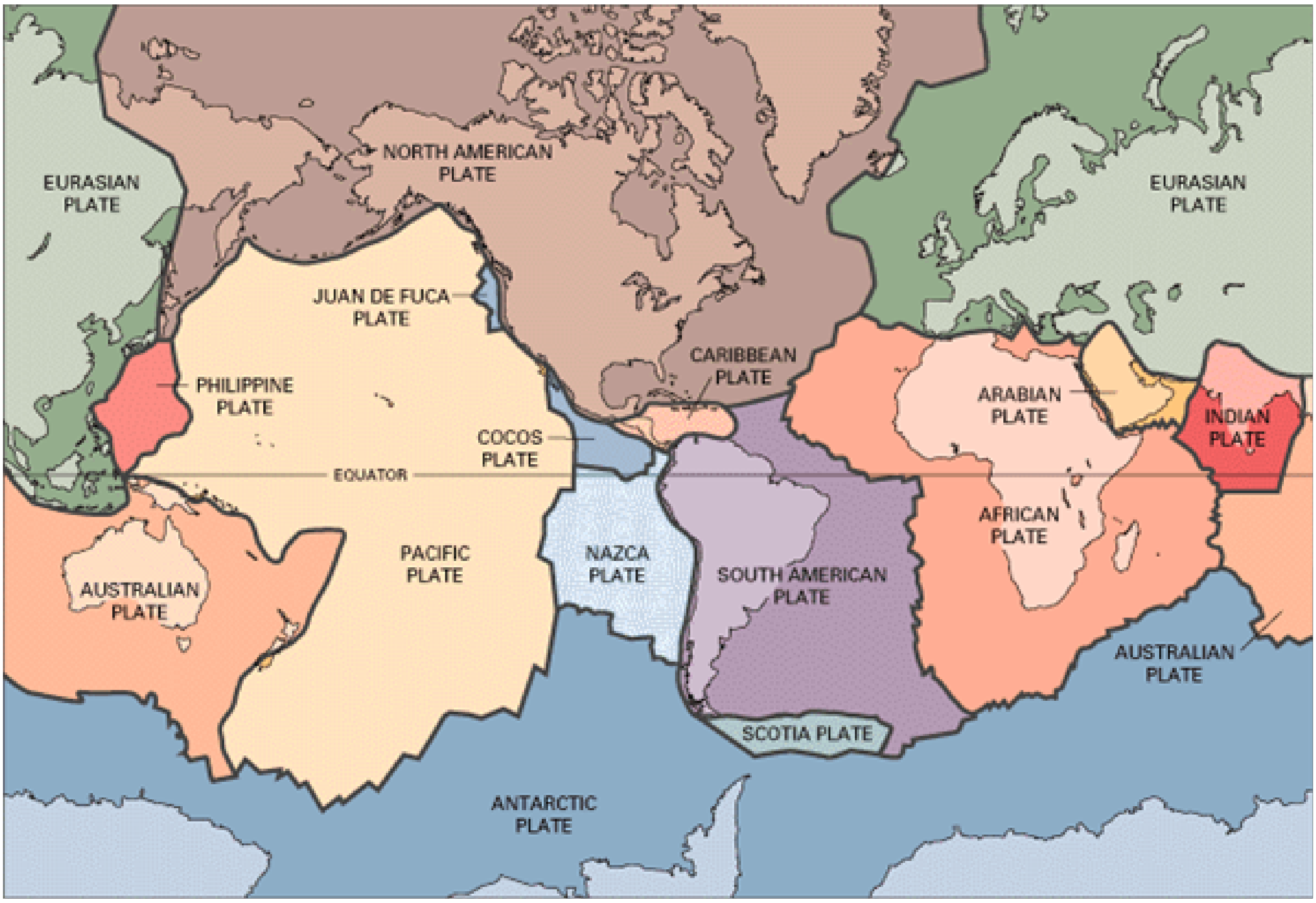
Detailed Features of Ocean-Ocean Collision



Detailed Features of Continent-Ocean Collision Orogeny



Detailed Features of Continent-Continent Collision Orogeny



Major Plates of the World

GEOPHYSICS

Waves:

Seismic Waves are the parcels of elastic strain energy that propagate outwards from a seismic source like earthquake.	**Body Waves** can propagate through the body of an elastic solid and are nondescriptive. Velocity of Body waves remains same by changing frequency. Two types as:	**S-Waves (Transverse waves)** propagate by a pure shear in a direction perpendicular to the direction of wave travel.
		P-Waves (Longitudinal waves) propagate by compressional dilation uniaxial strains in the direction of wave travel.
	Surface Waves can propagate only along the boundary of solid. Two types are:	**Rayliegh Waves** propagate along boundary between two dissimilar solid media, in a plane perpendicular to the surface and containing the direction of propagation.
		Love Waves are polarized shear wave with an associated oscillatory particle motion parallel to the free space and perpendicular to the direction wave motion.

Resolution:

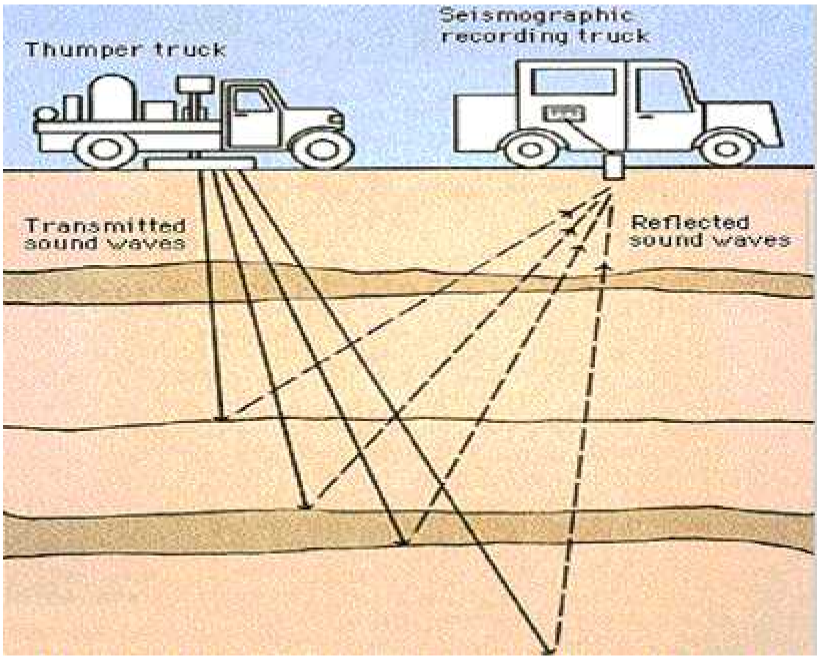
- It is a measure of ability to see two events separately in seismogram.
- Two types are:

1. Vertical Resolution
2. Horizontal Resolution

Multi Channel Seismic Reflection Surveying:

- It is the survey in which energy refracted record at different geophones from same signal shot.
- The two most common shot-detectors configurations in 2D as:

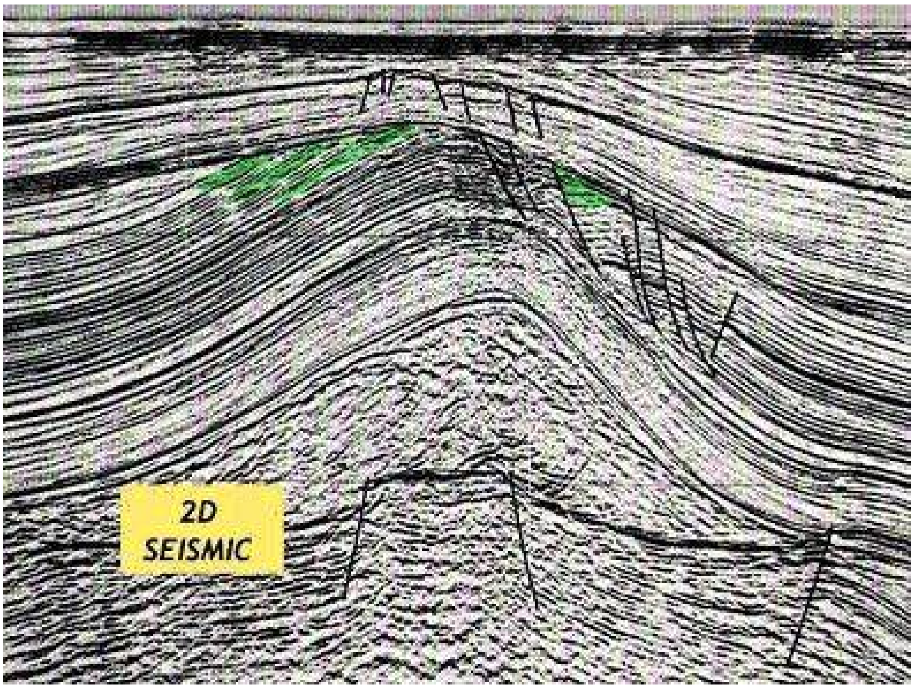
1. Split or Straddle Spread
2. Single ended Spread.



Seismic Reflection Survey

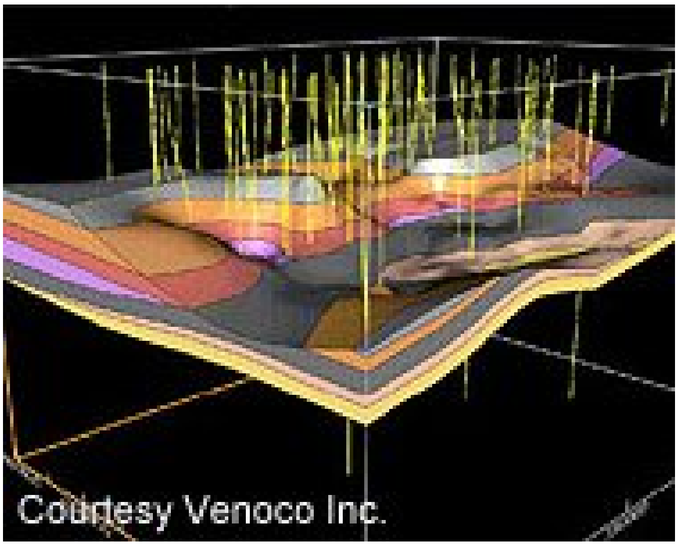
2D Seismic Surveying:

- It gives vertical plane of profile in which shots and detectors are spread linearly.
- It gives the area of selected location.



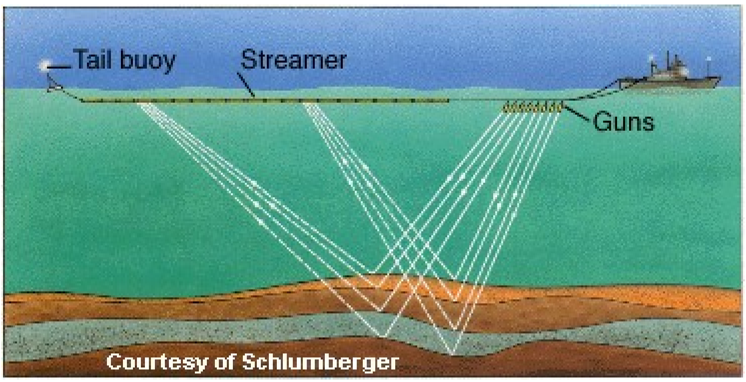
3D Seismic Surveying:

- It gives 3D vision profile in which shots and detectors are spread disorder or non linear.
- It gives the volumetric data of selected location.



Sources and Detectors:

- The main detector is geophone while in case of marine survey hydrophones are used.
- The main sources are:
    1. Air Guns and Water Guns
    2. Tail buoy
    3. Streamers
    4. Pinjers
    5. vibrators
    6. sparkers



The Main Sources

CDP Surveying:

- It is the most accurate field method for gathering subsurface reflections and computing velocity from the NMO effect.
- It is possible only in case of horizontal strata and failed in dipping strata.
- In 2D it is known as CDP profiling.
- It increases the improvement of SNR.

VSP Surveying:

- It is the form seismic reflections surveying that utilize boreholes.
- Shots are normally fixed at surface of the well head and recorded at different depths within the borehole using special detectors clamped to the borehole wall.

Seismic Stratigraphy:
It is the Analysis of reflection sequences as the seismic reflection of lithologically distinct depositional sequences.

Normal Moveout (NMO):

- It is the difference in travel time between reflected arrivals and zero offset.
- NMO=> ? T= $x^2 / 2V^2 t_o$
- It is very useful for determining depth and velocity.

Dip Moveout (DMO):

- It is the difference travel time of rays reflected from dipping strata to receives at equal or opposite offsets.
- DMO => ? T= 2x sinT / V

Static Correction:

- It is uniformly on all traces and applied for correcting time difference due to surface irregularities which may be of:

1. Elevation difference between individual shots and detectors because of undulating or topographic surface.
2. The presence of weathered layer which has low seismic velocity.

Dynamic Correction:

- It is applied to remove the offset of normal Moveout which is produced by horizontal strata.

Multiples:

- They are the reflectors where rays are reflecting at the same reflection more then one time.
- Long Path Multiples generate discrete pulse length, when time difference is more between primary and secondary reflection.
- Shot Path Multiples generate extended pulse length, when time difference is less between primary and secondary reflection.

