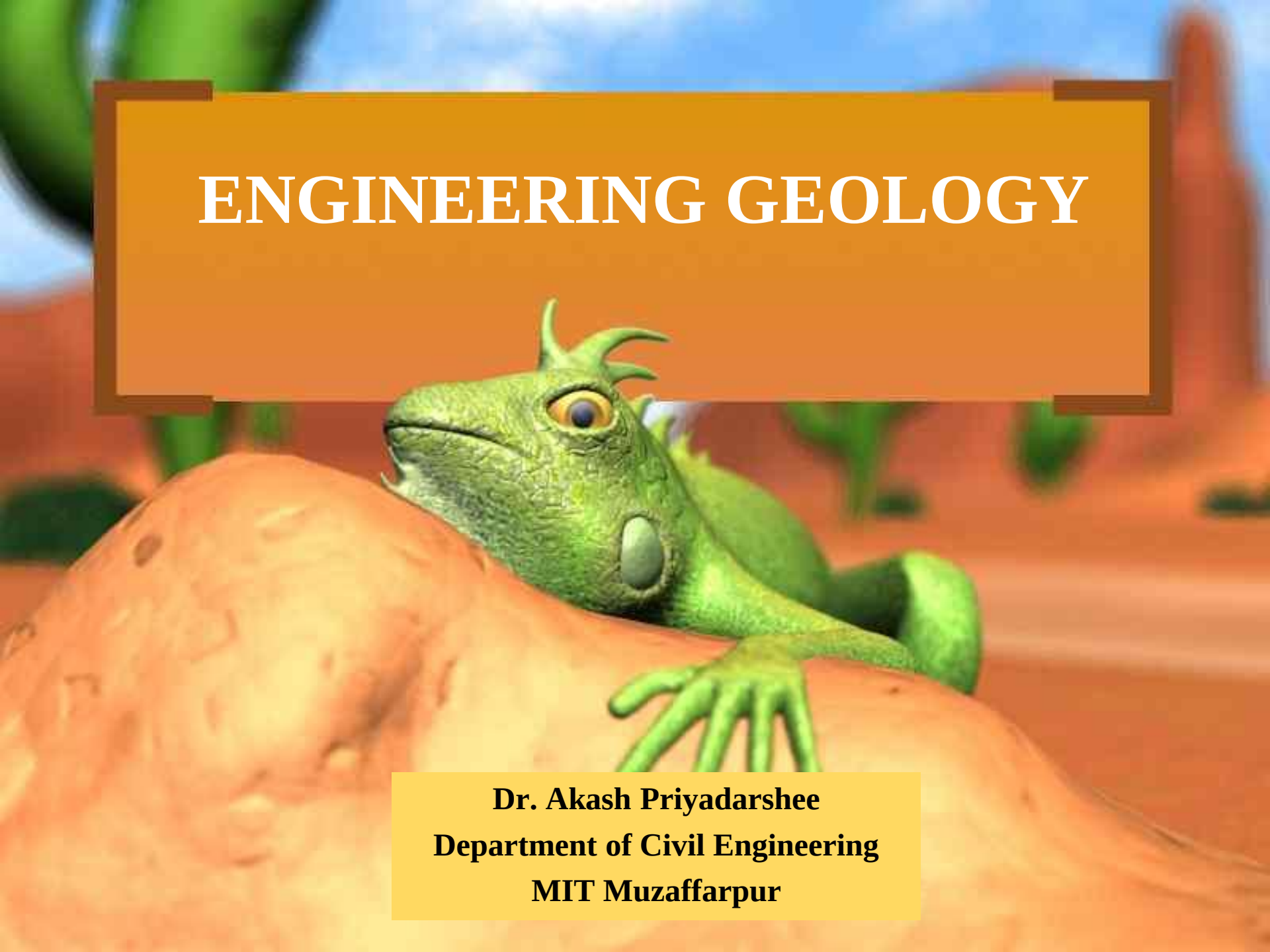
ENGINEERING GEOLOGY



Dr. Akash Priyadarshee
Department of Civil Engineering
MIT Muzaffarpur

Course Details

Engineering Geology	
Course Code	**PCC-CE202**
Course credit	**3**
L:T:P	**2:0:2**

Proposed Syllabus

Module 1: Introduction-Branches of geology useful to civil engineering, scope of geological studies in various civil engineering projects. Department dealing with this subject in India and their scope of work- GSI, Granite Dimension Stone Cell, NIRM. Mineralogy-Mineral, Origin and composition. Physical properties of minerals, susceptibility of minerals to alteration, basic of optical mineralogy, SEM, XRD., Rock forming minerals, megascopic identification of common primary & secondary minerals.

Module 2: Petrology-Rock forming processes. Specific gravity of rocks. Ternary diagram. Igneous petrology- Volcanic Phenomenon and different materials ejected by volcanoes. Types of volcanic eruption. Concept of Hot spring and Geysers. Characteristics of different types of magma. Division of rock on the basis of depth of formation, and their characteristics. Chemical and Mineralogical Composition. Texture and its types. Various forms of rocks.

IUGS Classification of phaneritic and volcanic rock.. Field Classification chart. Structures. Classification of Igneous rocks on the basis of Chemical composition. Detailed study of Acidic Igneous rocks like Granite, Rhyolite or Tuff, Felsite, Pegmatite, Hornfels. Metamorphic Aureole, Kaolinization. Landform as Tors. Engineering aspect to granite. Basic Igneous rocks Like Gabbro, Dolerite, Basalt. Engineering aspect to Basalt. Sedimentary petrology- mode of formation, Mineralogical Composition. Texture and its types, Structures, Gradation of Clastic rocks. Classification of sedimentary rocks and their characteristics. Detailed study of Conglomerate, Breccia, Sandstone, Mudstone and Shale, Limestone Metamorphic petrology- Agents and types of metamorphism, metamorphic grades, Mineralogical composition, structures & textures in metamorphic rocks. Important Distinguishing features of rocks as Rock cleavage, Schistosity, Foliation. Classification. Detailed study of Gneiss, Schist, Slate with engineering consideration.

Proposed Syllabus

Module3: Physical Geology- Weathering. Erosion and Denudation. Factors affecting weathering and product of weathering. Engineering consideration. Superficial deposits and its geotechnical importance: Water fall and Gorges, River meandering, Alluvium, Glacial deposits, Laterite (engineering aspects), Desert Landform, Loess, Residual deposits of Clay with flints, Solifluction deposits, mudflows, Coastal deposits.

Module 4:Strength Behavior of Rocks- Stress and Strain in rocks. Concept of Rock Deformation & Tectonics. Dip and Strike. Outcrop and width of outcrop. Inliers and Outliers. Main types of discontinuities according to size. Fold- Types and nomenclature, Criteria for their recognition in field. Faults: Classification, recognition in field, effects on outcrops. Joints & Unconformity; Types, Stresses responsible, geotechnical importance. Importance of structural elements in engineering operations. Consequences of failure as land sliding, Earthquake and Subsidence. Strength of Igneous rock structures.

Module 5: Geological Hazards- Rock Instability and Slope movement: Concept of sliding blocks. Different controlling factors. Instability in vertical rock structures and measures to prevent collapse. . Types of landslide. Prevention by surface drainage, slope reinforcement by Rock bolting and Rock anchoring, retaining wall, Slope treatment. Case study on black clay. Ground water: Factors controlling water bearing capacity of rock. Pervious & impervious rocks and ground water. Lowering of water table and Subsidence. Earthquake: Magnitude and intensity of earthquake. Seismic sea waves. Revelation from Seismic Records of structure of earth. Case Study on Elevation and Subsidence in Himalayan region in India. Seismic Zone in India.

Proposed Syllabus

Module 6: Rock masses as construction material: Definition of Rock masses. Main features constituting rock mass. Main features that affects the quality of rock engineering and design. Basic element and structures of rock those are relevant in civil engineering areas. Main types of works connected to rocks and rock masses. Important variables influencing rock properties and behavior such as Fresh rock Influence from some minerals. Effect of alteration and weathering. Measurement of velocity of sound in rock. Classification of Rock material strength. Core logging .Rock Quality Designation. Rock mass description.

Module 7: Geology of dam and reservoir site- Required geological consideration for selecting dam and reservoir site. Failure of Reservoir. Favorable & unfavorable conditions in different types of rocks in presence of various structural features, precautions to be taken to counteract unsuitable conditions, significance of discontinuities on the dam site and treatment giving to such structures.

Module 8: Rock Mechanics- Sub surface 9nvestigations in rocks and engineering characteristics or rocks masses; Structural geology of rocks. Classification of rocks, Field & laboratory tests on rocks, Stress deformation of rocks, Failure theories and sheer strength of rocks, Bearing capacity of rocks.

Practical

1. Study of physical properties of minerals.
2. Study of different group of minerals.
3. Study of Crystal and Crystal system.
4. Identification of minerals: Silica group: Quartz, Amethyst, Opal; Feldspar group: Orthoclase, Plagioclase; Cryptocrystalline group: Jasper; Carbonate group: Calcite; Element group: Graphite; Pyroxene group: Talc; Mica group: Muscovite; Amphibole group: Asbestos, Olivine, Hornblende, Magnetite, Hematite, Corundum, Kyanite, Garnet, Galena, Gypsum.
5. Identification of rocks (Igneous Petrology): Acidic Igneous rock: Granite and its varieties, Syenite, Rhyolite, Pumice, Obsidian, Scoria, Pegmatite, Volcanic Tuff. Basic rock: Gabbro, Dolerite, Basalt and its varieties, Trachyte.
6. Identification of rocks (Sedimentary Petrology): Conglomerate, Breccia, Sandstone and its varieties , Laterite, Limestone and its varieties, Shales and its varieties.
7. Identification of rocks (Metamorphic Petrolody): Marble, slate, Gneiss and its varieties, Schist and its varieties. Quartzite, Phyllite.
8. Study of topographical features from Geological maps. Identification of symbols in maps.

Text Book/ Reference

1.Engineering and General Geology, Parbin Singh, 8th Edition (2010), S K Kataria & Sons.

2.Text Book of Engineering Geology, N. Chenna Kesavulu, 2nd Edition (2009), Macmillan Publishers India.

Geology for Geotechnical Engineers, J.C.Harvey, Cambridge University Press (1982).

Objective of course

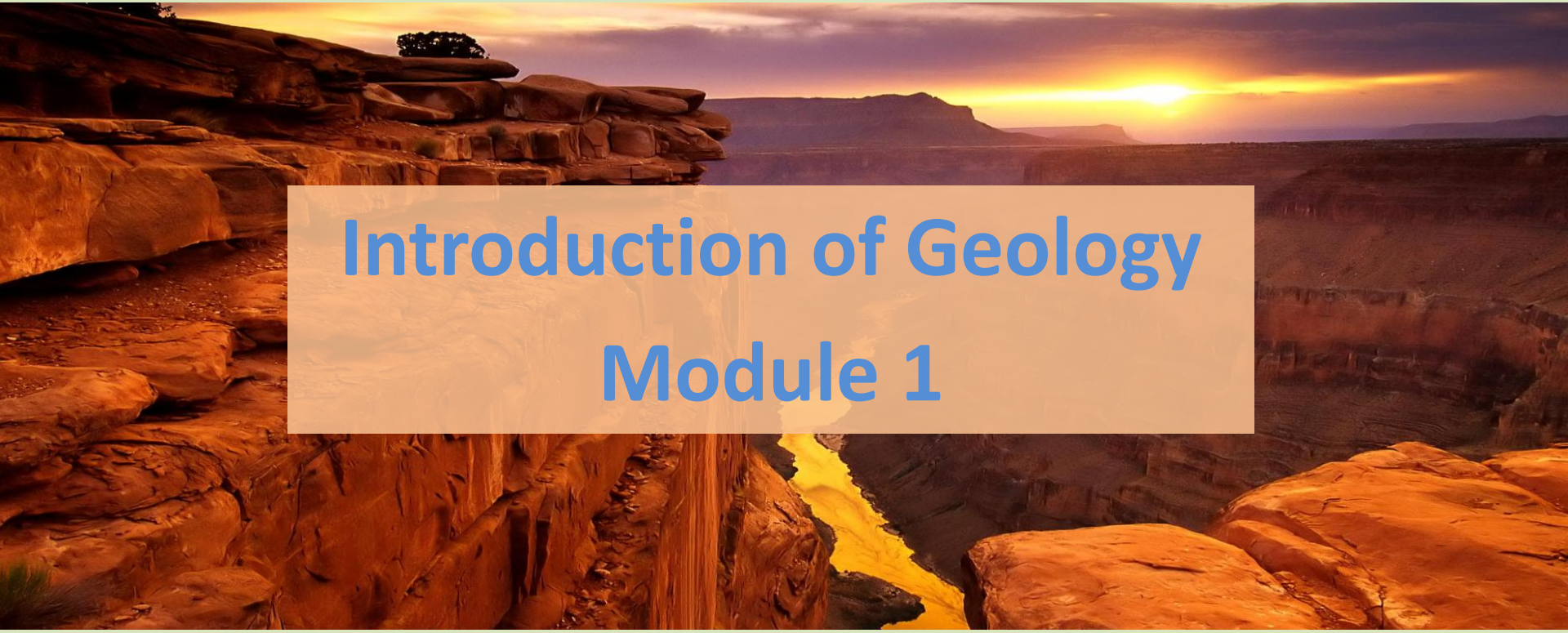
The objective of this Course is to focus on the core activities of engineering geologists – site characterization and geologic hazard identification and mitigation.

Course Outcomes

1. Understand basics of geology and minerals
2. Classify rock on the basis of geological and engineering properties
3. Understanding of weathering, erosion and denudation and its effect
4. Apply concept of engineering geology for Hazard analysis
5. Understand basic and engineering properties of rock
6. Apply Concept of geology for dam and reservoir site selection


THANK YOU

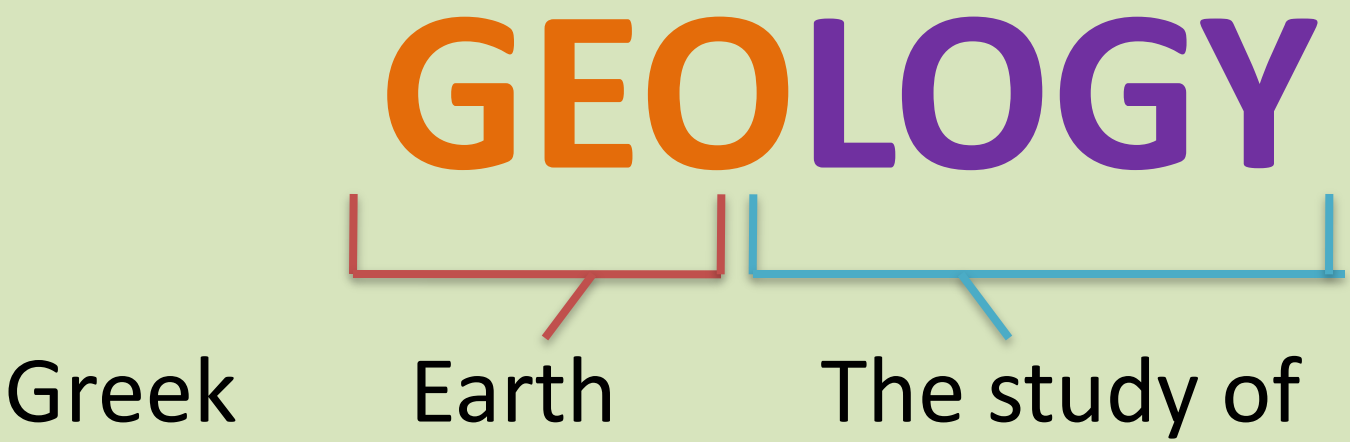
Engineering Geology
PCC-CE202



Introduction of Geology
Module 1

Dr. Akash Priyadarshee
Department of Civil Engineering
MIT Muzaffarpur

DEFINITION



Geology = The study of Earth

Study of Earth

- **Origin**
  - Hypothesis
  - Continental drift theory
  - Plate Tectonics
- **Age**
  - » By Radioactivity
- **»Structure**
  - Internal structure

Study of Earth

- **Evolution, modification and extinction of surface and subsurface features**
  - Mountains
  - Plateaus
  - Valleys
  - Basins
  - Caves
  - Costal, marine and submarine forms
- **Study of the materials making up earth**

Branches of Geology

- **Physical Geology:** It covers aspects of earth's structure, composition, physical properties, constituent rocks and minerals and other features.
- **Geomorphology:** The study of the features of the earth surfaces mainly the land like; mountains, plains, plateaus, valleys & basins
- **Mineralogy:** It deals with formation, occurrence, aggregation, properties & uses of minerals crystallography branch mineralogy.
- **Petrology:** Study of rocks
- **Economic Geology:** Economical aspect of rock for benefits of man.

Other

- **Geochemistry:** deals with chemical constitution of earth as whole
- **Geophysics:** aspects of physics, processes & methods of physics applied to solve geological problems
- **Geohydrology:** Study on the interaction between hydrology and geology
- **Mining geology:** Mining practice aspects
- **Rock mechanics**: Mechanics of rock
- **Meteorology:** Study of weather
- **Oceanography:** deals with oceans
- **Engineering Geology:** Geology + civil engineering

Engineering Geology

- Branch of applied science deals with the application of geology for
  - **Safe**
  - **Stable**
  - **Economical design and construction** of different civil engineering structures

Scope of Geology in Engineering

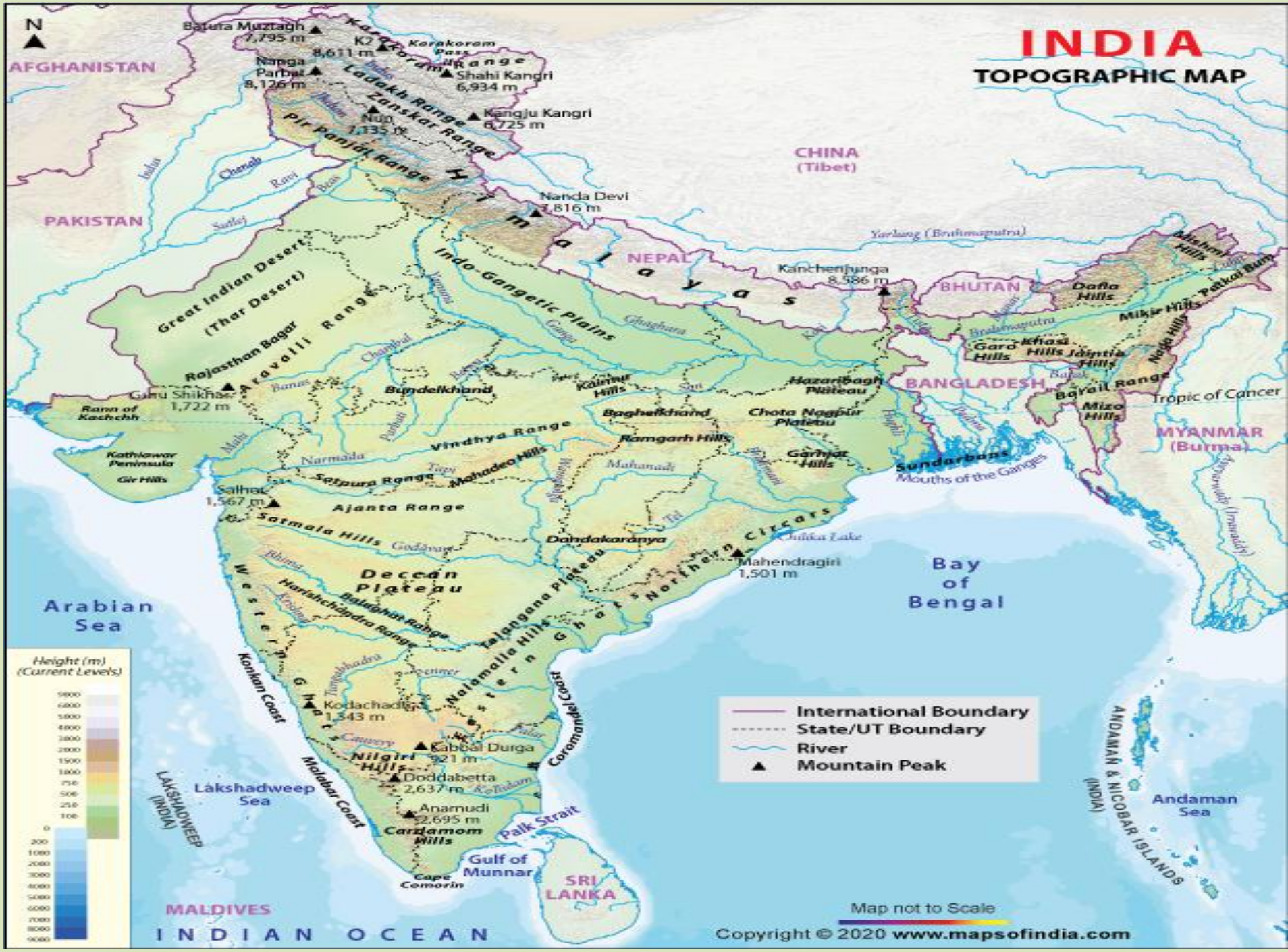
- **Following two objectives are fulfilled by EG:**
  - It helps **Civil Engineers** for understanding of engineering aspects utilized for construction in area where geological aspects needs to be consider.
  - It helps **geologist** to understand the geological information required for civil engineering construction.

Role of Civil Engineer

- Planning
- Design
- Construction
- Maintenance
  - **For construction job**
  - **Water resource development**
  - **Town & regional planning etc.**

Geology in Planning

- For better planning following maps required
  - Topographical Maps: It shows cartographic representation of the Earth's surface. It shows as accurately as possible the location and shape of both natural and man-made features.
  - Hydrological Maps: It shows the hydrologic features like; rivers and streams etc.
  - Geological Maps


INDIA
TOPOGRAPHIC MAP
N
AFGHANISTAN
PAKISTAN
CHINA
(Tibet)
NEPAL
BHUTAN
BANGLADESH
MYANMAR
(Burma)
Baltura Muztagh
7,795 m
K2
8,611 m
Karakoram Range
Karakoram Pass
Shahi Kangri
6,934 m
Nanga Parbat
8,126 m
Ladakh Range
Zanskar Range
Kanjju Kangri
6,725 m
Nun
7,135 m
Pir Panjal Range
Himalayas
Nanda Devi
7,816 m
Kanchenjunga
8,586 m
Great Indian Desert
(Thar Desert)
Rajasthan Bagar
Aravalli Range
Indo-Gangetic Plains
Guru Shikhar
1,722 m
Rann of Kachchh
Kathiawar Peninsula
Gir Hills
Bundelkhand
Baghelkhand
Kaimur Hills
Hazaribagh Plateau
Chota Nagpur Plateau
Ramgarh Hills
Garhjat Hills
Vindhya Range
Mahadeo Hills
Narmada
Tapi
Setpura Range
Salhet
1,567 m
Ajanta Range
Satmala Hills
Godavari
Bhima
Deccan Plateau
Harishchandra Range
Balaghat Range
Dandakaranya
Telangana Plateau
Nallamalla Hills
Mahendragiri
1,501 m
Chilka Lake
Eastern Ghats
Northern Circars
Coromandel Coast
Western Ghats
Konkan Coast
Malabar Coast
Kodachadri
1,343 m
Kabbal Durga
921 m
Nilgiri Hills
Doddabetta
2,637 m
Anamudi
2,695 m
Cardamom Hills
Palk Strait
Gulf of Munnar
Cape Comorin
SRI LANKA
MALDIVES
INDIAN OCEAN
Arabian Sea
Bay of Bengal
Lakshadweep Sea
LAKSHADWEEP (INDIA)
Andaman Sea
ANDAMAN & NICOBAR ISLANDS (INDIA)
Sundarbans
Mouths of the Ganges
Tropic of Tropic of Cancer
Yarlung (Brahmaputra)
Brahmaputra
Ganga
Yamuna
Ghaghara
Chambal
Sutlej
Ravi
Beas
Indus
Chenab
Jhelum
Banas
Betwa
Son
Damodar
Subarnarekha
Mahanadi
Godavari
Krishna
Tungabhadra
Cauvery
Periyar
Vaigai
Tamiraparani
Pennar
Palar
Kaveri
Kolidam
Penner
Vaigai
Tamiraparani
Indravati
Purna
Tapi
Narmada
Mahi
Sabarmati
Luni
Ghaggar
Hakra
Dhansiri
Barak
Kopili
Manas
Subansiri
Kameng
Dafla Hills
Miri Hills
Abor Hills
Mishmi Hills
Patkai Bum
Naga Hills
Garo Hills
Khasi Hills
Jaintia Hills
Barail Range
Mizo Hills
Height (m)
(Current Levels)
International Boundary
State/UT Boundary
River
Mountain Peak
Map not to Scale
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Geology in Design

- Information related to existence of hard bedrocks, depth and inclination
- Mechanical properties of existing rock, shear and other properties.
- Modulus of elasticity, permeability and resistance of decay of rock

Geology in Construction

- Quality control of the construction materials like; sands, gravels, gushed rocks and soil.

- All are best understood in geological perspective.

Department related to Geology in India

- Geological Survey of India
- National Institute of rock mechanics

NIRM - Google Search | National Institute of Rock Mec | Geological Survey of India - H | MANUAL-SERIES-NO-4.pdf | Granite Dimension stone cell p

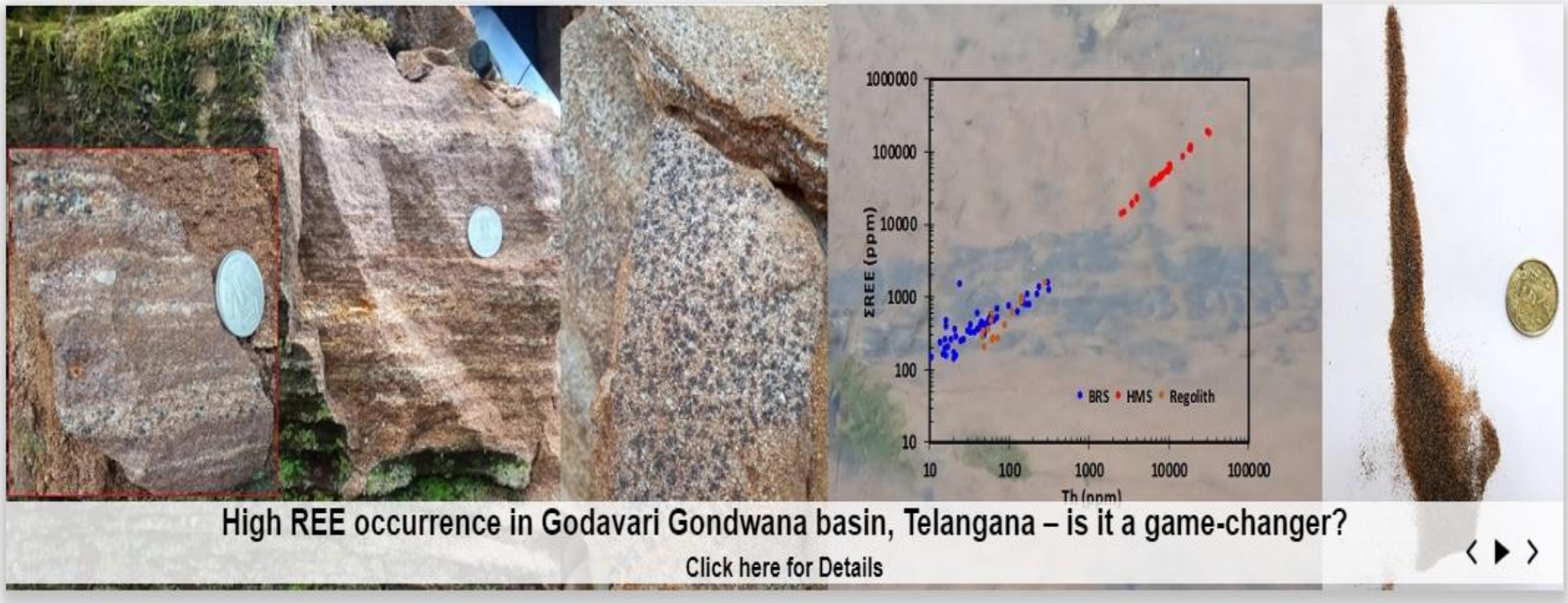
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High REE occurrence in Godavari Gondwana basin, Telangana – is it a game-changer?

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About GSI

- The arrival of Sir Thomas Oldham, Professor of Geology at Trinity College Dublin and the Chief of Irish Geological Survey at Calcutta on 4th March 1851, marked the beginning of the continuous period of the Geological Survey of India.
- The main functions of GSI relate to creation and updation of national geoscientific information and mineral resource assessment.
- GSI, headquartered at Kolkata, has six Regional offices located at Lucknow, Jaipur, Nagpur, Hyderabad, Shillong and Kolkata and State Unit offices in almost all States of the country. Presently, Geological Survey of India is an attached office to the Ministry of Mines.

National Institute of Rock Mechanics
राष्ट्रीय शिला यांत्रिकी संस्थान



Comodo SSL

About NIRM

- The National Institute of Rock Mechanics (NIRM), is an autonomous Research Institute under Ministry of Mines, Government of India. Set up in 1988 under Societies Act, 1860, NIRM has its Head Office (HO) at Bengaluru and Registered Office (RO) at Kolar Gold Fields in Karnataka.
- The Institute deals with field and laboratory investigations, basic and applied research, and solving complex problems in almost entire spectrum of Rock Mechanics and Rock Engineering related to Mining and Civil Engineering activities.

References

- https://www.mapsofindia.com/

Engineering Geology
PCC-CE202



Mineralogy
Module 1

Dr. Akash Priyadarshee
Department of Civil Engineering
MIT Muzaffarpur

Minerals

- These are inorganic substances which have more or less definite atomic structure and chemical composition.
- It has constant physical property which are used in identification of minerals in the field.
- Rock forming minerals are found in abundance of earth crust
- Ore forming minerals are economic valuable minerals

Origin of Minerals Grow?

- New minerals are forming everyday on the Earth's surface, in the Earth's crust, and deep within the Earth's interior.
- Minerals form from molten rock and volcanic magma within the Earth's interior and crust. In these environments, changes in temperature and pressure and chemical composition influence the type of minerals which form, the size of their individual crystals, and their growth rate.
- Minerals grow from saturated solutions in rock cavities. Differences in temperature, chemical composition, and the saturation content of the solution influence the type of minerals which form, the size of their individual crystals, and their growth rate.
- The arrangement of atoms during crystal formation determines what the mineral will be and what crystal shape it will have.
- The crystal form is one of several characteristics that Geologists use to identify different minerals.

Examples of Minerals:

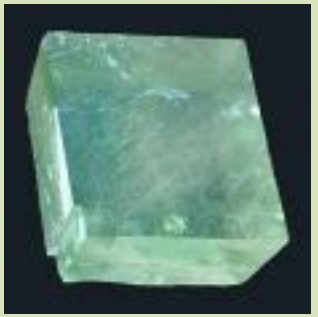
Quartz



Iron



Calcite



Hematite

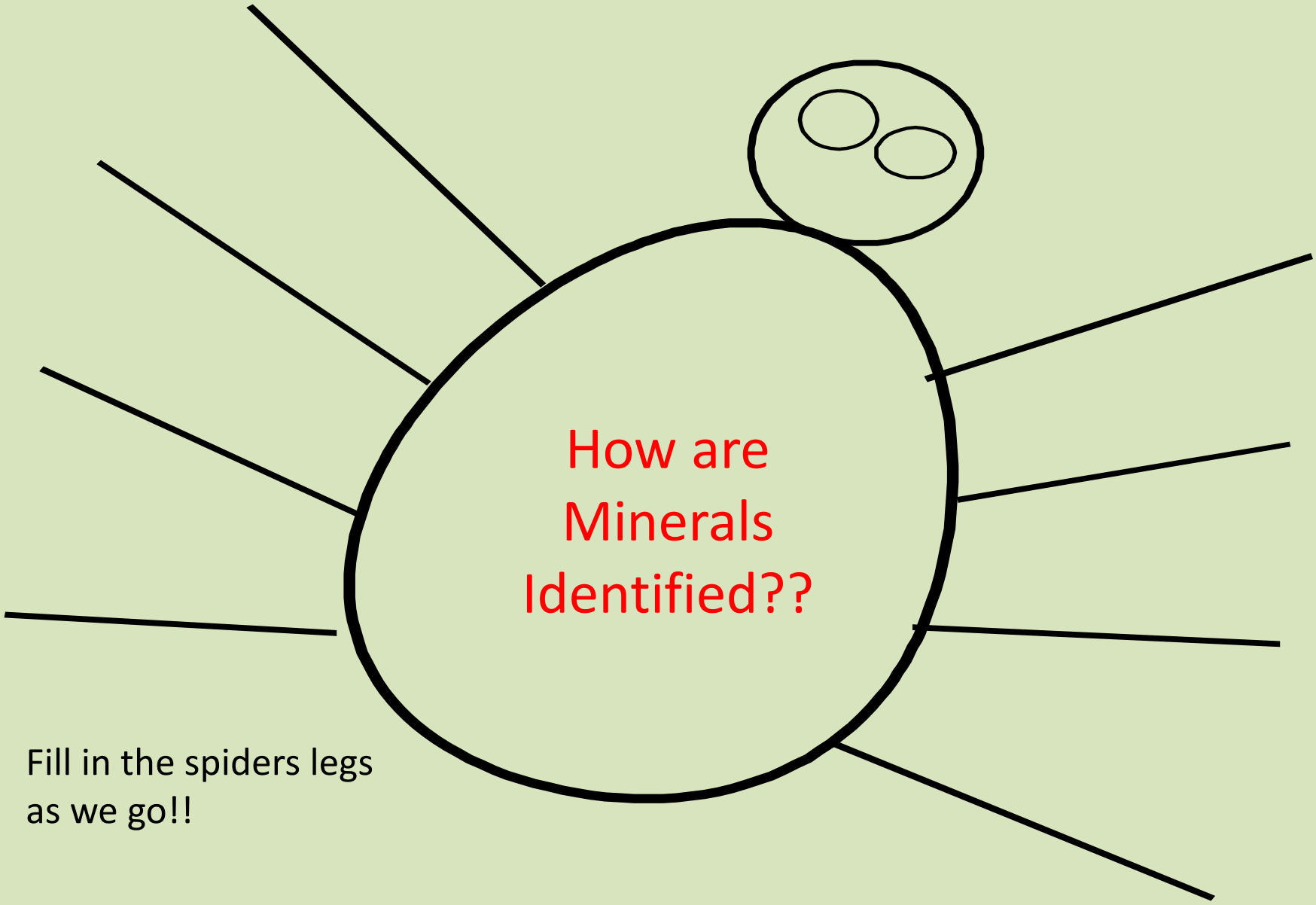


Calcite



Diamond





Fill in the spiders legs as we go!!

Properties of Common Minerals

LUSTER	HARDNESS	CLEAVAGE	FRACTURE	COMMON COLORS	DISTINGUISHING CHARACTERISTICS	USE(S)	COMPOSITION*	MINERAL NAME
Metallic luster	1–2	✔		silver to gray	black streak, greasy feel	pencil lead, lubricants	C	**Graphite**
	2.5	✔		metallic silver	gray-black streak, cubic cleavage, density = 7.6 g/cm^3	ore of lead, batteries	PbS	**Galena**
	5.5–6.5		✔	black to silver	black streak, magnetic	ore of iron, steel	Fe_3O_4	**Magnetite**
	6.5		✔	brassy yellow	green-black streak, (fool's gold)	ore of sulfur	FeS_2	**Pyrite**
Either	5.5–6.5 or 1		✔	metallic silver or earthy red	red-brown streak	ore of iron, jewelry	Fe_2O_3	**Hematite**
Nonmetallic luster	1	✔		white to green	greasy feel	ceramics, paper	$Mg_3Si_4O_{10}(OH)_2$	**Talc**
	2		✔	yellow to amber	white-yellow streak	sulfuric acid	S	**Sulfur**
	2	✔		white to pink or gray	easily scratched by fingernail	plaster of paris, drywall	$CaSO_4 \cdot 2H_2O$	**Selenite gypsum**
	2–2.5	✔		colorless to yellow	flexible in thin sheets	paint, roofing	$KAl_3Si_3O_{10}(OH)_2$	**Muscovite mica**
	2.5	✔		colorless to white	cubic cleavage, salty taste	food additive, melts ice	NaCl	**Halite**
	2.5–3	✔		black to dark brown	flexible in thin sheets	construction materials	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	**Biotite mica**
	3	✔		colorless or variable	bubbles with acid, rhombohedral cleavage	cement, lime	$CaCO_3$	**Calcite**
	3.5	✔		colorless or variable	bubbles with acid when powdered	building stones	$CaMg(CO_3)_2$	**Dolomite**
	4	✔		colorless or variable	cleaves in 4 directions	hydrofluoric acid	CaF_2	**Fluorite**
	5–6	✔		black to dark green	cleaves in 2 directions at 90°	mineral collections, jewelry	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$	**Pyroxene** (commonly augite)
	5.5	✔		black to dark green	cleaves at 56° and 124°	mineral collections, jewelry	$CaNa(Mg,Fe)_4(Al,Fe,Ti)_3Si_6O_{22}(O,OH)_2$	**Amphibole** (commonly hornblende)
	6	✔		white to pink	cleaves in 2 directions at 90°	ceramics, glass	$KAlSi_3O_8$	**Potassium feldspar** (commonly orthoclase)
	6	✔		white to gray	cleaves in 2 directions, striations visible	ceramics, glass	$(Na,Ca)AlSi_3O_8$	**Plagioclase feldspar**
	6.5		✔	green to gray or brown	commonly light green and granular	furnace bricks, jewelry	$(Fe,Mg)_2SiO_4$	**Olivine**
	7		✔	colorless or variable	glassy luster, may form hexagonal crystals	glass, jewelry, electronics	SiO_2	**Quartz**
	6.5–7.5		✔	dark red to green	often seen as red glassy grains in NYS metamorphic rocks	jewelry (NYS gem), abrasives	$Fe_3Al_2Si_3O_{12}$	**Garnet**

*Chemical symbols: Al = aluminum, C = carbon, Ca = calcium, Cl = chlorine, F = fluorine, Fe = iron, H = hydrogen, K = potassium, Mg = magnesium, Na = sodium, O = oxygen, Pb = lead, S = sulfur, Si = silicon, Ti = titanium

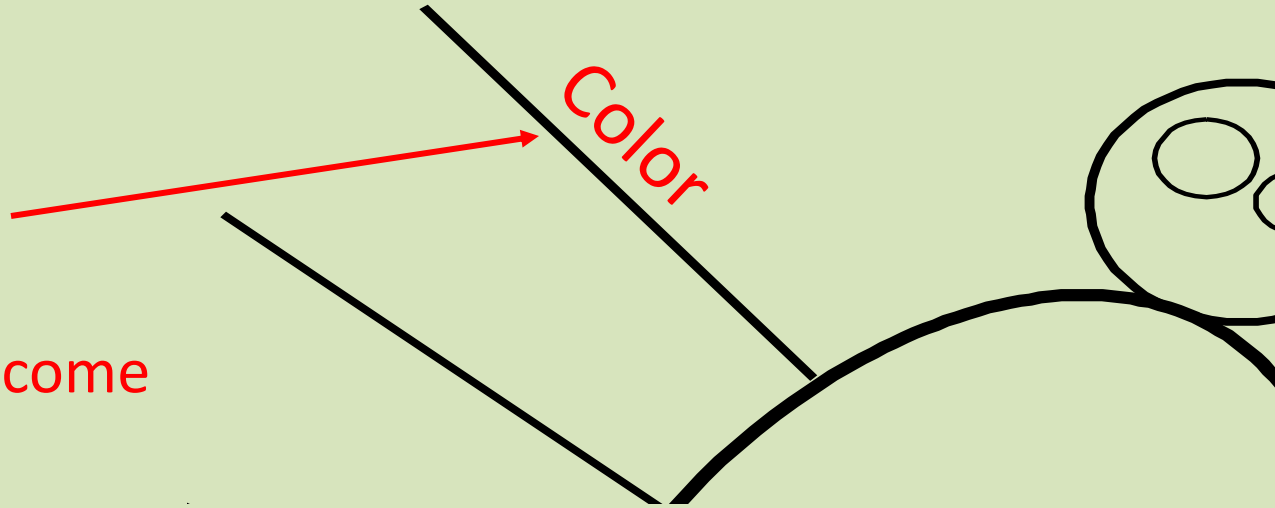
✔ = dominant form of breakage

Minerals can be identified by their chemical and physical properties.

How are Minerals Identified??

--Least useful for identification

--One mineral can come in many colors



EXAMPLE:

--Hematite: Comes in black, red and brown







How are Minerals Identified??

1. Some minerals are always the same color



Sulfur

2. Some minerals can have many colors



Smoky Quartz



Rose Quartz



Quartz

Colors can vary as a result of…

A. Chemical Impurities– Cobalt compounds tend to be pink, purple, or blue





Manganese—tends to produce pink colors

Colors can vary as a result of…

B. Oxidation—exposure to air and water changing the color of the mineral.

Ex. Rust

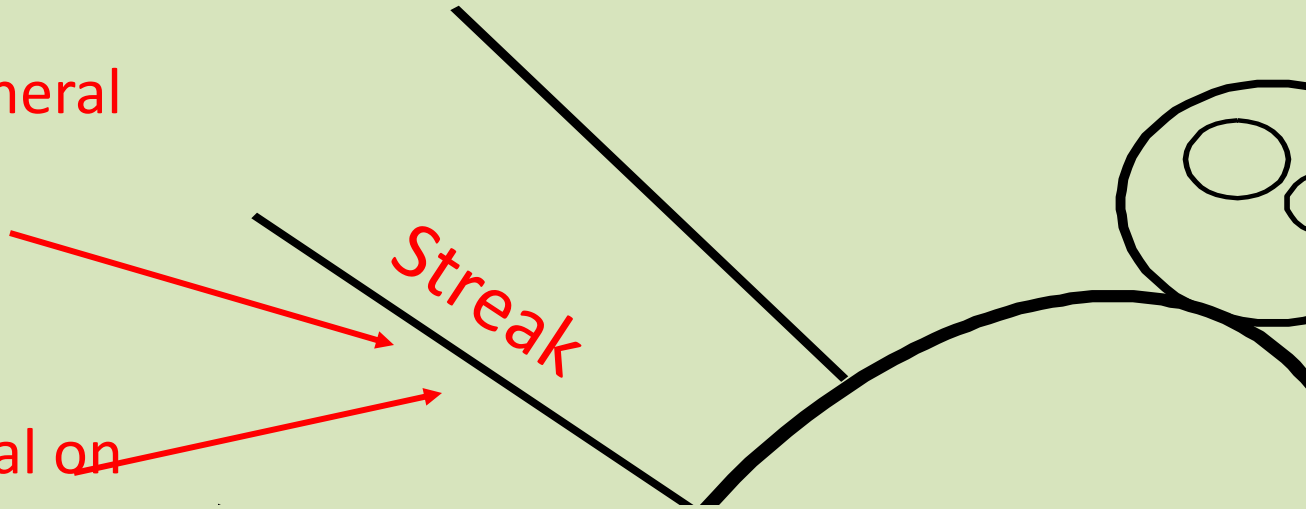


--Iron is the dominant coloring agent in rocks and soils

How are Minerals Identified??

--the color of a mineral when it is finely powdered

--determined by rubbing the mineral on a piece of tile



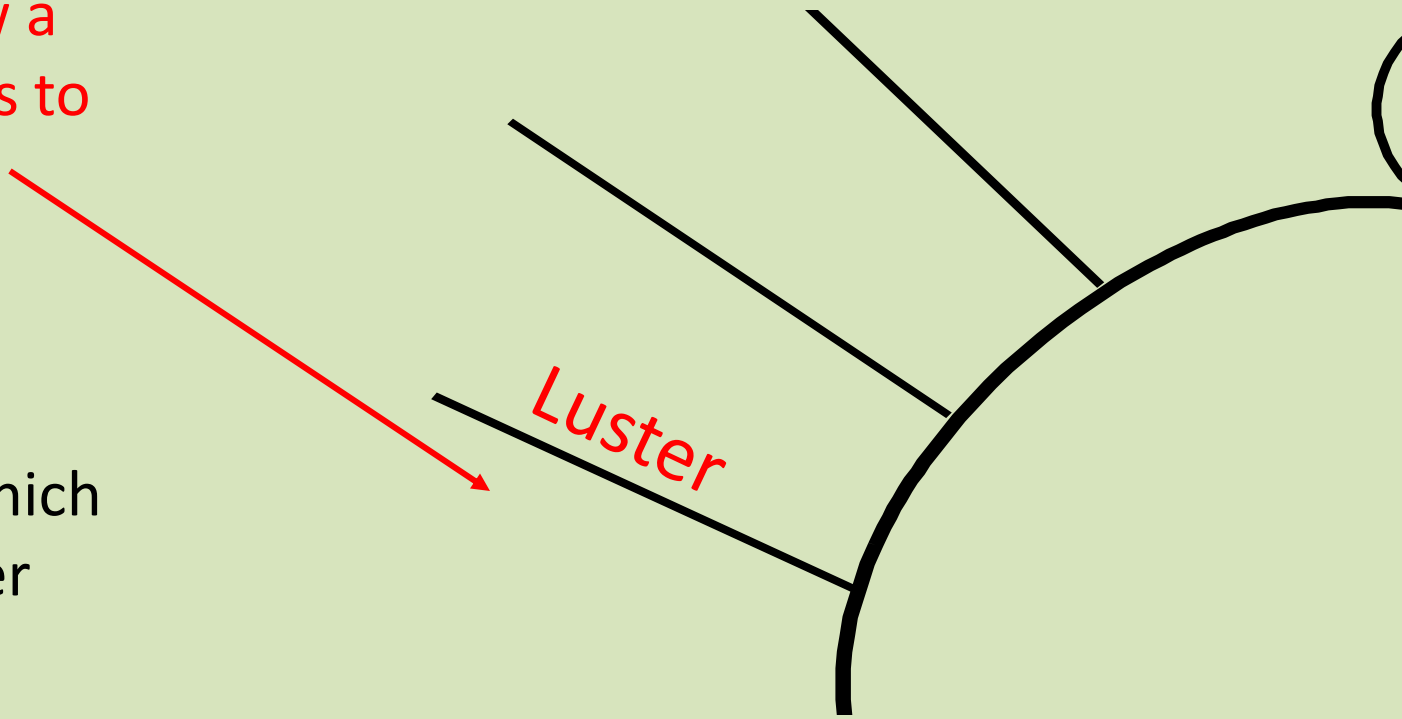
Hematite has a reddish-brown streak.



How are Minerals Identified??

--describes how a mineral appears to reflect light

There are 2 categories in which a minerals luster can fall…



Metallic OR Non-Metallic

How are Minerals Identified??

A. Metallic– reflects light like metal (shiny)



Graphite



Pyrite



Galena

How are Minerals Identified??

B. Non-Metallic—any mineral which DOES NOT exhibit shiny metallic characteristics

Ex. Quartz



Metallic or Non-Metallic??



Non-Metallic

Mica

Pearly luster



Metallic

Magnetite

Metallic or Non-Metallic??



Non-Metallic

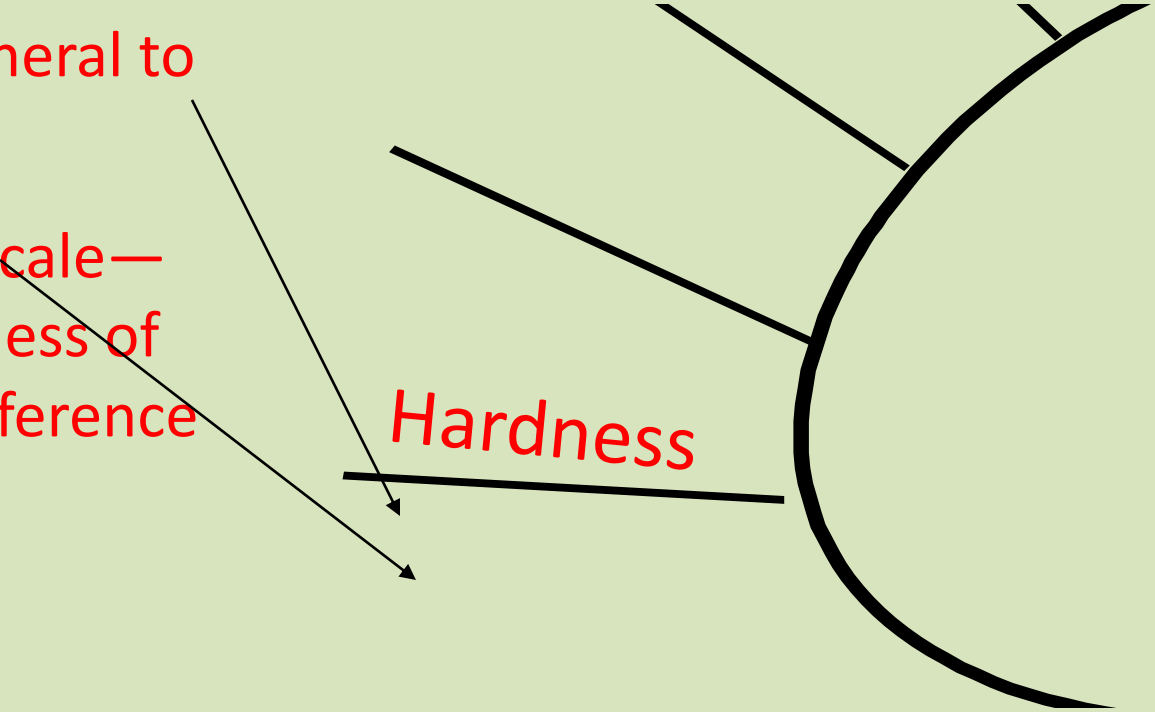
Pyroxene

Dull luster

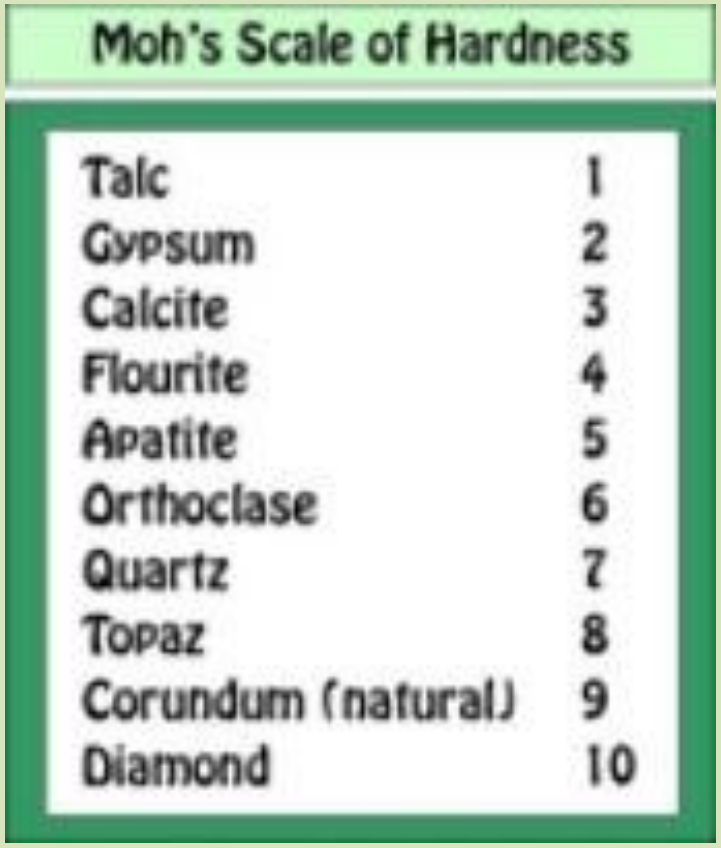
How are Minerals Identified??

--Resistance of a mineral to being scratched

--Moh's Hardness Scale—compares the hardness of the mineral to 10 reference minerals.



How is Hardness Determined??



Softest

Hardest

The scale consists of number 1 through 10; 1 being the softest and 10 being the hardest. Each number represents a different mineral- each harder than the previous. The 10 minerals are to the left.

How is Hardness Determined??

Several common household items have a fixed hardness, and can be used to test for hardness.

-Fingernail = 2.5
-Copper penny = 3-3.5
-Nail = 4.5
-Knife blade = 5.5
-Glass = 5.5
-Steel file = 6.5
-Streak plate = 7









What Determines Hardness?

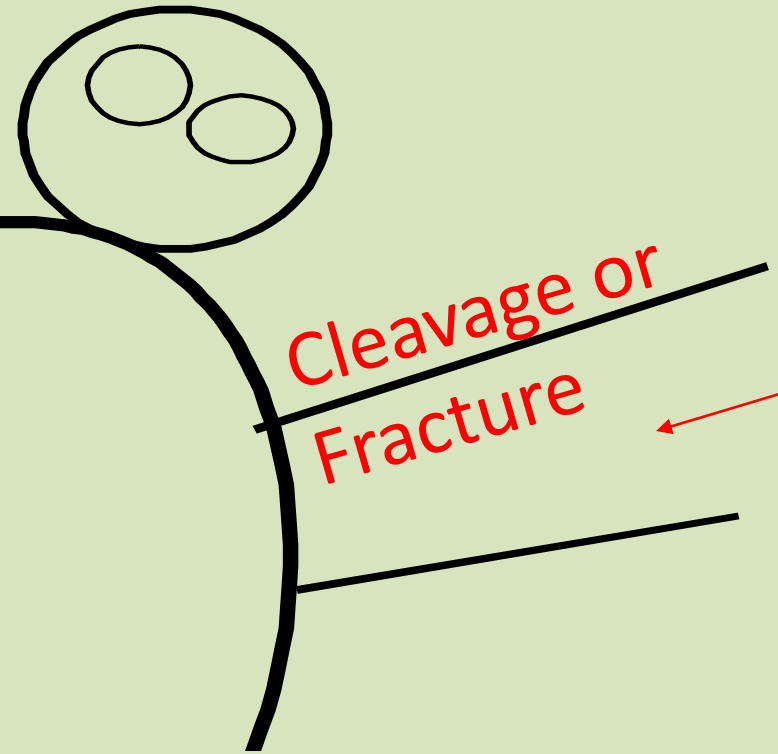
--Hardness is determined by a minerals internal arrangement of atoms.

Ex. Diamond vs. Graphite

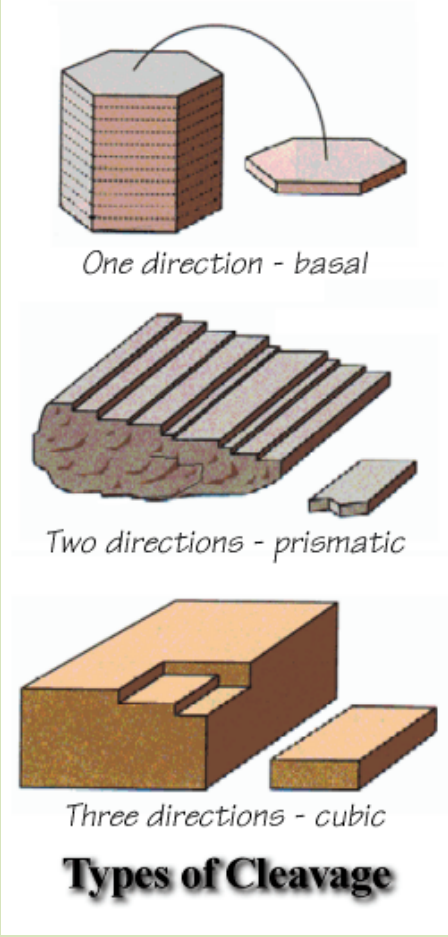
-Diamond has hardness of 10 and graphite is ranked between 1 and 2. Diamond is about 40 times harder than graphite due to the way the atoms are arranged.

--Hardness is the best property to use to identify a mineral.

How are Minerals Identified??



Cleavage—when a mineral breaks along a flat, smooth surface



Examples of Minerals that show Cleavage

Mica exhibits basal cleavage.



Galena exhibits cubic cleavage.

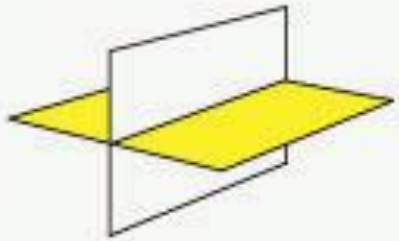






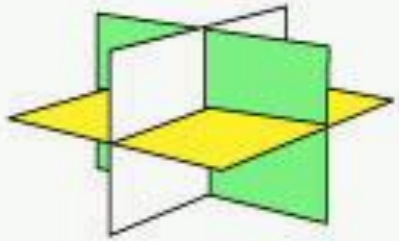
Cleavage in one direction. Example: MUSCOVITE





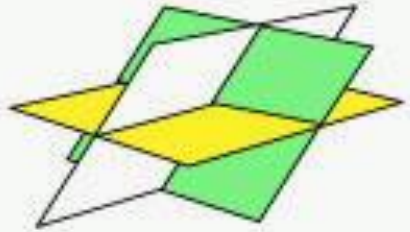
Cleavage in two directions. Example: FELDSPAR





Cleavage in three directions. Example: HALITE



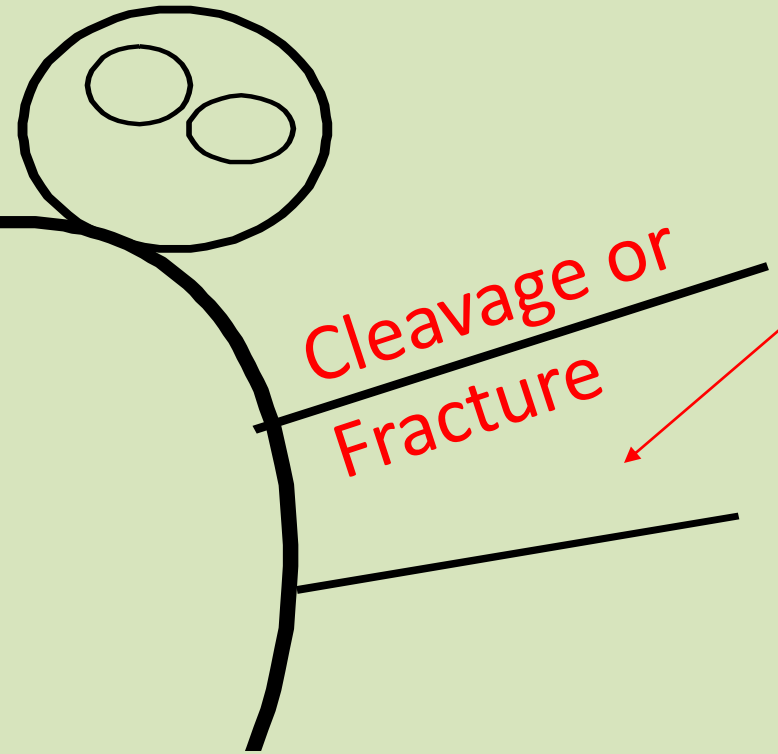


Cleavage in two directions. Example: CALCITE

What Determines Cleavage and Hardness?

A minerals internal arrangement of atoms!!

How are Minerals Identified??

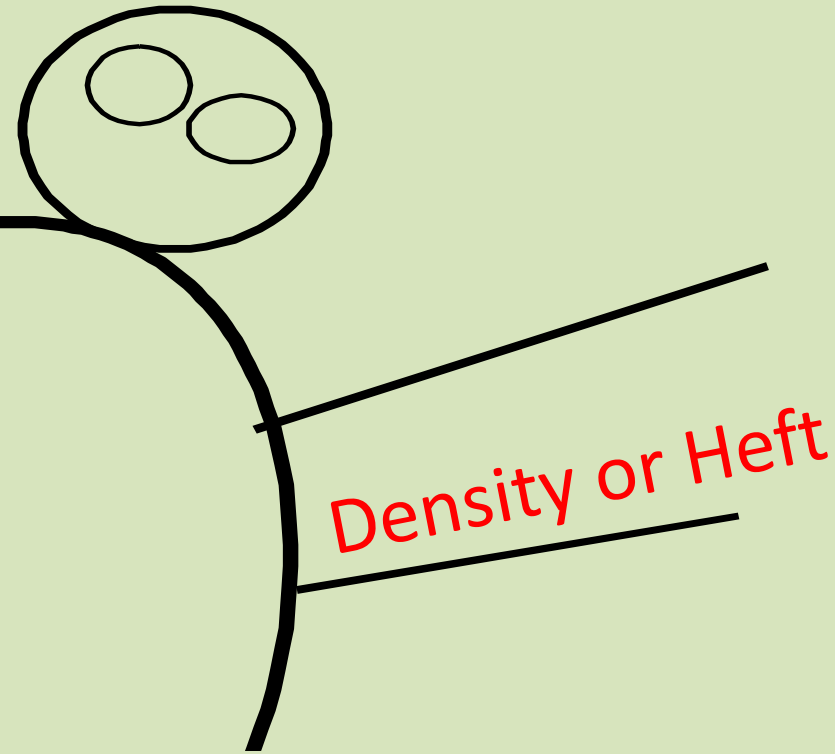


Fracture—When a mineral breaks along irregular rough surfaces.

EX. Quartz



How are Minerals Identified??



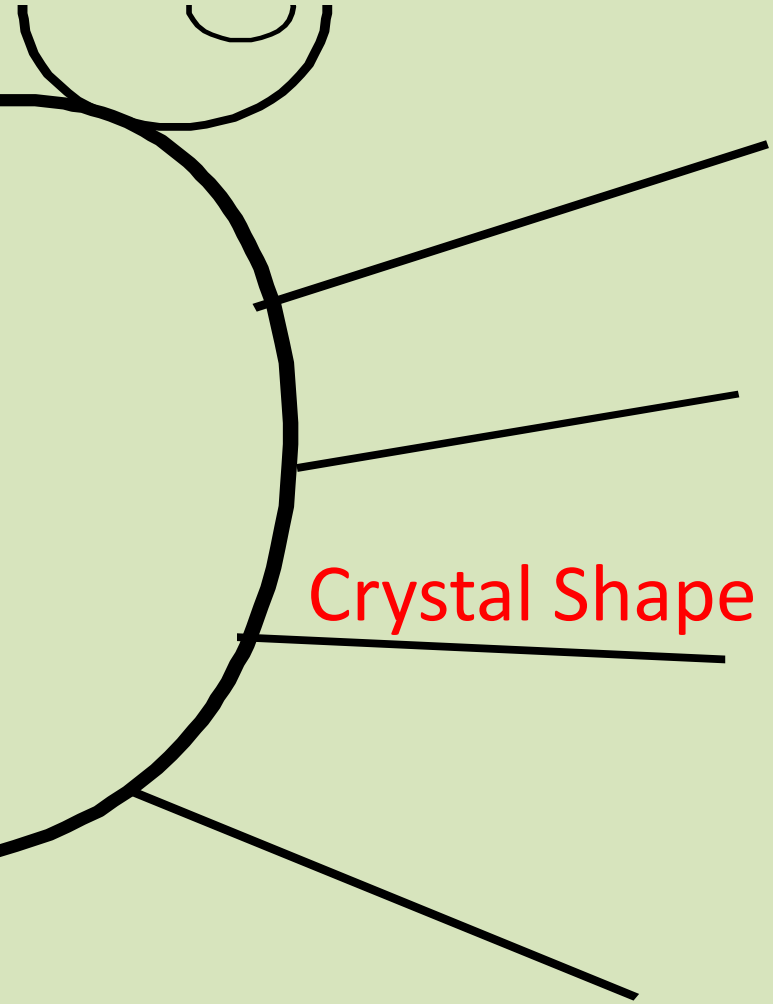
--The amount of matter in a given space (mass/volume)

Depends on…

-kind of atoms which make up the mineral

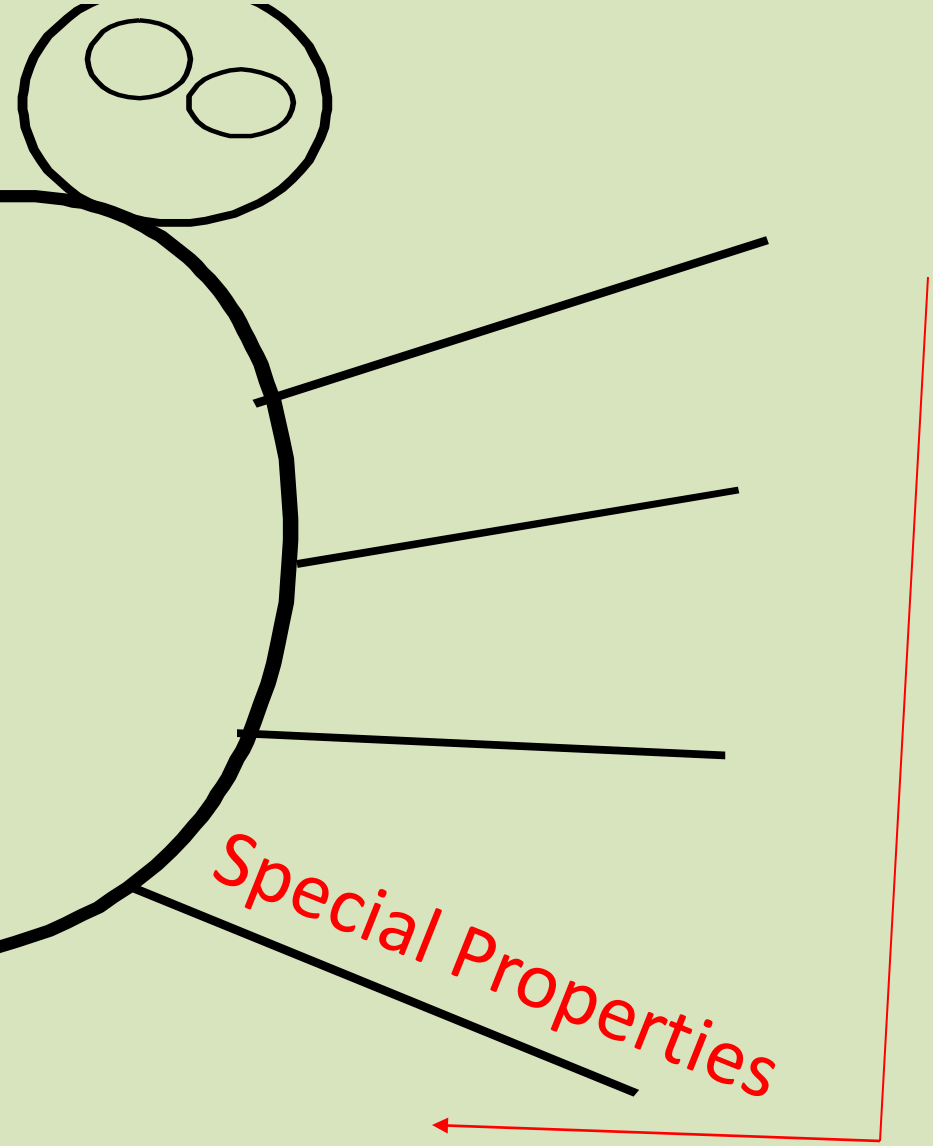
-how the atoms are arranged in the crystal lattice

How are Minerals Identified??



--Minerals have a characteristic crystal shape resulting from the atomic packing of the atoms when the mineral is forming

How are Minerals Identified??



-Magnetism (Magnetite)

-Glowing under ultraviolet light (Fluorite)

-Salty taste (Halite)

-Smell (Sulfur)

-Reaction to HCl (Calcite)


THANK YOU

Engineering Geology
PCC-CE202



Optical Property of Minerals
Module 1

Dr. Akash Priyadarshee
Department of Civil Engineering
MIT Muzaffarpur

Optical properties of minerals

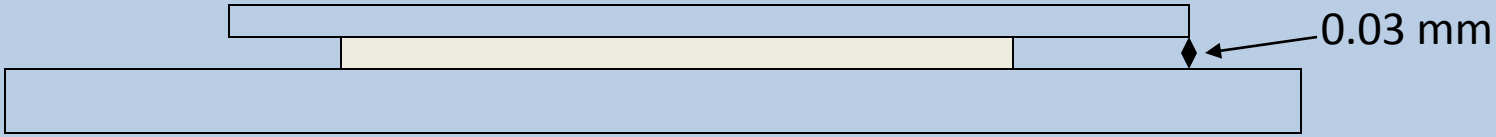
Petrographic Microscope



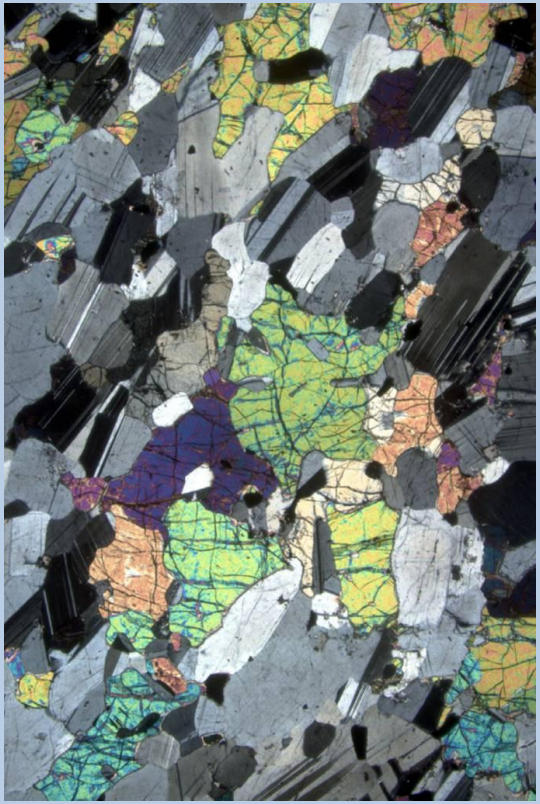
Thin section

Thin rectangular slice of rock that light can pass through.

- One side is polished smooth and then
- stuck to a glass slide with epoxy resin
- The other side is ground to 0.03 mm thickness, and then polished smooth.
- May be covered with a thin glass cover slip

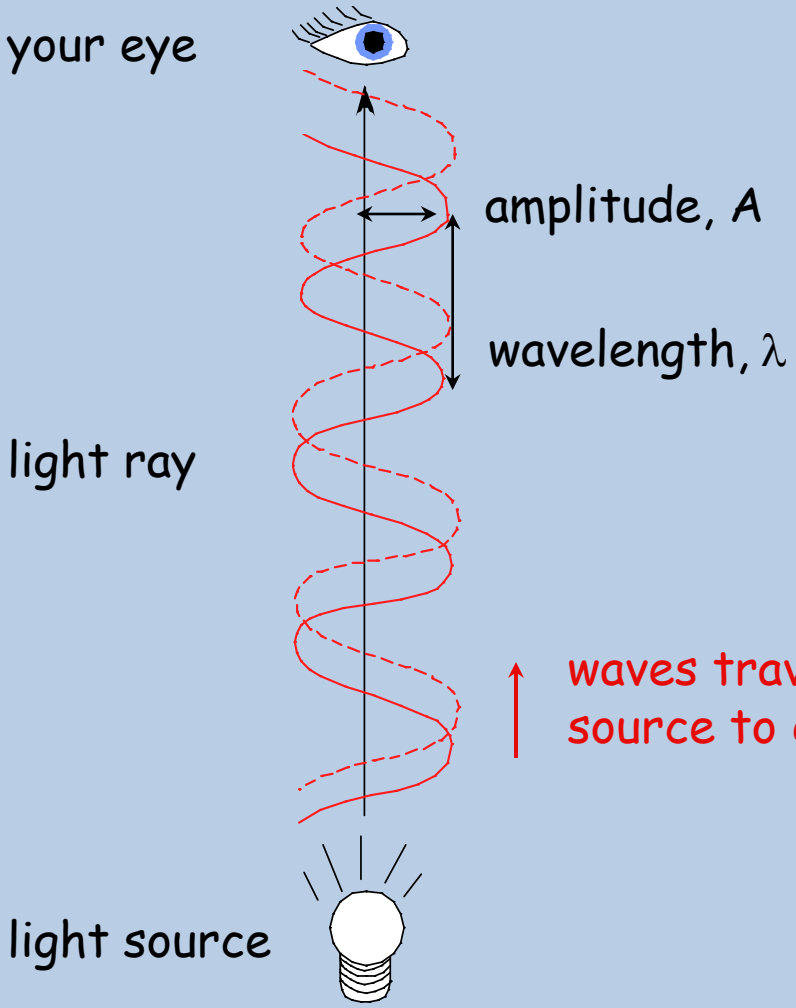


Why use the microscope??



- Identify minerals *(no guessing!)*
- Determine rock type
- Determine crystallization sequence
- Document deformation history
- Observe frozen-in reactions
- Constrain P-T history
- Note weathering/alteration
- Fun, powerful, and cheap!

What happens as light moves through the scope?



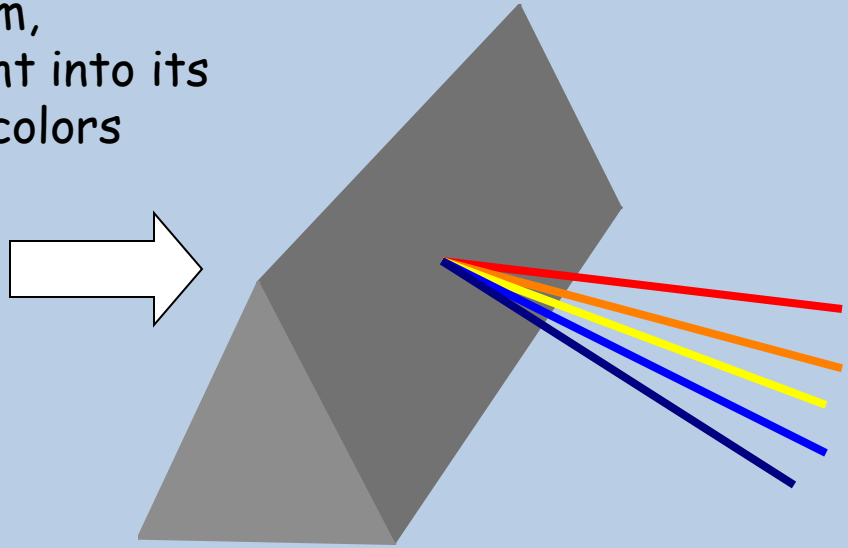
light travels as waves

What happens as light moves through the scope?