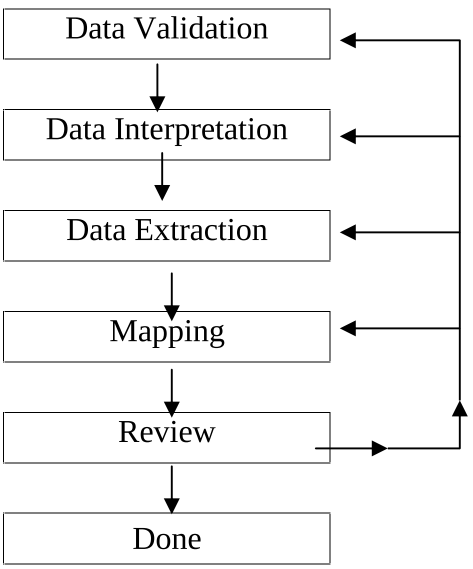
Migration:

- It is the process of reconstructing a seismic section so that reflections events are repositioned under their correct surface location and at a corrected vertical reflection time.
- It also improves the resolutions of seismic solutions by focusing energy spread over a Fresnel zone and by collapsing diffraction pattern produced by point reflector and faulted beds.
- Four types of migration are:
    1. Time Migration
    2. Depth Migration
    3. 2D Migration
    4. 3D Migration

Bright Spot Technique:
It is used for locating hydrocarbon accumulation which is on true seismic section by localized zones of anomously strong reflections.

Flat Spot Techniques:
It is horizontal or near horizontal reflections events discordant to the local geological dip which is the indication of the absence of hydrocarbon or bright spot.
Bow Tie Effect:
It is the event of syncline which is resulting from the existence of discrete reflections points for any surface locations.

Subsurface Mapping Procedure:



Projection of Well:

1. Plunge Projection
2. Strike Projection
3. Up or down dip Projection
4. Normal to the section line Projection
5. Parallel to Fault Projection

Types of Geophysical Maps:

1. Time Structure Map
2. Depth Contour Map
3. Log Map
4. Reservoir Analysis Map (RAM)
5. Facies Analysis Map (FAM)

3D Views:

1. Fence Diagrams
2. Isometric Projections
3. Log Maps
4. 3D Reservoir Analysis Model

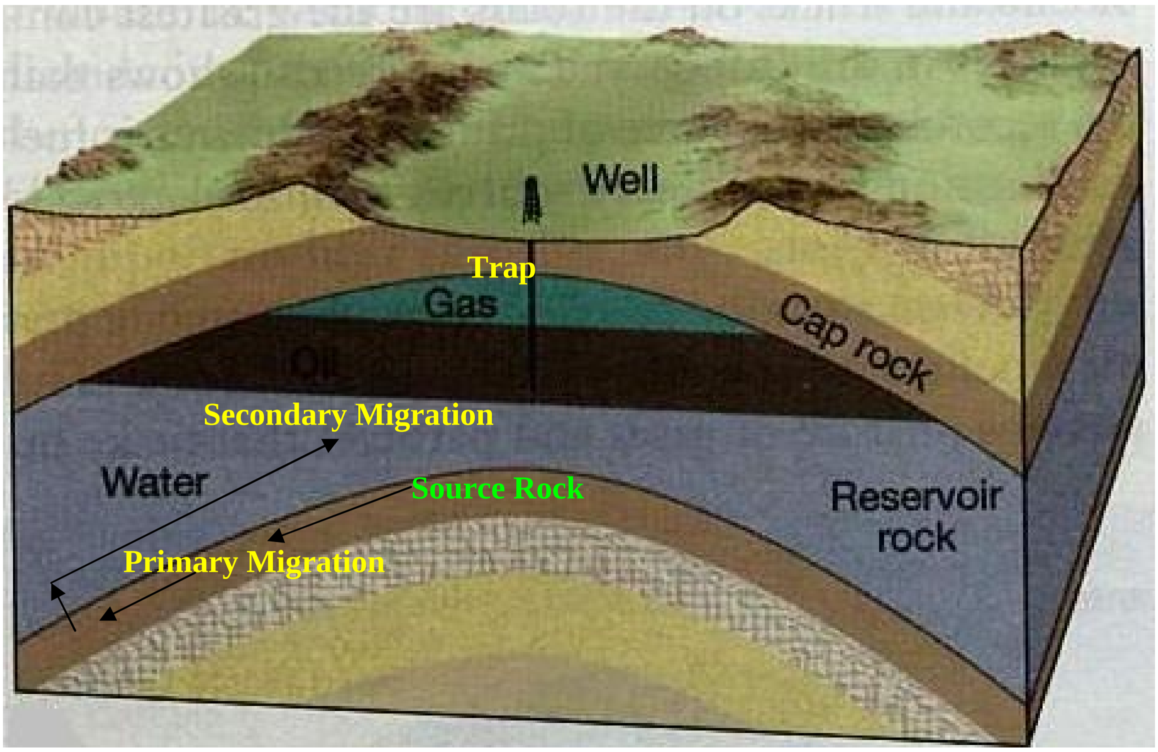
Petroleum Play:

Logical Order

Data

1. Reservoir
2. Trap
3. Seal or Cap
4. Secondary Hydrocarbon Migration
5. Primary Hydrocarbon Migration
6. Hydrocarbon Accumulation and Maturation
7. Source

- Organic Marine Organisms tends to generate oil whereas that from higher land plants tends to generate gas.
- Petroleum generation is a time and temperature dependent process.
- Petroleum from the thermal breakdown of Kerogen requires a threshold temperature of 50º-60ºC.
- Primary migration of petroleum most often occurs during the main phase of oil generation.
- In some sedimentary basins, significant (>60 miles) and vertical (>3000 feet) migration of petroleum can occur.
- C_1 –C_7 Light Gas Hydrocarbon
- C_8 –C_{14} Condensate type Hydrocarbon
- C_{15+} Hydrocarbon and Non Hydrocarbon



Reservoir:

- Argillaceous Marine or Non Marine Rock covered with Cap or Seal.
- Porous and Permeable Rock which contain Hydrocarbon (Gas, Oil and Water).
- Fluid Condition which may be Static or Dynamic.

Reservoir Classification:

On the Basis of:

Formation Procedure	Origin and Enviornament	Porosity and Permeability
1. Fragmental / Clastic / Detridal formed by deposition which has size colloidal from 1/256mm (Mud) to 256mm (Boulder). **2. Chemical Reservoir Rock** formed by precipitation, evaporation or deposition of insoluble precipitates. **3. Miscellaneous Reservoir Rock** formed by fracturing which may be sedimentary, igneous or metamorphic in nature.	1. **Marine Reservoir Rock** deposited in ocean basin or sea water. 2. **Non Marine Reservoir Rocks** deposited in fresh water, brackish water or glacial water.	1. **Sandstone Reservoir** Mechanical Porosity and Permeability. 2. **Carbonate Reservoir** Chemical Porosity and Permeability.

1. Sandstone Reservoir

- The best Sandstone Reservoir is those that are composed of primarily quartz grains of sand size, silica cement with minimal fragmented particles.
- Particular Grain Size between 62µm to 2mm.
- Porosity and Permeability depend upon degree of Compaction.
- They are generally 25m thick, lenticular and linear spatially, less than 250km² in Area.
- The range in age from the oldest being Cambrian (in Pakistan/Algeria) to the youngest being Pliocene (Caspian Region in Ukraine) and Miocene in Pakistan. In USA, two thirds of the sandstone reservoirs are of Cenozoic age.
- Sandstone Reservoirs forms extensive Stratigraphic Traps.
- Nearly 1mbbls of oil (42 gallon per barrel) contain sandstone reservoir of 1 sq. km in size with an average porosity of 15%, 1m thick and saturated with oil contains 15x10^4 m³ of oil in place.
- Initial Porosity/Permeability is controlled by grain size, sorting and packing.
- Permeability decreases with grain size and with poorer sorting.
- Porosity varies with sorting e.g. 28% for v. poor sorting while >42% for v. well sorting.
- Secondary changes include the authigenesis of clay and cement (e.g. Quartz, Calcite) in pore space can cause a major loss of porosity.

2. Carbonate Reservoir

- They are characterized by extremely heterogeneous porosity and permeability depend on:
  a. Environment of deposition **b.** Digenetic alteration of the original rock fabric.
- Main Porosity types are:
  1. Vuggy or Intercrystalline **2.** Intergranular **3.** Intragranular or Cellular **4.** Chalky
- Diagenetic events leading changes in porosity and permeability:

1. **Dissolution (Leaching):** normally improves porosity and permeability
2. **Dolomitization:** produces generally vuggy porosity but porosity may increase by creating larger pores or may reduce by the growth of crystals.
3. **Fracturing:** brecciation, faulting and jointing aids permeability.
4. **Recrystallization:** by adding neomorphism of micrite into larger crystal size enhances porosity.
5. **Cementation:** decreases porosity and permeability (pore threats are sealed).

- The best sorted carbonate rocks are Oolites which have same grain size and grain shape.
- Carbonates are the accumulation of the remains of carbonate secreting animals and plants. It may form in layers at slopping platforms like shelves in shallow warm saline water. It may also form as linear or continuous reef trends, as in the case of Jhill Limestone (Unit of Gaj Formation).

Trap:

- Term ‘Trap’ was 1st introduced by McCullough in 1934.
- It is the Accumulation of Petroleum Hydrocarbons in a reservoir rock when its migration and escape is prevented.
- It reserves the hydrocarbons in porous and permeable rocks.
- It obstructs their escape from reservoir rocks by suitable cap rock.

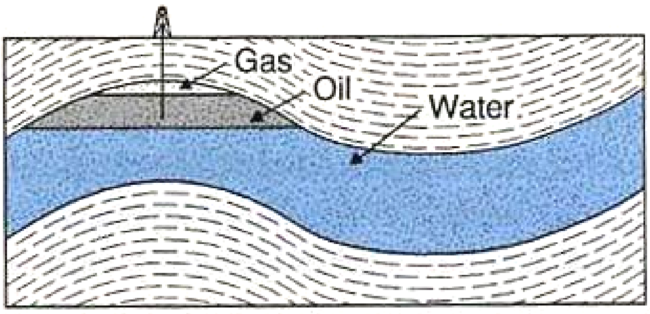
General Trap Classification:
on the basis of Trap Geometry.

Folded	Faulted	Stratigraphic	Salt Domes/Diapric	Non-Convex
1.Convex	1. Normal	1. Primary	1. Mud Diapric	1.Depositional Wedgeout
2.Bending	2. Reverse	2. Permeability	2. Piercement	2.Erosional Wedgeout
3.Drapped	3. Fractured	3. Lithologic	3. Deep Domes	3.Isolated Lenticular Bodies
4.Compressional	4. Thrusted	4. Secondary	4. Salt Diapric	4.Hydrodynamics
5.Rollover Anticline	5. Horst	5. Pinchout	5. Clay Diapric	5.Paleotopographic
6.Buckle	6. Graben	6. Reef	6. Intermediate Salt Domes	6.Traps Fluid Traps
7.Extensional	7. Gravitational	7. Depositional		7.Fault Cutt off Traps
8.Diapric		8. Diagenetic		
9.Contractional		9. Truncational		

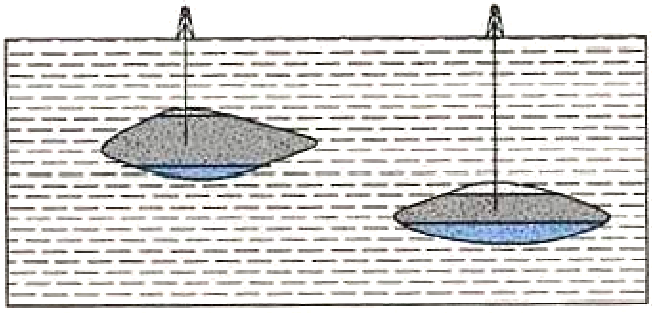
Trap Classification by Allen and Allen:
On the basis of process causing Trap Formation:

1. Structural	**1. Tectonic**	1. Extensional 2. Contractional
	2. Compactional	3. Drapped Structure
	3. Diapric	4. Salt Movement 5. Mud Movement
	4. Gravitational Structure	
2. Stratigraphic	**5. Depositional**	6. Reefs 7. Pinchout 8. Channels 9. Bars
	6. Unconformity	10. Truncation 11. Onlap
	7. Diagenetic	12. Mineral 13. Tarmats 14. Gas Hydrates 15. Permafrost
3. Hydrodynamic		