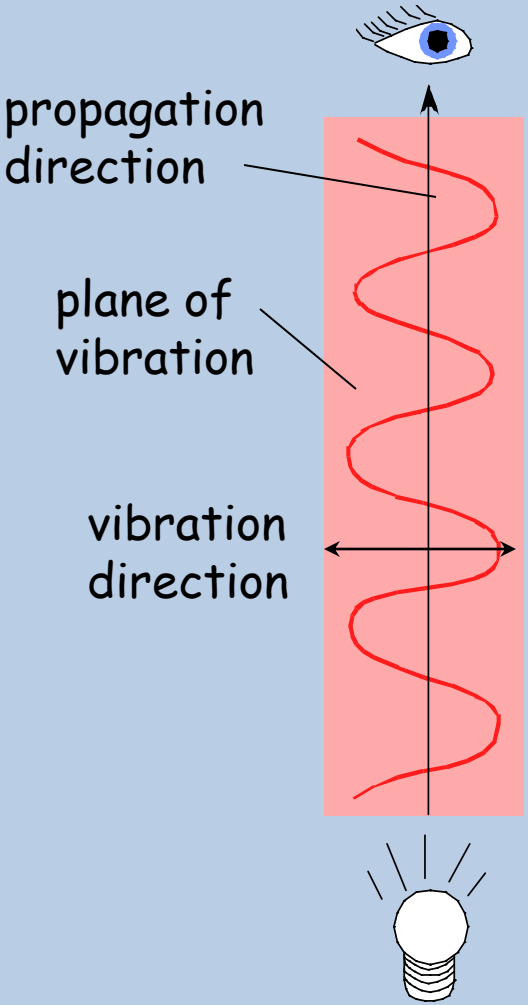


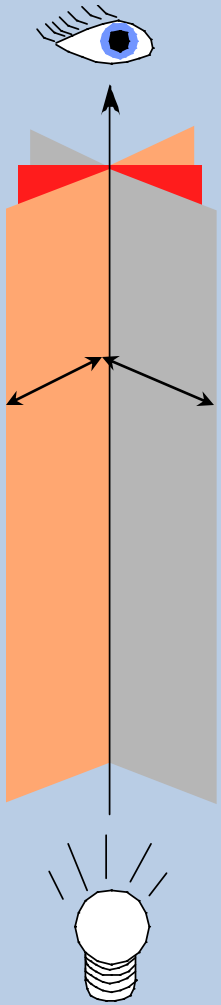
Microscope light is **white light**,
i.e. it's made up of lots of different wavelengths;
Each wavelength of light corresponds to a different color

Can prove this with a prism,
which separates white light into its constituent wavelengths/colors



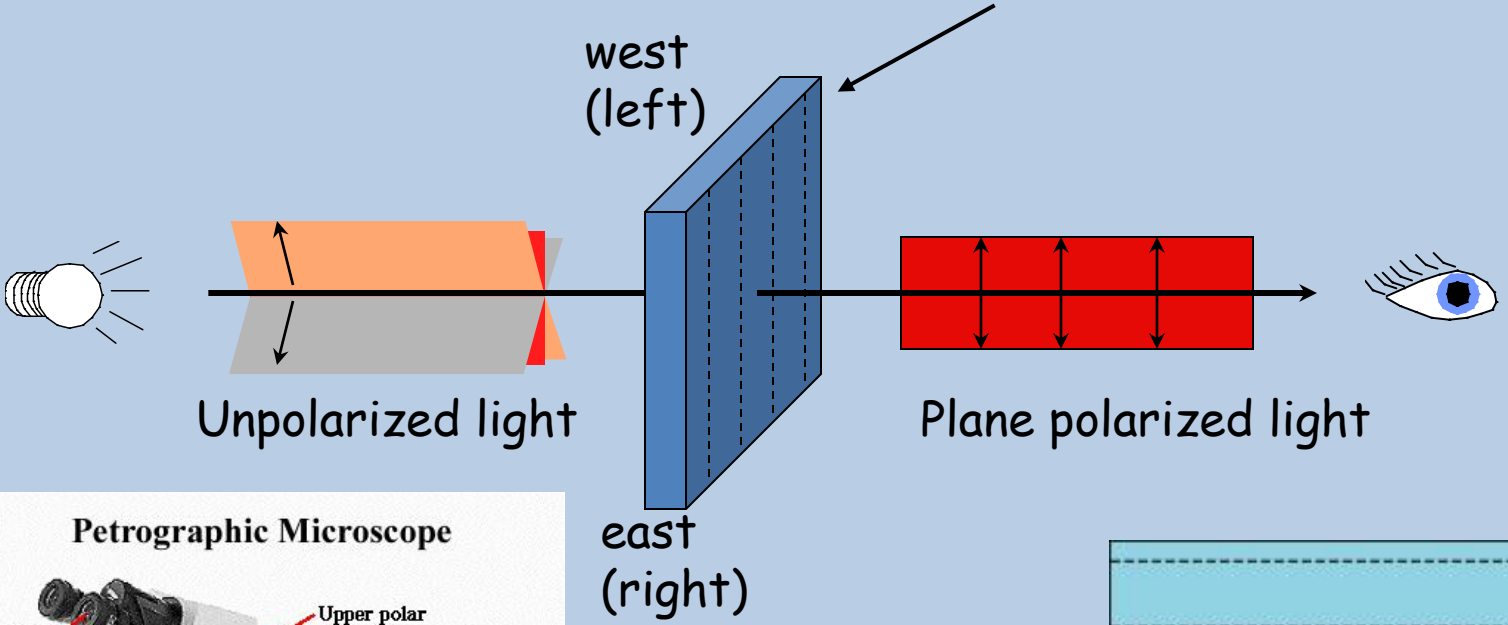
What happens as light moves through the scope?

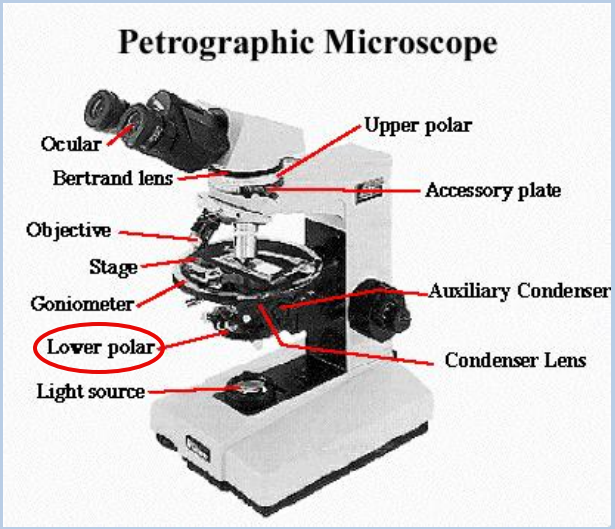




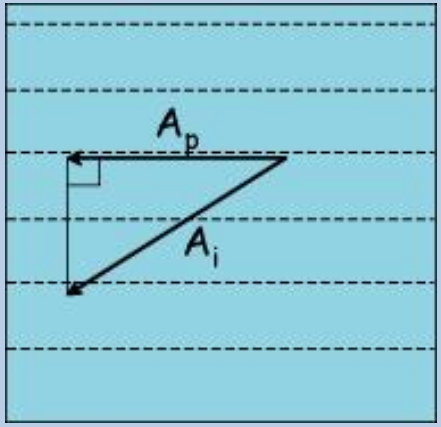
light vibrates in all planes that contain the light ray (i.e., all planes perpendicular to the propagation direction

1) Light passes through the **lower polarizer**



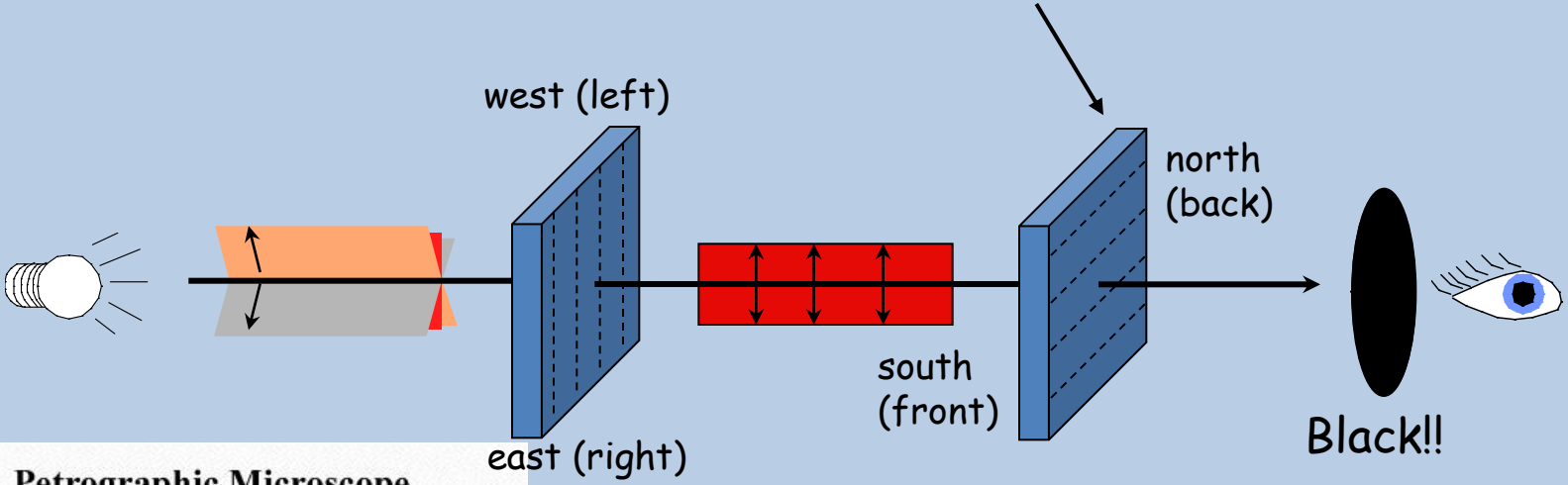


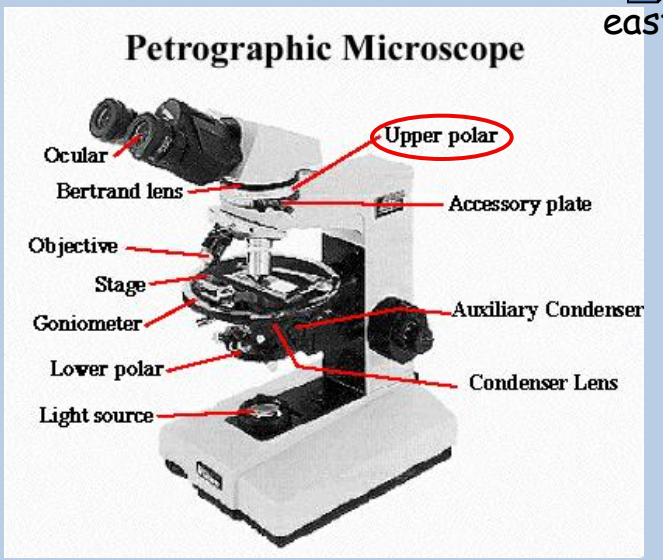
PPL=plane polarized light



Only the component of light vibrating in E-W direction can pass through lower polarizer – **light intensity decreases**

2) Insert the **upper polarizer**



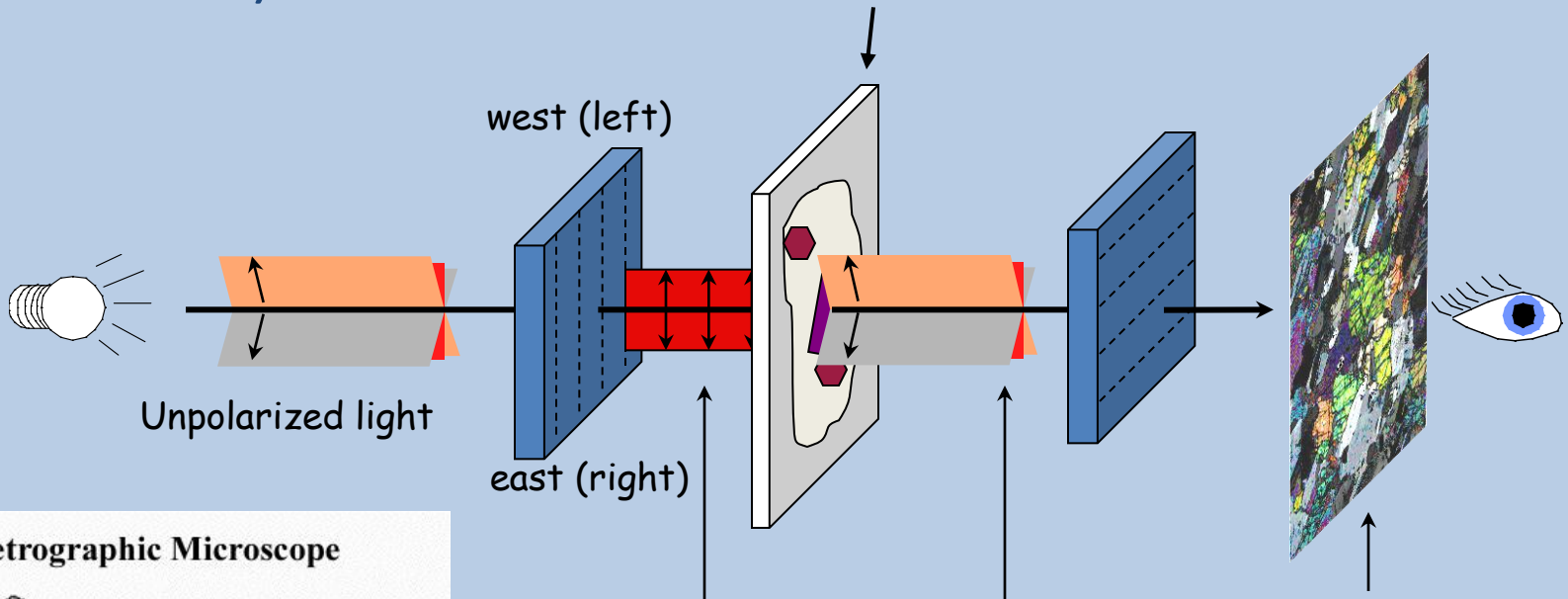


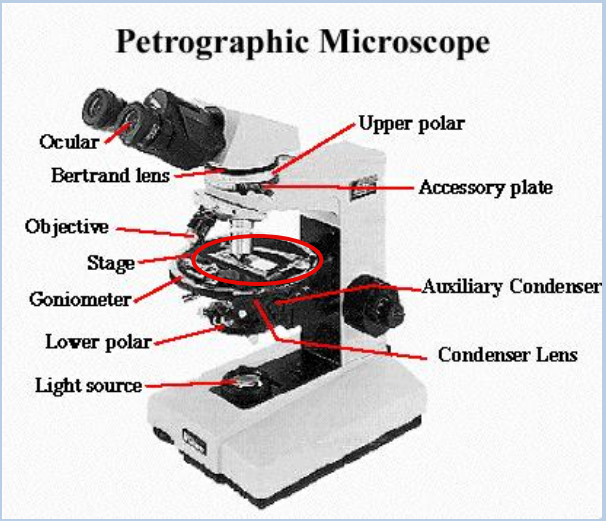
Now what happens?
What reaches your eye?

Why would anyone design a microscope that prevents light from reaching your eye???

XPL=crossed nicols
(crossed polars)

3) Now insert a **thin section** of a rock

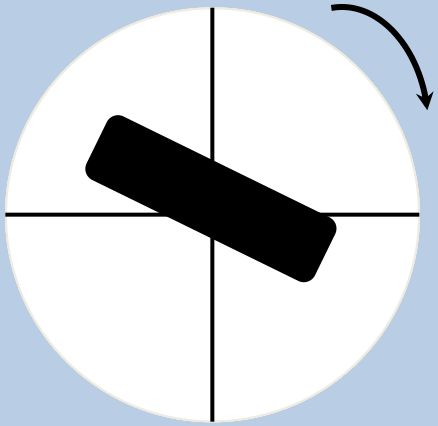




How does this work??

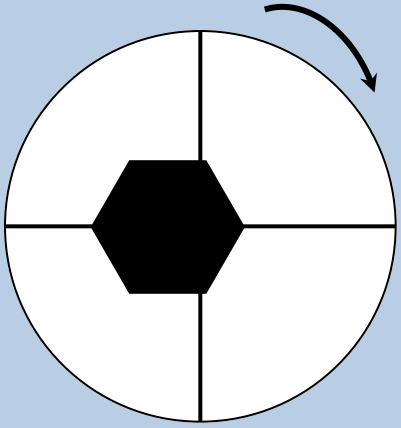
4) Note the rotating stage

Most mineral grains change color as the stage is rotated; these grains go black 4 times in 360° rotation-exactly every 90°



These minerals are anisotropic

Glass and a few minerals stay black in all orientations



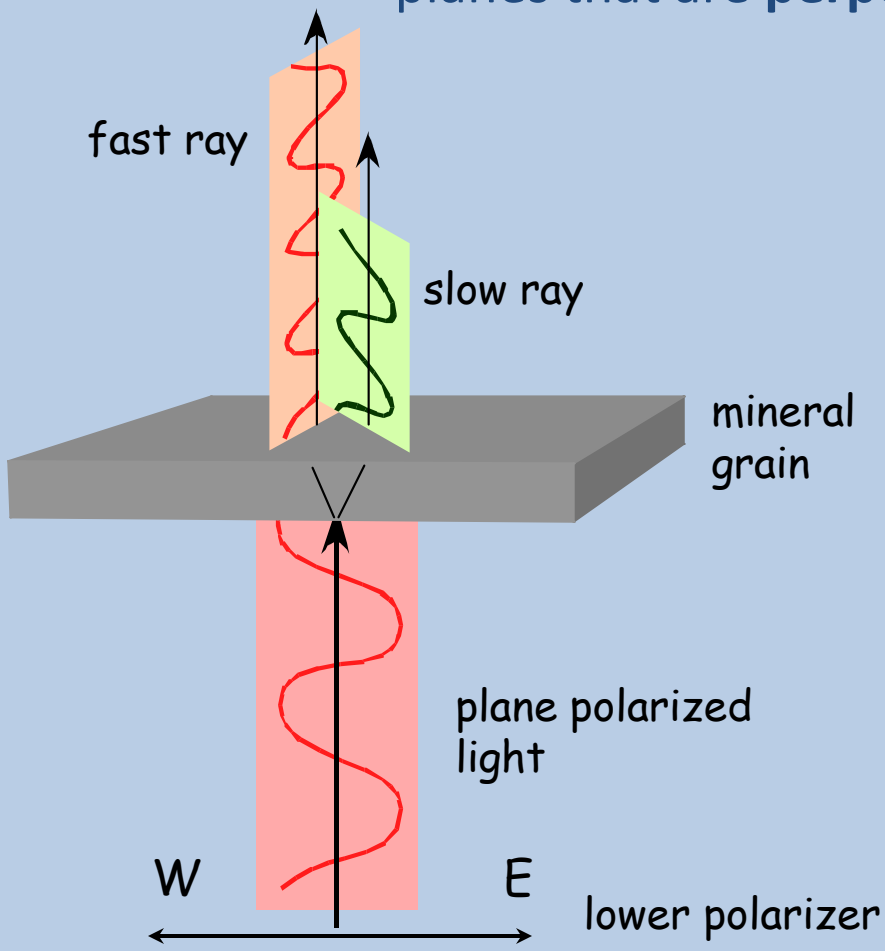
These minerals are isotropic

Now do question 1

Some generalizations and vocabulary

- All isometric minerals (e.g., *garnet*) are **isotropic** – they cannot reorient light. These minerals are always black in crossed polars.
- All other minerals are **anisotropic** – they are all capable of reorienting light (acting as magicians).
- All anisotropic minerals contain one or two special directions that do **not** reorient light.
  - Minerals with **one** special direction are called **uniaxial**
  - Minerals with **two** special directions are called **biaxial**

All **anisotropic** minerals can resolve light into **two** plane polarized components that travel at **different velocities** and vibrate in planes that are **perpendicular** to one another



Some light is now able to pass through the upper polarizer

When light gets split:
-velocity changes
-rays get bent (refracted)
-2 new vibration directions
-usually see new colors

A brief review…



- Isotropic minerals: light does not get rotated or split; propagates with same velocity in all directions

- Anisotropic minerals:
  - Uniaxial - light entering in all but **one** special direction is resolved into 2 plane polarized components that vibrate perpendicular to one another and travel with different speeds
  - Biaxial - light entering in all but **two** special directions is resolved into 2 plane polarized components…



  - Along the special directions ("optic axes"), the mineral thinks that it is isotropic - i.e., no splitting occurs
  - Uniaxial and biaxial minerals can be further subdivided into optically positive and optically negative, depending on orientation of fast and slow rays relative to xtl axes

How light behaves depends on crystal structure

(there is a reason you took mineralogy!)

Isotropic → Isometric

- All crystallographic axes are equal

Uniaxial → Hexagonal, trigonal, tetragonal

Biaxial

- All axes ⊥ c are equal but c is unique

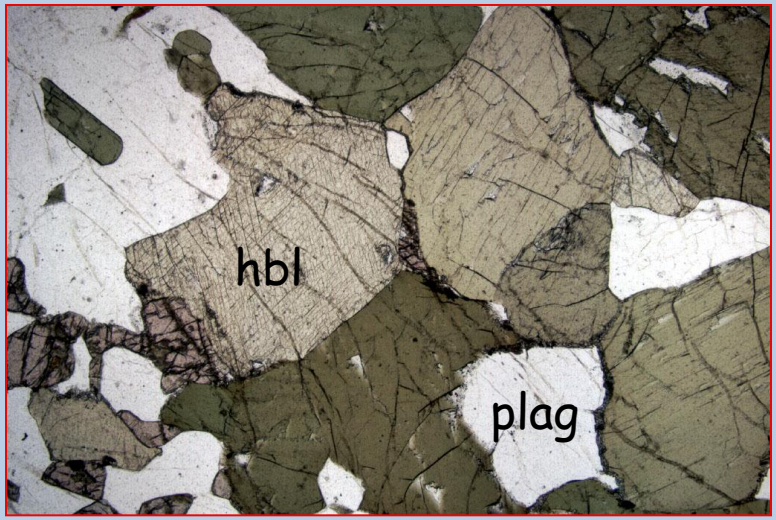
→ Orthorhombic, monoclinic, triclinic

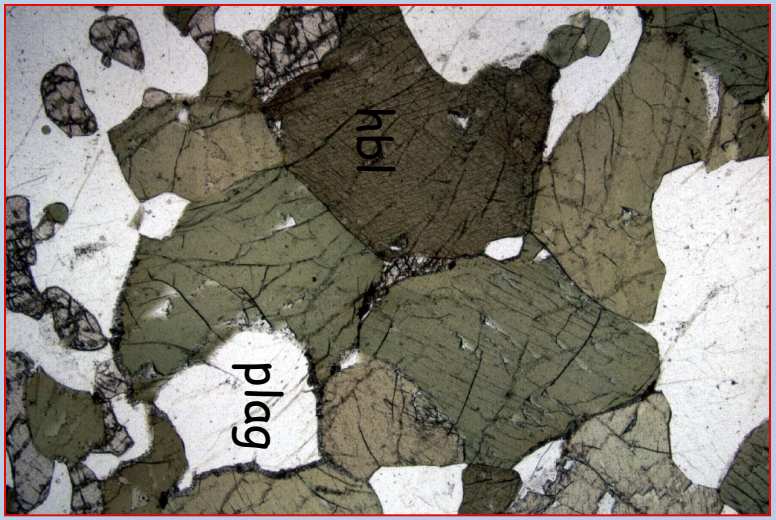
- All axes are unequal

Let's use all of this information to help us identify minerals

Mineral properties: **color & pleochroism**

- Color is observed only in PPL
- Not an inherent property - changes with light type/intensity
- Results from selective absorption of certain λ of light
- Pleochroism results when different λ are absorbed differently by different crystallographic directions - rotate stage to observe





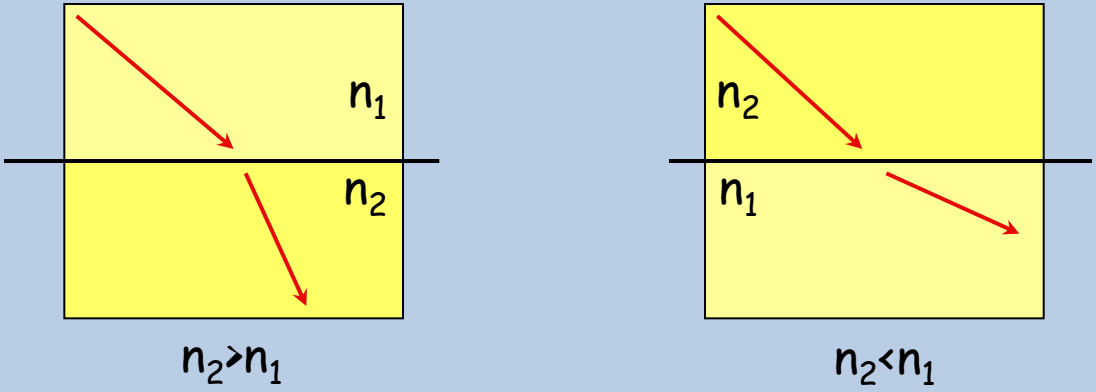
-Plagioclase is colorless
-Hornblende is pleochroic in olive greens

Now do question 2

Mineral properties: Index of refraction (R.I. *or* n)

$$n = \frac{\text{velocity in air}}{\text{velocity in mineral}}$$

Light is refracted when it passes from one substance to another; refraction is accompanied by a change in velocity

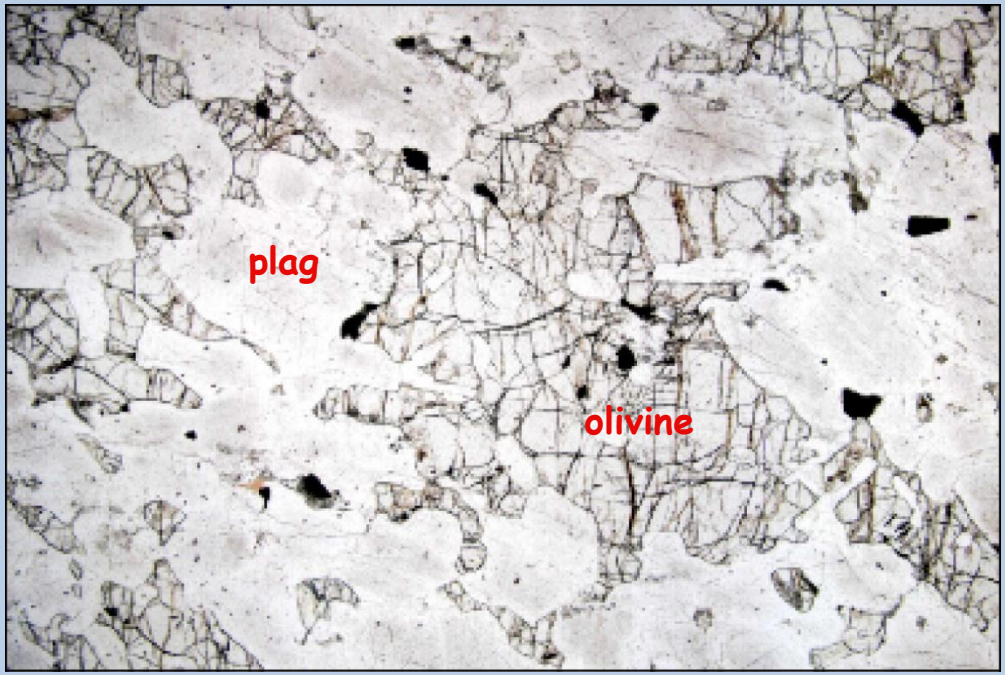


$n_2 > n_1$ $\quad$ $n_2 < n_1$

- n is a function of crystallographic orientation in anisotropic minerals
  - ⇨ isotropic minerals: characterized by one RI
  - ⇨ uniaxial minerals: characterized by two RI
  - ⇨ biaxial minerals: characterized by three RI
- n gives rise to 2 easily measured parameters: relief & birefringence

Mineral properties: **relief**

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n



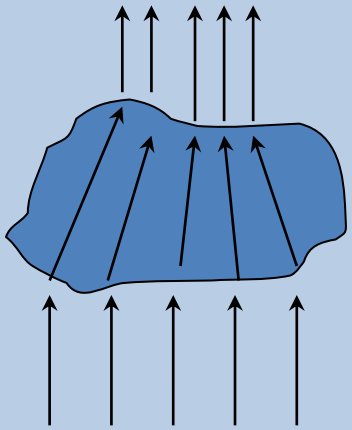
- Olivine has high relief
- Plag has low relief

olivine:	n=1.64-1.88
plag:	n=1.53-1.57
epoxy:	n=1.54

What causes relief?

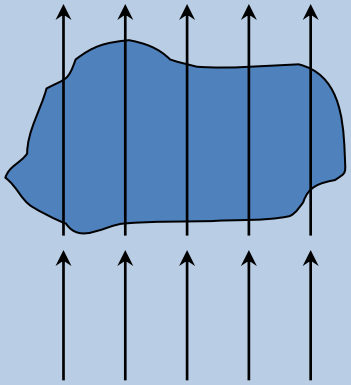
Difference in speed of light (n) in different materials causes refraction of light rays, which can lead to focusing or defocusing of grain edges relative to their surroundings

Hi relief (+)



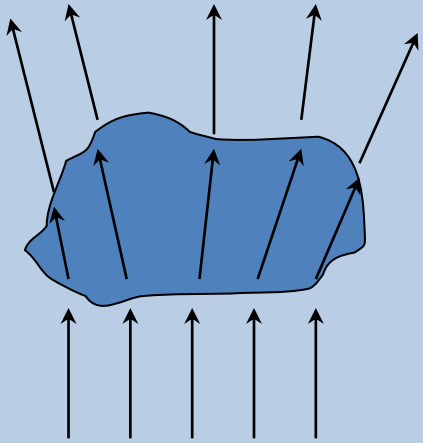
$n_{xtl} > n_{epoxy}$

Lo relief (+)



$n_{xtl} = n_{epoxy}$

Hi relief (-)

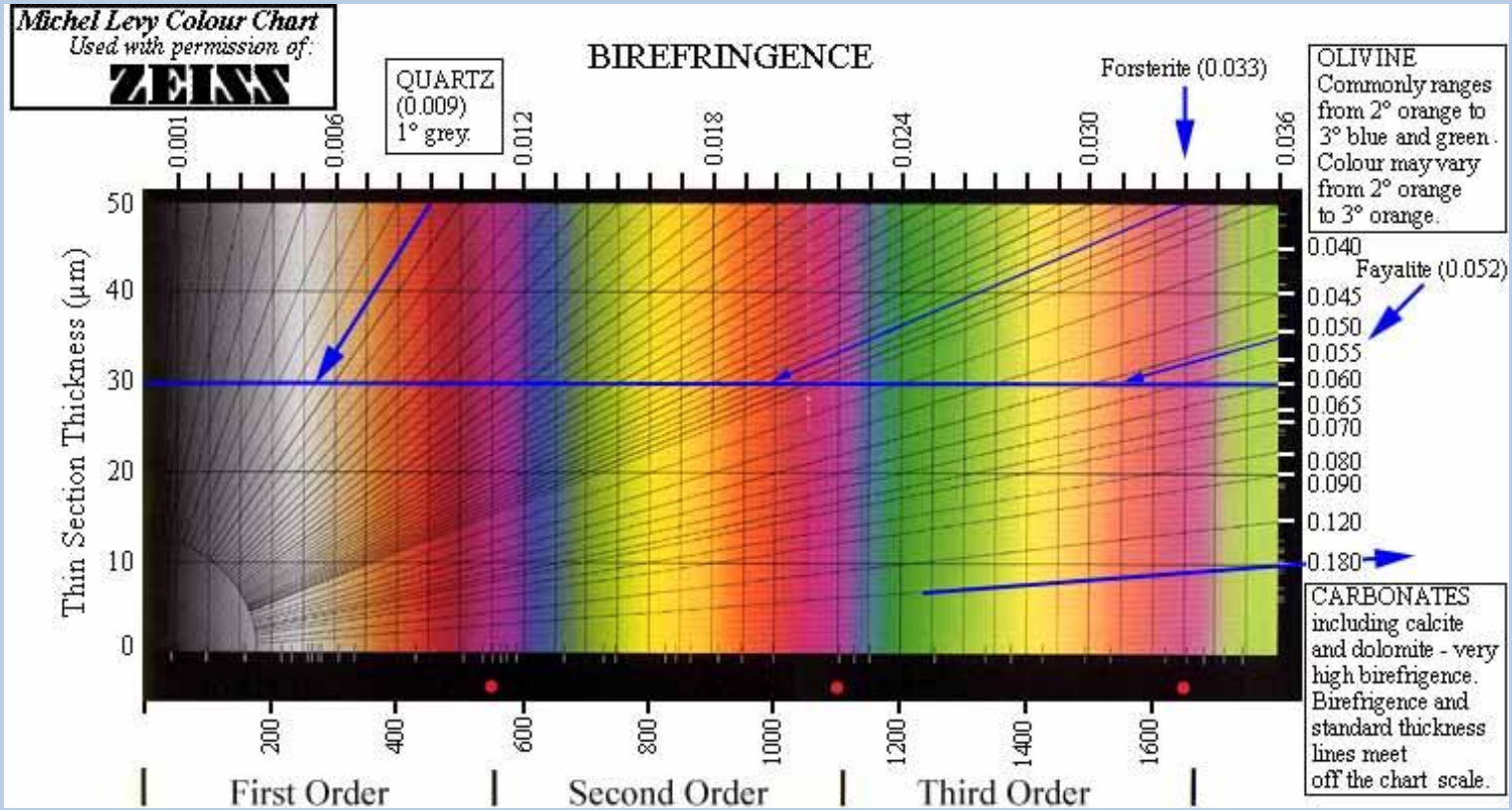


$n_{xtl} < n_{epoxy}$

Now do question 3

Mineral properties: interference colors/**birefringence**

- Colors one observes when polars are crossed (XPL)
- Color can be quantified numerically: $\delta = n_{high} - n_{low}$

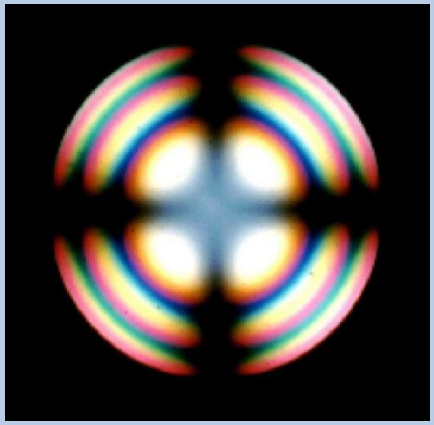


Now do question 4

More on this next week…

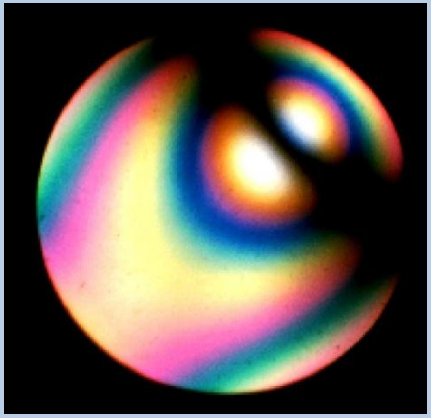
Use of interference figures, continued…

You will see a very small, circular field of view with one or more black **isogyres** -- rotate stage and watch isogyre(s)

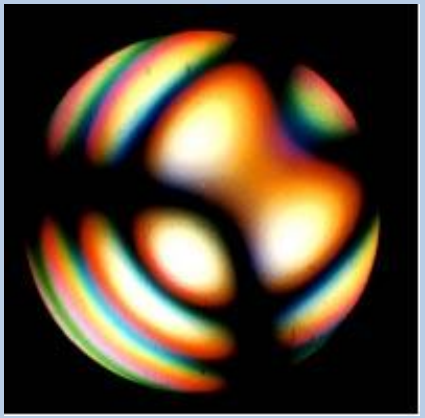


uniaxial

If uniaxial, isogyres define cross; arms remain N-S/E-W as stage is rotated



or



biaxial

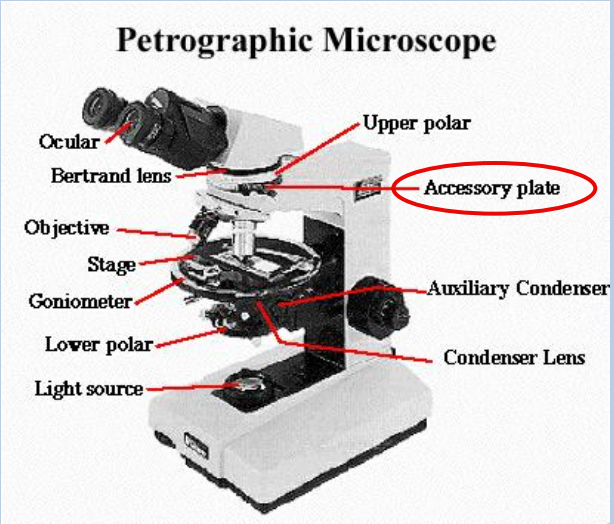
If biaxial, isogyres define curve that rotates with stage, or cross that breaks up as stage is rotated

Use of interference figures, continued…

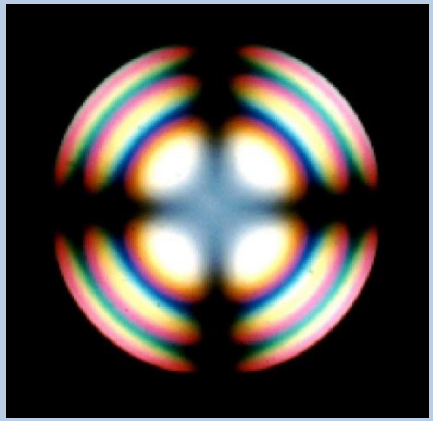
Now determine the optic sign of the mineral:

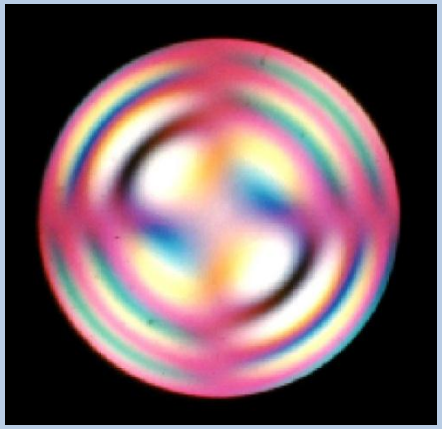
1. Rotate stage until isogyre is concave to NE (if biaxial)
2. Insert gypsum accessory plate
3. Note color in NE, immediately adjacent to isogyre --
   - Blue = (+)
   - Yellow = (-)

Now do question 5



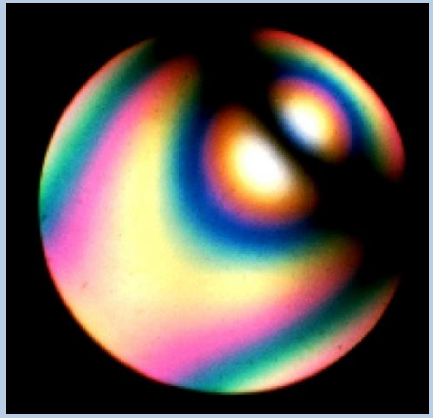
uniaxial

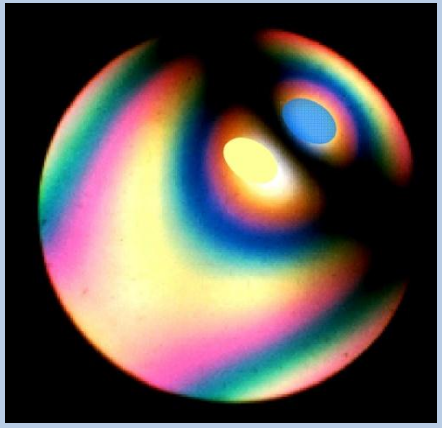




(+)

biaxial





(+)

A brief review…



- Isotropic minerals: light does not get rotated or split; propagates with same velocity in all directions

- Anisotropic minerals:
  - Uniaxial - light entering in all but **one** special direction is resolved into 2 plane polarized components that vibrate perpendicular to one another and travel with different speeds
  - Biaxial - light entering in all but **two** special directions is resolved into 2 plane polarized components…



  - Along the special directions ("optic axes"), the mineral thinks that it is isotropic - i.e., no splitting occurs
  - Uniaxial and biaxial minerals can be further subdivided into optically positive and optically negative, depending on orientation of fast and slow rays relative to xtl axes

You are now well on your way to being able to identify all of the common minerals (and many of the uncommon ones, too)!!

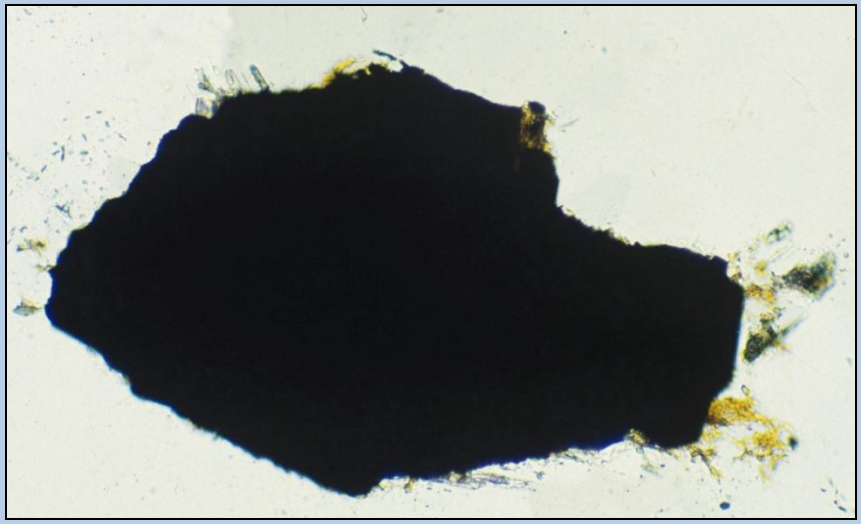
Opaque Mineral

Sulphides and oxides

PPL does not pass through

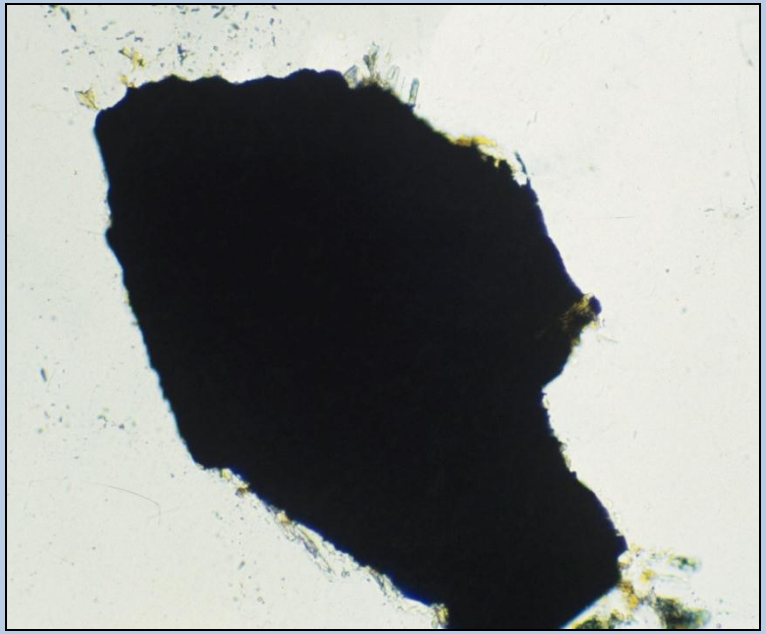
Minerals looks black in PPL regardless of orientation of mineral or polarizers

Mineral cannot be identified in transmitted light; needs reflected light



Opaque mineral in granite

Rotated 45° in PPL

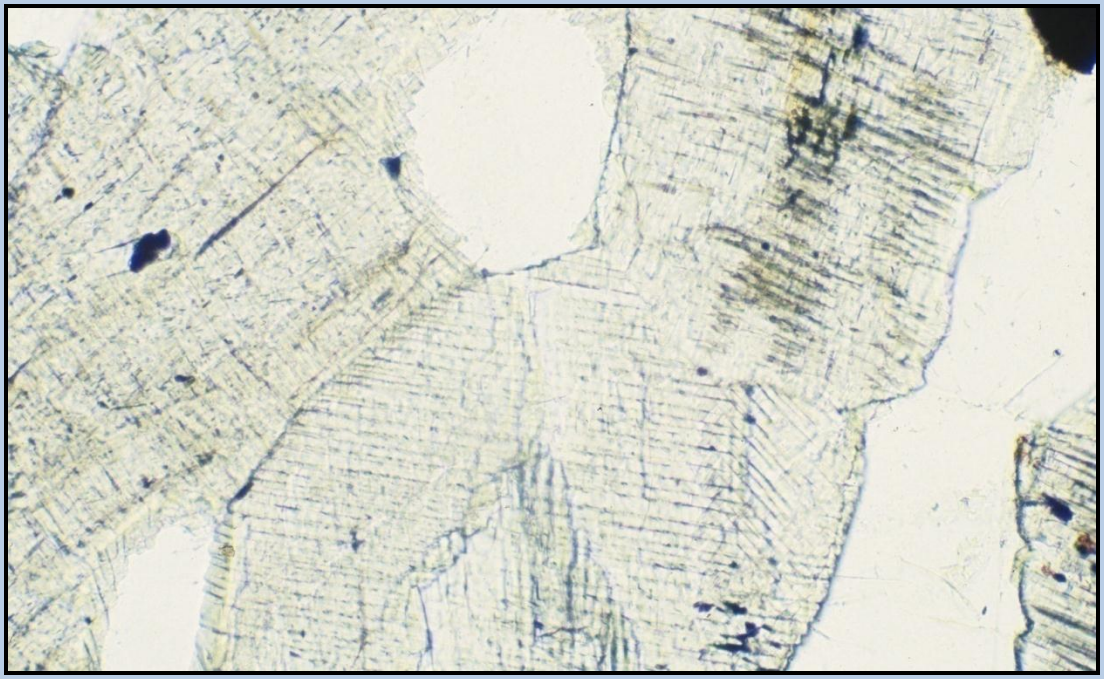


Transparent mineral

PPL passes through the 30μm thickness of the thin section

The electromagnetic light waves interact with the electrons in the minerals and slow down

The higher the density of electrons the slower the light wave travels



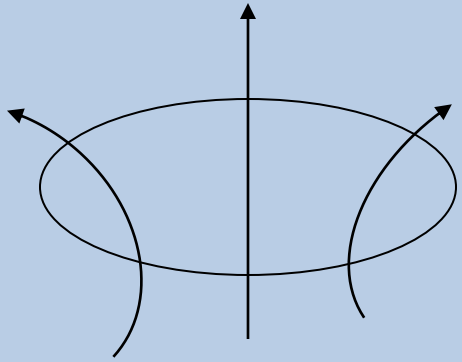
CPX in gabbro
PPL

Becke Line

A white line of light between two minerals allows the Relative Refractive Index (R.R.I.) to be measured

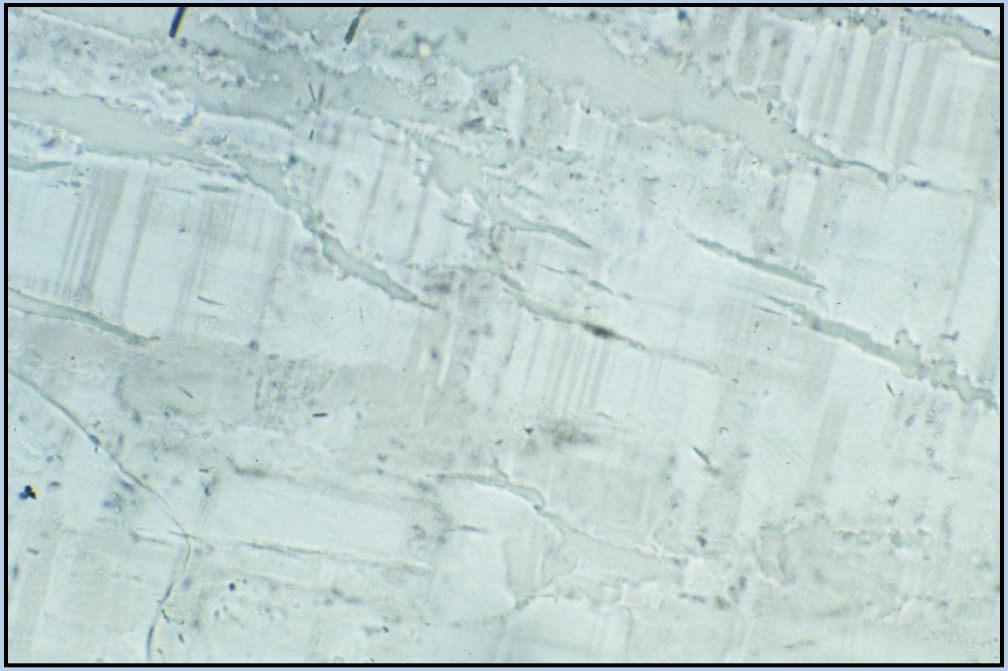
This is relative to an adjacent medium which can be glass, epoxy, or another mineral

R.I. epoxy: 1.54 to 1.55



The edge of the grain acts like a lens distorting the light

Perthite:
Microcline with exsolved albite showing Becke Line between the two minerals
(PPL)



To measure relative refractive index of two touching minerals or mineral/epoxy

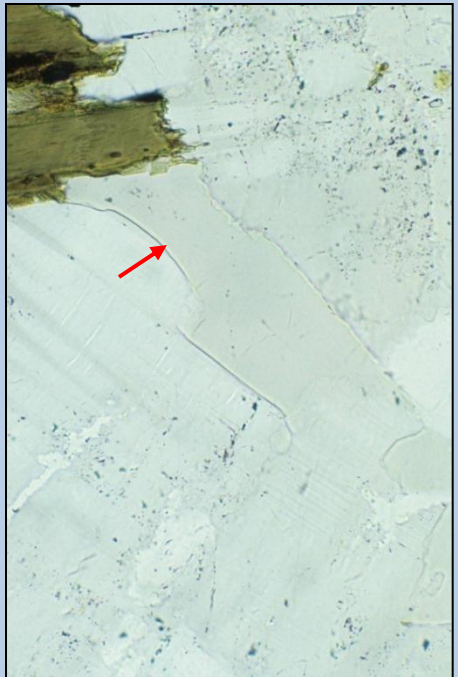
Use PPL (upper polarizer out)

Partly close the substage diaphragm, reducing light by 50-75%

Slightly raise and lower the microscope stage, observing the movement of the Becke Line at boundary of grain.

When **decreasing** the distance between the ocular and the stage, (raising the stage) the line moves into the material of **lower** R.I.



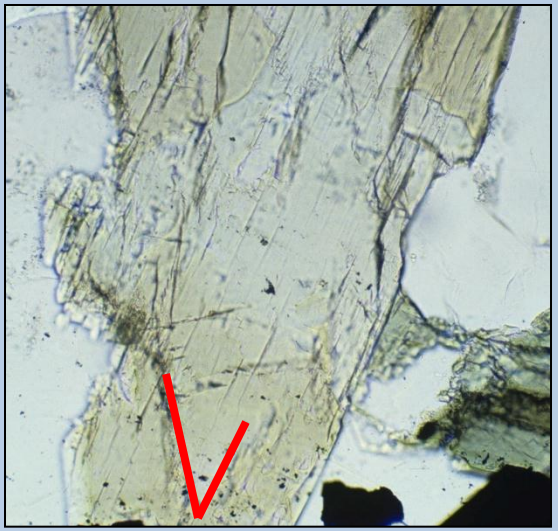




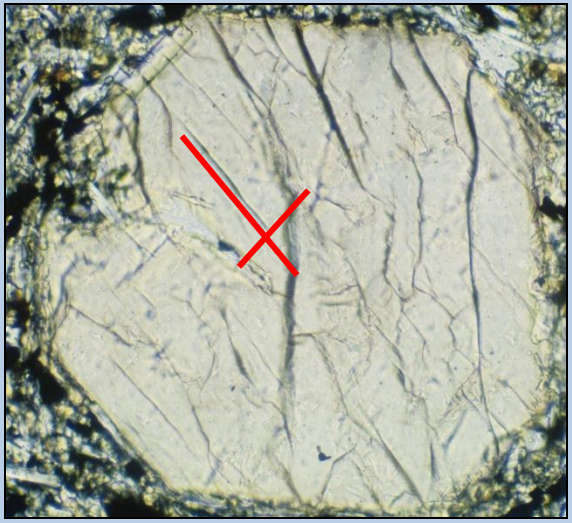


Cleavage

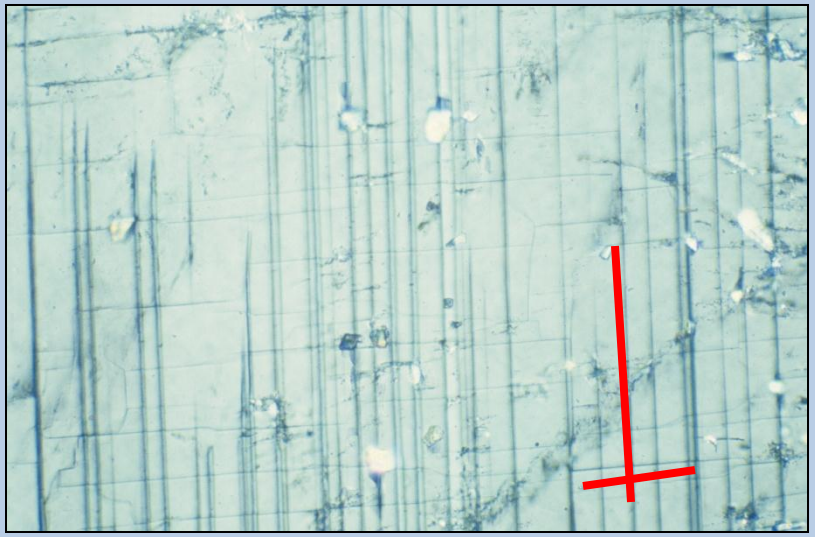
- Parallel cracks in mineral related to crystal structure, often diagnostic of a mineral
- In thin sections cleavage is developed during grinding of thin section
- Note how many directions of cleavages are present
- Measure the angle between cleavages or between cleavage and some mineral feature e.g. edge of grain, extinction.



Amphiboles
e.g. hornblende ~ 54°/126°



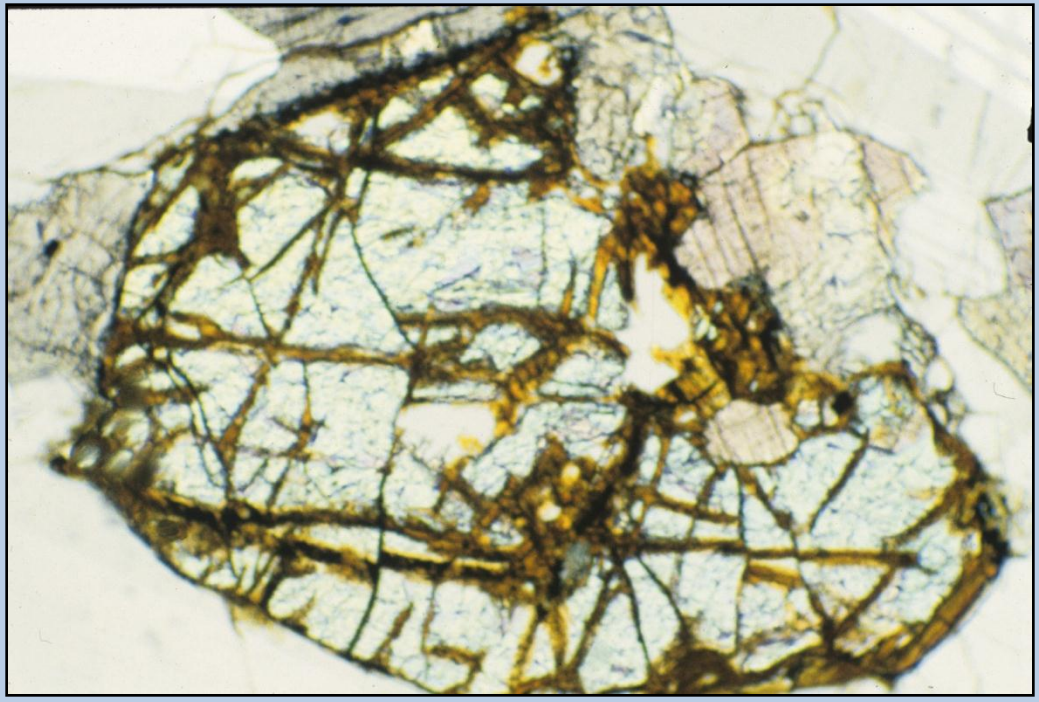
Pyroxene e.g. augite ~ 90°;



Plagioclase: ~90°

Fracture:

Irregular cracks not related to atomic structure e.g. olivine



Olivine in gabbro (PPL)

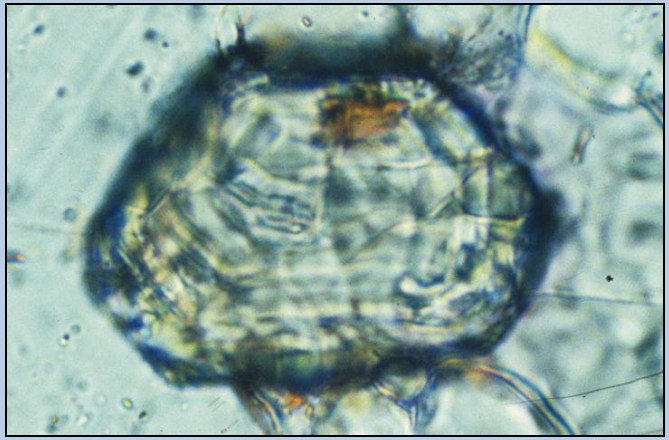
Metamict Texture

Intense fracturing cause by radiation

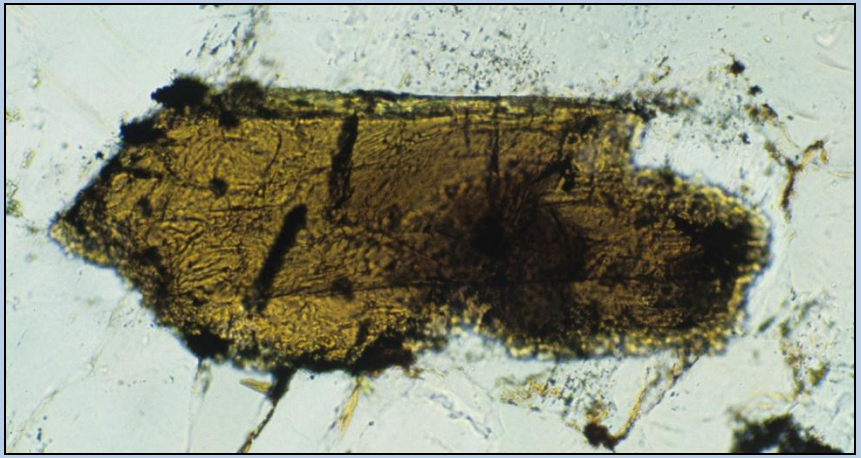
Disruption of crystal lattice can decrease optical properties

The mineral may appear isotropic

Zircon



Allanite



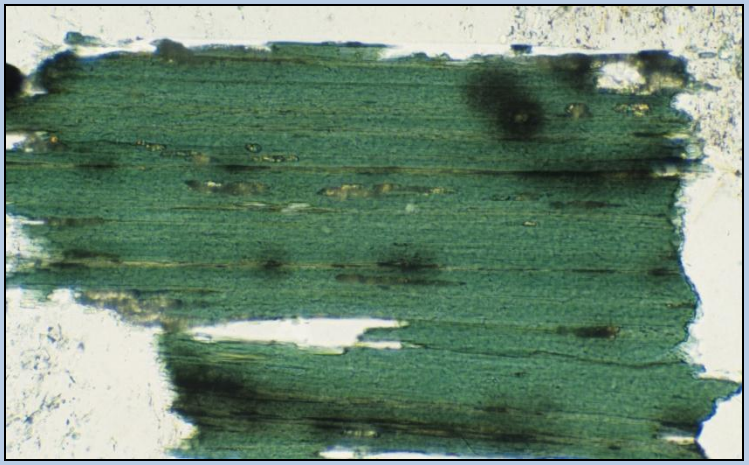
Colour in PPL

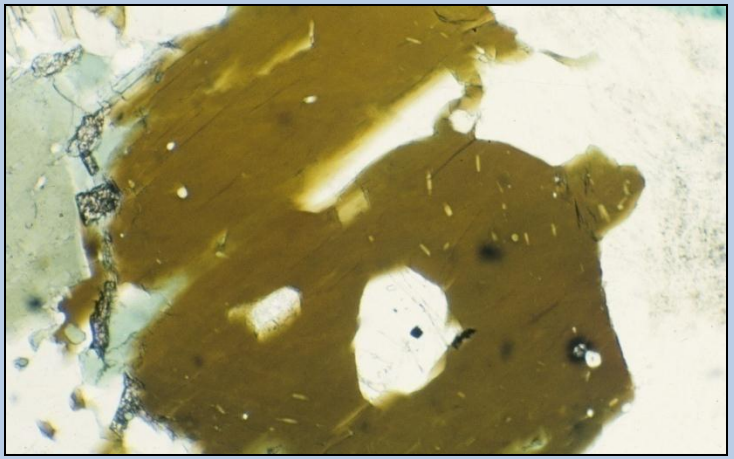
Due to absorption of selective wavelengths of light by electrons e.g absorption of red gives a green colour

May be diagnostic of the mineral e.g. green chlorite

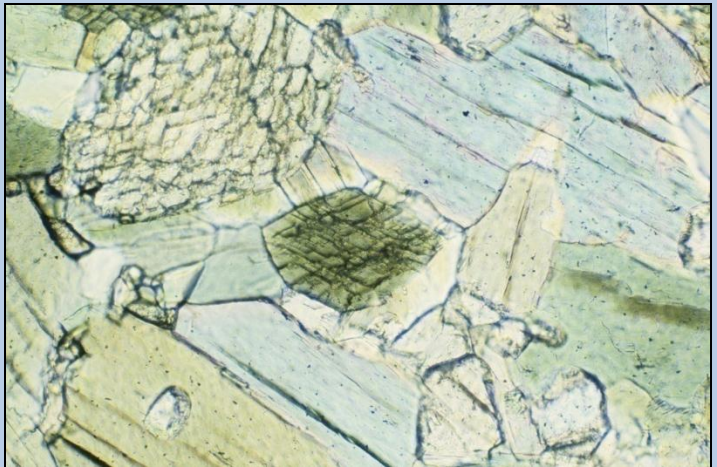
Beware: biotite and hornblende may be either brown or green

Green chlorite in granite



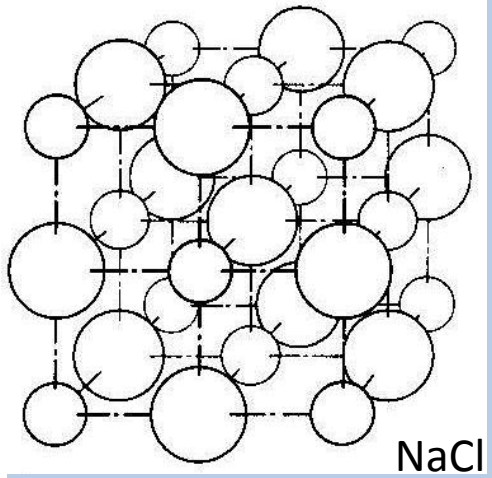


Brown biotite in granite



Green/blue hornblende in amphibolite

Isotropic Minerals



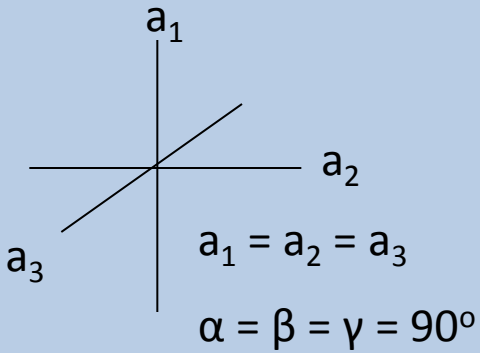
Isometric (cubic) minerals e.g. garnet, halite

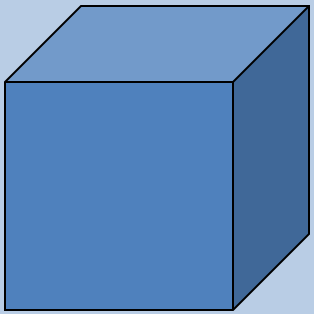
Amorphous materials: glass, epoxy resin, air

Atomic structure is the same is all directions

Light travels through the mineral with equal velocity in all directions

Refractive Index: one value (*n*) regardless of orientation

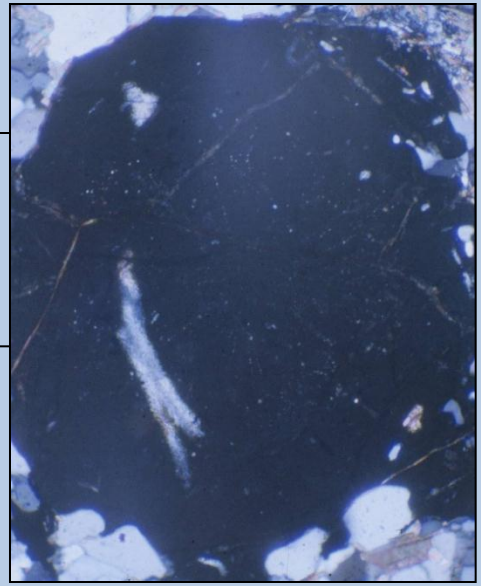


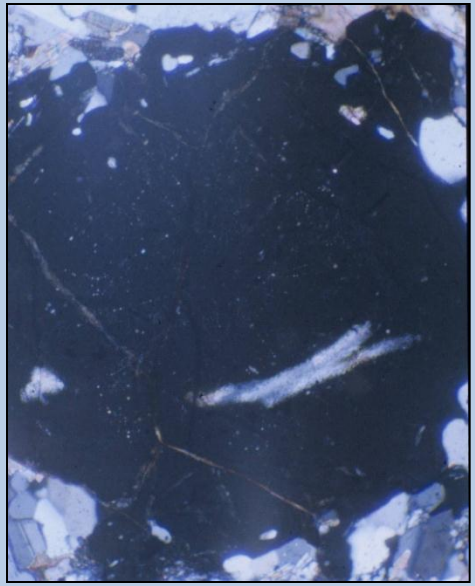


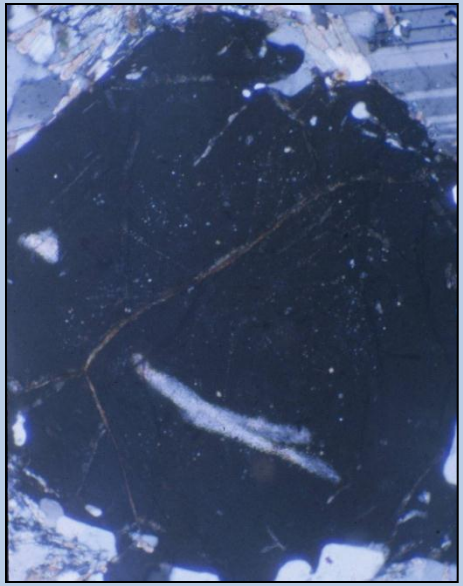
Between crossed polars

Isotropic minerals always look black regardless of orientation of crystal or rotation of stage

Garnet rotated in XPL







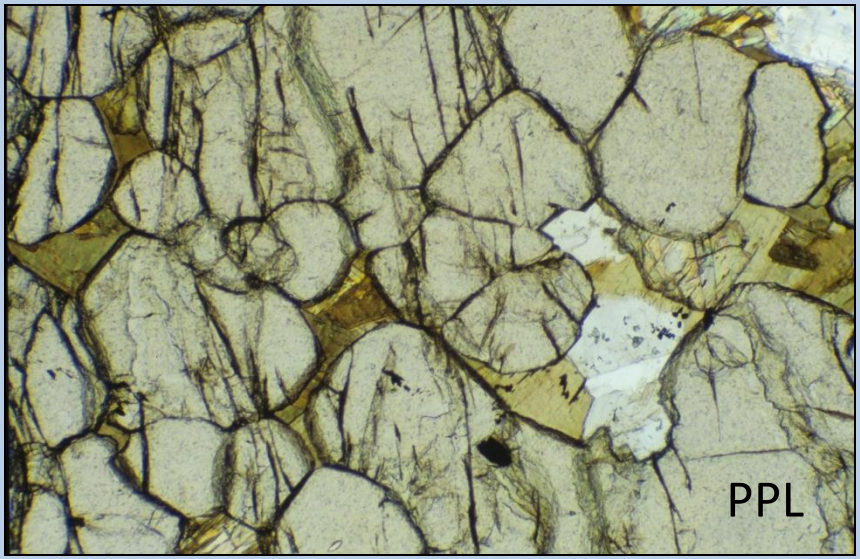
Isotropic Minerals

Colour in PPL may be diagnostic

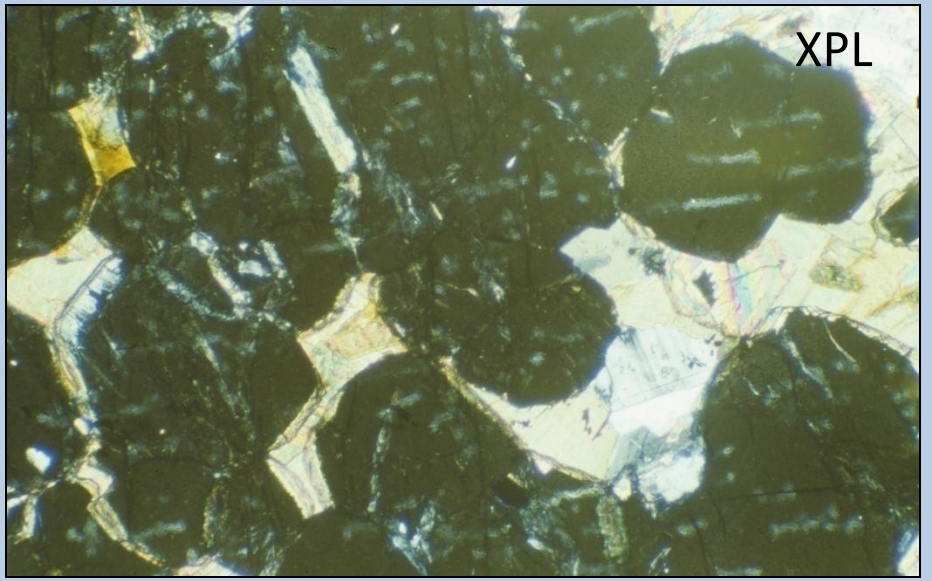
Absorption of light is the same in all directions so the colour will be the same regardless of orientation of crystal and remains constant when stage is rotated

Cleavage: rare but **fracture** common

Always in **extinction** between crossed polars



Garnet



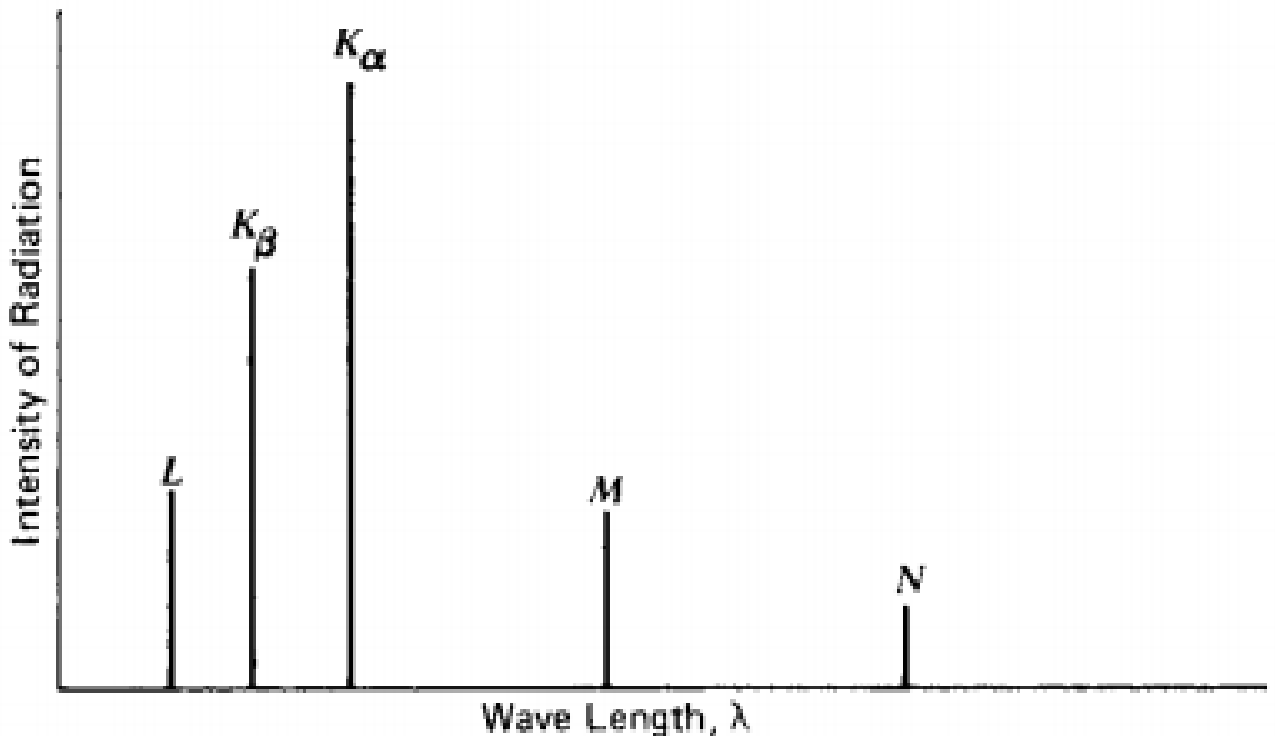
XRD Analysis & SEM

XRD analysis

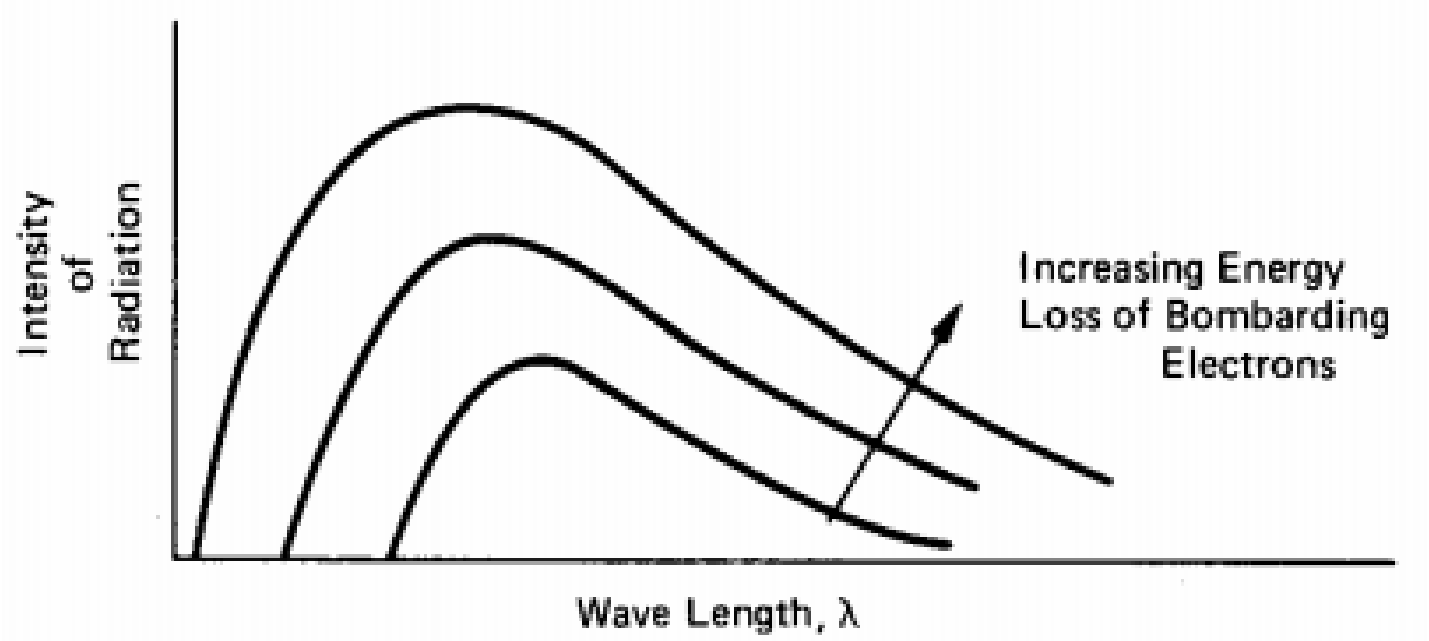
- Most widely used method for identification of minerals and the study of their crystal structure.
- X-rays are one of several types of waves in the electromagnetic spectrum having wavelength in range of 0.01 A to 100 A.
- Two phenomenon may occur when high-speed electrons impinge on a target material.