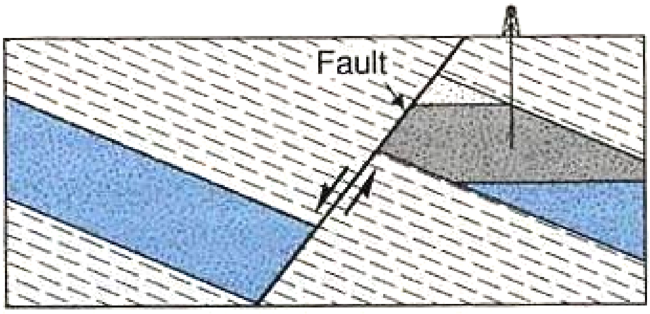
Some Associated Trap Figures



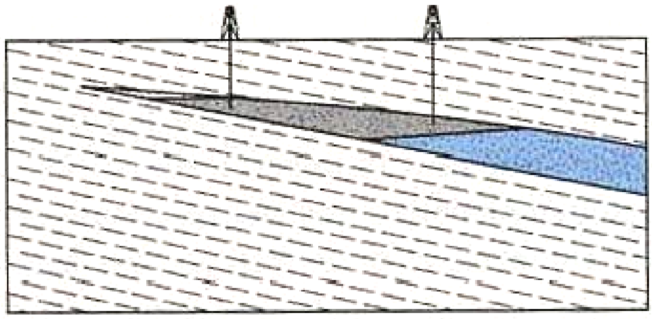
A Anticline



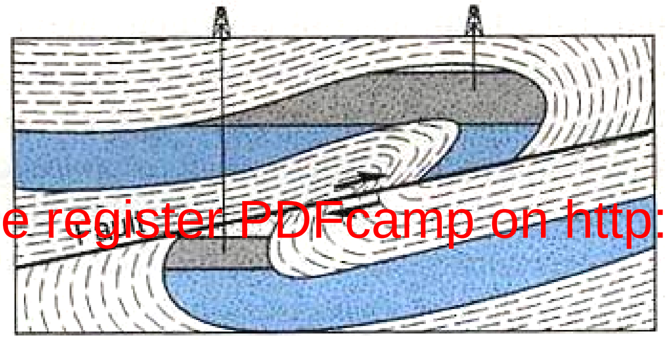
E Sandstone lenses



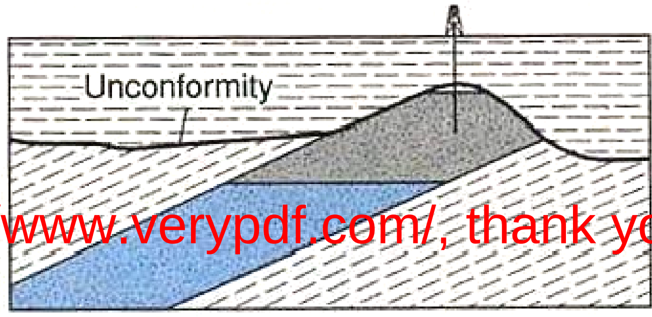
B Normal fault



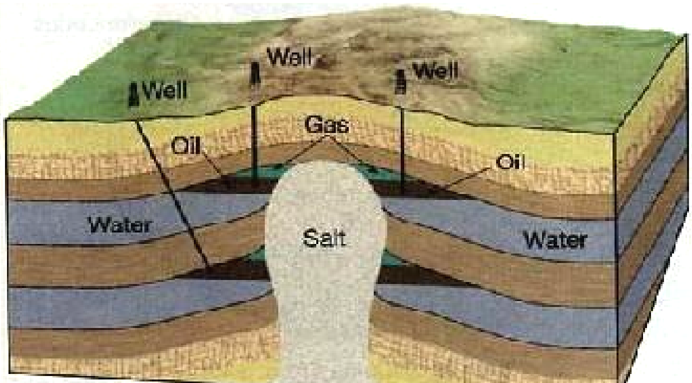
F Sandstone pinchout



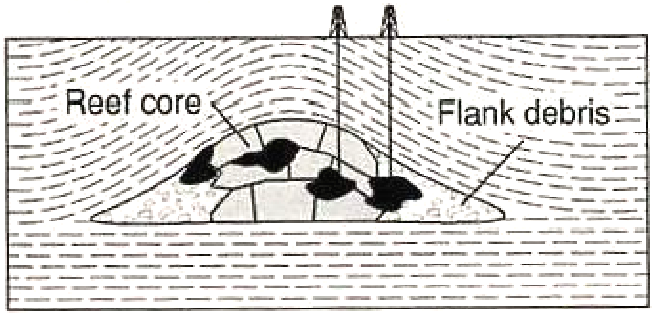
C Thrust fault



G Unconformity



D.Salt Plug



G Reef (a small "patch" reef)

D. Salt Dome

Salt Plug Stages:

1. **The Pillow stage** intrusion of the overlying sediments has taken place (Trap Form 'Domes')
2. **Diapir Stage** thick clastics may Pinchout onto the flanks of the plug (Trap Form 'Stratigraphic')
3. **The Post Diapir Stage** as the Diapir grows salt is depleted and it can only continue to rise by complete detachment from the mother salt.

Seal or Cap:

Factors affect the cap rock effectiveness are:

1. **Lithology**
   - Clastic Rocks which have small pore size like Clays and Shale.
   - Evaporates Rocks like Anhydrite Gypsum and Rock Salt.
   - Organic rich rocks like Oolitic Limestone, Reefal Limestone.
   - About 40% recoverable oil reserves are from oil fields caped by evaporates while 60% by different types of Argillaceous rocks especially Shale.
   - About 34% are caped by Evaporates for Gas Fields while for Oil Fields about 66% capped by shales.
2. **Ductility** (Less prone to Faulting) has following decreasing order:
   Salt----Anhydrite----Organic rich Shale----Shale----Silty Shale----Calcareous Mudstone----Cherts
3. **Thickness**
   - Enogh to ensure cap pressure.
   - Thick cap rock improves the chances of maintaining a seal over the entire basin.
   - Cap rock thickness ranges from 10s m to 100s m.
4. **Lateral Continuity**
   The search of the petroleum is focused on the base of regional seal, rather than in any particular reservoir horizon in other words cover broad area.
5. **Burial depth of Cap rock** not an important factor but maximum depth may be important:

Western Europe	84%	2000 to 3000m
Africa	66%	2000 to 3000m
Middle East	59%	1000 to 2000m
North America	54%	<1000m

Secondary Hydrocarbon Migration:

The process where hydrocarbons move through a permeable carrier rock to the reservoir rock until they are trapped in the subsurface by an impervious layer and following conditions are necessary for being migrated hydrocarbons:

1. Larger Pore Spaces
2. Fewer Capillary restrictions
3. Less semisolid or Structure Water
4. Less Fluid Pressure

Primary Hydrocarbon Migration:

The process where Hydrocarbons move out of their fine grained source rock. A number of Primary Migration has been proposed in which:

- For organic rich rocks
  1. Oil Phase Migration
  2. Organic Network Migration
- For organic Lean rocks
  3. Molecular Solution
  4. Micellar or Colloidal Solution
  5. Diffusion Mechanism
  6. Gas Phase Migration

Source Rock Evaluation:

1. Organic Richness
2. Type of Organic Matter
3. Level of Hydrocarbon generation and maturation
4. Expulsion efficiency of the generated Hydrocarbons

Principle Methods of source evaluation are:

- Organic Richness
    1. Total Organic Carbon Content (TOC)
    2. Rock Eval Pyrolysis Analysis or Total Hydrocarbon Yield (THY)
    3. C_{15+} Extractable Bitumen and Hydrocarbons (THC)
- Organic Quality
    4. Visual Kerogen Assessment
    5. Elemental Analysis
    6. Pyrolysis
- Thermal Maturity
    7. Vitrinite Reflectance Analysis ($\%R_O$)
    8. Thermal Alteration Index (TAI)
    9. Pyrolysis (T-max ^oC)
    10. Geochemical Parameters

Total Organic Carbon:

TOC for Shales %	TOC for Carbonates %	Descriptive Terminology
0.00 – 0.50	0.00 – 0.12	Poor
0.50 – 1.00	0.12 – 0.25	Fair
1.00 – 2.00	0.25 – 0.50	Good
2.00 – 4.00	0.50 – 1.00	Very Good
4.00 – 8.00$^+$	1.00 – 2.00$^+$	Excellent

Rock Eval Pyrolysis:

The four Primary Rock Eval Parameters are:

1. S_1 – Quantity of free or absorbed Hydrocarbons in rock.
2. S_2 – Quantity of Hydrocarbons generated during Pyrolysis of Kerogen.
3. S_3 – Quantity of CO generated during Pyrolysis of Kerogen.
4. T_{max} – Temperature of maximum S_2 Generation.

C_{15+} Total Hydrocarbon Content

THC (ppm w/w)	Descriptive Terminology
0 – 50	Very Poor
50 – 100	Poor
100 – 200	Fair
200 – 400	Good
400 – 800	Very Good
800$^+$	Excellent

Vitrinitic Reflectance Analysis:

Vitrinitic Reflectance ($\%R_O$)	Associated Hydrocarbon Types
0.30 – 0.35	Biogenic Gas
0.35 – 0.60	Biogenic Gas and Immature Oil
0.60 – 0.80	Immature Heavy Oil
0.80 – 1.20	Mature Oil
1.20 – 1.50	Mature Oil, Condensate, Wet Gas
1.50 – 2.00	Condensate, Wet Gas
2.00$^+$	Petrogenic Methane Gas

Important Indices:

Indices	Symbol	Farmula
Hydrogen Index	HI	S_2/TOC
Oxygen Index	OI	S_3/TOC, (S_1/(S_1+ S_2))
Thermal Index	TI	S_1/TOC
Maturation Index	MI	S_0/ S_1 / S_1+ S_2+ S_3, oil and gas shows S_0+ S_1
Genetic Potential	GP	S_0+ S_1+ S_2
Potential Yield	PY	S_1+ S_2

Sedimentation Rate:

	Low	**High**
Oxic Environment	No source rock	Gas prone source rock
Anoxic Environment	Lean oil prone source rock	Oil rich prone source rock

Requirements for deposition and preservation of Effective Source Rock:

- High Organic Matter input
- High Oil Proclivity of Organic Material.
- Short Transport History
- Anoxic depositional condition with concentrated bacterial activity
- Low energy system

Kerogen:

Kerogen Type	**Kerogen Name**	**Associated Organic Matter Type**	**Associated Organic Matter**	**Associated Hydrocarbon**
1. Type I	Sapropelic Kerogens	Alginite	Amorphous	very oil prone
2. Type II	Exinitic Kerogens	Exinite	Herbaceous	oil prone
3. Type III	Vitrinitic Kerogens	Liptinite/Vitrinite	Woody	mainly gas prone
4. Type IV	Inertinitic Kerogens	Inertinite	Coaly	inert gases

Transformation of Organic Matter:

	Potential Source	**Temperature**	**Processes**	**Main Product**	**Bi-Product**
1. Diagenesis	Biological Matter	<50ºC low	Hydrolysis, Decarboxylation, Condensation, Polymerization	Kerogen (90%)	Biogenic Methane, Water, CO_2
2. Catagenesis	Immature Kerogen	50º – 150ºC int	Thermal Breakdown, Bond Cracking, Aromatization	Wet Gas Hydrocarbons, Late Mature Kerogen	Water, CO_2
3. Metagenesis	Late Mature Kerogen	>150ºC high	Bond Cracking, Aromatization	Residual Kerogen	Methane and Inorganic gases

Depositional Environments and their effects on preservation:

Depositional Environment	Depositional Environment Conditions	Source of Organic Matter	Type of Organic Matter	Preservation of Organic Matter	Hydrocarbon Potential
Peat/Coal Swamp	Low energy anoxic	Terrestrial	Woody/Humic	High amounts unoxidized	Minor to moderate oil and gas
Eutrophics Lakes	Low energy partially oxic	Terrestrial	Woody/Humic and Algal	High amounts relatively unoxidized	Oil and gas if preserved
Fluvial/Deltaic/ Coastal	High energy oxic	Terrestrial	Woody/Humic	Low amounts oxidized	Mainly gas with minor oil
Stratified Lake	Low energy anoxic	Lacustrine	Algal	High amounts unoxidized	Good to very good oil
Coastal	High energy anoxic	Marine	Algal	Low to moderate amounts partially oxidized	Minor to moderate oil and gas
Continental Shelf	Moderate to low energy anoxic	Marine	Algal	High amounts unoxidized	Moderate to good oil and gas
Open Ocean	Low energy variable conditions	Marine	Algal	Low to moderate amounts variably oxidized	Very poor oil and gas

Burial History Plot:

- Sedimentation Rate
- Structure of an Area
- Unconformity
- Age of the Reservoir
- Temperature analysis by means of Depth
- Rate of Trap Formation is determined by Rt = ? D/? T

Introduction of Dimension and Unit

There are two types of Dimensions:

1. Primary Dimension
2. Secondary Dimension

There are two types of Fundamental units:

1. International or MKS System of Fundamental Units (SI Units)
2. British Engineering or FPS System of Fundamental Units (BG Units)

Primary Dimensions	SI Units (MKS)	BG Units (FPS)	Conversion Factor
Length (L)	Meter (m)	Foot (ft)	1ft = 0.3048 m, 1 m = 3.3 ft
Mass (M)	Kilogram (kg)	Slug (slug)	1 slug = 14.59391kg 1 kg = 0.0685slug
Force	Newton (N)	Pound (lb)	
Time (T)	Second (s)	Second (s)	
Temperature	Degree Celsius (°C) Kelvin (°K) (at absolute Scale) °K= °C + 273	Degree Fahrenheit (°F) Rankin (°R) (at absolute Scale) °R = °F + 459.69	1 °K = 1.8 °R 1 °R = 0.556 °K

Secondary Dimensions	SI Units (MKS)	BG Units (FPS)	Conversion Factor
Area (L^2)	m^2	ft^2	1 m^2 = 10.764 ft^2, 1 ft^2 = 0.0929 m^2
Volume (L^3)	m^3	ft^3	1 m^3 = 35.315 ft^3, 1 ft^3 = 0.0823 m^3
Velocity (L/T)	m/s	ft/s	1 ft/s = 0.3048 m/s, 1 m/s = 3.28 ft/s
Acceleration (L/T^2)	m/s^2	ft/s^2	1 ft/s^2 = 0.3048m/s^2, 1 m/s^2 = 3.28 ft/s^2
Pressure or Stress ($M/(LT^2)$)	Pa = N/m^2	lb/ft^2	1 lb/ft^2 = 47.88 N/m^2, 1 N/m^2 = 0.0209 lb/ft^2
Angular Velocity (1/T or T?)	s?	s?	1 s? = 1 s?
Energy, Heat, Work (ML^2/T^2)	J = N.m	ft-lb	1 ft-lb = 1.3558 J, 1 J = 0.7376 ft-lb
Power (ML^2/T^3)	W = J/s	(ft-lb)/s	1 (ft-lb)/s = 1.3558 W, 1 J = 0.7376 ft-lb
Density (M/L^3)	kg/m^3	$slugs/ft^3$	1 $slugs/ft^3$ = 515.4 kg/m^3, 1 kg/m^3 = 0.00194 $slugs/ft^3$
Viscosity (M/(LT))	kg/(m.s)	slugs/(ft-s)	1 slugs/(ft-s) = 47.88 kg/(m.s), 1 kg/(m.s) = 0.0209 slugs/(ft-s)
Specific Heat ($L^2/(T^2$?))	$m^2/(s^2.°K)$	$ft^2/(s^2-°R)$	1 $m^2/(s^2.°K)$ = 5.98 $ft^2/(s^2-°R)$, 1 $ft^2/(s^2-°R)$ = 0.1672 $m^2/(s^2.°K)$

Unit Consistency: it is especially true of the oil industry as it has its own specific units.