XRD analysis

- 1. The high speed electron strikes and displace electron from the inner shell of one of the atom of the target materials, due to which X-ray photon get generated.
- 2. The high speed electron get slow down in the intense electric fields near nuclei. Due to decrease in energy get converted into heat and to X-Ray photons.



X-Ray generation by electron displacement- Phenomenon 1



X-Ray generation by deceleration electron displacement- Phenomenon 2

X-Ray generation

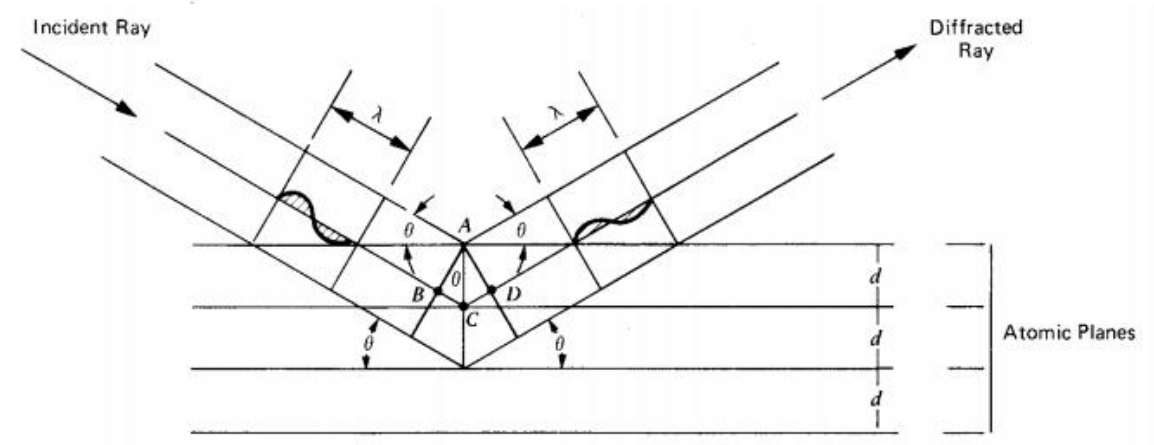
- X-rays are generated using a tube in which electrons stream from a filament to a target material across a voltage drop of 20 to 50 kV. Curved crystal monochrometers can be used to give X-rays of a single wavelength.
- Alternatively, certain materials are able to absorb X-rays of different wavelengths, so it is possible to filter the output of an X-ray tube to give rays of only one wavelength.
- The wavelengths of monochromatic radiation produced from commonly used target materials range from 0.71 A˚ for molybdenum to 2.29 A ˚ for chromium. Copper radiation, which is most frequently used for mineral identification, has a wavelength of 1.54 A.

Diffraction of X-ray

- X-rays are useful for crystal analysis.
- When X-rays strike a crystal, they penetrate to a depth of several million layers before being absorbed. At each atomic plane a minute portion of the beam is absorbed by individual atoms that then oscillate as dipoles and radiate waves in all directions.
- Radiated waves in certain directions will be in phase and can be interpreted in simplistic fashion as a wave resulting from a reflection of the incident beam.

Diffraction of X-ray (Bragg's Theory)

- In-phase radiations emerge as a coherent beam that can be detected on film or by a radiation counting device.



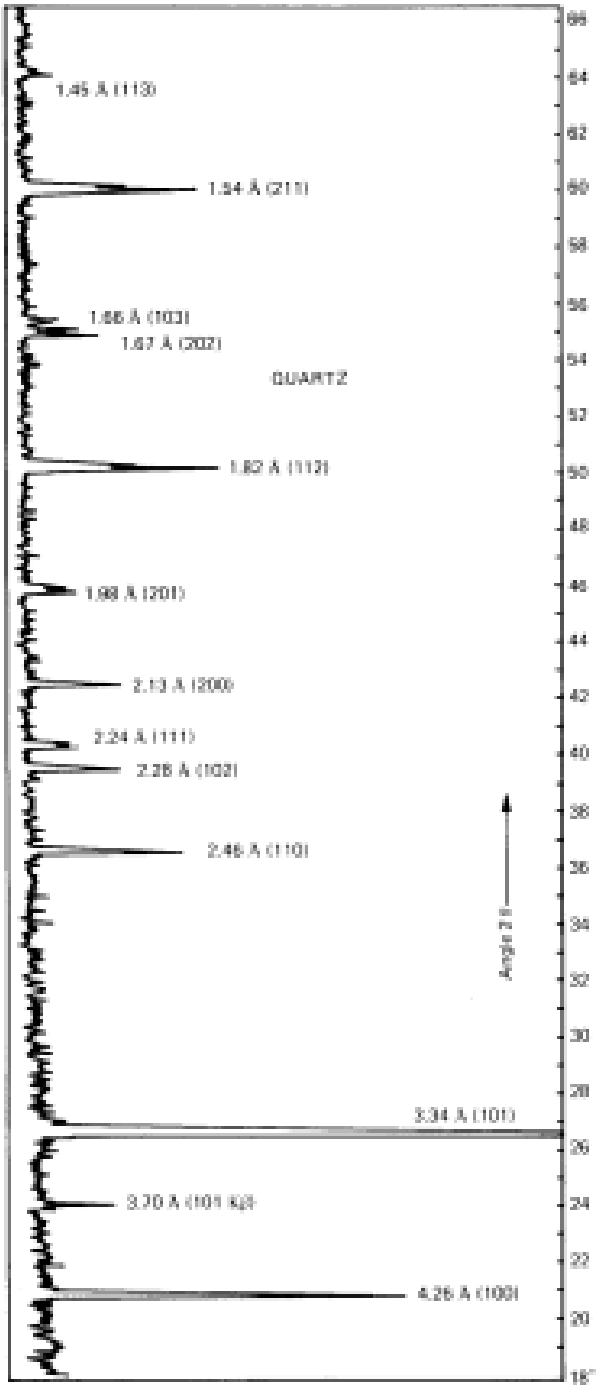
$$BC + CD = n\lambda$$

$$n\lambda = 2d \sin \theta$$

- No two minerals have same spacıng.

Analysis of X-Ray pattern

- A complete X-ray diffraction pattern consists of a series of reflections of different intensities at different values of 2θ.
- The test pattern may be compared directly with patterns for known materials..

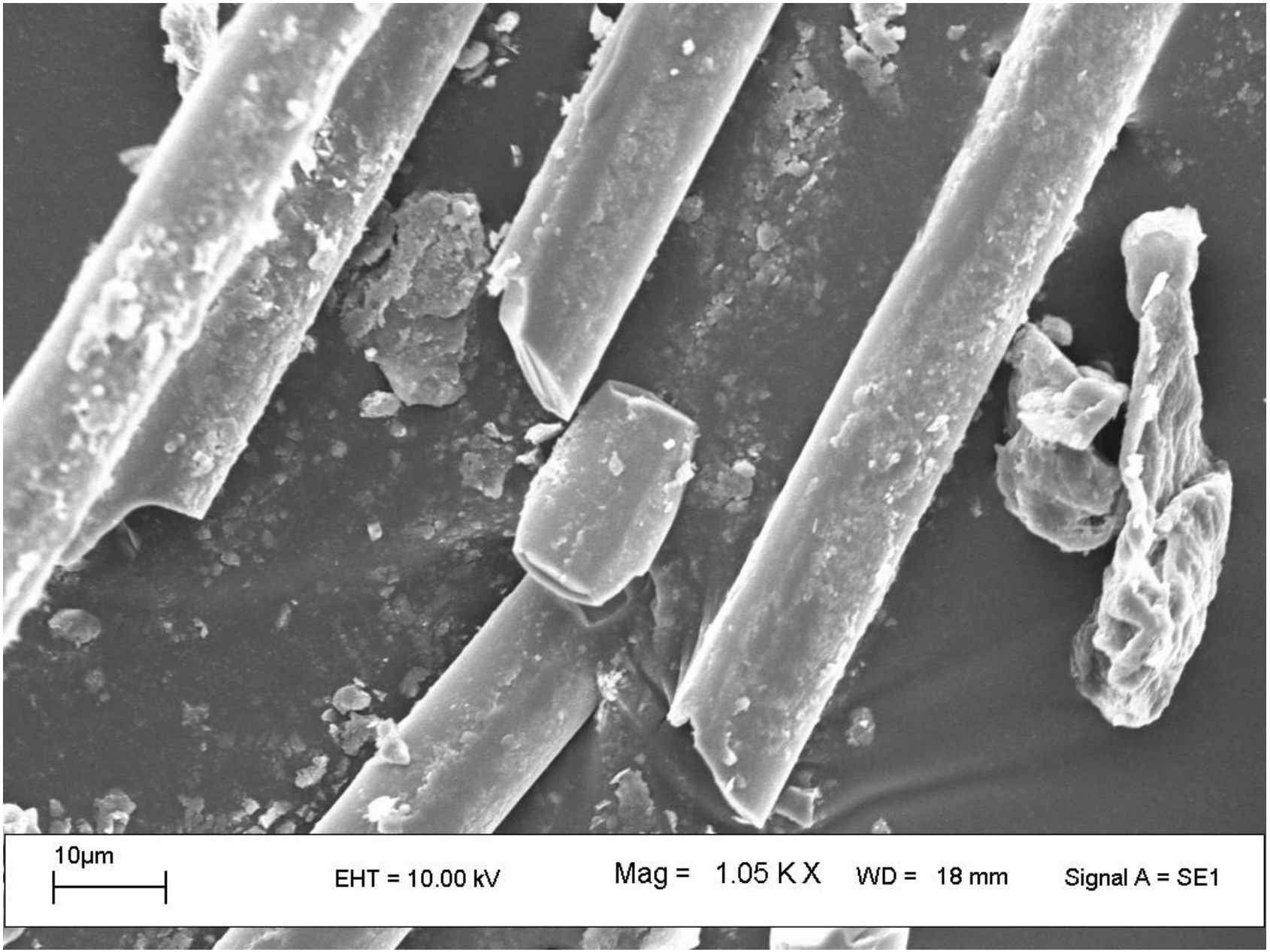

1.45 Å (113)
1.54 Å (211)
1.66 Å (103)
1.67 Å (202)
QUARTZ
1.82 Å (112)
1.98 Å (201)
2.13 Å (200)
2.24 Å (111)
2.28 Å (102)
2.46 Å (110)
Angle 2 θ
3.34 Å (101)
3.70 Å (101 Kβ)
4.26 Å (100)
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18°

Quartz

Electron microscope

- With modern electron microscopes it is possible to resolve distances to less than 100 A˚, thus making study of small clay particles feasible.
- Electron diffraction is similar to X-ray diffraction except an electron beam instead of an X-ray beam is used.
- Magnetic lenses that refract an electron beam form the basis of the transmission electron microscope (TEM) optical system.
- An electron beam is focused on the specimen, which is usually a replica of the surface structure of the material under study.
- Some of the electrons are scattered from the specimen, and different parts of the specimen appear light or dark in proportion to the amount of scattering.

- After passing through a series of lenses, the image is displayed on a fluorescent screen for viewing.
- Probably the most critical aspect of successful transmission electron microscopy is specimen preparation
- In the scanning electron microscope (SEM), secondary electrons emitted from a sample surface form what appear to be three-dimensional images.
- The SEM has a20 to150,000 magnification range and a depth of field some 300 times greater than that of the light microscope.


10µm
EHT = 10.00 kV
Mag = 1.05 K X
WD = 18 mm
Signal A = SE1

Reference

- Mitchell, J.K. and Soga K. (2005), Fundamentals of Soil Behavior. Wiley, USA.

PETROLOGY

What is a Rock?

- Naturally-occurring mixtures of minerals, mineraloids, glass or organic matter.

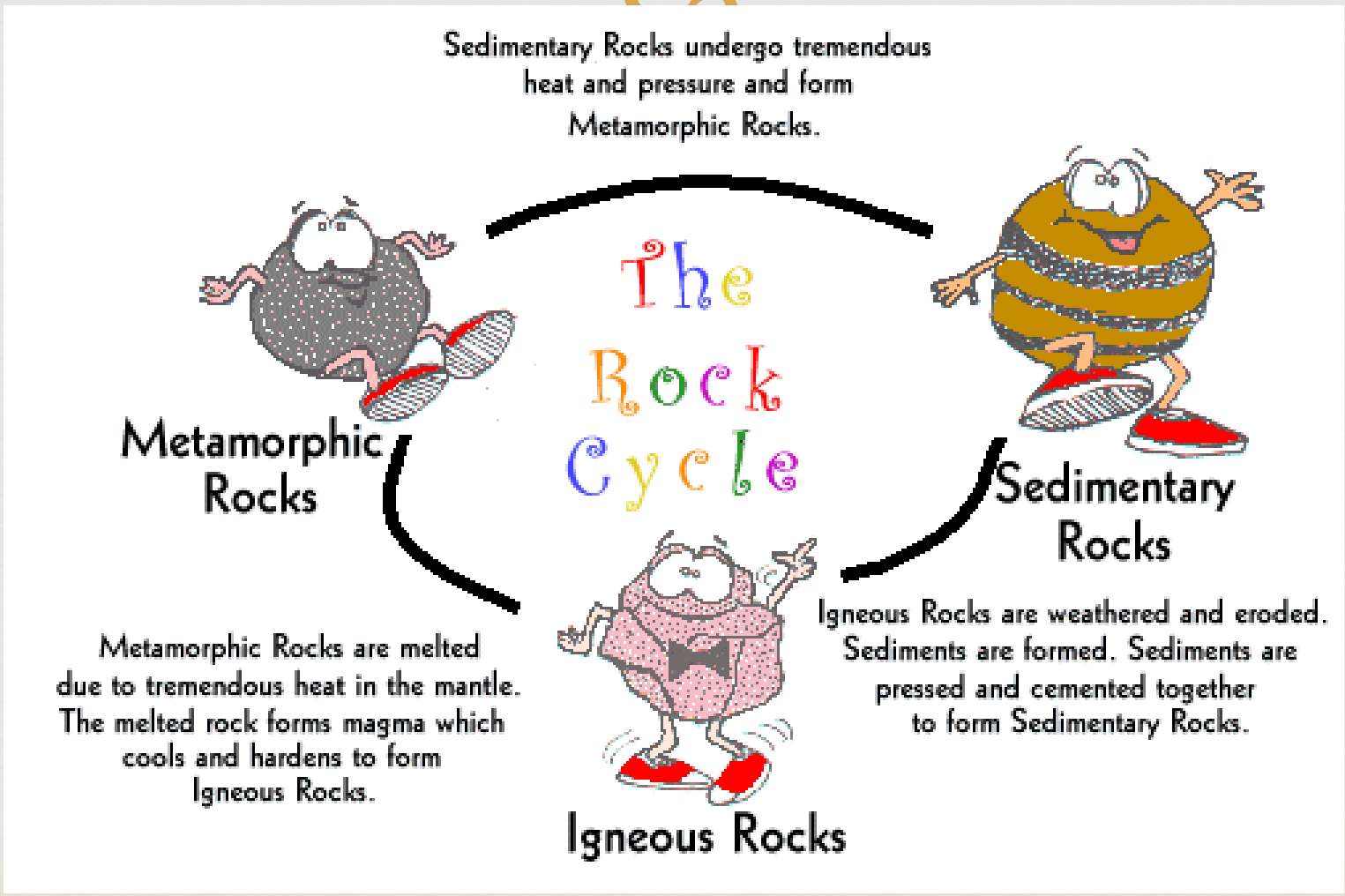
Rocks

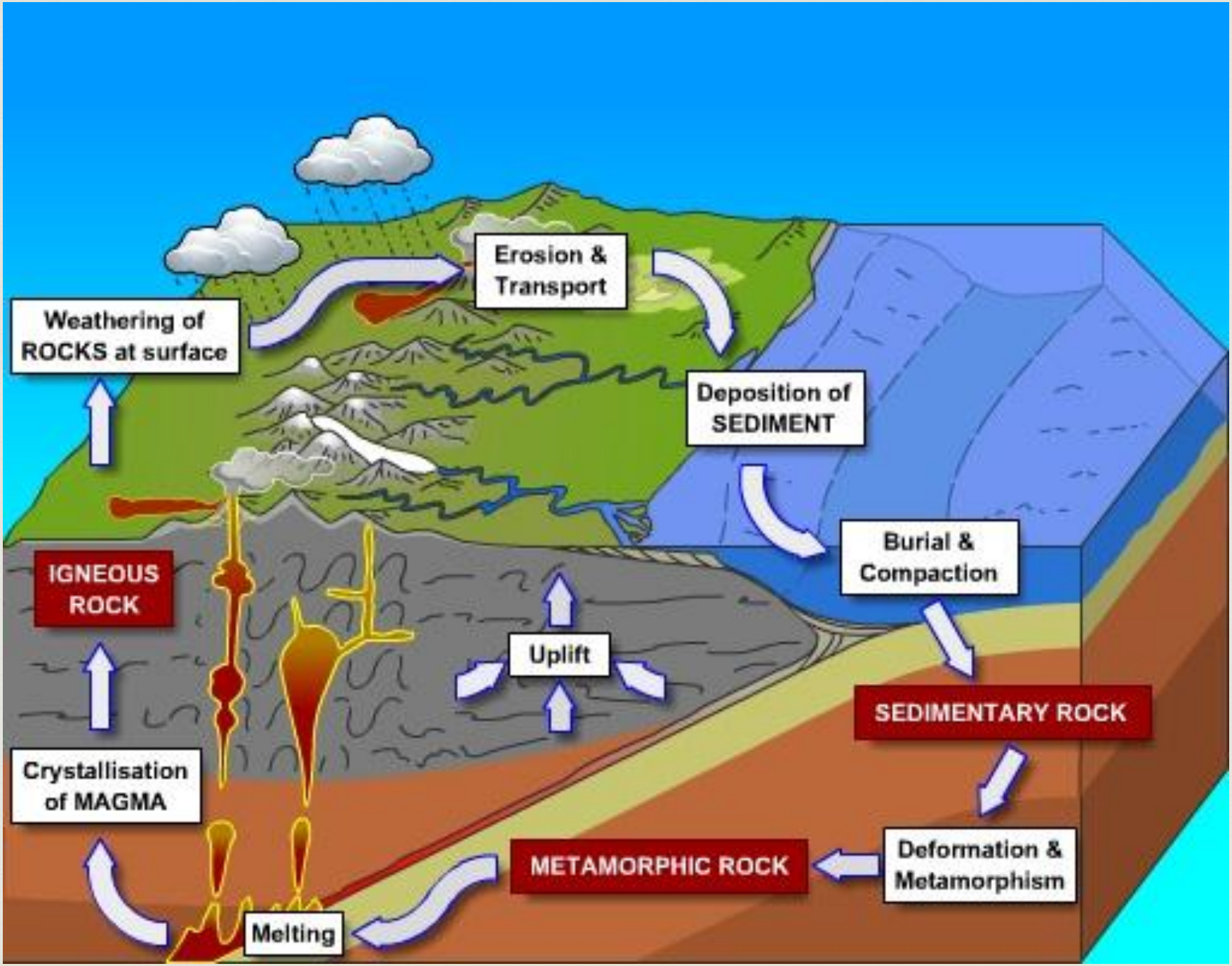
Parent Material for all Rock??

Magma!!

What is the process through which rocks change?

- The Rock Cycle—earth materials change back and forth among the different types of rocks




Erosion &
Transport
Weathering of
ROCKS at surface
Deposition of
SEDIMENT
Burial &
Compaction
IGNEOUS
ROCK
Uplift
SEDIMENTARY ROCK
Crystallisation
of MAGMA
Deformation &
Metamorphism
METAMORPHIC ROCK
Melting

Specific Gravity of Rocks

- The specific gravity of a material is a comparison of its weight with the weight of an equal volume of water. Specific gravity measures the density of a material.
- Range= 2.5 to 2.8.
- Non-porous and compact rocks have higher density and toughness.
- Normally rocks have three times the density of water.
- Pumice rock has density less than that of water.
- Basalt: 3 g/cm3 ; granite: 2.7 g/cm3 ; sandstone: 2.3 g/cm3.
- High density rocks like massive gabbro, basalt and quartzite are very hard and most suitable for foundation purposes.

Chemical composition

Element	(%)	Element	(%)
SiO_2	59.14	MgO	3.49
Al_2O_3	15.35	Na_2O	3.84
FeO	3.80	K_2O	3.13
Fe_2O_3	3.08	H_2O	1.15
CaO	5.08	Others	1.94

Mineralogical composition

Minerals	(%)	Minerals	(%)
Felspars	59.5	Titanium	1.5
Pyroxenes	16.8	Apatite	0.6
Quartz	12	Accessory Minerals	5.8
Biotite	3.8		

Igneous Rock



- **“Ignis” = Latin for “fire”**
- **Formed from the cooling of either magma or lava**
- **The most abundant type of rock**
- **Classified according to their origin and composition**

- Above ground = from lava (extrusive igneous rock)
  - Usually have <u>SMALL or NO</u> crystals (they cooled too <u>quickly</u>)









What happens to molten rock as it cools?

- When the temperature of molten rock begins to drop there is a loss of energy that causes ions to slow down. As the ions slow down, they group together and arrange themselves into orderly crystalline structures. This process is referred to as **crystallization**.



- During crystallization, the silicon and oxygen atoms are the first to link together forming silicon-oxygen tetrahedrons, which are the building block of all silicate minerals.

- As crystallization continues, these individual silicon-oxygen tetrahedrons join with one another, and other ions, to form the basic structure of most minerals and igneous rocks.

- Environmental conditions including temperature and the presence of water or gases during crystallization affect the composition, the size, and the arrangement of the mineral grains.

- The size and arrangement of mineral crystals, also referred to as grains, define the texture of the rock.

- Geologists use mineral and textural classifications to infer information about the environmental setting in which different igneous rocks are formed.

Volcanic eruptions

- Volcanic eruptions happen when lava and gas are discharged from a volcanic vent.
- Magma is molten material occurring naturally below the surface of earth. It is called lava when erupted through volcanoes.
- On Earth, volcanoes are most often found where tectonic plates are diverging or converging, and most are found underwater.
- Volcanoes can also form where there is stretching and thinning of the crust's plates

Volcanic Erupted Materials

- The material that is expelled in a volcanic eruption can be classified into three types:
  - Volcanic gases, a mixture made mostly of steam, carbon dioxide, and a sulfur compound (either sulfur dioxide, SO_2, or hydrogen sulfide, H_2S, depending on the temperature)
  - Lava, the name of magma when it emerges and flows over the surface
  - Tephra, particles of solid material of all shapes and sizes ejected and thrown through the air[2]

Composition of Lava

- If the erupted magma contains a high percentage (>63%) of silica, the lava is described as *felsic*. Felsic lavas (dacites or rhyolites) are highly viscous and are erupted as domes or short, stubby flows.
- If the erupted magma contains 52–63% silica, the lava is of *intermediate composition* or *andesitic*. Intermediate magmas are characteristic of stratovolcanoes.
- If the erupted magma contains <52% and >45% silica, the lava is called *mafic* (because it contains higher percentages of magnesium (Mg) and iron (Fe)) or basaltic.
- Some erupted magmas contain <=45% silica and produce *ultramafic* lava. Ultramafic flows, also known as komatiites, are very rare

Type volcanic eruption

- Magmatic eruption
- Phretomagmatic eruption
- Phreatic eruptions

Magmatic eruptions

- Magmatic eruptions are driven primarily by gas release due to decompression. Low-viscosity magma with little dissolved gas produces relatively gentle effusive eruptions. High-viscosity magma with a high content of dissolved gas produces violent explosive eruptions.

Phreatomagmatic Eruption

- Phreatomagmatic eruptions are characterized by interaction of rising magma with groundwater. They are driven by the resulting rapid buildup of pressure in the superheated groundwater.

Phreatic eruptions

- Phreatic eruptions are characterized by superheating of groundwater that comes in contact with hot rock or magma. They are distinguished from phreatomagmatic eruptions because the erupted material is all country rock; no new magma is erupted.

Texture of Igneous Rocks

- It is determined by shape, size, and arrangement within the body of the rock.
- Degree of Crystallization, granularity, fabric affects texture.
- Textures are divided into five categories
  - Equigranular
  - Inquigranular
  - Directive
  - Intergrowth
  - Intergranular

Texture of Igneous Rocks

- **Equigranular:** All those textures in which rock are broadly equal in size. E.g.: granitic and gelstic texture.
- **Inequigranular texture:** grains have unequal in size. E.g.: Felspar, Augite etc.
- **Directive texture:** This texture show parallelism of crystals. E.g. Trachytic and Trachytoid
- **Intergrowth:** In this two or more minerals may crystallize out simultaneously in a limited space.
- **Intergranular texture:** In this texture glassy masses get filled in crystalline structure.

Classification of igneous rocks

- Mode of occurrence
  - **Plutonic rocks:-** formed at greater depths or deeper zones. E.g.:- Granites, syenites etc.
  - **Volcanic rocks:-** Rocks which are formed at the surface of earth. E.g.:- basalt
  - **Hypabyssal rocks:-** formed at intermediate type. E.g.:- dykes, loccoliths and lapoliths

References

- https://civiltoday.com/geotechnical-engineering/geology/258-rock-cycle-process-steps-with-diagram
- https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/volcanic-eruptions/

PETROLOGY

Based on silica percentage

- Oversaturated rocks: these rocks contain free sillica more than 66%. E.g. : Quartz
- Saturated rocks: These rocks contain about 50-66% silica and are called saturated or intermediate rocks.
- Unsaturated rocks: rocks which consist of less than 50% silica. E.g. : leucite, nepheline etc.

Chemical Classification

- CIPW classification is bases upon set of standard minerals, called Norm.
- Salic minerals: Quartz, Felspars, leucite etc.
- Femic minerals: Acmite, diopside, olivine etc.

Chemical Classification

S. No.	Salic/femic ratio	Class name
1	>7	Persalic
2	7-1.66	Dosalic
3	1.66-0.6	Salfemic
4	0.6-0.14	Dofemic
5	<0.14	perfemmic

Some Important Igneous rocks

- Granites
- Diorite
- Andesit
- Syntites
- Gabbro
- Dolete
- Basalts
- Pegmatites
- Aplite
- Ampophyres
- Periodotites

Granite

- Reference for self study
- http://www.sasurieengg.com/e-course-material/CIVIL/II-Year%20Sem%203/CE6301%20Engineering%20Geology.pdf
- Prabin singh “Engineering and general geology” page-282-288.



Diorite



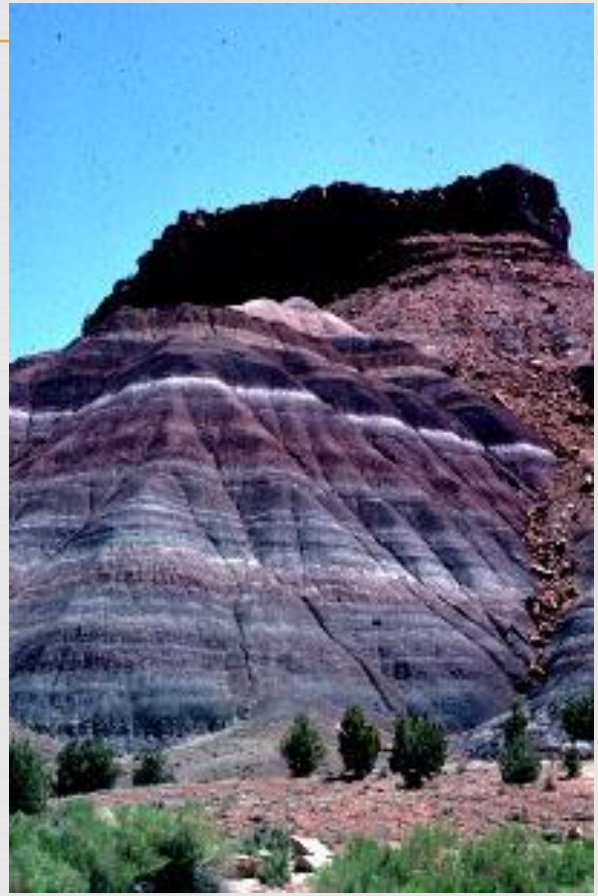
Basalt



Sedimentary Rocks

Sedimentary Rocks

- **Formed from <u>sediments</u> (rock fragments, mineral grains, animal & plant remains) that are pressed or cemented together or when sediments <u>precipitate</u> out of a solution.**

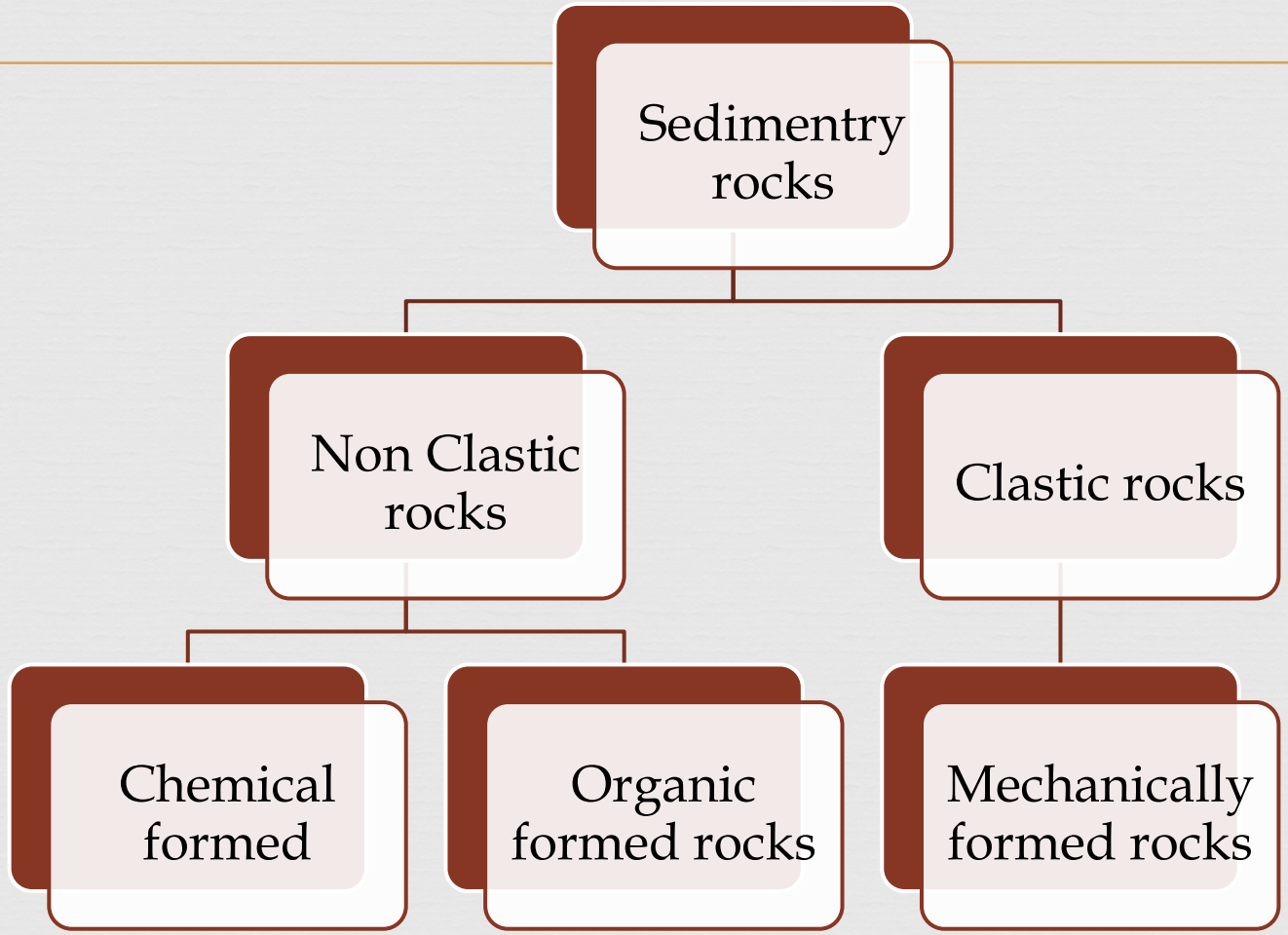


Sedimentary Rocks

- These sediments are moved by wind, water, ice or gravity.
- Sedimentary rocks represent 7% of the Earth's crust, but they cover 70% of the Earth's surface.
- Sedimentary rocks are fossil-carrying rocks.



Types of sedimentary rocks



Clastic Rocks

- Clastic (also called Detrial)—made of <u>broken</u> pieces of other rocks





Non-Clastic Rock

- **Organic—remains of plants and animals are deposited in thick layers**
- ***Examples:*** **Fossil rich limestone is made from the shells of ocean animals; used to make chalk**





Non-Clastic Rock

- Chemical—<u>minerals</u> dissolved in lakes, seas, or underground water. E.g. travertine





Formation of Sedimentary Rock –

•Through the process of

weathering

, rock is loosened and carried away with wind and water by

erosion

. The sediment then settles out of the wind and water during deposition. The sediment begins to settle out and form

layers

.

As the layers stack up, they become heavier until the weight squeezes the layers together during

compaction

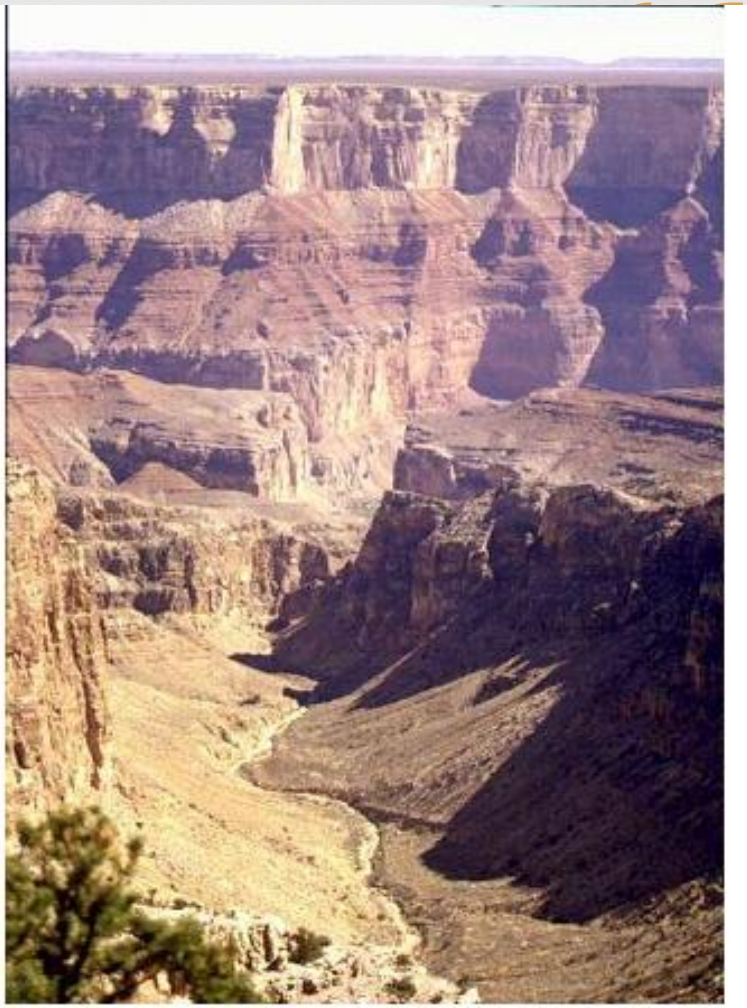
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Dissolved minerals act as glue in a process known as

Cementation

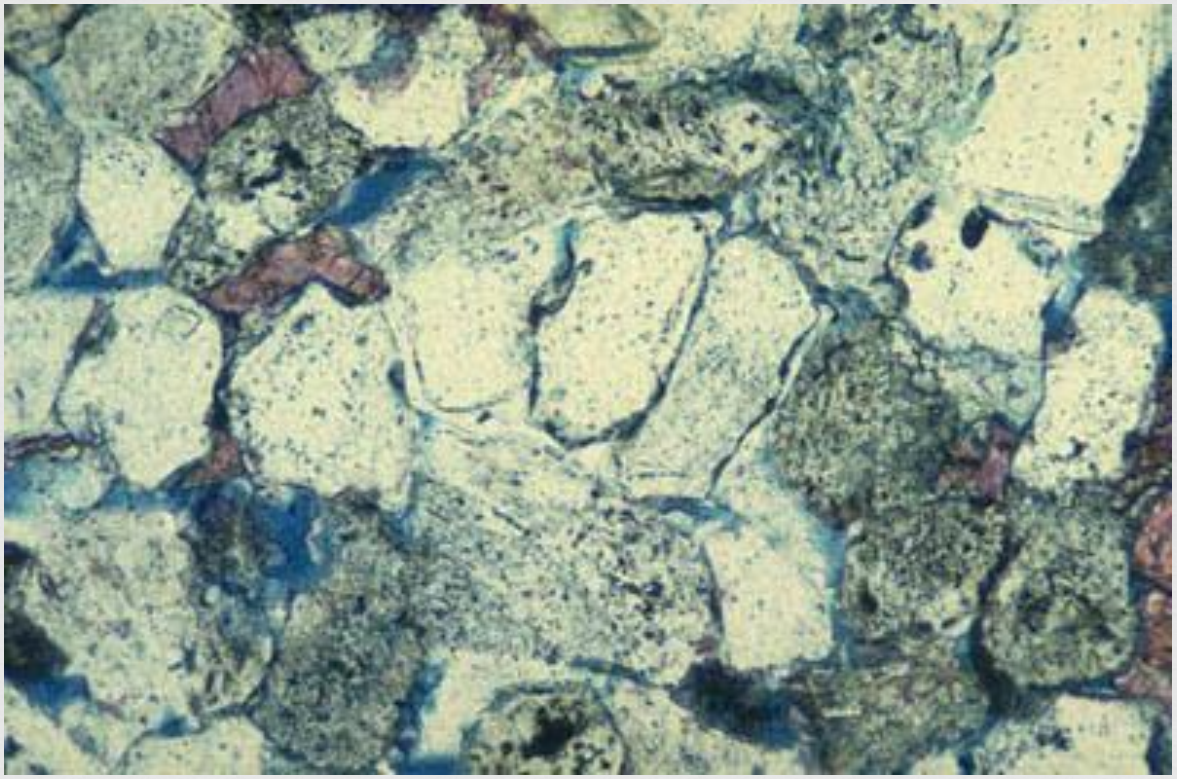
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- **The heavy sediments <u>press down</u> on the layers beneath (compaction)**



Sediments harden by compaction and cementation to form sedimentary rocks as seen in the Grand Canyon.

- **Dissolved minerals flow between the particles and <u>cement</u> them together (cementation)**



How can sedimentary layers help us understand the age of fossils?

- As sedimentary rocks are deposited, they form horizontal layers
- Scientists know that the layers on <u>top</u> (and the fossils in the top layer) are <u>YOUNGER</u> than the fossils in lower layers.



Texture of sedimentary rock

- **Origin of rocks:** A sedimentary rock may be partially or wholly composed of clastic (or allogenic) grains, or of chemically formed or organically contributed parts. Thus the rock may show a clastic texture or a non-clastic texture.
- **Size of grains:** The grain size in the sedimentary rocks varies within wide limits. Individual grains of less than 0.002 mm and more than 250 mm may form a part or whole of these rocks. Three textures recognized on the basis of grain size are: Coarse grained rocks, medium grained rocks, fine grained rocks

Texture of sedimentary rock

- **Shape of grains:** The sediments making the rocks may be of various shapes: rounded, sub rounded, angular and sub angular.
- They may show spherecity to various degrees.
- Roundness and spherecity are the indications of varying degree of transport and abrasion suffered during that process.
- Thus, Breccias are made up mostly of rough and angular fragments indicating least transport and abrasion.
- Conglomerates are full of rounded and smooth-surfaced pebbles and gravels indicating lot of transport and rubbing action during their transport before getting deposited and consolidated into a rock mass

- **Packing of grains:** Sedimentary rocks may be open-packed or porous in textures or densely packed depending upon their environment of formation.
- The degree of packing is generally related to the load of the overlying sediments during the process of deposition.
- **Fabric of grains:** A given sedimentary rock may contain many elongate particles. Ø
- Their orientation is studied and described in terms of orientation of their longer axes. Ø
- If all or most of the elongated particles are arranged in such a way that their longer axes lie in the same general direction, the rock is said to show a high degree of preferred orientation. This direction is generally indicative of the direction of flow of the current during the period of deposition.

Texture of sedimentary rock

- **Crystallization trend:**
- In sedimentary rocks of chemical origin, the texture is generally defined by the degree and nature of crystallized grains.
- Rocks may show perfectly interlocking grains giving rise to crystalline granular texture or they may be made up of non-crystalline, colloidal particles when they are termed as amorphous.

Mineralogical composition

- Mostly sedimentary rocks contains one or two minerals only. It depends upon following factors:
- **The nature of the gathering ground:** sediments which are bases of the sedimentary rocks depends upon the nature of the ground from they get eroded. Carbon rich hills provide carbonate particles. Silica rich terrain may contain quartz. The mixed strata will provide sediments with different minerals.

- **Duration of transport:** the time and the distance covered by sediment affects the nature of the rock. Soft and fragile wear out easily.
- **Mixing up of sediments:** near sea shore variety of sediment get deposited due the different stream and get mixed due to the waves of ocean. In such situation complex composition get formed.
- **Allogeneic authigenic minerals:** Allogenic minerals are those which have been formed outside the basin of deposition. The authigenic minerlas are those tht have been formed within the basin of deposition.

Structures of sedimentary rocks

- Mechanical structure
  - Stratification
  - Lamination
  - Cross Bedding
  - Graded bedding
  - Mud cracks
  - Rain prints
  - Ripple marks
- Chemical Structures
  - Concretionary structures
  - Nodular structures
  - Geode structures
- Organic structures
  - Fossiliferous structures
  - Stromatolitic structure

Mechanical Structures

- **Stratification:** It is layered arrangement in sedimentary rock. Different layers are called beds or strata may be similar or dissimilar in color, composition, grains size and texture.
- **Lamination:** This is also a layered structure similar to stratification as found in the sedimentary rocks. In lamination, the individual layers are quite thin (less than 1 cm).
- **Cross bedding:** In this structure layers lying one above are not parallel.
- **Graded bedding:** Stratified according to their grain size, coarsest at bottom and finest at top.

Mechanical Structures

- **Mud Cracks:** Found in fine-grained sedimentary rocks. The structure have polygonal or irregular cracks spread over the surface.
- **Rain prints:** These are irregular small crater-shaped depression seen on fine-grained dried sediments.
- **Ripple marks:** These are found in shallow water environment. They are defined as symmetrical or asymmetrical wave like undulations or irregularity in a layer.

Chemical Structures

- **Concretionary structures:** Formed by concretions of various shapes and dimensions. The individual concretions may be rounded, surrounded, rough or smooth etc. E.g. Bauxite, Oolitic etc.
- **Nodular structure:** Formed by irregularly shaped nodules of chert, iron oxides, iron carbonates and clayey ironstones.
- **Geode structure:** A geode is actually hollow shell of rock, the interior of which is lined with inwardly projecting crystals. Generally the rocks shell is made up of chalcedony and inner encrustations are of quartz crystals.

Organic structures

- **Fossilifeous structures:** It is due to the presence of the fossils of plants or animal life in the rock.

- **Stromatolite structure:** These are produced by the presence of remains of algae, kind of lower vegetation in the rocks

Some important sedimentary rocks

- Conglomerate
- Breccia,
- Sandstone
- Mudstones
- shale

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PETROLOGY

Metamorphic Rocks

Metamorphic rocks

- Metamorphism is process responsible for all the changes that takes place in an original rocks under the influence of changes in the surrounding conditions of temperature, pressure and chemically active fluids.
- Temperature, pressure, chemical environment are the **agents of metamorphism.**

Types of Metamorphism

- Thermal metamorphism
- Dynamic metamorphism
- Dynamo thermal metamorphism

Thermal metamorphism

- In this metamorphism heat factor playas important role.
- Contact metamorphism is a common type of thermal metamorphism observed in rocks existiing close to the magmatic intrusions injections and lava flows.
- Phometamorphism is another type of thermal metamorphism in which case a part of country rock may actually get entrapped within a magmatic body.
- Plutonic metamorphism is a process of metamorphism that takes place due to equally important role of imposed loads and very high temperature that become natural at those greater depth.

Dynamic Metamorphism

- Also known as clastic metamorhism, mechanical metamorphism or dislocation metmorphism and happen due to the pressure factors.
- In dynamic metamorphism there is no or very little formation of new minerals.
- The original textures and structures of the rocks that are partially or totally obliterated.

Dynamothermal metamorphism

- This is also known as regional metamorphism.
- This involves development of large-scale changes in the structural and chemical constitution.
- The combined action of pressure, temperature and fluids act.

Metamorphic grades

- Grade indicate change in original rock due to metamorphism.
- Three grades are broadly summarized as follows:
- **Low grade**: It prevails within a temperature range of 200-400 C and a large pressure range. Important index minerals are laumonite, prehnite and lawsonite etc.
- **Medium grade:** this grade prevails upto a temprature range of 650 c and indicated by index minerals like staurolite and cordierite.
- **High-grade:** Begin at temparature around 580 C under pressure of 3.5 kb and continues upto temperature of 800 C and above.

Mineralogical Composition

- Metamorphic rocks show great variation depending upon the composition of parent rocks and type and degree of metamorphism undergone by the rock.
- Example: marble consist of calcite which changes from limestone, quartzite made by recrystallization of silica.
- Two form of minerals forms during metamorphism-
  - Stress mineral formed by stress factor
  - Anti-stress mineral formed by temperature factor

Texture of metamorphic Rocks

- **Crystalloblastic texture:** All texture which are newly imposed upon the rock during the metamorphism process.
- **Palimpest (Relict texture) :** It includes all the textures which were present in the parent rock and have been retained by the rock despite metamorphic changes.

Structure of metamorphic rock

- Cataclastic structure
- Schistose structure
- Gneissose strcutre
- Maculose strcuture
- Augen strcuture
- Granulose strcture

Structure of metamorphic rock

- **Cataclastic structure:** It is characterized by development of extremely fine rock mass under influence of sever crushing and shearing effects of stresses operating during metamorphism. e.g. Mylonite
- **Schistose structure:** The rock with schistose structure is made up of broadly parallel or sub parallel layers or bands of flaky, platy or rod like minerals. E.g. Schists
- **Gneissose structure:** In this strcutre, bands or folia of platy and flaky minerals alternate with those of equidimensional and granular minerals. These bands are generally of contrasting colours, composition and texture.

Structure of metamorphic rock

- **Maculose structure:** It is characterized by a spotted appearance of the rock that may be caused due to the formation of the large-sized crystals within an otherwise fine grained rock.
- **Augen strcuture:** It is similar to maculose type and is typical of metamorphic rocks in which the effects of crushing under pressure are clearly associated with recrystallization.
- **Granulose structure:** It is typical structure of metamorphic rocks like marble and quartzite and is characterized by essentially granular character of the constituent materials. The individual grains may be irregular in outline but are interlocking.

Rock cleavage

- It is capacity of rock to slit along certain directions yielding parallel or subparallel smooth surfaces.
- **Flow cleavage:** It is also known as slaty cleavage. Formed by parallel arrangement of highly cleavable flaky and platy minerals like mica, talc and chlorite
- **Fracture cleavage:** this type of cleavage is developed due to parallel orientation of very fine fractures, often called micro fractures, that may be developed in minerals of a rock undergoing dynamic metamorphism.

Schistosity

- It is structural feature of many metamorphic rocks called schiests and signifies that the rocks is made up of parallel or sub parallel bands or layers of platy and flaky minerals like mica, chlorite, tourmaline etc.
- Schistosity results due to combined effect of heat and pressure during metamorphism involving both recrystallisation and reorientation of platy minerals as irregular layers or bands.

Foliation

- In broader term it can be explained as layered structure in metamorphic rocks and if often understood to include cleavage and schistosity.
- Folliation generally results due to dynmothermal metamorphism in coarse-grained igneous rocks like; granites and sandstones and metamorphic rocks like shcists.
- It expresses segregation of minerals in an alternating manners.

Classification of metamorphic rocks

- Based upon the presence or absence of foliation rock can be classified as:
  - Foliated rocks
  - Non-foliated rocks

Important rocks

- Geniss
- Schist
- Slate
- phyllite



Thank you

PHYSICAL GEOLOGY
Module 3

Introduction

- Different natural agencies like; atmosphere, gases, heat, moisture, surface and subsurface water, wind etc. attack rock directly or indirectly.
- Natural agencies may be destructive or constructive in nature in relation to the existing landform of an area at any given point of time

Weathering

- It is defined as process of decay and disintegration of rocks under the influence of certain physical and chemical agencies of the atmosphere.
- The decayed and disintegrated product remains generally at or near the parent rock bod because the weathering agencies do not involve themselves in the removal of the end products to any significant distances

Erosion

- It is process of breakdown of rocks of the crust by natural agencies that are characterized with some motion as wind, running water and moving ice.
- Depending upon the velocity these agents not only gradually disintegrate the rocks but also remove the broken particles and fragments broken down from the rock.

Denudation

- It is general term expressing the sum of total of the processes of weathering and erosion operating for a geological time in a certain region.
- A denuded landscape is one that has been produces and is presently exposed as a proof of the collective work of the agencies operating in that area.

Factors affecting weathering

- **Nature of rock:** Some rock get affected easily other may remain totally unaffected under same condition. It is due to different chemical composition.
- **Climate:** Different climate have different impact over rock.
- **Physical environment:** Rocks forming bare cliffs, mountain slopes devoid of vegetation and valley sides are more prone to weathering than same rocks exposed in level lands in similar climates and under vegetable cover.

Product of weathering

- **Eluvium:** It is the end product of weathering that happens to lie over and above the parent rocks.
- **Deluvium:** It is that category of end product of weathering that has been moved to some distance after its formation due to weathering process.

Regolith

- The term regolith has been broadly used to express all the weathered material, eluvium or deluvium that covers that parents rock or is lying close to it.
- The term soil refers to the upper part of regolith that has further undergone biochemical decomposition and modifications reducing it to a uniformly pulverized state.

Soil Profile

- It is defined as the record of behavior of the material with depth below the surface upto which the effects of weathering can be easily established.
- In a typical soil profile, following four weathering zones are commonly recognized.

- Zone A: It is made up entirely of completely weathered soil that may be supporting a vegetable cover.
- Zone B: It is a zone of mixed composition, partly of soil and partly of weathered rock, the latter becoming more dominating with depth
- Zone C: This practically soil free zone and has enough evidence that rocks at this level are already under attack by weathering although the effects have yet not become pronounced and the rocks are not disintegrated or decayed.
- Zone D: It is the zone of the so far intact rock, the parent rock, the overlying part of which has already been attacked by weathering processes.

Engineering considerations

- For construction following point should be considered:
- To what extent the area for a proposed project has already been physically deteriorated by cumulative effects of weathering processes operative in that area
- What would be the like effect of the weathering on the construction materials proposed to be used in the project.

Thank you

PHYSICAL GEOLOGY
Module 3

Deposition by different agents

- Deposition by wind
  - Dunes
  - Loess
- Deposition by river
  - Alluvial fans and cones
  - Flood plains
  - Deltas
  - Channel Deposits
- Glacial Deposit (Drift)
  - Till
  - Stratified drift
  - Erractics

- **Dunes:** These are variously shaped deposits of sand-grade particles accumulated by winds. There are two types:
  - **The Crescentic dunes** :A crescentic due is characterized with two slopes in such a way that the windward slope is Convex and rises gently between 7-20 degree. It has a well-defined crest where from the steep slope or leeward slope or downward slope starts abruptly.
  - **The sigmoidal Dune:** A typical sigmoidal dune is characterized with the absence of horns or cusps and a curved outline. In its simplest form a sigmoidal dune is a steep sided ridge that extends in sinuous or S-shaped outline.

- **Loess:** The term loiess is used for wind blown deposits of silt and clay grade particles. Typical loess is unconsolidated< unstratified and porous accumulatioon of particles of size range 0.01-0.05 mm in diameter.
- The loess deposits are considered most widespread example of aeolian deposits

Fluvial Deposits

- **Alluvial fans and cones:** Cone shaped accumulation of stream deposits at small intermittent streamlets coming from hill slopes enter the low lands.
- The apex of such deposit points up-hill and its slope may range from almost flat to as much as 50 degree.
- The term alluvial fan is used when the slope of deposit is below 10 degree and alluvial cone when the slope is in range of 10-50 degree.
-

Flood plains

- Flood waters of river deposit most of the load as a thick layer of mud. With repeated process level or plain is formed which is known as flood plains.
- There are two plains convex flood plains and flat food plains.
- Convex plains are of convex shape with fine sand, silt and clay deposit. Flat flood plains are flat in cross-section and are made up mostly of sand and silt sediments.

Deltas

- Deltas are defined as alluvial deposits of roughly triangular shape that are deposited by major river at their mouths.
- Delta are made of three layers the bottom set beds, fore-set beds, top set beds.
- Absence of any strong sea currents, presence of good quality of load, the slope of sea shore where the stream enters helps to grow delta.

Channel deposits

- Many streams are forced by some natural cause to deposit some of their load along their river beds. These are so called channel deposits that are great economic use, being the source of sands and gravels quite suitable for use as construction material.

Glacial deposits

- **Till:** It is also called unstratified drift, and is the most common form of glacial deposit. Consist of unassorted mixture of boulders and clay particles and loosely packed.
- **Stratified drift:** It represents all those accumulations of glacial origin where melt waters have played a prominent part in their deposition. Consequently stratified drift deposits exhibit a definite sorting.
- **Erractics:** these are variously sized boulders and blocks of rocks that are clearly and undoubtedly foreingn to the place of their present occurance.

Waterfalls

- These are magnificent jumps made by stream or river water at certain specific parts of their course where there is a sudden and considerable drop in the gradient of the channel.
- Successive falls of smaller height are sometimes referred as rapids and cascades.
- Softer rock get eroded quickly than hard.

River Meandering

- The curved, zingzag path acquiring a loop-shaped course is called meandering.
- Meanders are developed mostly in the middle and lower reaches of major streams where lateral erosion and deposition along opposite banks become almost concurrent geological activities of the stream.
- In stream velocity at the convex bank may be little less than the velocity of the same river on the opposite concave bank.
- Because of this erosion on the concave side takes place and deposition on the convex side takes place.
- Due to this channel on the concave side and making it progress further inland, while on convex side mover further inwards.

Laterite

- Laterite is both a soil and rock type rich in iron and aluminum and is commonly considered to have formed in hot and wet tropical areas.
- Because of high iron oxide content its color is rusty-red.
- Laterites are formed from the leaching of parent rocks, which leaves the more insoluble ions, predominantly iron and aluminum.
- The mechanism of leaching involves acid dissolving the host mineral lattice, followed by hydrolysis and precipitation of insoluble oxides and sulfates of iron, aluminum and silica under the high temperature conditions of a humid sub-tropical monsoon climate.

Laterite

- Laterites consists mainly of quartz, zircon, and oxides of titanium, iron, tin aluminum and manganese.
- Laterites can be used in brick or in other masonry structure, road construction etc.

THANK YOU

PHYSICAL GEOLOGY
Module 3

Desert landform

- Examples of desert landforms are
  - rock pedestals,
  - Yardangs,
  - Desert pavements,
  - Deflation hollows,
  - Oasis
  - Sand dunes.

Rock Pedestals



- Rock pedestals are landforms created by abrasion in which grains cut away the base of rock structures but leaves their tips intact. This is due to wind-borne sand grains following bouncing trajectories that carry sand as high as 1m above the ground.

Deflation Hollows



- Deflation hollows are an example of wind erosion causing deflation yet these depressions also tend to collect rainwater and hold this water for a time depending on evaporation rates through the stones.

Oasis



- Oasis' are found in the middle of deserts as fertile spots containing one or more springs surrounded by vegetation.

This is caused by a variety of different temperature extremes causing islands of life.

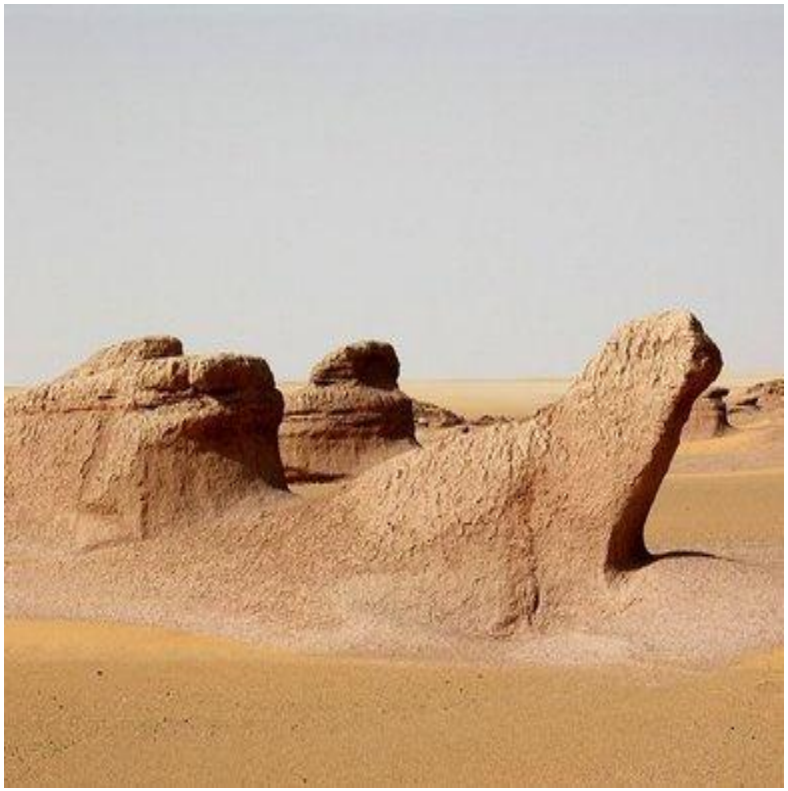
This outcome is due to oasis usually been located in parts of the desert where the elevation is low enough meaning the water table is underneath the surface, allowing life to grow through their roots extending into the moist land..

Sand Dunes



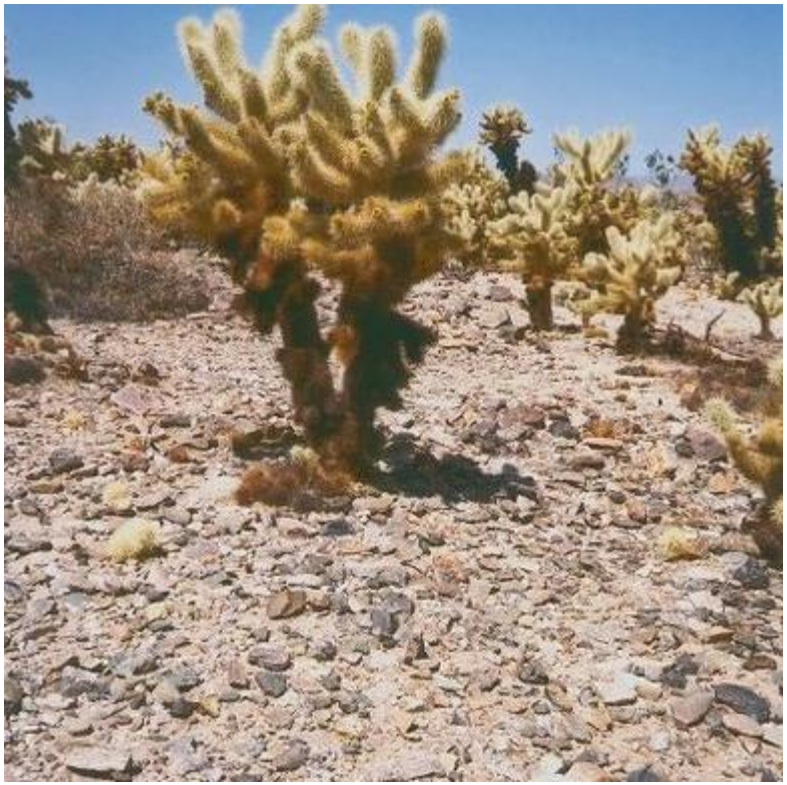
- There are two different types of sand dunes which are the barchan dunes and seif dunes.
- These are differentiated as barchan dunes are produced by the action of wind predominately convex facing from one direction forming crescent-shaped dunes , whereas the seif dunes are long and narrow or can be a chain of dunes.

Yardangs



- Similarly Yardangs are also the result of sand grains pushed by persistent winds to form low ridges of sand carved in soft rock.
- This is commonly found in flat deserts where steady winds blow away dust and silt.
- Higher front faces of Yardangs are undercut as erosion is concentrated in the lower areas because wind driven sand stays near the ground. These are an example of erosional landforms

Desert Pavements



- Pavements are commonly covered with stones rather than sand. This may be due to the wind blowing away the finest material leaving the stones behind as they are the bigger particles and remain as a lag deposit or may be through various physical processes including the soil in the ground as the fine materials are moved down beneath the pebbles. This results in the stones remaining on top. Desert pavements can be used as mulch for plants or as a shelter for ants and rodents

Residual deposits of clay with flints

- A residual deposit formed from the dissolution, decalcification and cryoturbation of bedrock strata of the Chalk Group and Palaeogene formations and, in the extreme west of the outcrop, the Upper Greensand Formation.
- It is unbedded and heterogenous. The dominant lithology is orange-brown and red-brown sandy clay with abundant nodules and rounded pebbles of flint. Angular flints are derived from the Chalk, and rounded flints, sand and clay from Palaeogene formations.
- The deposit locally includes bodies of yellow fine- to medium- grained sand, reddish brown clayey silt, and sandy clay with beds of well-rounded flint pebbles, derived from Palaeogene formations

Solifluction

- **Solifluction**, flowage of water-saturated soil down a steep slope. Because permafrost is impermeable to water, soil overlying it may become oversaturated and slide downslope under the pull of gravity. Soil that has been opened and weakened by frost action is most susceptible. Movement is at a maximum rate of a few inches per day, eventually producing smooth, gentle, concave slopes. Original stratifications of the soil become contorted if not completely destroyed.

Mudflow

- A **mudflow** or **mud flow** is a form of mass wasting involving "very rapid surging flow" of debris that has become partially or fully liquified by the addition of significant amounts of water to the source material.
- It contain a significant proportion of clay, which makes them more fluid than debris flows; thus, they are able to travel farther and across lower slope angles.
- Mudflows are often called **mudslides**, a term applied indiscriminately by the mass media to a variety of mass wasting events. Mudflows often start as slides, becoming flows as water is entrained along the flow path; such events are often called **flow slides**.
- Other types of mudflows include lahars (involving fine-grained pyroclastic deposits on the flanks of volcanoes) and jökulhlaups (outbursts from under glaciers or icecaps)

Marine deposits

- **Shallow (Neritic deposits):**
- Through action of wave water deposits derived from the land and shore rock. Beaches, spits, bars and tombolos are neritic
- **Beaches:** There are loose deposits made by sea near the shore from the materials eroded from nearby regions.
- **Spits and Bars:** There are ridge shaped deposits that extend across embayment. A spit is formed somewhat in this way: when a sediment laden shore current comes near an embayment on the coast, there is strong tendency for normal course.
- **Tombola:** It is a form of bar that connects a headland and an island or one island with another island.
- **Deep water deposits**
- These deposits consists mostly of mud and oozes.
- The oozes consists of small organisms (planktons).
- Reefs are one of such deposits.

References

- https://desertlandforms.weebly.com/desert-landforms.html
- https://en.wikipedia.org/wiki/Mudflow

Thank you

STRENGTH BEHAVIOR OF ROCKS

Module 4



Mechanical or Strength Properties of Rocks

Strength : Ability of a material to resist an externally applied load, but

In Rock mechanics, strength is the Force per unit Area required to bring about rupture in a rock mass at a given environmental conditions.

Classification of strength: depending upon type of loading and the stresses, the strength in general may be classified as

- Compressive Strength
- Tensile strength, and
- Shear Strength

For determining the above strength values the tests are conducted either on intact rock specimens in the **laboratory tests** or on rockmass in the field, i.e., **insitu strength tests**

In the laboratory there are direct Methods for the determination of above strength values in the laboratory and also indirect methods for the determination of above strength values roughly in the laboratory or at the field site



Mechanical or Strength Properties of Rocks

Compressive Strength

The compressive strength of a material is a measure of its ability to resist uniaxial compressive loads without yielding or fracture.

The most common measure of compressive strength is the Uniaxial compressive strength or unconfined compressive strength. It is one of the most important properties used in design, analysis and modeling.

Direct Methods:

1.Uni axial Compression Test

2.Tri axial Compression Test

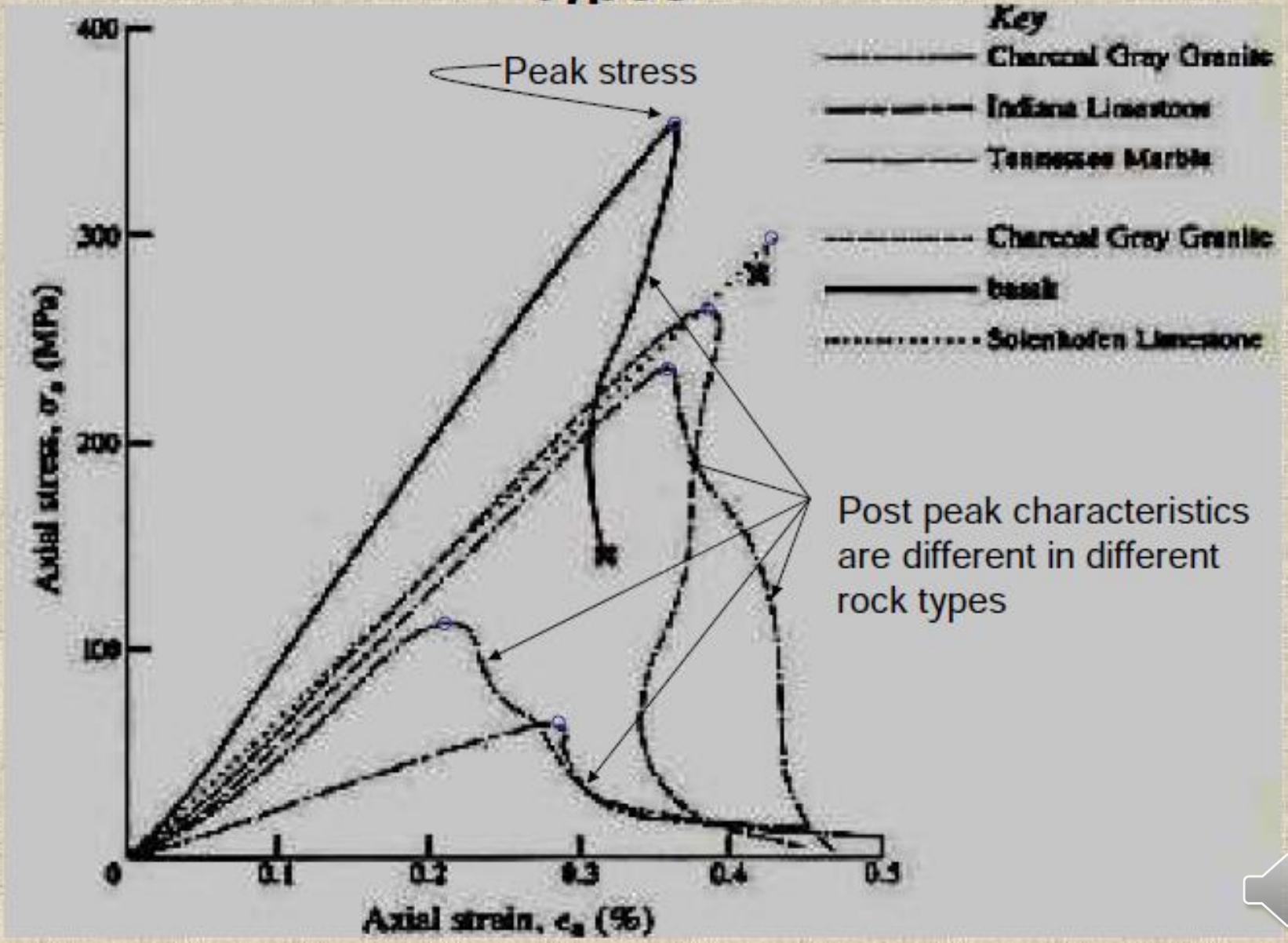
Indirect Method :

1.Point Load Test

2.Schmidt hammer Test

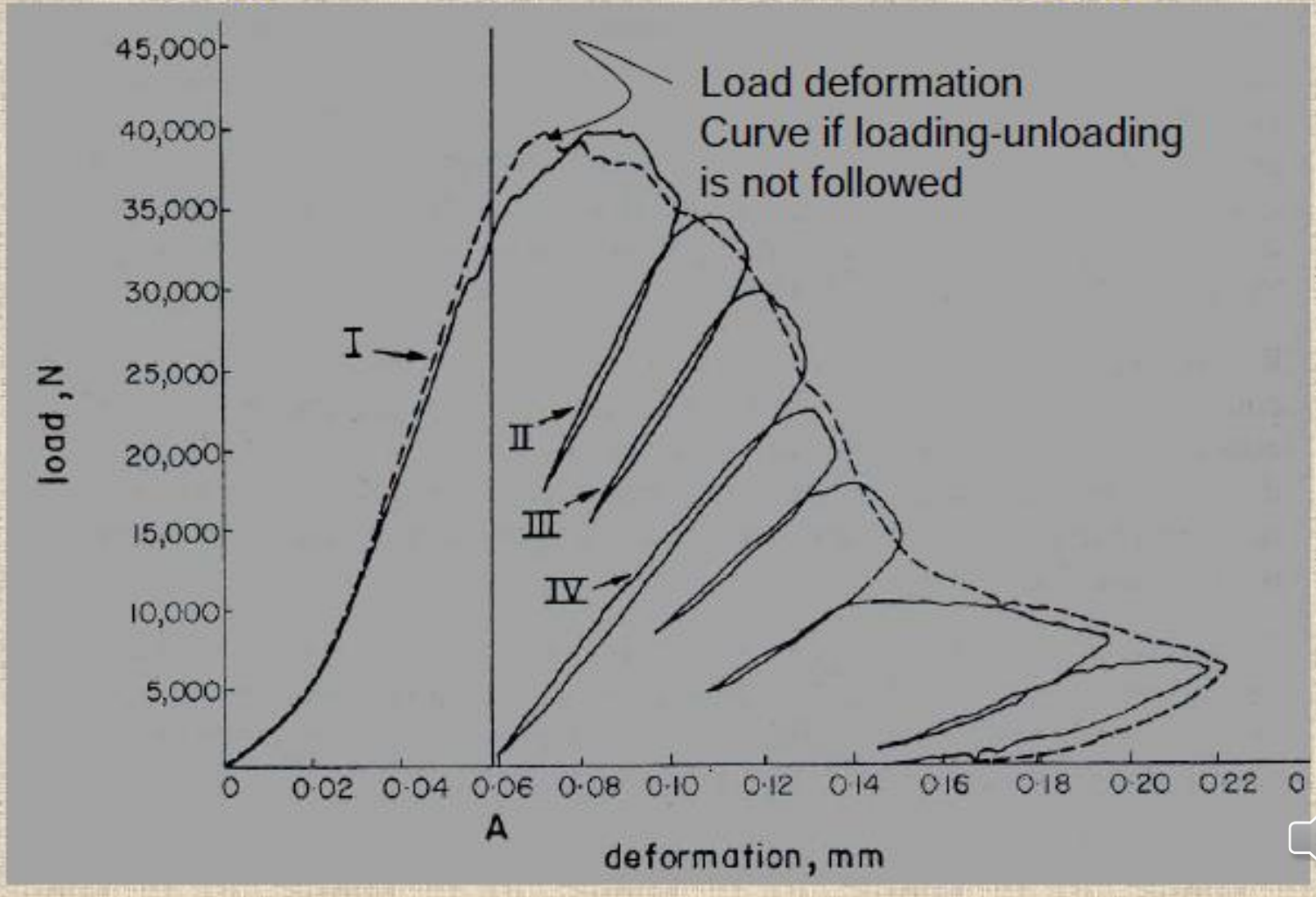


Uniaxial stress-strain curves for different rock types



Post failure behaviour of rock in compression Cyclic loading

The behaviour of the rock under compression until the rock has lost its strength is as shown in the following figure.