Quantity	Oil Industry Unit	Conversion into SI units	Conversion into BG units
Volume	BBL	1 BBL = 0.1589 m^3	1 BBL = 5.612ft^3
Pressure	psi	1 psi = 6894 Pa	1 psi = 144.0846lb/ft^2
Viscosity	cp	1 cp = 0.001 Pa.s	1 cp = 0.14409(lb-s)/ft^2
Flow Rate	BBLS/D	1 BBLS/D = 1.84 x 10^-6 m^3/s	1 BBLS/D = 6.5 x 10^-5 ft^3/s
Area	acres	1 acres = 4046 m^2	1 acres = 43351.144ft^2

1 mile = 1.65 km
1 day = 3.1 x 10^-8 yr
1 N/ m^3 = 6.37 x 10^-3 lb/ ft^3

Thermodynamic Properties of Fluid

Fluid Properties	Formula	Constant terms	Conversion Factor
1. Pressure (p)	p = znRT/V p = ?RT/m p = ?RT pr = p / pc ppr = p / ppc	R = 10.73 psia ft³ lb-mole °R R = 82.06 atm cm³ g-mole, K R = 62.37 mm Hg litters g-mole, K	1 atm = 14.7 lb/in² = 2116 lb/ft² = 101,300 Pa = 101.3 kPa
2. Density (?)	? = M/V ? = ? /g ? = mp/RT	At 20°C and 1 atm. ?air = 1.205 kg/m³ = 0.0024slugs/ft³ ?water = 998 kg/m³ = 1.94slugs/ft³	
3. Temperature (T)	Tr = T / Tc Tpr = T / Tpc	°R = °F + 459.69 °K= °C + 273	1 °K = 1.8 °R 1 °R = 0.556 °K
4. Specific or unit Weight (?)	? = p/RT ? = 1 / V ? = ?g	At 20°C and 1 atm. ?air = 11.8 N/m³ = 0.0752 lb/ft³ ?water = 9790 N/m³ = 62.4 lb/ft³	
5. Specic Gravity (SG)	SGgas = ?gas /?air SGliquid = ?liquid /?water SGgas = ?gas / ?air SGgas = MW/ MWair SGliquid = ?liquid / ?water	gearth = 32.174 ft/s² = 9.807 m/s² SGHg = 13.60721 SGwater = 1 SGair = 1	°API = 141.5/SG – 131.5 SG =141.5/(°API+131.5) SGgas = ?gas/1.205 kg/m³ SGliq = ?liq /9985 kg/m³ SGgas = ?gas/11.8 kg/m³ SGgas = MW/ 29 SGliq = ?liq /9790 kg/m³
6. Coefficient of Viscosity (?)	? = µ / ? **?** is kinematic viscosity in centistokes. **µ** is absolute viscosity in centipoises. **?** is density in gm/cm³.	1.5 – 2 centipoises at 50 °F 0.7 – 1 centipoises at 100 °F 0.4 – 0.6 centipoises at 150 °F	
7. Surface Tension (s) 8. Capillarity (h)	s = rh? / 2cos? s is surface tension. r is radius of tube. h is height of capillary. rise or depression. ? is sp.weight of liquid. ? is wetting angle.	If tube is clean, ? = 0° for water ? = 140° for mercury	
9. Isothermal Conditions	p1V1 = p2V2 ?1 / ?2 = p1 / p2 = constant E = p		
10. Formation Volume Factor (Bo)	Bo = Vres / Vsc = z T Psc / zsc Tsc p	Psc = 14.7 psia, zsc = 1, Tsc = 520 °R in bbls/SCF ÷ by 5.615	Bg = 0.0283 z T / p ft³/SCF Bg = 0.005034 z T / p bbls/SCF
11. Isothermal Compressibility (Co)	Co = Cpr / ppc		

General Properties of Gases

Fluid Properties	Formula	Constant terms	Conversion Factor
1. Atomic Weight unit (a) Molecular Weight unit (M)	M = m / n	Mair = 28.97	
2. Mole & Pound	m = nM	Avogadro No = 2.733×10^26	1 Mole = 30.07pound (lb)
3. Density (?)	? = M/V ? = ? /g ? = Mp/RT	At 20°C and 1 atm. ?air = 1.205 kg/m³ = 0.0024slugs/ft³ ?water = 998 kg/m³ = 1.94slugs/ft³	
4. Pressure (p)	p = znRT/V p = ?RT/m p = ?RT pr = p / pc ppr = p / ppc pc = S gi pci	R = 10.73 psia ft³ lb-mole °R R = 82.06 atm cm³ g-mole, K R = 62.37 mm Hg litters g-mole, K	1 atm = 14.7 lb/in² = 2116 lb/ft² = 101,300 Pa = 101.3 kPa
5. Temperature (T)	Tr = T / Tc Tpr = T / Tpc Tc = S gi Tci	°R = °F + 459.69 °K= °C + 273	1 °K = 1.8 °R 1 °R = 0.556 °K
6. Specific or unit Weight (?)	? = p/RT ? = 1 / V ? = ?g	At 20°C and 1 atm. ?air = 11.8 N/m³ = 0.0752 lb/ft³ ?water = 9790 N/m³ = 62.4 lb/ft³	
7. Specic Gravity (SG)	SGgas = ?gas /?air SGgas = ?gas / ?air SGgas = MW/ MWair	gearth = 32.174 ft/s² = 9.807 m/s² SGHg = 13.60721 SGwater = 1 SGair = 1	°API = 141.5/SG – 131.5 SG =141.5/(°API+131.5) SGgas = ?gas/1.205 kg/m³ SGgas = ?gas/11.8 kg/m³ SGgas = MW/ 29
8. Isothermal Conditions	p1V1 = p2V2 ?1 / ?2 = p1 / p2 p1V1/T1 = p2V2/T2 =constant		
9. Formation Volume Factor (Bg)	Bg = Vres / Vsc = zTPsc/zscTscp	Psc = 14.7 psia, zsc = 1, Tsc = 520 °R in bbls/SCF ÷ by 5.615	Bg = 0.0283 z T / p ft³/SCF Bg = 0.005034 z T / p bbls/SCF
10. Isothermal Compressibility (Cg)	Cg = Cpr / ppc		

Standard constant terms:
V = 379.4 ft³, p = 14.7 psia, T = 60 °F + 459.69 = 520 °R, R = 10.73 psia ft³ lb-mole °R,
pr = reduced pressure, pc = critical pressure, ppr = pseudo reduced pressure,
ppc = pseudo critical pressure, Tr = reduced temperature, Tc = critical temperature,
Tpr = pseudo reduced temperature, Tpc = pseudo critical temperature.

Permeability Concept

1. Permeability

The ability to flow is permeability.

$$kro = \left(1- \frac{Sw - Swi}{1- Swi - Sor}\right)^2$$

$$krw = Sw \quad \frac{Sw - Swi}{1- Swi}$$

Absolute permeability

$ka = 1.2 \times 10^3 f$

Effective permeability of oil is given by:

kroe = kro * ka

Effective permeability of water is given by:

krwe = kwo * ka

Kro = Ko/K

Kwo = Kw/K

Kw + Ko = 1

Kw + Ko + Kg = 1

2. Saturation:

Sw + So = 1

Sw + So + Sg = 1

3. Flow rates:

Q = KA (? P)/µL

Qw = kroe A (? P)/µo L

Qo = kroe A (? P)/µo L

4. Volume:

Volume of grain => $Vg = n (4/3) p r^3$

5. Porosity:

f = (Vb – Vg)*100 / Vb

Fluid Flow in Reservoir

Series / Harmonic Mean

=> Qt = Q1 = Q2 = Q3

=> P1 – P2 = ? P1 = ? P2 = ? P3

=> L = L1 + L2 + L3 = S Lj

1/k = 1/L S (Li/ki)

Radial System:

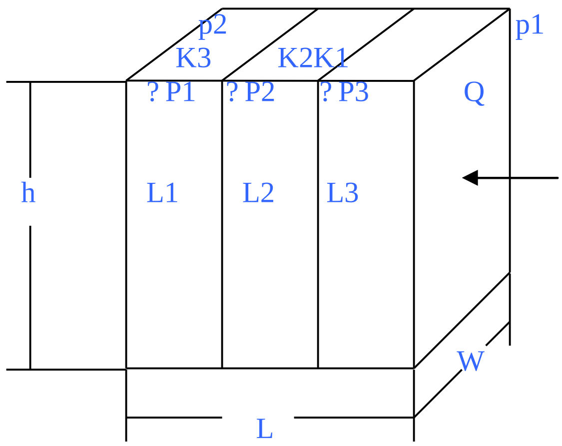
k = (log re/rw) / S log (rj/rj – 1) / ki

Heterogeneous System / Geometric Mean:

log k = 1/n S log ki

Flow rate:

Q = (KA/µ) (? P/L ± ?g sin ?)

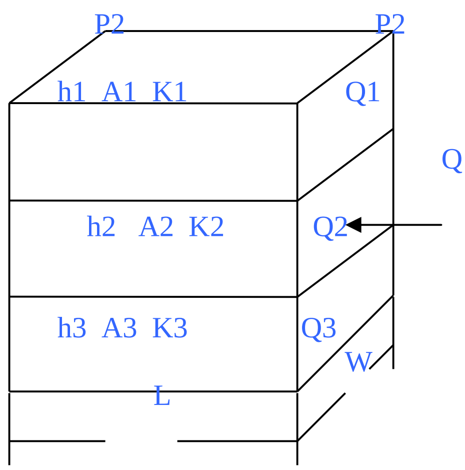


Parallel / Arithematic

Qt = Q1 + Q2 + Q3

At = A1+A2+A3

k = 1/A S KiAi



Volumetric Calculation

Volumetric Calculation by different Farmulae:

- Formula 1: ? V = h/2(An + An+1)
  For Trapezoid
  ? V = Ah/3 for Pyramid
- Formula 2: ? V=h/2(An+An+1+(An*An+1)1/2)
  For Successive Trapezoid
  ? V = Ah/3 for Pyramid
- Formula 3: ? V = h/2 (Ao+2A1+2A3+…… . . + 2An-1+An) + Avg.A

Pressure by Different formulae:

- Reservoir or Well Pressure = S p/n
- Area Average pressure = S pA / SA
- Volume Average Pressure = S pAh / SAh

Net thickness of Reservoir:

- Net thickness of Reservoir = Total thickness **-** (shale + impervious sandstone + claystone)

Hydrocarbon In Place

- OOIP = 7758(Ahf (1-Sw))/Bo *(in STB)*
- Gas MMSCF = 43.58(Ahf (1-Sw))/Bg *(in MMSCF)*
- Initial Gas in Place is, G1 = 43560 (f * 1-Sw *A*h) / Bgi

Recovery Reserves Concepts:

- Recovery gas volume = 43560 f (1- Sw)
- Unit Recovery = Reservoir gas volume (1/Bgi – 1/Bga)
- Recovery Factor = (1 – (Bgi/Bga))*100
- Recovery Factor = ((1-Swi)/Bgi – Sgr/ Bga)/ ((1-Swi)/Bgi) *100
- Unit Recovery = 43650 f ((1-Swi)/Bgi – Sgr/Bga)
- Recovery gas volume = 43560 f Sgr

Gas Gravity:

- gas gravity = S yj Mj / Mair
- gas gravity = MWg/MWair

Pseudocritical Properties by browns approximation:

- Tpc = 167 + 316.678 gas gravity
- ppc = 702.5 – 50 gas gravity

Coefficient of Viscosity:

- Y1 = $\frac{(9.4 + MWg)\ (T+ 460)^{1.5}}{(209+19MWg+T+460)}$
- Y2 = 3.5+0.01MWg + (986/ (T+460))
- Y3 = 2.4 – 0.2Y2
- Y4 = 0.00752*(MWg/Bg)
- Y5 = Y2 (Y4^Y3)
- µg = (Y1 (e^Y5))/1000

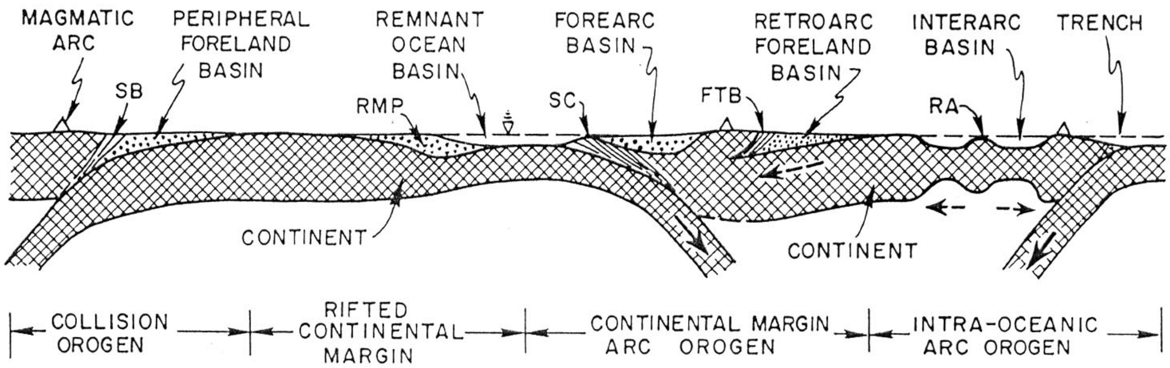
BASIN ANALYSYS

- A sedimentary basin is an area in which sediments have accumulated during a particular time period at a significantly greater rate and to a significantly greater thickness than surrounding areas.
- A low area on the Earth's surface relative to surroundings e.g. deep ocean basin (5-10 km deep), intramontane basin (2-3 km a.s.l.)
- Basins may be small (kms2) or large (106+ km2)
- Basins may be simple or composite (sub-basins)
- Basins may change in size & shape due to:
  1. erosion
  2. sedimentation
  3. tectonic activity
  4. eustatic sea-level changes
- Basins may overlap each other in time
- Controls on Basin Formation
  1. Accommodation Space,
     a. Space available for the accumulation of sediment
     b. T + E = S + W
        T=tectonic subsidence
        E= Eustatic sea level rise
        S=Rate of sedimentation
        W=increase in water depth
  2. Source of Sediment
     a. Topographic Controls
     b. Climate/Vegetation Controls
     c. Oceanographic Controls (Chemical/Biochemical Conditions)
- The evolution of sedimentary basins may include:
  1. tectonic activity (initiation, termination)
  2. magmatic activity
  3. metamorphism
  4. as well as sedimentation
- Axial elements of sedimentary basins:
  1. **Basin axis** is the lowest point on the basement surface
  2. **Topographic axis** is the lowest point on the depositional surface
  3. **Depocentre** is the point of thickest sediment accumulation
- The driving mechanisms of subsidence are ultimately related to processes within the relatively rigid, cooled thermal boundary layer of the Earth known as the *lithosphere.* The lithosphere is composed of a number of tectonic plates that are in relative motion with one another. The relative motion produces deformation concentrated along plate boundaries which are of three basic types:
  1. *Divergent boundaries* form where new oceanic lithosphere is formed and plates diverge. These occur at the mid-ocean ridges.
  2. *Convergent boundaries* form where plates converge. One plate is usually subducted beneath the other at a convergent plate boundary. Convergent boundaries may be of different types, depending on the types of lithosphere involved. This result in a wide diversity of basin types formed at convergent boundaries.
  3. *Transform boundaries* form where plates move laterally past one another. These can be complex and are associated with a variety of basin types.
- Many basins form at *continental margins.*
  Using the plate tectonics paradigm, sedimentary basins have been classified principally in terms of the type of lithospheric substratum (continental, oceanic, transitional), the position with respect to a plate boundary (interplate, intraplate) and the type of plate margin (divergent, convergent, transform) closest to the basin.

- Plate Tectonic Setting for Basin Formation
    1. Size and Shape of basin deposits, including the nature of the floor and flanks of the basin
    2. Type of Sedimentary infill
        - Rate of Subsidence/Infill
        - Depositional Systems
        - Provenance
        - Texture/Mineralogy maturity of strata
    3. Contemporaneous Structure and Syndepositional deformation
    4. Heat Flow, Subsidence History and Diagenesis
- Interrelationship Between Tectonics - Paleoclimates - and Eustacy
    1. Anorogenic Areas------>
        - Climate and Eustacy Dominate
    2. Orogenic Areas--------->

Sedimentation responds to Tectonism

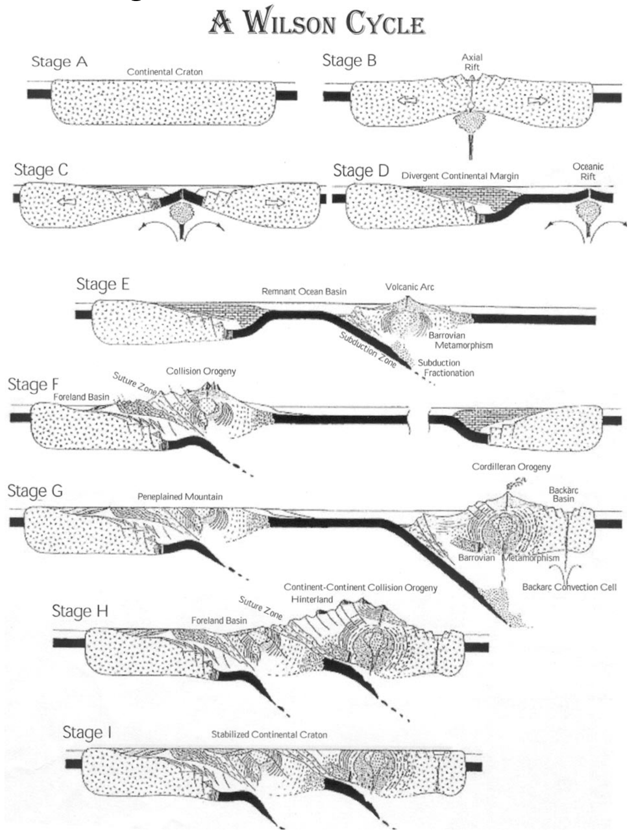
Plate Tectonics and Sedimentary Basin



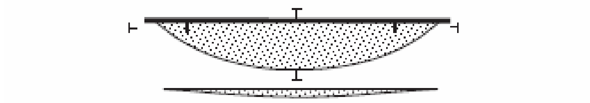
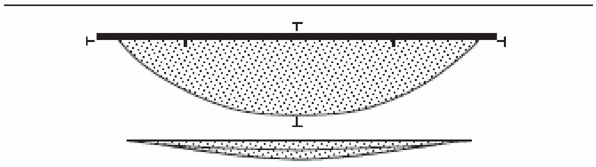
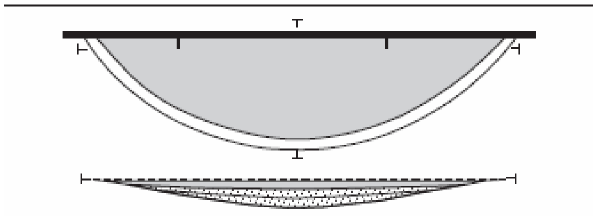
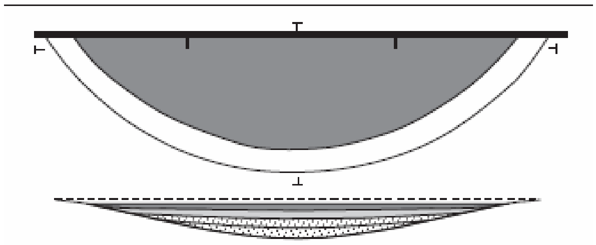
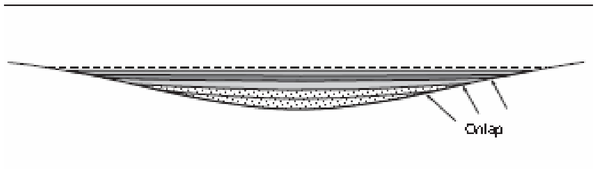
Types

SB = Suture Belt
RMP = Rifted margin prism
S C = Subduction complex
FTB = Fold and thrust belt
RA = Remnant arc

Wilson Cycle about opening and closing of ocean basins and creation of continental crust.

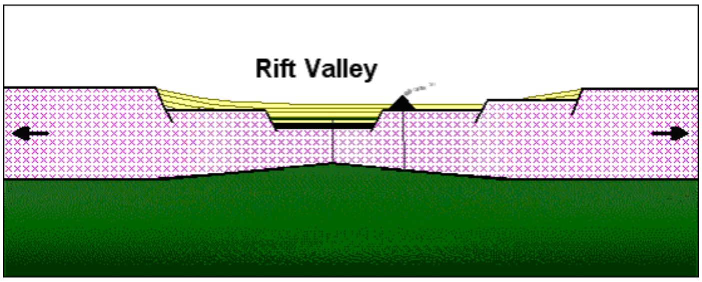


Structural Controls on Sedimentary Systems in Basins Forming:

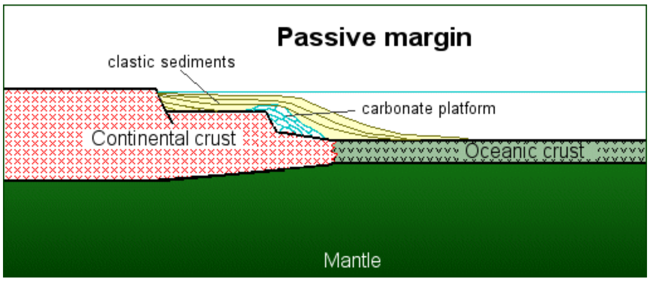
Stage 1: Capacity < Sediment **Fluvial sedimentation**	
Stage 2: Capacity = Sediment **Fluvial lacustrine Transition**	
Stage 3: Capacity > Sediment **Water Volume > excess capacity** **Shallow-water lacustrine sedimentation**	
Stage 4: Capacity >> Sediment **Water volume = excess capacity** **Deep-water lacustrine sedimentation**	
Stage 5: Capacity > Sediment **Water volume < excess capacity** **Shallow-water lacustrine sedimentation**	

BASIN CLASSIFICATION:

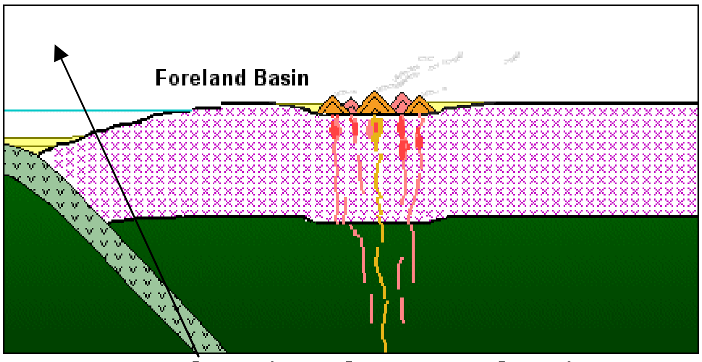
Structural Setting	Basin Type	Geological Origin	Example
Intra-Plate	**Intracratonic basins**	Forms within stable continental crustal mass	Congo Basin, Lake Eyre Basin, Peshawar Basin.
Divergent Plate Margins	**Rift Related Basin**	**Large scale mantle convection. Regional updoming ± regional basaltic (flood) volcanism.**	
	Rift basin	The down-dropped basin formed during rifting because of stretching and thinning of the continental crust or Result of continental extension.	East Africa Rift
	Passive margin basin	Subsidence along a passive margin, mostly due to long-term accumulation of sediments on the continental shelf.	East coast of North America
	Aulacogene basins	Narrow continental rifts control by normal listric Faults.	
	Oceanic Rift basins	Initially narrow may evolve into open oceanic basins.	Red Sea
Convergent Plate Margins	**Subduction Related Basins**	**Two Plates subducting each other which may be collision between O-O, O-C, C-C**	
	Trench (accretionary wedge) basin	Downward flexure of the subducting and non-subducting plates (sites of accretionary wedges)	Western edge of Vancouver Island, Modern Mariana Islands
	Back arc basin	Subduction faster than compression Extensional basins	Izu-bonin arc-trench system, west pacific
	Backarc-foreland basin	Form at active continental margins in association with subduction and the development of island arcs.	
	Forearc basin	The area between the accretionary wedge and the magmatic arc, largely caused by the negative buoyancy of the subducting plate pulling down on the overlying continental crust	Georgia Strait
	Retroarc foreland basins	mechanical subsidence/sediment loading	Rocky Mountain Western interior
	Peripheral foreland basins	tectonic/sediment loading	“Molasses" deposits of the Catskill (Devonian) Deltas, Himalayan Neogene Siwalik Hills.
Transform Margins	**Strike Slip related Basin**	**strike-slip along non-linear faults**	
	Transtensional Basins	Mechanical and Thermal Subsidence/Uplift of A pull-apart block (e.g. between two transform faults) that subsides opening "holes" or basins at fault jogs or bends	Salton Trough (Neogene; So CA, San Andreas Fault system, USA)
	Transpressional Basins	Mechanical Subsidence/Uplift	Ridge Basin (Neogene; So CA, San Andreas Fault system, USA)