Compressive Strength

The load-deformation characteristics in UCS for loading and unloading cycles follow the following behaviour:

1. On loading , the curve eventually joins that for a specimen in which the axial displacement increases with time

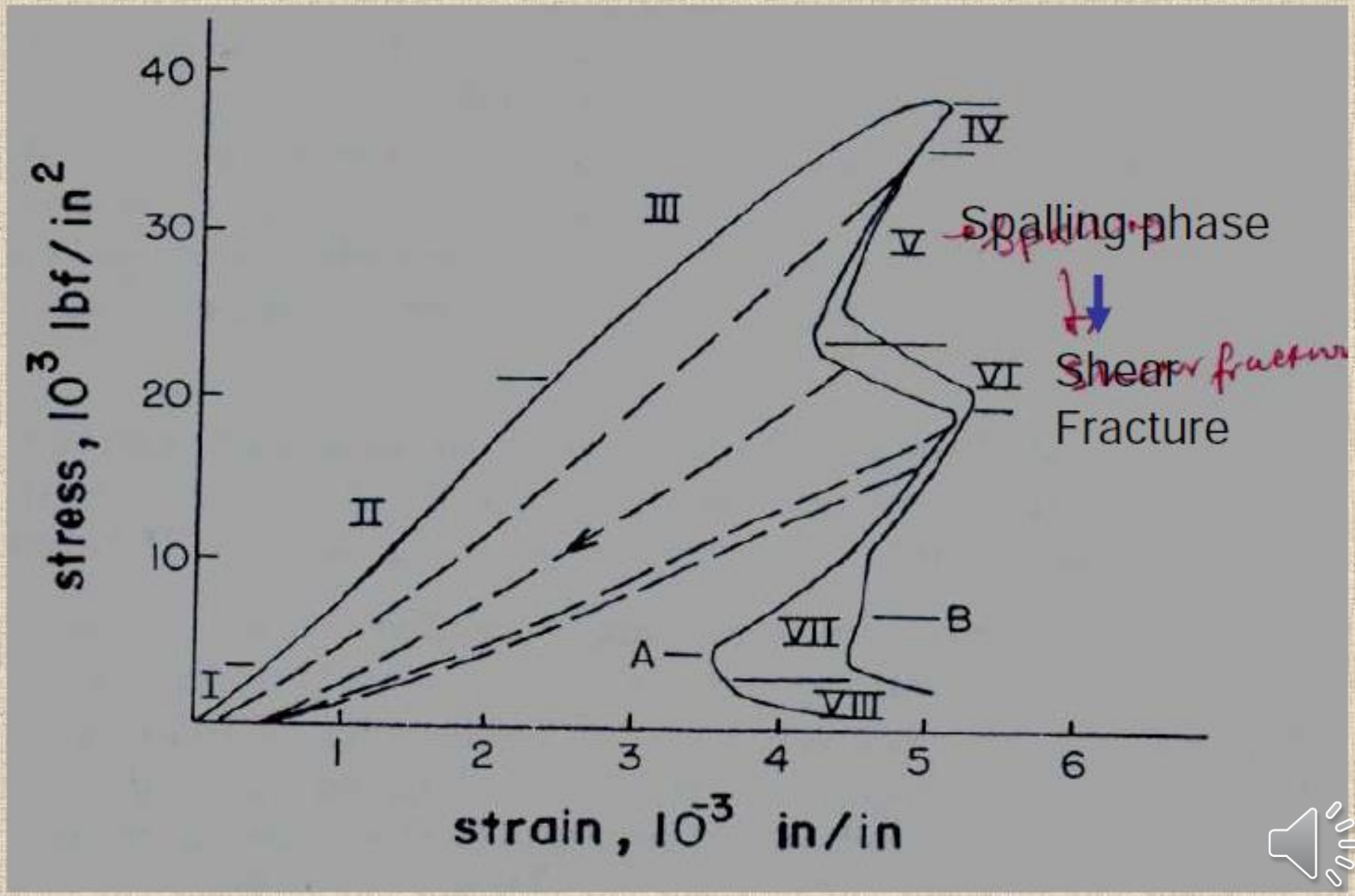
2. As displacement continues in the post-peak region, the portion of the total displacement that is irrecoverable increases

3. The loading-unloading-loading loop shows some hysteresis

4. The apparent modulus of the rock which can be calculated from the slope of the reloading curve, decreases with post-peak deformation and progressive fragmentation of the specimen



Rock Failure characteristics in UCS



The fracture pattern of specimen is divided into 8 distinct regions.

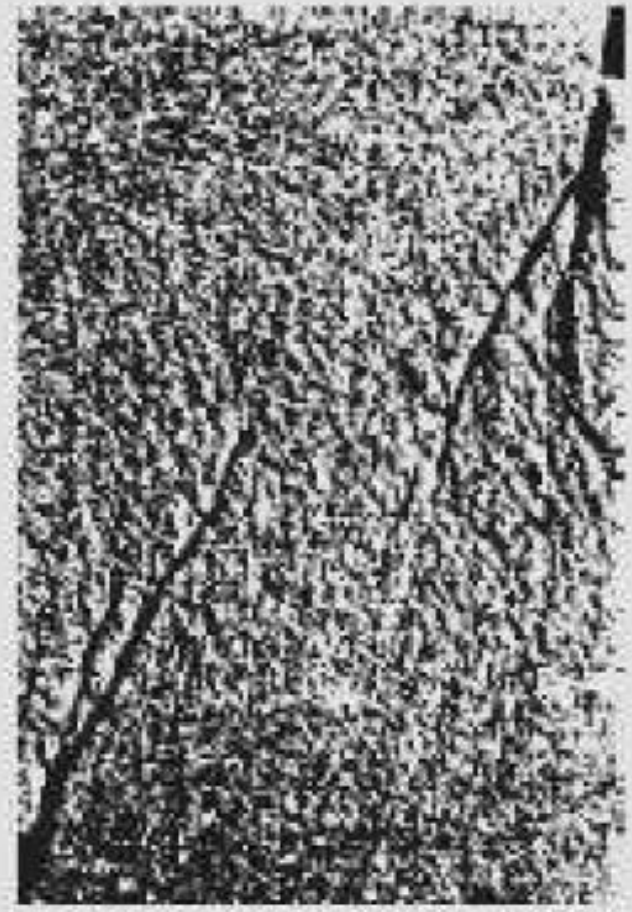
I-III are marked with closure of pre-existing cracks as well as coalescence of random crack formation, crack growth and sliding on existing crack surface

IV extension of the small fractures parallel to the line of loading. The cracks appear at the center of the specimen height and dilation is prominently seen. The peak strength is also reached

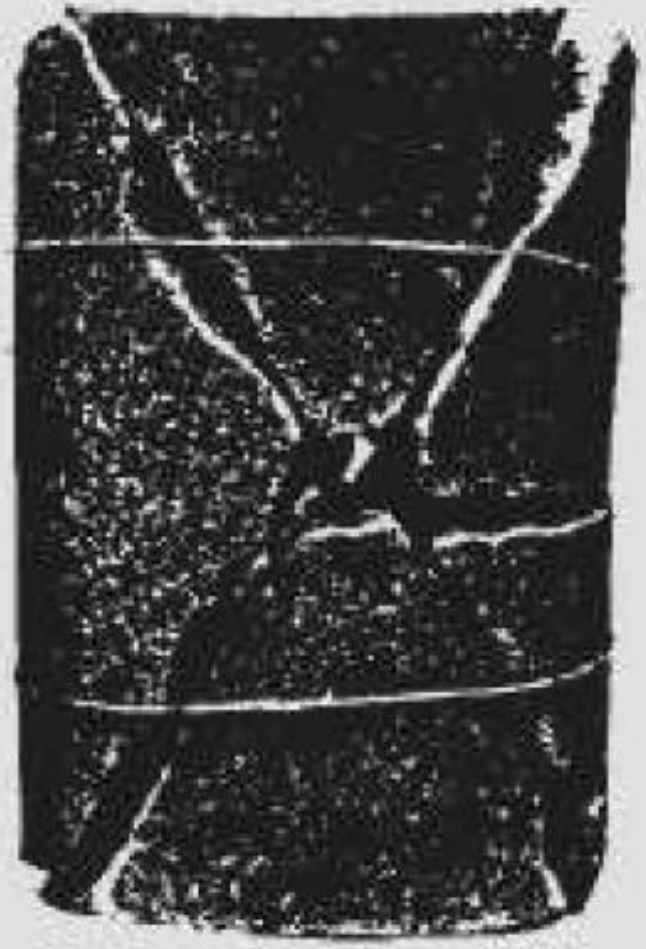
V Spalling of the dilated specimen starts at the beginning of the region V of stress-strain curve, continues in the region VI followed by a steeply inclined shear fracture plane and it grows into the region VII

VIII Loose mass of the broken material is held together due to friction

Failure modes in compression



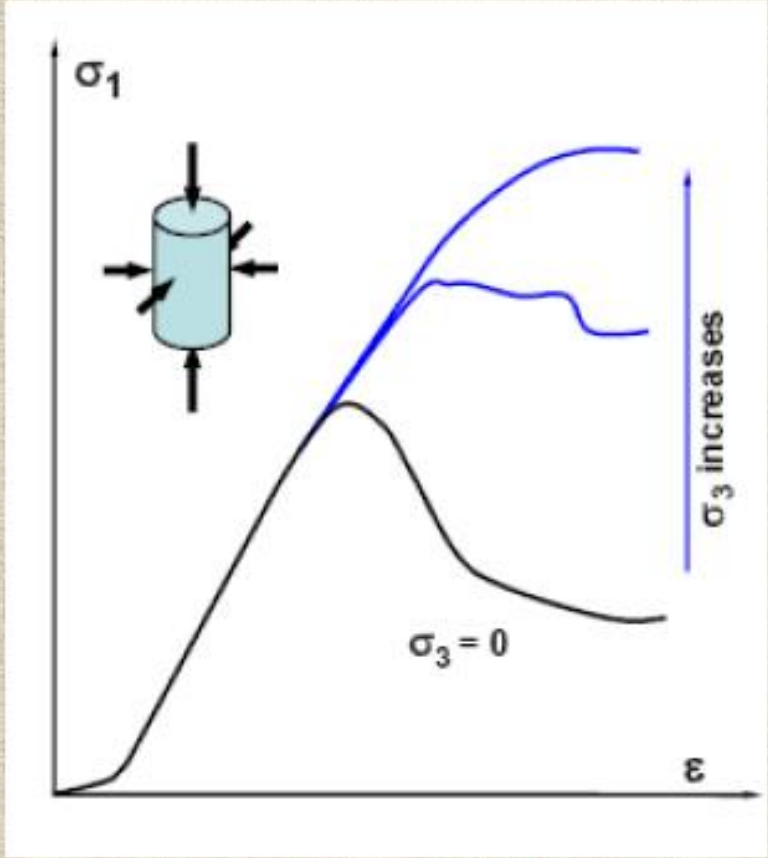
Around peak stress (IV-V)



Post peak stress (VI)


Rock Specimens before & After failure in Uni-Axial compression

Triaxial compression of rock samples – Direct Method



Stress Strain Curve in Triaxial Compression

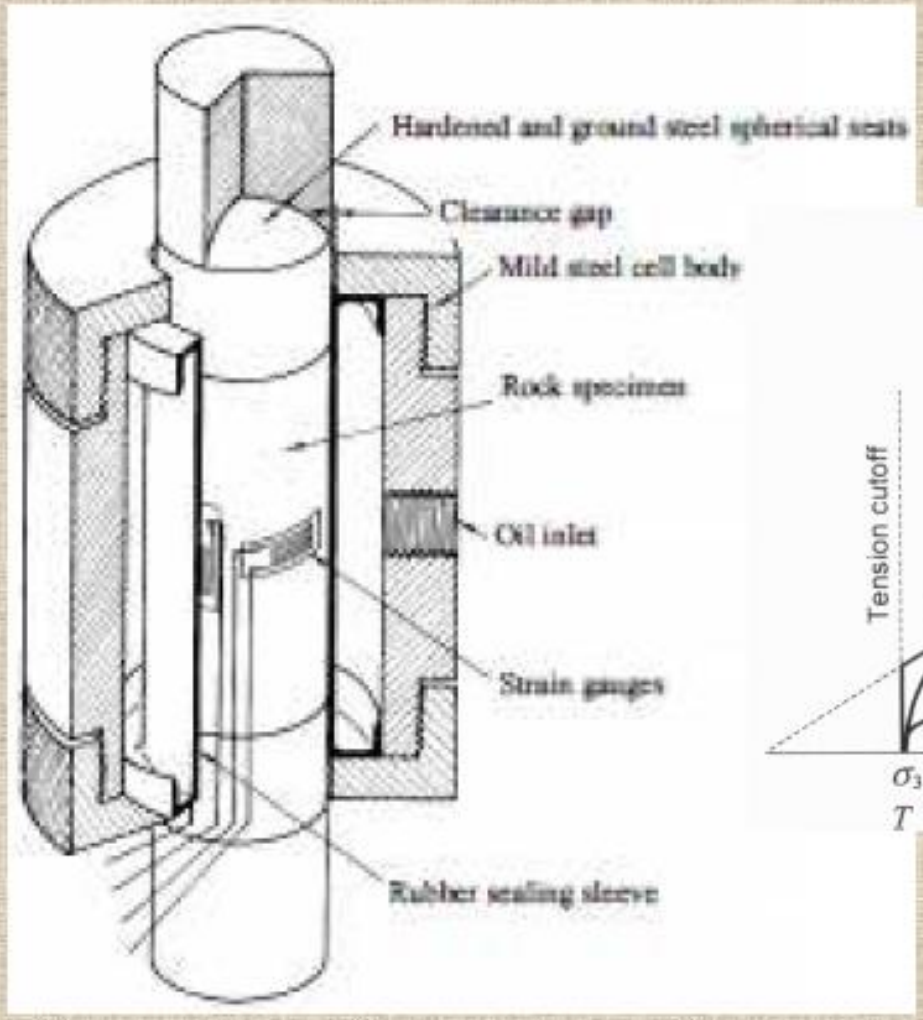
When the rock specimen is subjected to confining pressure in addition to vertical pressure, the strength exhibited by rock specimen is known as Triaxial compressive strength

Axial loading by Compressive testing machine and Confining pressure usually oil pressure from external source

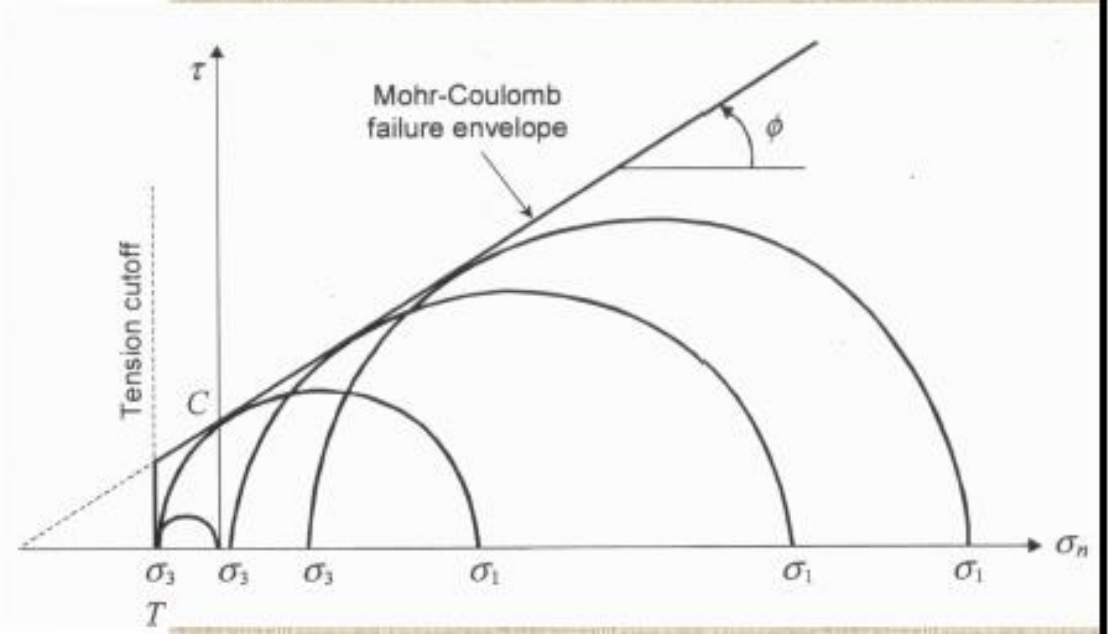
Usually tests on atleast five specimens, each at a different confining pressure needed to define peak strength envelope Sigma 1 Vs Sigma 3

This test also helps in determining shear strength parameters of rock material from the Mohr's envelope drawn from test results

Axi Symmetric Triaxial compression



Triaxial Cell



Mohr's Envelope

Tri-axial compression

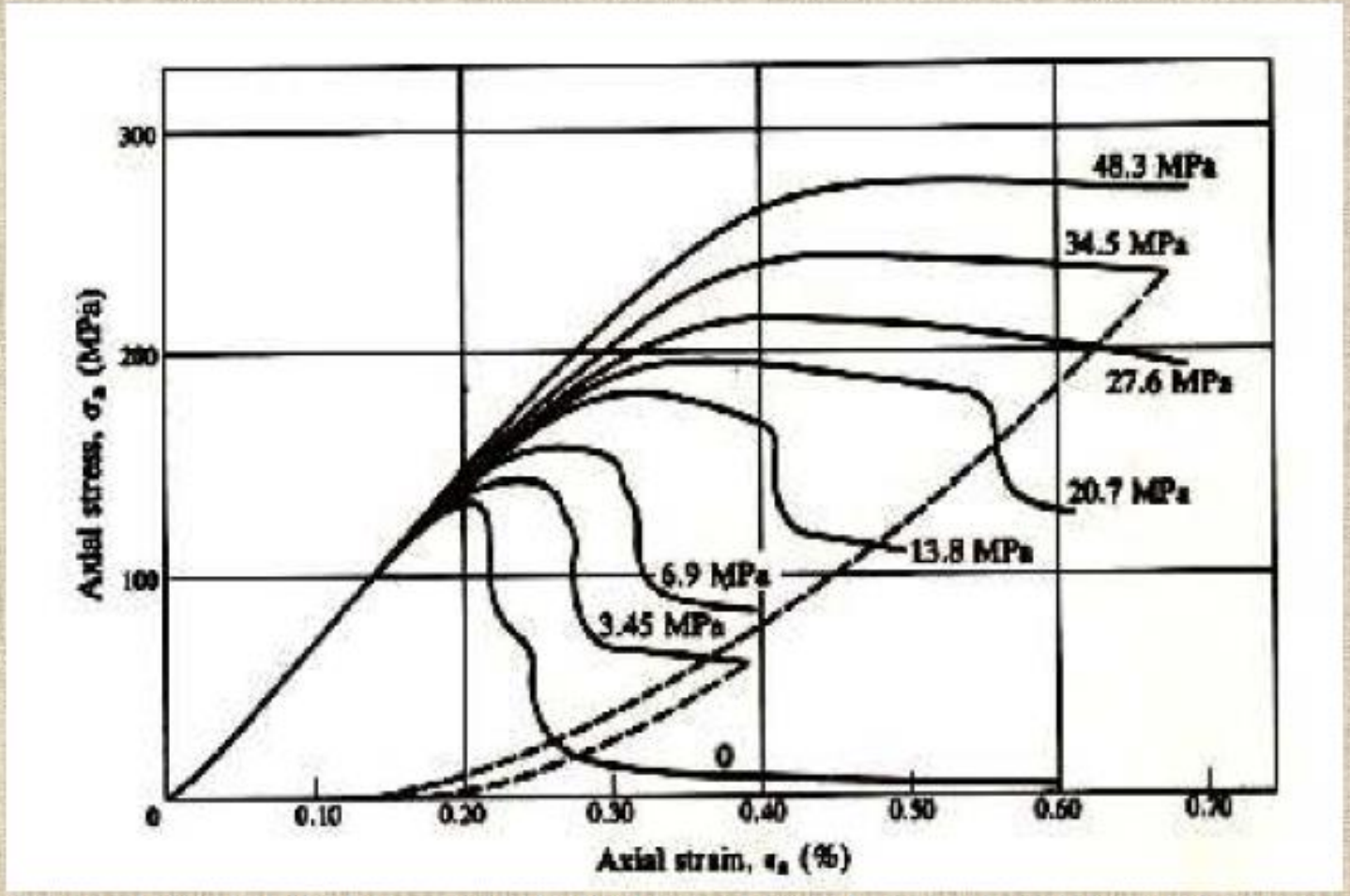


Figure Complete axial stress-axial strain curves obtained in tri-axial compression tests on Tennessee Marble at various confining pressures (Wawersik & Fairhurst 1970).

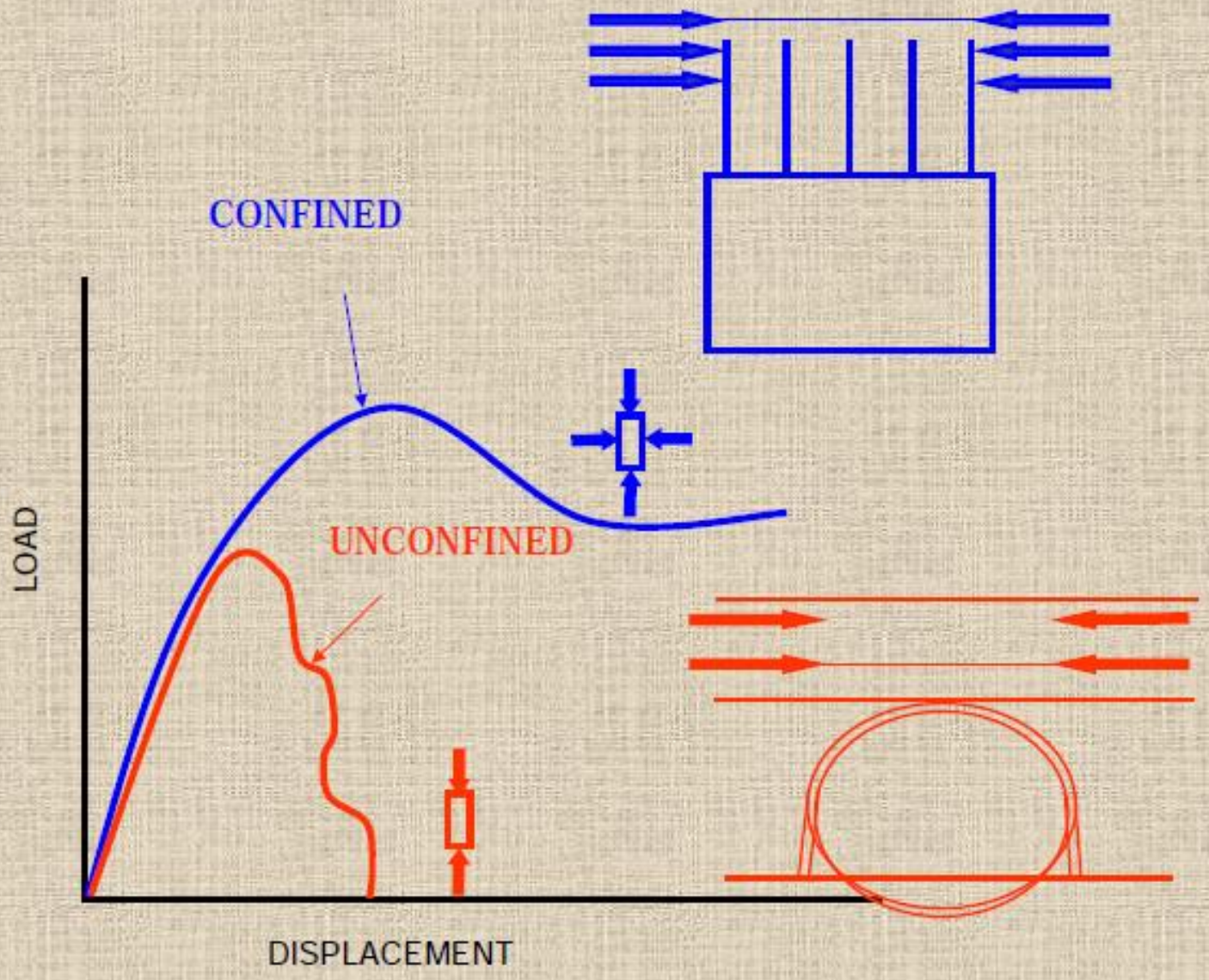
Effects of Confining Pressure

A number of important features of the behaviour of rock in tri-axial compression can be seen, such as with increasing confining pressure,

(a) the peak strength increases;
(b) there is a transition from typically brittle to fully ductile behaviour with the introduction of plastic mechanism of deformation;
(c) the region incorporating the peak of the axial stress-axial strain curve flattens and widens;
(d) the post-peak drop in stress to the residual strength reduces and disappears at high confining stress.

The confining pressure that causes the post-peak reduction in strength disappears and the behaviour becomes fully ductile (48.3 MPa in the figure), is known as the brittle-ductile transition pressure. This brittle-ductile transition pressure varies with rock type.





Effects of Confining Pressure

THANK YOU



STRENGTH BEHAVIOR OF ROCKS

Defects in rocks

PRIMARY AND SECONDARY STRUCTURES

- Structural features that are developed in the body of rock during formation stages are termed as primary structure. E.g. stratification and lamination (sedimentary rocks), crystalline structure (igneous rock), foliation (metamorphic rock)
- All modifications of the original structures and development of new forms, shape and rearrangement of component gains, crystals or minerals are known as secondary structures.

STRUCTURAL FABRICS AND DEFECTS





- Folds
- Joints
- Faults
- Foliations
- These are internal weaknesses of rocks which may affect the stability of human engineered structures.

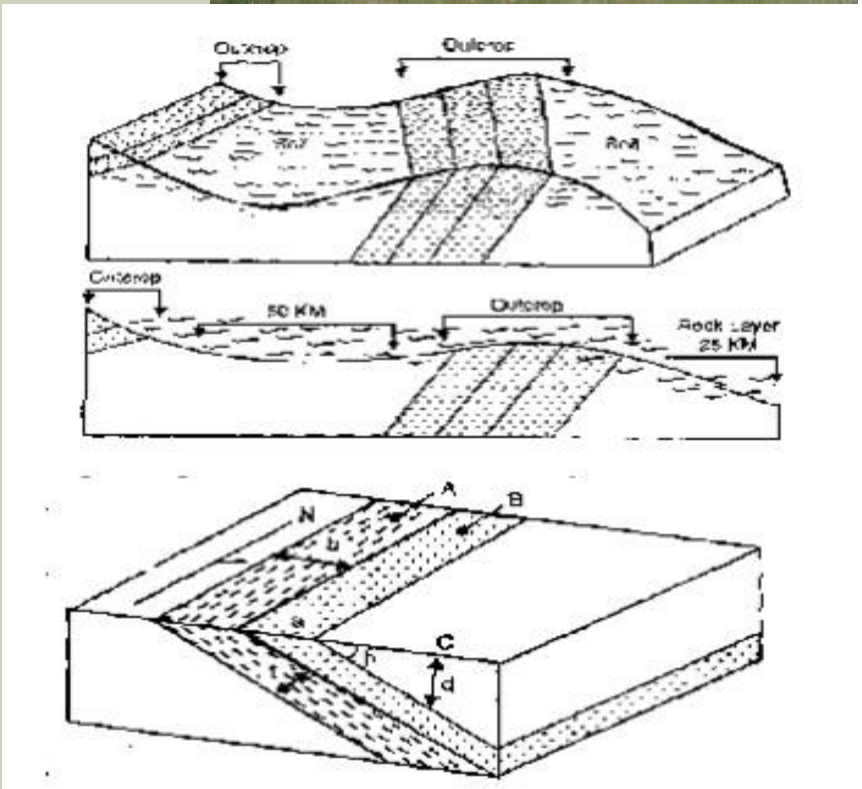




BASIC TERMS



- **Outcrops:** Rocks are not exposed everywhere on the surface. Outcrops is simply defined as and exposure of solid rock on the surface of the earth.



DIMENSION OF OUTCROP

- The width or breadth of the outcrop of a particular bed is given by the distance between the top and bottom edges f the bed as measured on the surface of the ground in a direction perpendicular to the strike of that particular bed.
- The thickness of a particular layer or bed is the perpendicular distance between top and bottom surface of the same layer as seen in vertical section at right angles to the strike of the layer
- The depth to a particular layer or bed at any place from the surface.

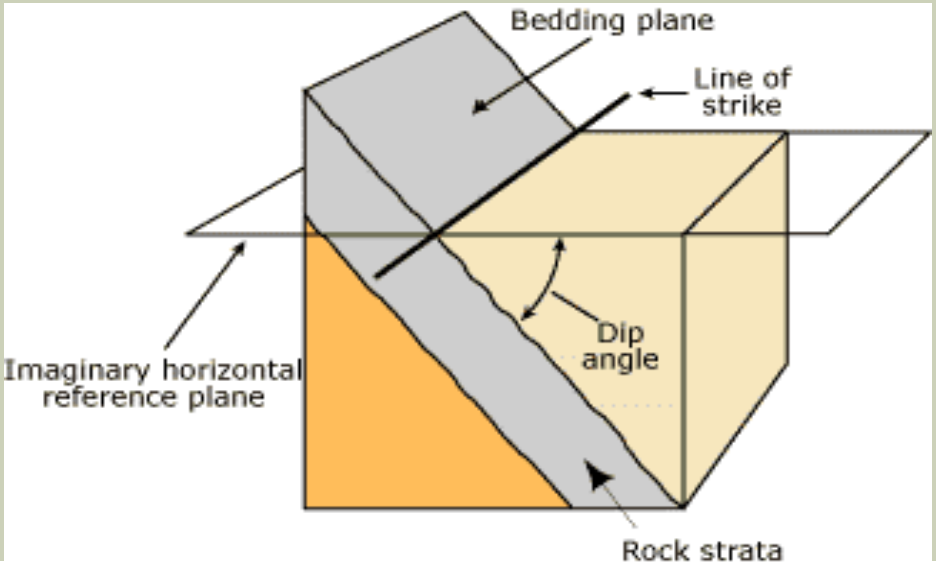
INLIERS AND OUTLIERS

- An **inlier** is an area of older rocks surrounded by younger rocks. Inliers are typically formed by the erosion of overlying younger rocks to reveal a limited exposure of the older underlying rocks.
- Conversely an **outlier** is an area of younger rock completely surrounded by older rocks. An outlier is typically formed when sufficient erosion of surrounding rocks has taken place to sever the younger rock's original continuity with a larger mass of the same younger rocks nearby.

- **<u>Bedding or stratification:</u>** sedimentary rocks are deposited under conditions which favour development of distinct layers piled up one above another.



- **Dip and strike** : the dip of and exposed bedding stratum is the angle between the bedding and a horizontal plane.
- Strike of a bed is its general trend measured on a horizontal surface. It is the direction of a line formed by the intersection of the bedding and horizontal plane.



TRUE AND APPARENT DIP

- When the dip of layer is measured in a direction that is essentially at the right angles to the strike of that particular layer, then its is called **true dip.**
- When the dip of a layer is measure in the other direction, which is not at right angles to its strike direction, it is called **apparent dip.**

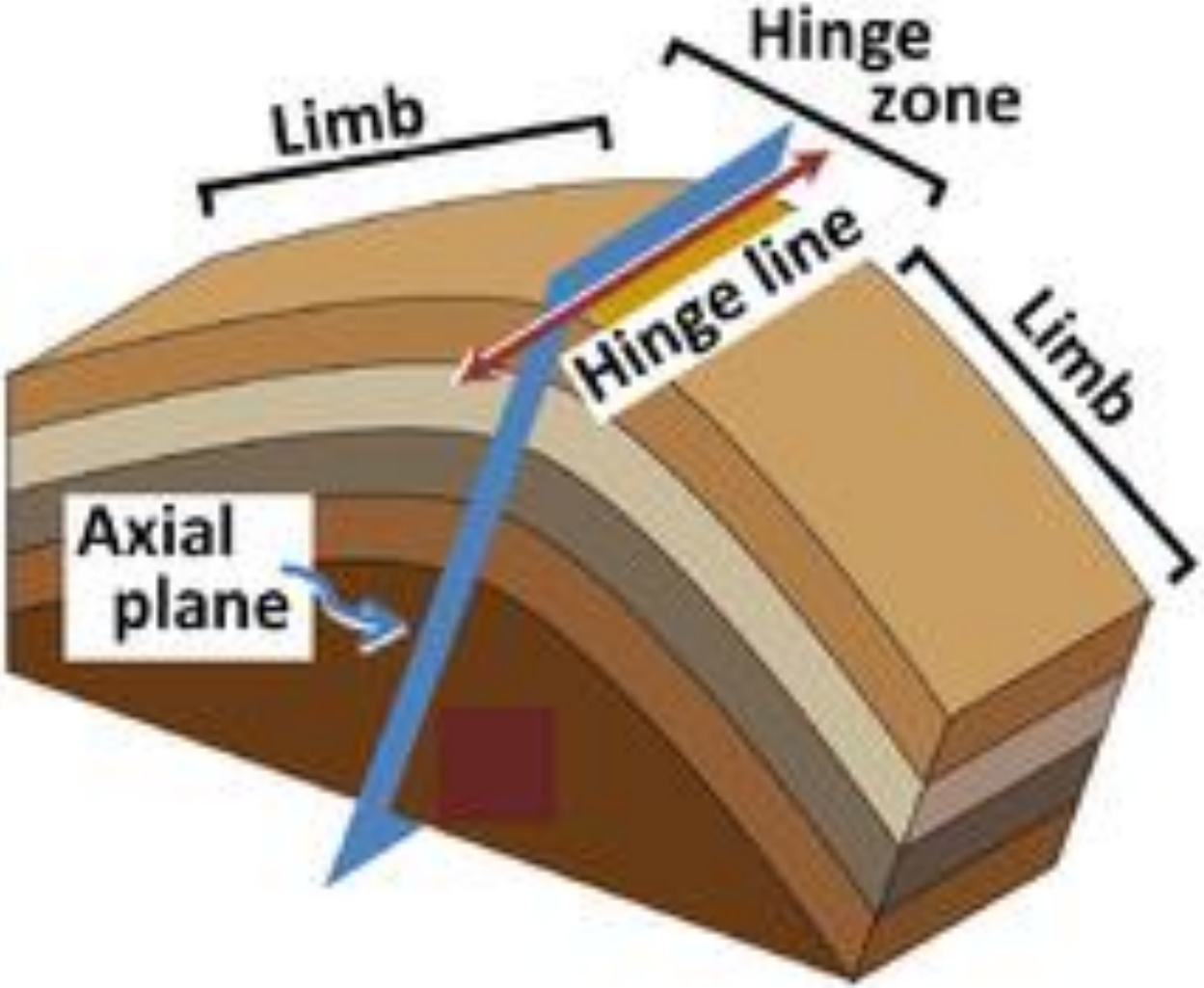
THANK YOU

Strength behavior of rocks

Folds

Folds

- Any bent or curved in a rock strata as a result of permanent deformation due to tectonic forces, is called as FOLD.
- They occur singly as isolated folds and in extensive fold trains of different sizes, on a variety of scales.
- A set of folds distributed on a regional scale constitutes a fold belt, a common feature of orogenic zones.
- Folds are commonly formed by shortening of existing layers.