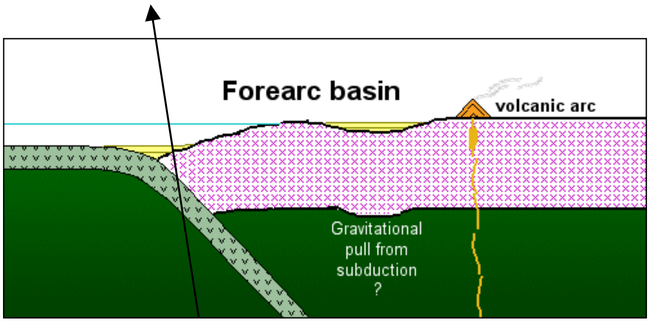
Rift Basin



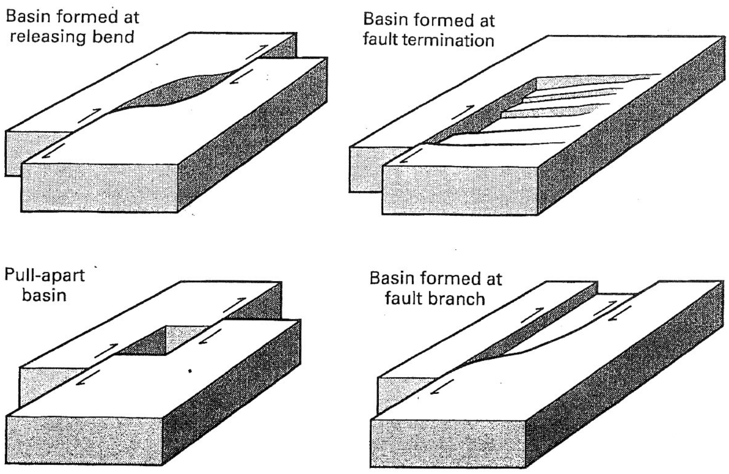
Passive Margin Basin



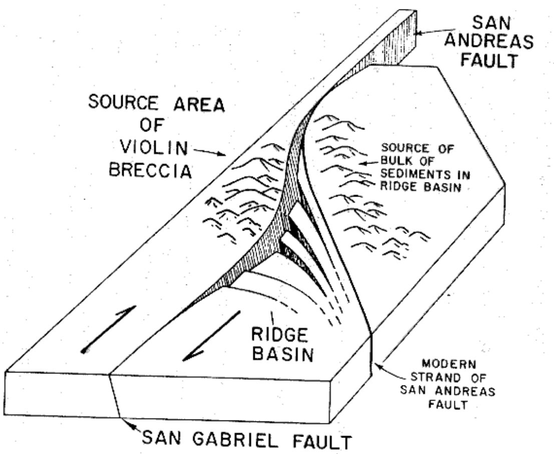
Trench Basin and Fore Land Basin



Trench Basin and Forearc Basin



Transtensional Basin or Pull-apart Basin



Transpressional Basin

1. Major Basins of Pakistan:

- Upper Indus Basin — Sargodha high
- Middle Indus Basin — Jacobabad high
- Lower Indus Basin
- Baluchistan Basin — Axial Belt

Upper Indus Basin (UIB):

Group	Name	Type Locality	Lithology	Age
	Kirana Group	Not Designed	Slate	Late Precambrian
	Salt Range Formation	Khewra gorge, eastern Salt Range, Punjab	Gypsum beds, dolomite, clay, greenish & low grade oil shale	Precambrian
J H E L U M	Khewra Sandstone	Khewra gorge Khewra, Salt Range, Punjab	Sandstone	Early Cambrian
	Kussak Formation	Kussak Fort , eastern Salt Range, Punjab	Sandstone, Siltstone	
	Jutana Formation	Jutana Village, eastern Salt Range, Punjab	Dolomite	Early Mid. Cambrian Late Early Cambrian
	Baghanwala Formation	Baghanwala Village, eastern Salt Range, Punjab	Shale, Clay	Mid. Cambrian
	Khisor Formation	Saiyiduwali (Khisor Range)	Upper part: Shale Lower part: Gypsum	Early Mid. Cambrian
N I L A W A H A N	Tobra Formation	Tobra village, eastern Salt Range) Punjab	Tillitic facies with marine sandstone. Fresh water facies: few or no boulders, alternating siltstone and shale with spores; Complex facies: diamietite, sandstone & boulder bed	Early Permian
	Dandot Formation	Dandot village, eastern Salt Range, Punjab	Sandstone, shale, fossiliferous in the basal part	Early Permian
	Warcha Sandstone	Warcha gorge, Salt Range, Punjab	Sandstone, bedded pebbles of granite	Early Permian
	Sardhai Formation	Sardhai gorge, eastern Salt Range, Punjab	Clay, sandstone and siltstone and carbonaceous shale & chalcopyrite & copper	Early Permian
Z A L U C H	Amb Formation	Amb village, central Salt Range, Punjab	Shale, limestone	Lower Permian
	Wargal Limestone	Wargal village, central Salt Range, Punjab	Limestone & dolomite	Mid. Permian

Group	Name	Type Locality	Lithology	Age
	Chhidru Formation	Chhidru nala, Salt Range, Punjab	Sandstone, shale	Late Permian
M O S A K H E L	Mianwali Formation	Not designated: Ref Sections: Zaluch Nala, western Salt Range & Tappan Wahan, Khisor Range	Shale, varied facies	Lower. Triassic
	Tredian Formation	Not design: Ref sections: Zaluch Nala western Salt Range & Tappan Wahan, Khisor Range	Non marine unit. Sandstone, Shale	Mid. Triassic
	Kingriali Formation	Not designated, (reference sections: Zaluch Nala, western Salt Range & Tappan Wahan, Khisor Range	Dolomite & dolomite Limestone , marl, Shale	Mid. Triassic
	Chak Jabbi Limestone	North of Chak Jabbi (Kala Chitta Range) Ref: Section Gabh village	Limestone	Mid. Triassic
B A R O C H	Datta Formation	Datta Nala, Surghar Range	Siltstone & mudstone, glass sand, fire clay	Jurassic
	Shinawari Formation	Shinawari village (western Samana Range Kohat NWFP)	Limestone, shale	Middle Jurassic - Early Jurassic
	Samana Suk Formation	NE of Shinawari (Samana Range, NWFP)	Limestone	Mid. Jurassic
	Chichaili Formation	Chichaili Pass (Surghar Range)	Sandstone, glauconitic shale with phosphate nodules	Cretaceous
	Lumshiwal Formation	Lumshiwal Nala (Salt Range)	Sandstone, shale, limestone	L. Cretaceous
	Kawagarh Formation	Kawagarh hills (north of Kala Chitta Cambellpur District)	Mari, challor, dark & shale	Upp. Cretaceous
M A K A R W A L	Hangu Formation	Fort Lockhart, Samana Range Kohat, NWFP	Shale, Carbonaceous Shale, nodular	Early Paleocene (faunal evidence)
	Lockhart Limestone	Fort Lockhart Samana Range Kohat, NWFP	Limestone, trans, fossiliferous	Paleocene (faunal evidence)
	Patala Formation	Patala Nala Range Punjab	Shale & marl, limestone	Late Paleocene
	Kirthar Formation	Kohat Region also	Interbeds of limestone, shale with minor marl,	M. Eocene to Oligocene

Group	Name	Type Locality	Lithology	Age
	Panoba Shale	South of Panoba village Kohat	Shale	Early Eocene
	Shekhan Formation	Shekhan Nala Kohat, NWFP	Shale, limestone	Early Eocene
	Bahadar Khel Salt	Bahadar Khel Salt Quarry Kohat, NWFP	Salt, sandstone & clay	Early Eocene
	Margala Hill Limestone	Jatta Gypsum Quarry, Kohat NWFP	Marl, limestone	Early Eocene
	Jatta Gypsum	Jatta Gypsum Quarry Kohat NWFP	Gypsum	Early Eocene
	Kuldana Formation	Kuldana Village Muree Hill, Hazara NWFP (Frontier Province)	Shale, marl, bleached dolomite	Early to Mid.Eocene
	Kohat Formation	Section along Kohat Kushal garh highway	Interbeds of limestone & shale	Early to Mid.Eocene
C H A R A T	Nammal Formation	Nammal Gorge Salt Range, Punjab	Shale intercalation, marl, limestone	Early Eocene
	Sakesar Limestone	Sakesar Peak, Salt Range, Punjab	Marl, limestone	Early Eocene
	Chorgali Formation	Chorgali Pass Khair –Murat Range Potwar, Punjab	Shale, limestone	Early Eocene
R A W A L P I N D I	Muree Formation	North of Dhok Maiki, Campbellpur, Punjab	Silstone, fossiliferous, Monotonous sequence of clay	Early Miocene
	Kamliall	Southwest of Kamlail, Campbellpur, Punjab	Sandstone	Mid. to Late Miocene
S I W A L I K S	Chinji Formation	South of Chinji, Campbellpur, Punjab	Clay, sandstone	Late Miocene
	Nagri Formation	Nagri village, Campbellpur District, Punjab	Salt, conglomerate, clay	Early Pliocene
	Dhok Pathan Formation	Dhok village Campbellpur District, Punjab	Sandstone, clay, conglomerate	Mid. Pliocene
	Soan Formation	Gaji Jagir, Sahil Road near Mujahid village north.of Soan River, Campellpur District, Punjab	Conglomerate, siltstone	Pliocene
	Lei Conglomerate	Lei River Section SE of Rawalpindi Punjab	Congl, Silstone, Eocene rocks	Pleistocene

Lower Indus Basin (LIB) :

S.No	Name	Type Locality	Lithology	Age
	Nagar Parkar Granite of Indian Shield	Not Designed Ref: Tharparker	Granite, grey, composed of orthoclase	Late Precambrian
1	Wulgai Formation	Wulgai village Muslimbagh, Baluchistan	Shale, limestone	Early to Late Triassic
2	Shirinab Formation	Shirinab River section (Chapppar Mingochar & Shirinab valley, Kalat, Baluchistan)	Interbedded limestone & shale	Early Jurassic
3	Chiltan Limestone	Chiltan Range S.W of Quetta, Baluchistan	Limestone, chert	Mid. Jurassic
4	Mazar Drik Formation	Mazar Drik, Masri Hills Baluchistan	Interbeds of shale & limestone, fossiliferous	Triassic
5	Sembar Formation	Sembar Pass, (Marri Hills) Baluchistan	Shale, Sandy Shale, Limestone	Late Jurassic
6	Goru Formation	Goru village (Nar River, southern Kirthar Range)	Siltstone, shale	Mainly Early Cretaceous
7	Parh Limestone	Parh Range (Gaj River up reaches Baluchistan)	Limestone, Marl, Calcareous Shale	Late Cretaceous
8	Moghalkot Formation	Moghal Kot, Zhob & D.I. Khan Road	Mudstone, shale, marl	Upp. Cretaceous
9	Fort Munro Formation	Western flank of Fort Munro anticline (Frt. Munro-DG Khan Road)	Limestone calcareous shale	Upp. Cretaceous
10	Pab Sandstone	Pab range Wirahab Nai (Kirthar Province)	Sandstone	Upp. Cretaceous
11	Moro Formation	Moro River (Johan Bibi Nani) Baluchistan	Limestone, marl	Upp. Cretaceous
12	Ranikot Group	Ranikot Fort northern part of Lakhi Range in Sindh	Limestone, sandstone, shale	Paleocene
13	Khadro Formation	Khadro Bara Nai section northern Lakhi Range Sindh	Sandstone, shale, basaltic flows	Early Paleocene
14	Bara Formation	Bara Nai, Northern Lakhi Range, Sindh	Sandstone, shale	Middle Paleocene

S.No	Name	Type Locality	Lithology	Age
15	Lakhra Formation	Lakhra Bolari section, southern lank of Lakkra anticline, lakhi Range Sindh	Limestone, Sandstone, shale interbeds	Late Paleocene
16	Dungan Formation	Mirhat Tangi, 8km NE of hanai, Loralai Distt, Balochistan	Limestone, Marl, conglomerate	Paleocene to Lr. Eocene
17	Ghazij Formation	Spintangi, Hanai Distt. Baluchistan	Shale, claystone, albaster,	Lower Eocene
18	Laki Formation	Mari Nai, SW of Bara Nai northern Lakhi range Sindh	Limestone, calcareous shale, sandstone, laterite	Early Eocene
19	Kirthar Formation	Gaj River Section Kirthar Range Dadu, Sindh	Interbeds of limestone, shale with minor marl,	M. Eocene to Oligocene
20	Nari Formation	Gaj River Section Kirthar range, Dadu, Sindh	Shale, sandstone	Oligocene to Early Miocene
21	Gaj Formation	Gaj River,Dadu, Sindh	Shale, fossiliferous	Early to Middle Miocene
22	Chinji Formation	South of Chinji, Campbellpur, Punjab	Clay, sandstone	Late Miocene
23	Nagri Formation	Nagri village, Campbellpur District, Punjab	Salt, conglomerate, clay	Early Pliocene
24	Dhok Pathan Formation	Dhok village Campbellpur District, Punjab	Sandstone, clay, conglomerate	Mid. Pliocene
25	Soan Formation	Gaji Jagir, Sahil Road near Mujahid village north.of Soan River, Campellpur District, Punjab	Conglomerate, siltstone	Plieocene
26	Lei Conglomerate	Lei River Section SE of Rawalpindi Punjab	Congl, Silstone, Eocene rocks	Pleistocene

Baluchistan Basin (BB):

S.No	Name	Type Locality	Lithology	Age
1	Sinjrani Volcanic Group	Sinjrani District, Chagai Baluchistan	Agglomerate & Volcanic onglomerate, tuff, calcareous shale	Cretaceous
2	Humai Formation	Koh Humai Hill Koh- i – Sultan Chaghi,Baluchistan)	Shale, sandstone, siltstone, conglomerate,	Creteceous
3	Rakhshani Formation	Rokhshani (eastern end of Dalbandin Chagai) Baluchistan	Sandstone, tuff	Paleocene
4	Ispikan Conglomerate	Ispikan, north Makran Balochistan	Conglomerate, limestone & andesitic rocks	Paleocene
5	Saindak Formation	Saindak Fort, Chaga Baluchistan	Interbeds of shale, sandstone, volcanic rocks,	Eocene to Oligocene
6	Kharan Formation	Near Jalwar, Kharan District. Baluchistan	Limestone,	Early to Mid Eocene
7	Nisai Formation	North of Nisai Railway. Station Muslim Bagh, Baluchistan	Limestone, Marl, Shale	Eocene to Oligocene
8	Amalaf Formation	Amalf Section Chagai Baluchistan	Volcanic rocks sandstone, agglomerate,	Oligocene
9	Khojak Formation	Nauroz, 30 km NE of Kharan Kalat, Baluchistan	Shale, siltstone	Eocene to Early Miocene
10	Hingalaj Formation	Not Designated Talar Gorge & Jiwani	Shale, mudstone minor conglomerate	Miocene to Pliocene
11	Gawadar Formation	Gawadar, Makran, Balochistan	Sandy clay	Late Pliocene
12	Jiwani Formation	East of Jiwani to Ganj, Makran, Baluchistan	Shally, conglomerate, sandstone	Pleistocene
13	Haro Conglomerate	Kech Valley near Gish Kaur, Kharan, Balochistan	Congl , claystone, siltstone	Pleistocene
14	Bostan Formation	Pishi Lora valley, Pishin District. Baluchistan	Clay, conglomerate	Pleistocene

References:

"Geology & Tectonic of Pakistan" by Kazmi & Jan.
"Petroleum Geology of Pakistan" by I.B Kadri.

Axial Belt:

S.No	Name	Type Locality	Lithology	Age
1	Hazara Formation	Not designed	Slate, phyllite & shale	Late Precambrian
2	Tanawul Formation	Not designed	Biotite, muscovite quartz schist and andalusite staurotite schist	Cambrian
3	Abbottabad Formation	Sirban Hill, Abottabad, (NWFP)	Dolomite, quartize & phyllite	Early Cambrian
4	Hazira Formation	Hazira Village	Siltstone, shaly	Early Cambrian
5	Landikotal Formation	Landikotal, (N.W.F.P)	Phyllite, slate	Paleozoic to Mesozoic
6	Attock Formation	Not designed	Sedimentary and metamorphic sequences- Limestone, Phyllite	Ordivician-Early Silurian- Precambrian
7	Kandar Pyhllite	5 Km north of Nowshere (Nowshera-Risalpur Road)	Phyllite, limestone	Late Silurian
8	Nowshera Formation	5 Km north of Nowshere (Nowshera-Risalpur Road)	Limestone & dolomite, reef core, carbonate/reef breccia	Late Silurian to Early Devonian
9	Misri Banda quartzite	12 Km east of Nowshera (Nowshera-Risalpur Road)	Quartzite and dolomite lenses	Devonian
10	Pir Sabak Formation	Not designed	Limestone, dolomitic limestone	Carboniferous- Pre late Devonian
11	Khyber Carbonates	Not designated	Series of shale, quartzite, limestone, dolomite and marble	Early Devonian to Mid. Silurian to Carbonifereous
12	Shagai Limestone	1 Km N.E. of Shagai (Khyber area, NWFP)	Dolomitic limestone	Early Devonian
13	Ali Masjid Formation	Ali Masjid village (Khyber Pass, NWFP)	Sandstone & quartzite, limestone, siltstone, conglomerate	Late Devonian
14	Khyber Limestone	Ali Masjid village (Khyber Pass, NWFP)	Limestone	Permian
15	Shakhai Formation	Shakhai 16 km west of Nowshera, NWFP	Dolomitic	Permo- Carbonifeous
16	Permian rocks of Baluchistan	Not designed (Wulgai, Gaza band- Kalat Balochistan)	Limestone with marl and clay	Permian
17	Bela Volcanic Group	Bela Town, Lasbela Baluchistan	Tuff, chert, limestone, shale, marl	Cretaceous
18	Pab Sandstone	Pab range Wirahab Nai (Kirthar Province)	Sandstone	Cretaceous
19	Moro Formation	Moro River (Johan Bibi Nani) Baluchistan	Limestone, marl	Cretaceous
20	Rakhshani Formation	Rokhshani (eastern end of Dalbandin Chagai) Baluchistan	Sandstone, tuff	Paleocene
21	Khadro Formation	Khadro Bara Nai section northern Lakhi Range Sindh	Sandstone, shale, basaltic flows	Early Paleocene
22	Bara Formation	Bara Nai, Northern Lakhi Range, Sindh	Sandstone, shale	Middle Paleocene

S.No	Name	Type Locality	Lithology	Age
23	Lakhra Formation	Lakhra Bolari section, southern lank of Lakkra anticline, lakhi Range Sindh	Limestone, Sandstone, shale interbeds	Late Paleocene
24	Dungan Formation	Mirhat Tangi, 8km NE of hanai, Loralai Distt, Balochistan	Limestone, Marl, conglomerate	Paleocene to Lr. Eocene
25	Nisai Formation	North of Nisai Railway. Station Muslim Bagh, Baluchistan	Limestone, Marl, Shale	Eocene to Oligocene
26	Ghazij Formation	Spintangi, Hanai Distt. Baluchistan	Shale, claystone, albaster,	Lower Eocene
27	Kirthar Formation	Gaj River Section Kirthar Range Dadu, Sindh	Interbeds of limestone, shale with minor marl,	M. Eocene to Oligocene
28	Nari Formation	Gaj River Section Kirthar range, Dadu, Sindh	Shale, sandstone	Oligocene to Early Miocene
29	Hinglaj Formation	Not Designated Talar Gorge & Jiwani	Shale, mudstone minor conglomerate	Oligocene to Pleistocene in Axial Belt
30	Gaj Formation	Gaj River,Dadu, Sindh	Shale, fossiliferous	Early to Middle Miocene
31	Nagri Formation	Nagri village, Campbellpur District, Punjab	Salt, conglomerate, clay	Early Pliocene
32	Dhok Pathan Formation	Dhok village Campbellpur District, Punjab	Sandstone, clay, conglomerate	Mid. Pliocene
33	Soan Formation	Gaji Jagir, Sahil Road near Mujahid village north.of Soan River, Campellpur District, Punjab	Conglomerate, siltstone	Plieocene
34	Haro Conglomerate	Kech Valley near Gish Kaur, Kharan, Balochistan	Congl , claystone, siltstone	Pleistocene
35	Bostan Formation	Pishi Lora valley, Pishin District. Baluchistan	Clay, conglomerate	Pleistocene
36	Lei Conglomerate	Lei River Section SE of Rawalpindi Punjab	Congl, Silstone, Eocene rocks	Pleistocene

Northern Montane Area:

S.No	Name	Type Locality	Lithology	Age
1	Salkhala Formation	Salkhala village, Kishan Ganja River, Kashmir	Slate	Late Precambrian
2	Cambrian rocks of N.E. (undefine)		Greywacke, shale and limestone	Cambrian
3	Devonian rock - Chitral	-	Limestone	Early Devonian
4	Sarikol Slate	Not designed	Slate, quartzite, calcareous beds and few volcanic rock	Carboniferous-Permian
5	Darkot Group	Not designed	Slate, Limestone, quartzite, conglomerate, schist, marble, gneiss and volcanic rocks	Permo - Carbonifeous
6	Chalt Schist	Not designated (SW of Chalt Hunza)?	Schist, quartz biotite schist, phyllite	Carboniferous-Permian
7	Baltit Group	Not designated (near Baltit Hunza)?	Garnet staurolite, schist, garnet, mica schist, garnet amphibolite, coarsely, crystalline marble, and micaceous.	Carboniferous-Permian
8	Pasu Slate	Not designated (Pasu valley Gilligit)?	Interbedded with quartzite and limestone	Carboniferous-Permian
9	Panjal Formation & Agglomerate Slate	Not designated (at apex of Hazara syntaxis)?	Volcanic greenstone, metamorphosed lava flows	Carboniferous-Permian

References:
www.gsp.com.pk
"Geology & Tectonic of Pakistan" by Kazmi & Jan.
"Petroleum Geology of Pakistan" by I.B Kadri.

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2. **Petroleum Basin Plays:**
   - **Baluchistan Basin Play:**

	Age	Formation	Lithology
Seal/Cap	Miocene	Parkini	Shale
Reservoir		Panjgur	Sandstone
Source	Oligocene	Hoshab/Siahan	Shales

   - **Upper Indus Basin Play:**

	Age	Formation	Lithology	Oil/Gas Fields	
Seal/Cap	Early Cambrian	Kussak	Shale	Adhi Missa Keswal	Gas / Condensate
Reservoir		Khewra	Sandstone		
Source	Precambrian	Sehwal Marl Member of Salt Range Formation	Marly Shale		
Seal/Cap	Early Permian	Dandot	Shale	Adhi, Dhurnal	Oil
Reservoir		Tobra	Conglomerate		
Source	M.Cambrian	Baghanwala	Shale		
Seal/Cap	Early Permian	Sardhai	Clayey Shale		
Reservoir		Warcha	Sandstone		
Source		Dandot	Shale		
Seal/Cap	Early Triassic	Mianwali	Shale		
Reservoir	Late Permian	Zaluch Group (Amb Wargal Chidru)	Limestone		
Source	Early Permian	Sardhai	Clay Shale		
Seal/Cap	Early Jurassic	Shiniwari	Shale	Dhulian, Toot, Meyal, Dkhni	Oil
Reservoir		Datta	Sandstone		
Source	Late Triassic	Kingriali	Marly Shale		
Seal/Cap	Late Jurassic	Chichali	Shale		
Reservoir	Mid. Jurassic	Samansuk	Limstone		
Source	Early Jurassic	Shiniwari	Shale		
Seal/Cap	Paleocene	Patala	Shale	Dhurnal, Chak Naurang, Balkassar, Dakhni	Oil
Reservoir		Lochart	Limastone		
Source		Hangu	Shaly Sand		
Seal/Cap	Early Eocene	Chorgali	Sahly Marl		
Reservoir		Sakessar	Limestone		
Source		Nammal	Shaly Marl		
Seal/Cap	Eocene	Murree	Clayey Shale		
Reservoir		Chorgali	Limestone		
Source		Nammal/Sakessar	Shalr Part		

- Paleocene and Eocene Shale are proven source rocks in UIB.
- Cumulative thickness of Reservoirs is about 800 to 1000 maters.

- **Middle Indus Basin Plays:**

	Age	Formation	Lithology	Oil/Gas Fields	
Seal/Cap	Early Cretaceous	Lower Goru (Lower Sahle and Talhar Shale)	Shale	PirKoh, Rodho, Dhodhak	Gas / Condensate
Reservoir		Lower Goru (Basal Sand and Massive Sand)	Sandstone		
Source		Sembar	Shale		
Seal/Cap	Early Paleocene	Ranikot	Shale part		
Reservoir	Late Cretaceous	Pab	Sandstone		
Source	Late to Early Cretaceous	Mughal Kot / Fort Munro / Sembar	Shale		
Seal/Cap	Late Paleocene	Bara/Lakhra	Shale	PirKoh, Rodho, Dhodhak	Gas / Condensate
Reservoir	Early Paleocene	Ranikot	Limestone/Sandstone		
Source	E. Cretaceous	Sembar	Shale		
Seal/Cap	Mid. Eocene	Domanda Member	Shale	Sui, Kandkhot, Loti, Zin, Uch, Khairpur, Mazarani.	Gas
Reservoir		Habib Rahi	Limestone		
Source	E.Eocen/ E.Cret	Baska / Sembar	Shale		
Seal/Cap	E. Eocene	Ghazij	Shale		
Reservoir	Mid. Eocene	Sui upper Limestone	Limestone		
Source	L. Paleocene to L. Cretaceous	Lakhra / Sembar	Shale		
Seal/Cap	E. Eocene	Ghazij	Shale		
Reservoir	Mid. Eocene	Sui main Limestone	Limestone		
Source	L. Paleocene to L. Cretaceous	Lakhra / Sembar	Shale		

- Sembar is proven source rock in MIB.
- Cumulative thickness of Reservoirs about 1500 meters.

- **Lower Indus Basin Plays:**

	Age	Formation	Lithology	Oil/Gas Fields	
Seal/Cap	Early Cretaceous	Lower Goru (Lower Sahle and Talhar Shale)	Shale	Badin, Khaskheli, Laghari, Mazari, Turk, Golarchi, Mial, Kadanwari, Sehwan, Bhit	Gas / Oil
Reservoir		Lower Goru (Basal Sand and Massive Sand)	Sandstone		
Source		Sembar	Shale		
Seal/Cap	Late Paleocene	Bara/Lakhra	Shale	Sari, Hindi, Kothar	Gas
Reservoir	Early Paleocene	Ranikot	Limestone/Sandstone		
Source	E. Cretaceous	Sembar	Shale		

- Cumulative thickness of Reservoirs about 400 meters.

Reference:

“Petroleum Geology of Pakistan” by I.B Kadri.

3. Nomenclature of Lower Goru:

<table>
<tr><th></th><th colspan="3">OGDCL</th><th colspan="2">UTP (BP Pakistan)</th><th>OMV Pakistan</th><th>LASMO (Eni Pakistan)</th></tr>
<tr><td rowspan="14">L O W E R G O R U</td><td rowspan="7">U p p e r S a n d</td><td>Layer 1</td><td>A Sand</td><td rowspan="7">U p p e r S a n d</td><td>A Sand</td><td rowspan="7">Shale out in North</td><td rowspan="7">Shale out in North</td></tr>
<tr><td>Layer 2</td><td>Turk Shale</td><td>Turk Shale</td></tr>
<tr><td>Layer 3</td><td>B Sand</td><td>B Sand</td></tr>
<tr><td>Layer 4</td><td>Badin Shale</td><td>Badin Shale</td></tr>
<tr><td rowspan="3">Layer 5</td><td>C Sand</td><td>C Sand</td></tr>
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<tr><td colspan="5">Talhar Shale</td><td>C& D Sands within Shale</td></tr>
<tr><td colspan="5">Massive Sand</td><td>A Sand</td><td>B Sand</td></tr>
<tr><td colspan="6">SEMBAR</td><td>A Sand</td></tr>
</table>

Reference:
"Lower Goru Shales; Hydrocarbon Source Rocks In Part of Lower Indus", Zaidi.N.A, Shahid.M, Rehman.K

Decan Trap: = Kadhro, Bara, Lakra
Mainly Basaltic Lawa Flows horizontal but in some places it may be at 10°.

Productus Limestone: = Zaluch Group

- Upper PL
    - ð Amb Formation (Sandstone and Marl)
    - ð Brachiopod (Productus indicus, Productus spiralis), Lamellibrachs (Schizodus), Gastropods (Bellerophone), Ammonites (Xenodiscus, Planetoceras)
- Middle PL
    - ð Wargal Formation (Limestone and dolostone rich in fossil)
    - ð Brachiopods (Productus indicus, Productus lineatus, sperifer, athyris), Lamellibrachs (pseudomonotis), Gastropods (Pleurotomaria), Ammonites (Xenaspis)
- Lower PL
    - ð Chidro Formation (Calcareous Snadstone and carbonaceous shale)
    - ð Brachiopods (Productus spiralis, sperifer marcoui)

Khewra Trap: (Kherite)

- Theolitic Rock intermingled with Gypsum Marl and Salt at Eastern Salt Range Khewra.
- In Mari Indus Range it becomes Quartz crystal
- In Salt Range it becomes Khewrite

4. MAJOR TECTONIC ZONES OF PAKISTAN:

1. INDUS PLATFORM & FOREDEEP:

1) **Indus Plattform and Foredeep:**
   a) Sarghodha Shahpur Ridge
   b) Nagar Parkar High
2) **Zones of upwarp:**
   a) Mari – Khandkhot High
   b) Jaccobabad – khairpur High
   c) Thatta – Hyderabad High
   d) Tharparkar High
3) **Zones of downwarp & Platform slope:**
   a) Northern Punjab Monocline
   b) Southern Punjab Monocline
   c) Cholistan Shelf
   d) Panno Aqil Grabben
   e) Nawabshah Slope
   f) Lower Indus Trough
   g) Nabisar Slope

2. BALUCHISTAN OPHOLITE & THRUST BELT:

1) **Bela Opholite & Thrust Belt**
2) **Zhob Opholite & Thrust Belt**

3. SULAIMAN – KIRTHAR FOLD BELT:

1) **Sulaiman Fold Belt**
   a) Mari – Bugti Fold Zone
   b) Sibi Trough
2) **Kirthar Fold Belt**
   a) Kalat Anticlinorium
   b) Kalat Plateau
   c) Khuzdar Knot
   d) Khude Range
   e) Nagau Kirthar Range
   f) Karachi Embayment zone
   g) Sanbakh – Lakhra Uplift zone

4. NW HIMALAYAN FOLD & THRUST BELT:

1) **Hazara – Kashmir Syntaxis**
2) **Outer Himalayas**
3) **Salt Range – Kohat – Potawar Plateau**
4) **Kalachitta Margilla Thrust Belt**
5) **Lesser Himalayas**
6) **Swat – Hazara crystalline & Thrust Belt**
   a) Peshawar Basin
   b) Khyber – Hazara Metasedimentary Fold & Thrust Belt
   c) Zones of crystalline Nappe
   d) Kashmir Basin

METALLIC MINERAL RESOURCES OF PAKISTAN

MINERAL/ COMMODITY	ORE RESERVES (In Tones)	LOCATION	QUALITY
Aluminium (Laterite/Bauxite)	74,000,000	Muzaffarabad-AJK Ziarat, Kalat - Balochistan Khushab - Punjab	Low to medium grade.
Chromite	F.L.D.	Muslimbagh, Wadh, Kharan - (B) Dargai, Kohistan -NWFP	Medium to high grade
Copper	500,000,000	Saindak, Chagai - Balochistan Waziristan Areas.	Low to medium grade
Lead/zinc Ore	46,000,000	Lasbela, Khuzdar - Balochistan Basham - NWFP.	Medium to high grade
Gold	30	Saindak, Chagai - Balochistan Northern Areas.	N.E.
Silver	50	Saindak, Chagai - Balochistan.	N.E.
Iron Ore	+600,000,000	Chagai and Kalat districts , Balochistan; Nizampur, NWFP; Kalabagh/Mianwali - Punjab.	Low to medium grade
Platinum	N.E.	Dargai, Kohistan - NWFP Muslimbagh - Balochistan	N.E.
Tungsten	N.E.	Chitral - Northern Areas.	N.E.
Lithium	N.E.	Northern Areas	N.E

Keys:-
N.E. Not Estimated
F.L.D. Fairly Large Deposits

NON-METALLIC MINERAL RESOURCES OF PAKISTAN

MINERAL/COMMODITY	RESERVES (In Tons)	LOCATION	QUALITY
Barite	30,000,000	Lasbela, Khuzdar - Balochistan Hazara - NWFP	Mostly drilling mud type
Building Stones	V.L.D.	Many districst of Balochistan - NWFP - Sindh	Good
Cement Raw Material	V.L.D.	All provinces of Pakistan	V. Good
Clays (including China Clay)	+34,000,000	NWFP - Punjab - Sindh	Good
Coal	184,000 MT	Sindh, Balochistan, Sindh, N.W.F.P.Mianwali, Attock - Punjab	Lig. A to Bit. A
Dolomite	V.L.D.	Jhimpir - Sindh	Medium
Fire Clay	100,000,000	Kala Chitta and Salt Range - Punjab Meting Jhimpir - Sindh	Good
Fluorite	100,000	Kalat	Good
Fuller's Earth	F.L.D.	Khairpur, Dadu - Sindh	Good
Gemstone	N.E.	Northern Areas	Good
Gypsum and Anhydrite	350,000,000	Salt Range, D.G.Khan - Punjab Spintangi - Balochistan, Dadu - Sindh	Good
Limestone	V.L.D.	All provinces and AJK	Good
Magnesite	12,000,000	Abbottabad - NWFP Muslimbagh, Wad - Balochistan	Medium
Marble/Aragonite	V.L.D.	Chagai - Balochistan Noushehra - NWFP	V. Good
Phosphate	22,000,000	Kakul - NWFP	Medium to low grade
Rock Salt	V.L.D.	Salt Range - Punjab	V. Good
Silica Sand	V.L.D.	Surghar Range - Punjab Thano Bulla Khan - Sindh	Medium
Soap Stone	600,000	Parachinar - NWFP	Good
Sulphur	800,000	Koh-i-Sultan - Balochistan	Medium to low grade

Keys: -

N.E. Not Estimated
F.L.D. Fairly Large Deposits
V.L.D. Very Large Deposits
MT Million Tons
Lig. Lignite
Bit. Bituminous

WIRELINE LOGGING

Gamma Ray and Spectral Log:

Track: 1^{st} Track

Unit: API units for Gamma ray while for Spectral log is ppm.

Scale: Linear scale of 10 divisions.

Basic Principle: it is a formation's radioactivity which is the radiation emanates from naturally occurring Uranium Thorium and Potassium based on radiation laws of physics.

Principle Uses: to drive shale volume as well as to correlate permeable zone, to suggests Facies and Sequences, to identify shalyness while Spectral gamma ray in addition to derive radioactive mineral volume and more accurate shale volume, to indicate clay mineral types, fractures, give indications of depositional Enviornament and help to localize source rock.

Density Log and photoelectric factor log:

Track: 2^{nd} and 3^{rd} Track

Unit: gm/cm^3

Scale: Linear scale of 20 divisions

Basic Principle: It is a continuous record of formations bulk density and based on density laws of physics.

Principle Uses: to calculate porosity and indirectly hydrocarbon density. Also to indicate Lithology, to identify some minerals, can help to assess source rock organic matter content and may help to identify overpressure and fractured porosity.

Sonic Log:

Track: 3^{rd} Track

Unit: US/F (micro second per foot???)

Scale: Linear Scale of 10 divisions

Basic Principle: It provides a formation's travel time and based on reflection laws of physics.

Principle Uses: to evaluate porosity in liquid filled holes in addition to give interval velocities and velocity profiles, and can be calibrated with seismic section. Cross multiple with density log it is used to produce the acoustic impedance log, the first step in making a synthetic seismic trace. It is also used to subtle textural variations in both sand and shale and also to identify Lithology, and may help to indicate source rock, normal compaction and over pressure and to some extent fractures. It is frequently used in correlations.

Neutron Log:

Track: 2^{nd} and 3^{rd} Track

Unit: neutron phi unit

Scale: Linear scale of 20 divisions.

Basic Principle: It provides a continuous record of a formation's reaction to fast neutron bombardment which is related to hydrogen index and based on neutron laws of physics.

Principle Uses: to measure porosity as well as to identify gross Lithology, evaporites hydrated minerals and volcanic rock. It is an excellent discriminator between gas and oil. By combining with density log on compatible scale, it is one of the best subsurface Lithology indicators available.

Caliper Log:
Track: 1^{st} Track
Unit: Inches of diameter defined by Bit Size
Scale: Linear scale from company defined of 10 digits which may be from.

1. 6 to 16 in.
2. 15 to 25 in
3. 20 to 30 in

Basic Principle: Physics Laws of Newton
Principle Uses: for Bore hole Geometry

SP Log:
Track: 1^{st} Track
Unit: millivolts.
Scale: Linear Scale 10 digits of horizontal scale wit +ve –ve deflection.
Basic Principle: It is the measurement of the natural potential difference or self potential between an electrode in the bore hole and other at the surface, no artificial currents are used.
Principle Uses: to calculate formation water resistivity and to indicate permeability. Other uses are to indicate shale volume, to indicate Facies, and in some cases to correlate permeable zone.

Resistivity and Conductivity Log:
Track: 2^{nd} and 3^{rd} Track
Unit: ohm meter
Scale: Logarithmic scale
Basic Principle: It is the measurement of formation's resistivity that is it's resistance to the passage of an electric current.
Principle Uses: to find Hydrocarbon zone as well as Lithology, texture, Facies, overpressure and source rock aspects:

Dipmeter Log:
Track: 2^{nd} and 3^{rd} Track
Unit: LBS (pound second)
Scale: Linear Scale of 20 divisions.
Basic Principle: It is a continuous record of formation dip and direction of dip, and based on reflection laws of physics.
Principle Uses: for providing dips, structural geology and sedimentary geology. It provides also information on structural dip, unconformities, faults, and folds. Also used in log correlations with seismic sections dips. It may provide Facies information, bed form orientation and paleocurrent directions.

FORMULAS FROM GEOMETRY

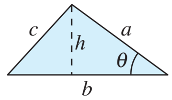
Triangle

$h = a \sin \theta$

Area $= \dfrac{1}{2}bh$

(Law of Cosines)

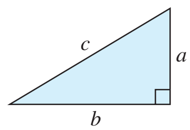
$c^2 = a^2 + b^2 - 2ab \cos \theta$



Right Triangle

(Pythagorean Theorem)

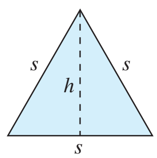
$c^2 = a^2 + b^2$



Equilateral Triangle

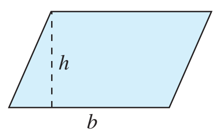
$h = \dfrac{\sqrt{3}s}{2}$

Area $= \dfrac{\sqrt{3}s^2}{4}$



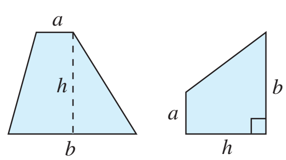
Parallelogram

Area $= bh$



Trapezoid

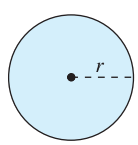
Area $= \dfrac{h}{2}(a + b)$



Circle

Area $= \pi r^2$

Circumference $= 2\pi r$

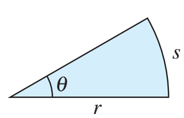


Sector of Circle

(θ in radians)

Area $= \dfrac{\theta r^2}{2}$

$s = r\theta$



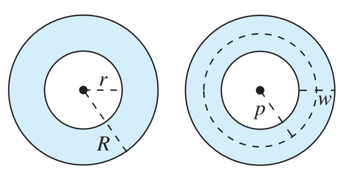
Circular Ring

(p = average radius,

w = width of ring)

Area $= \pi(R^2 - r^2)$

$= 2\pi pw$



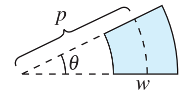
Sector of Circular Ring

(p = average radius,

w = width of ring,

θ in radians)

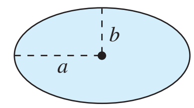
Area $= \theta pw$



Ellipse

Area $= \pi ab$

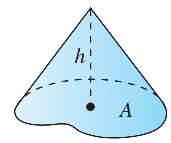
Circumference $\approx 2\pi\sqrt{\dfrac{a^2 + b^2}{2}}$



Cone

(A = area of base)

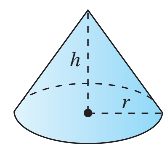
Volume $= \dfrac{Ah}{3}$



Right Circular Cone

Volume $= \dfrac{\pi r^2 h}{3}$

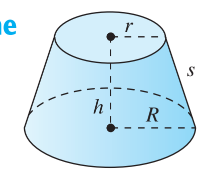
Lateral Surface Area $= \pi r\sqrt{r^2 + h^2}$



Frustum of Right Circular Cone

Volume $= \dfrac{\pi(r^2 + rR + R^2)h}{3}$

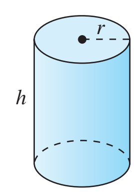
Lateral Surface Area $= \pi s(R + r)$



Right Circular Cylinder

Volume $= \pi r^2 h$

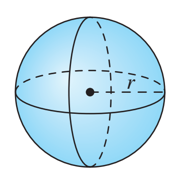
Lateral Surface Area $= 2\pi rh$



Sphere

Volume $= \dfrac{4}{3}\pi r^3$

Surface Area $= 4\pi r^2$



Wedge

(A = area of upper face,

B = area of base)

$A = B \sec \theta$