Hinge
zone
Limb
Hinge line
Limb
Axial
plane







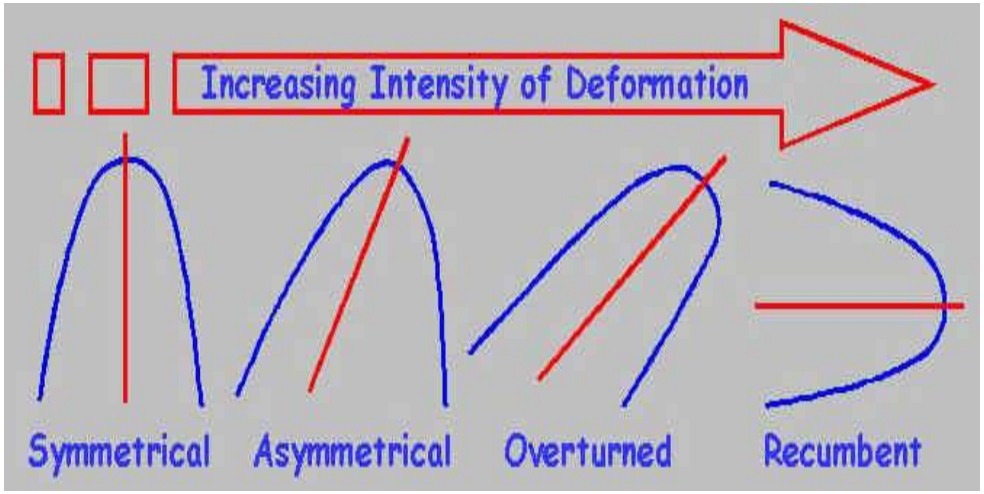
Classification of folds

- Anticline
- Syncline
- Anticlinoium
- Synclimorium
- Geosyncline
- Symmetrical fold
- Asymmetrical fold
- Overturned fold

- Recumbent
- Box fold
- Fan fold
- Open fold
- Closed fold
- Chevron fold
- basin

- **Overturned fold:** An overturned fold is one in which the axial plane is inclined and both links of fold dip in same direction, with varying dip angle
- **Recumbent fold:** An recumbent fold is one in which the axial plane is essentially horizontal. Rock strata in the inverted limb are generally thinner than the corresponding beds in normal limb.
- **Geosyncline:** the term geosyncline is used for large depression which is hundreds of kilometer in width. Oceans are considered geosynclines.

- **Symmetrical fold:** A symmetrical fold is one in which the axial surface is vertical
- **Asymmetrical fold**: An asymmetrical fold is one in which the axial surface is inclined





- **Open fold**: In an open fold the rock constituents of a bed do not move in other words no flowage occurs
- **Closed fold:** in a closed tight fold the rock constituents come out from the limbs of the fold and gradually thickness at rest and troughs.
- **Chevron fold:** a chevron fold is defined as a fold in which the hinges are sharp and anglular
- **Dome:** a dome is described as anticlinal uplift that has no distinct trend
- **Basin:** A basin is described as a synclinal depression that has no distinct trend

Causes of folding

1. Tectonic process
2. Non-tectonic process

- Folds resulting from a tectonic process formed mainly due to the forces within the custal layers of earth
- Folds resulting form a non-tectnic process are formed mainly due to the geological process operating on the exposed lithological formation

Tectonic process

- Horizontal compression folds are formed due to a compressive force acting parallel to the surface of the earth. However, the intensity of compressive force decreases gradually below the crystal layers of earth
- According to the concentration theory, fold may be formed due to
  - Cooling of earth materials
  - Formation of denser materials within the earth
  - Intrusion o magma

Non-tectonic process

- The geological process operating on the surface of the earth are responsible for formation of non-tectonic folds. For instance, weathered strata liberated from hills spore accumulated as hillside waste, creeping of the strata results in the formation o folded structure of rock materials

Thank you

Strength behavior of rocks

Joints in rocks

Joint

- Any fracture, without any movement is called as joint.
- When rock are under stress, and are at shallow depth then they may show brittle behavior and may get cracked.
- Often rocks are cracked at their elastic limit, which may vary respect to their material properties.

- **Attitude:** Joints are fracture planes or surfaces and their occurances often takes place in such a way that their position in space or attitude (dip and strike) may be described conveniently either independently or with respect to the attitude of the rocks in which they occur.
- **Grouping**: joints generally occur in groups of two or more joint planes.
- **Joint set:** it is a group of two or more joint surfaces trending the same direction with almost the same dip
- **Joint system:** it is a group of two or more joint sets.

Causes of joints patterns

- Joints are mainly cause due to the action of stress an strain on a rock mass.
- Tension joints are formed due to the drying and shrinking of sedimentary deposits, mud, cracks, folding or igneous rocks by contraction of magma.
- In igneous rocks, the stress which develops due to shearing influences of the primary rocks, overcomes the shear strength of rock material, which results in the formation of sets of joints.

Classification of joints

- Geometric types of joints
- Genetic classification

Geometric types of joints

- **Strike joints:** in this joints sets strike parallel to the strike of the rocks.
- **Dip joints:** in which the joints sets strike parallel to the dip direction of the rocks.
- **Oblique joints**: those joints where the strike of the joints is at any angle between the dip and strike of the layers. These are also called diagonal joins when they occur midway between the dip and strike of the layers.
- **Bedding joints:** in stratified rocks, some joints may develop essentially parallel to the bedding planes.

Genetic classification

- **Shear joints:** formed mainly due to the shearing stresses originating during folding and faulting of rock bodies.
- **Tension joint:** these type of joints formed due to the effect of tensile stresses. The best examples of this type of joint is columnar joints.

Civil engineering importance of structure

- Fold axes are considered as weak plane.
- In civil engineering construction such as large-scale hydraulic structures, tunneling and landslides, folded strata create engineering problems.
- Faults are considered to be weak planes. In dam or reservoir construction and tunnel alignment the presence of faults is a challenge to the civil engineering.
- Joints affects the properties of rocks both in a negative as well as positive manner with respect to the activities of a professional civil and mining engineer.

Cont…

- Along the heavily jointed region risk of leakage of water under the dam or from the reservoir may take place. Similarly if roof of side rocks in the case of tunnel are much fractured, slippage of rock along these fractures and leakage of water may cause many troubles.
- As regards to the positive effects of joints in rocks, these are greatly sought after in the exploration for ground water and oil reserves in the given area.
- Only well-jointed and porous rock can form a good acquifer or a good oil and gas reservoir.

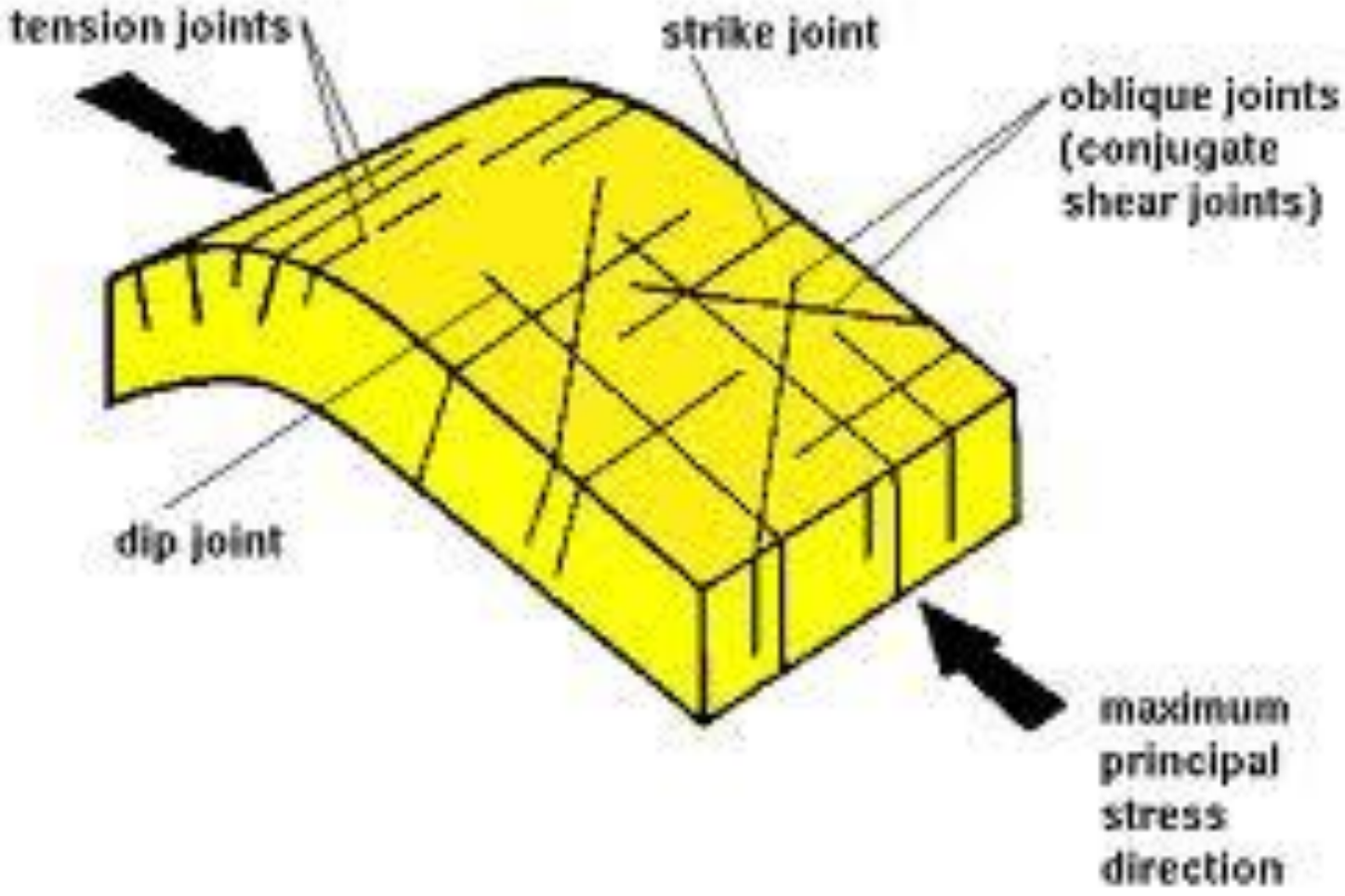


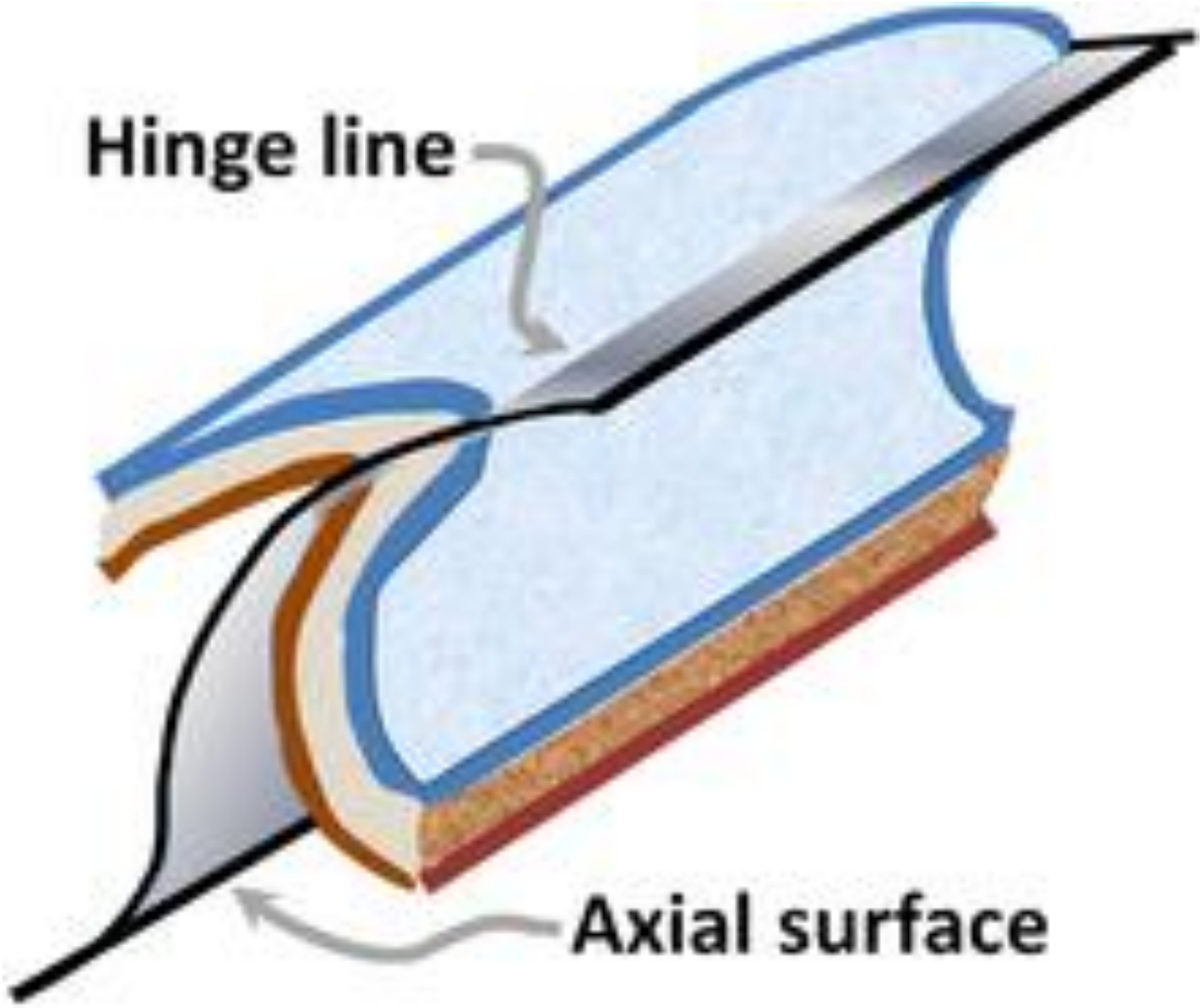
- Joints can be classified into three groups depending on their geometrical relationship with the country rock:

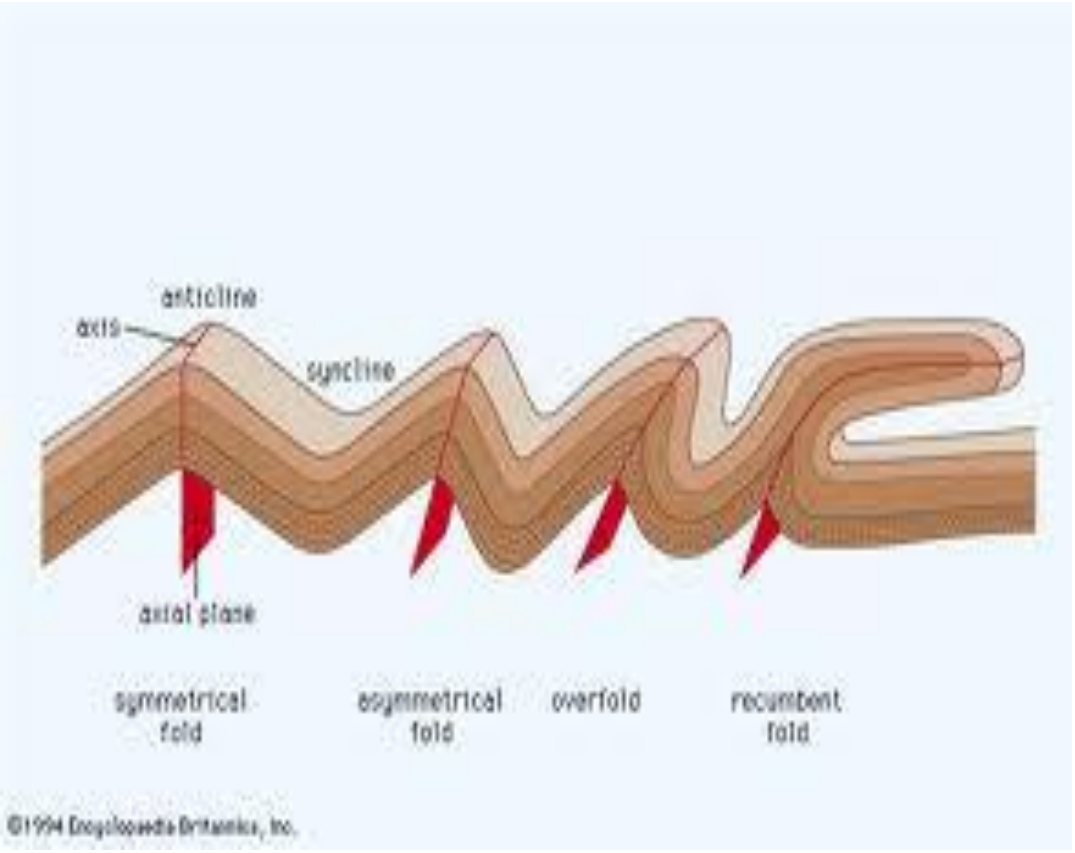
- *Strike joints* – Joints which run parallel to the direction of strike of country rocks are called "strike joints“.

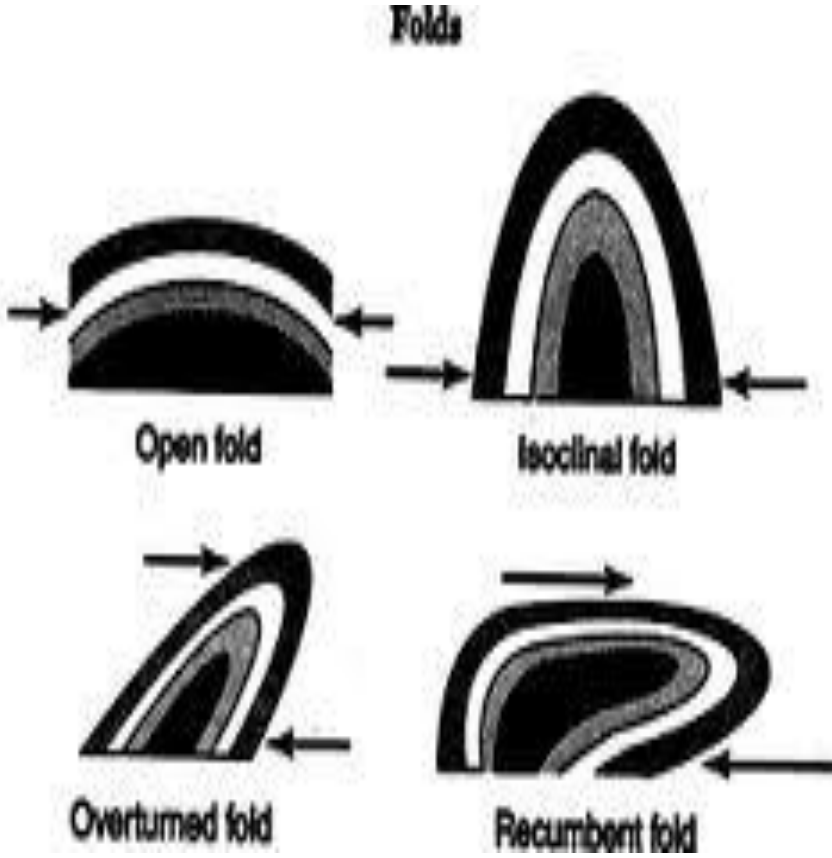
- *Dip joints* – Joints which run parallel to the direction of dip of country rocks are called "dip joints“.

- *Oblique joints* – Joints which run oblique to the dip and strike directions of the country rocks are called "oblique joints".


tension joints
strike joint
oblique joints
(conjugate
shear joints)
dip joint
maximum
principal
stress
direction


Hinge line
Axial surface

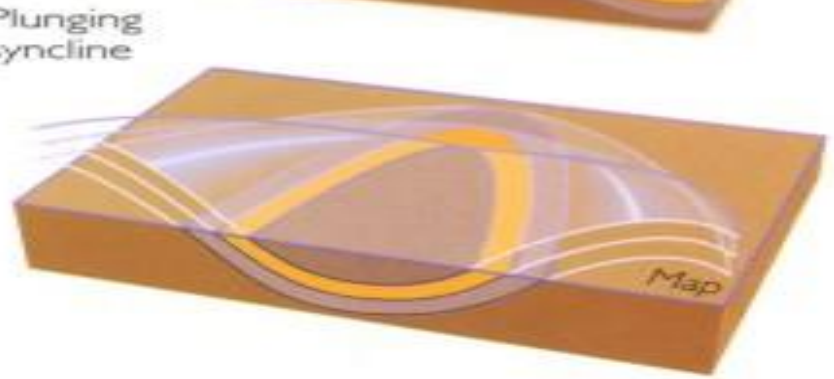

anticline
axis
syncline
axial plane
symmetrical fold
asymmetrical fold
overfold
recumbent fold
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Folds
Open fold
Isoclinal fold
Overturned fold
Recumbent fold









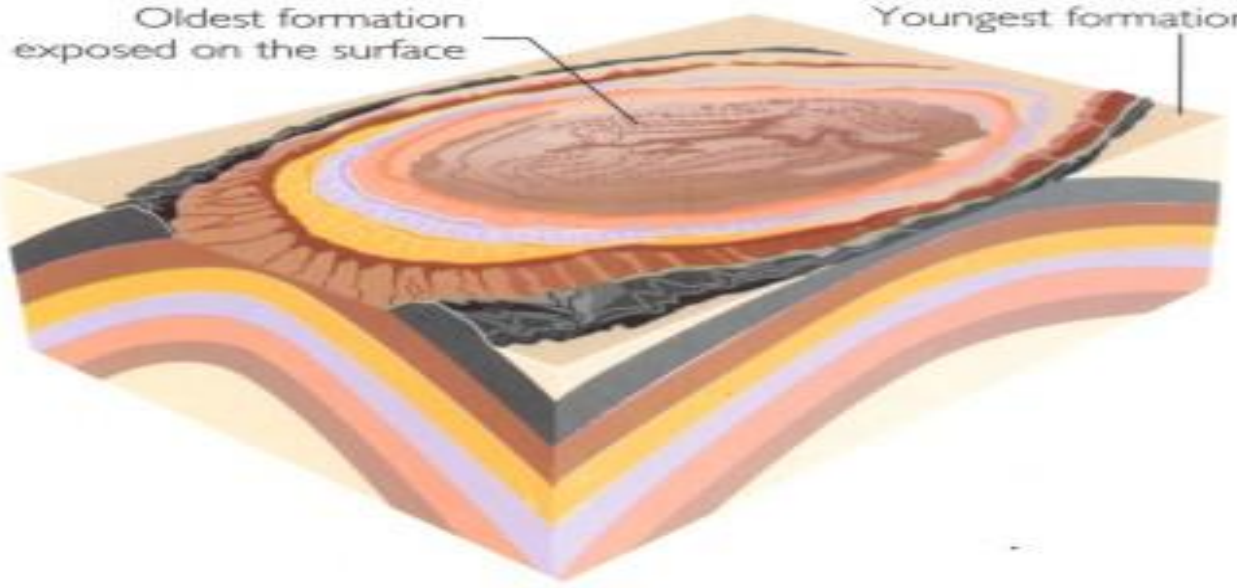
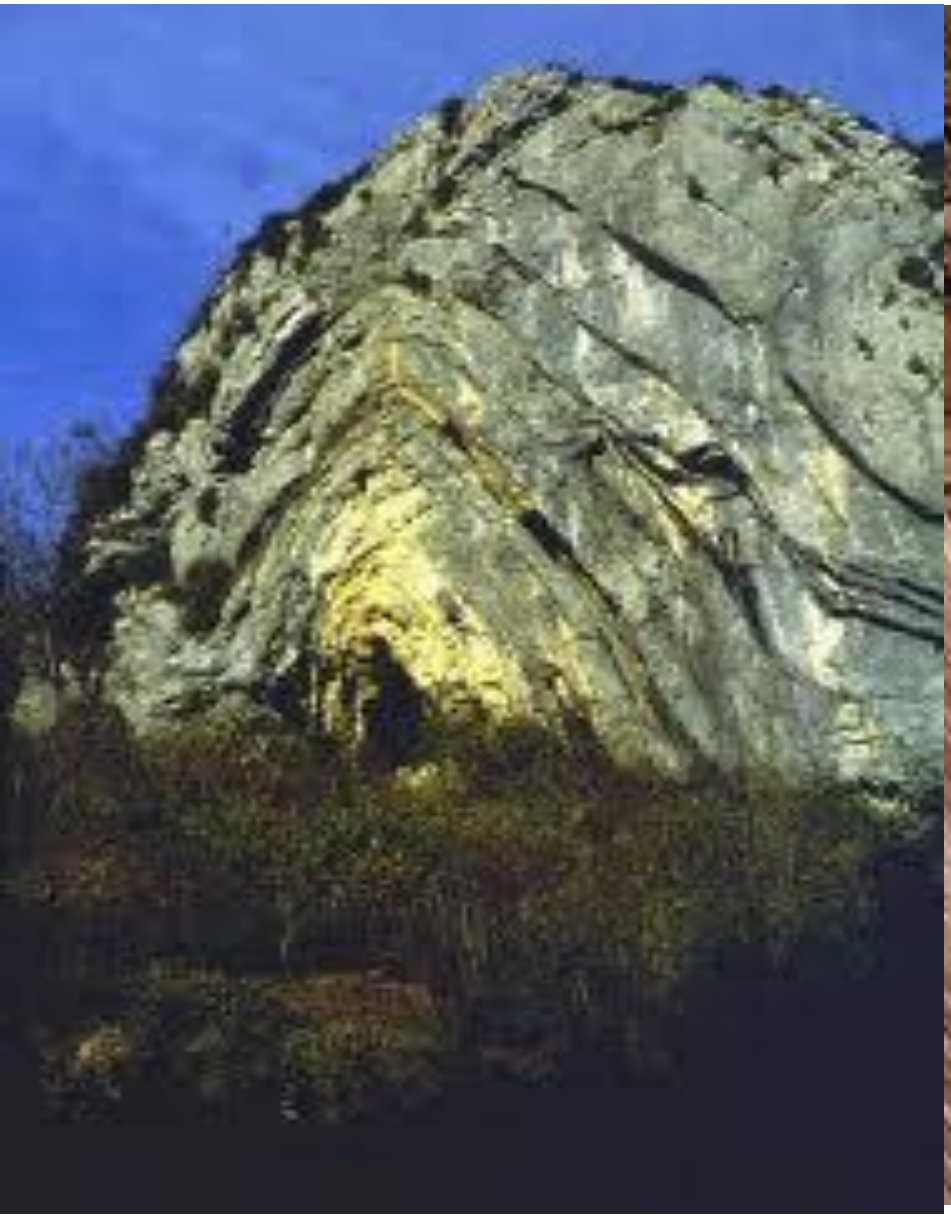


Figure 10.14, 10.16

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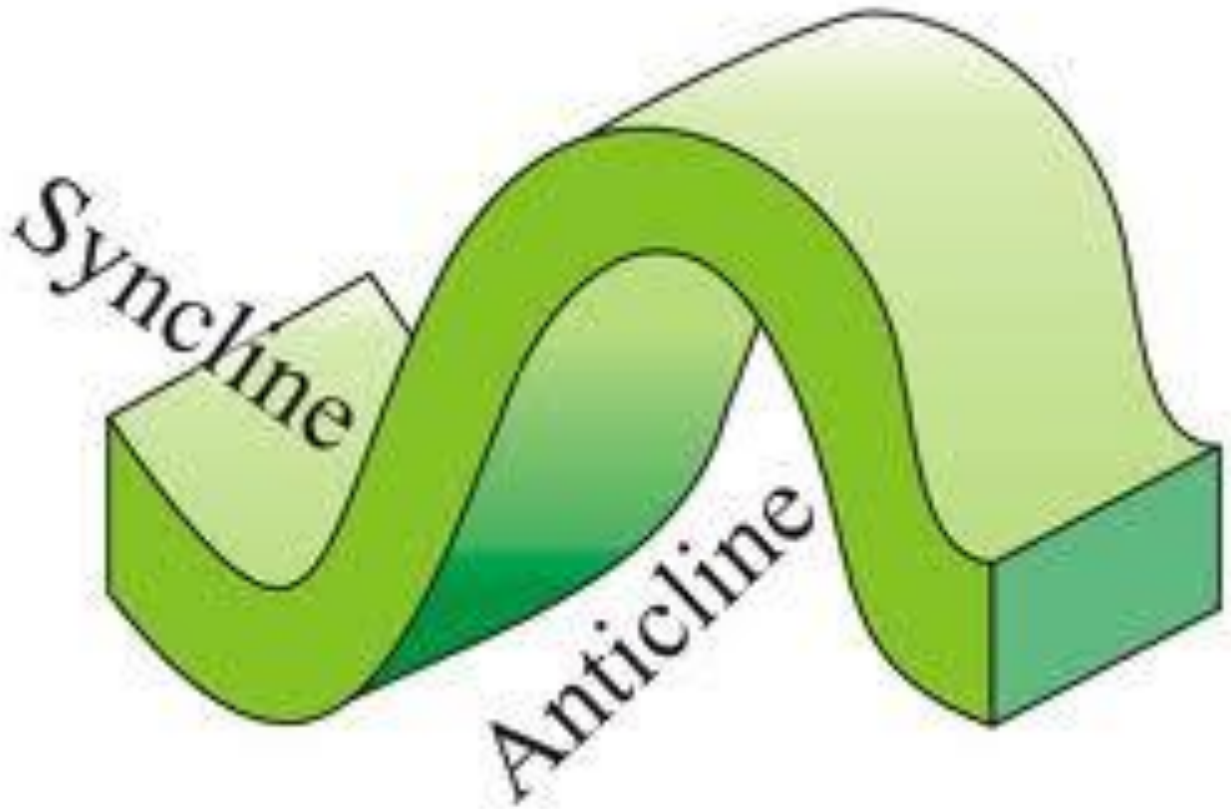
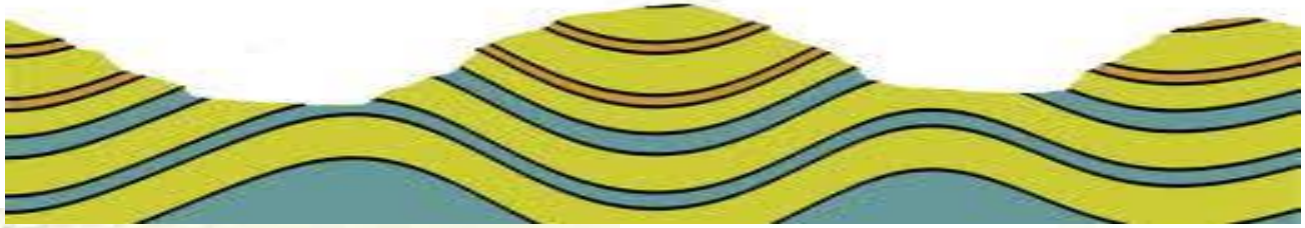
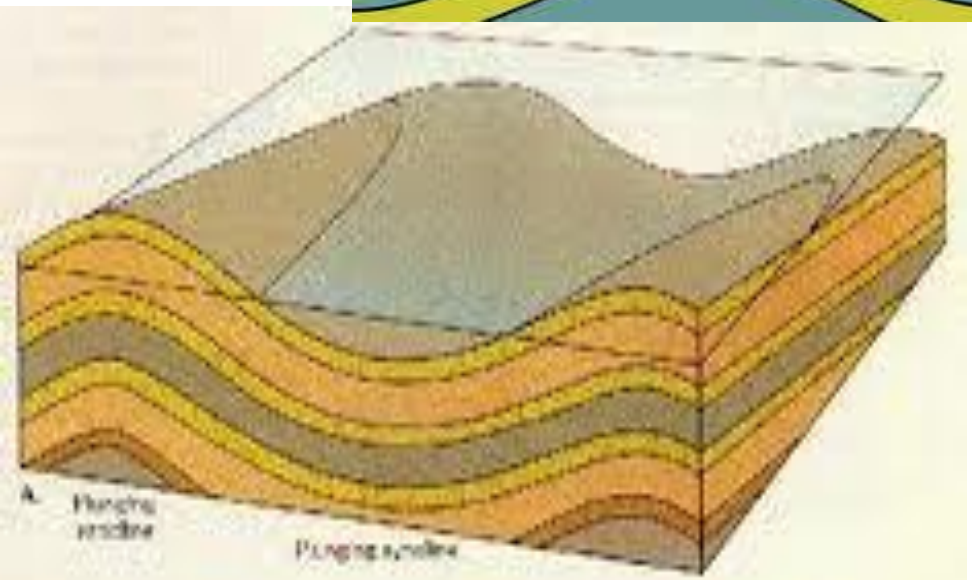
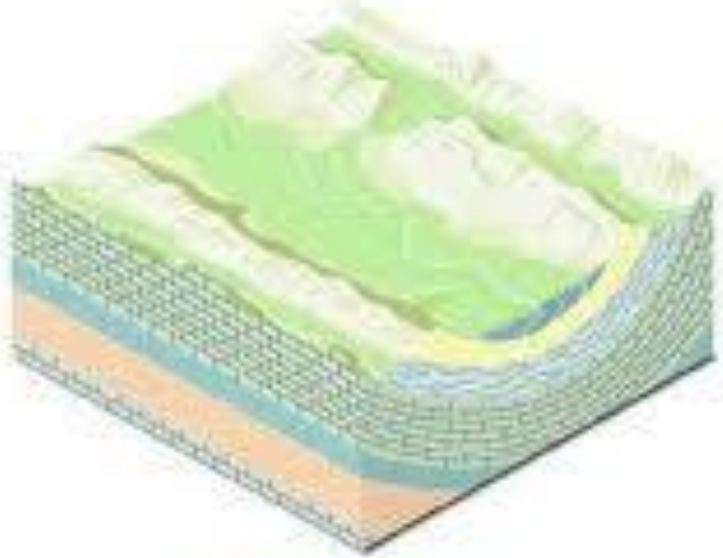
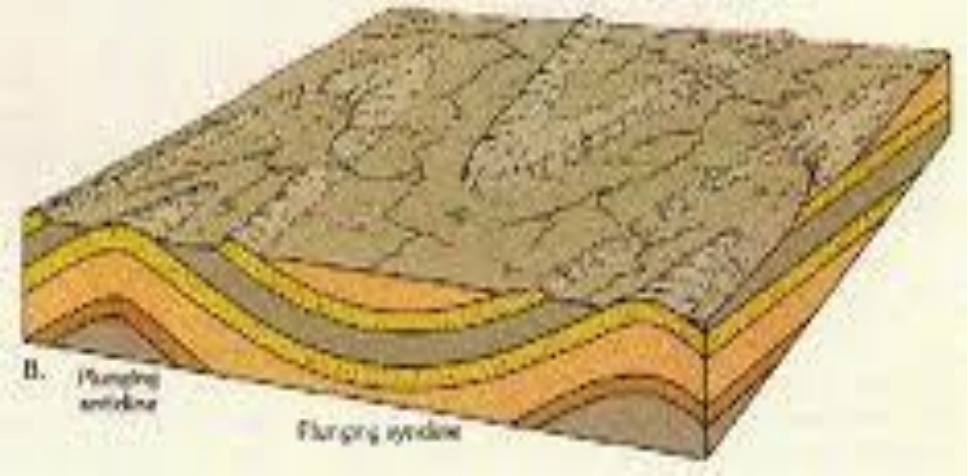

Syncline
Anticline

Figure 3: Erosion, breached anticlines











Thank you

Strength behavior of rocks

Faults

Faults

- **Fault** is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement.
- Energy release associated with rapid movement on active faults is the cause of most earthquakes.
- These earth quake may cause tremendous loss of life and property.

Faults



Faults

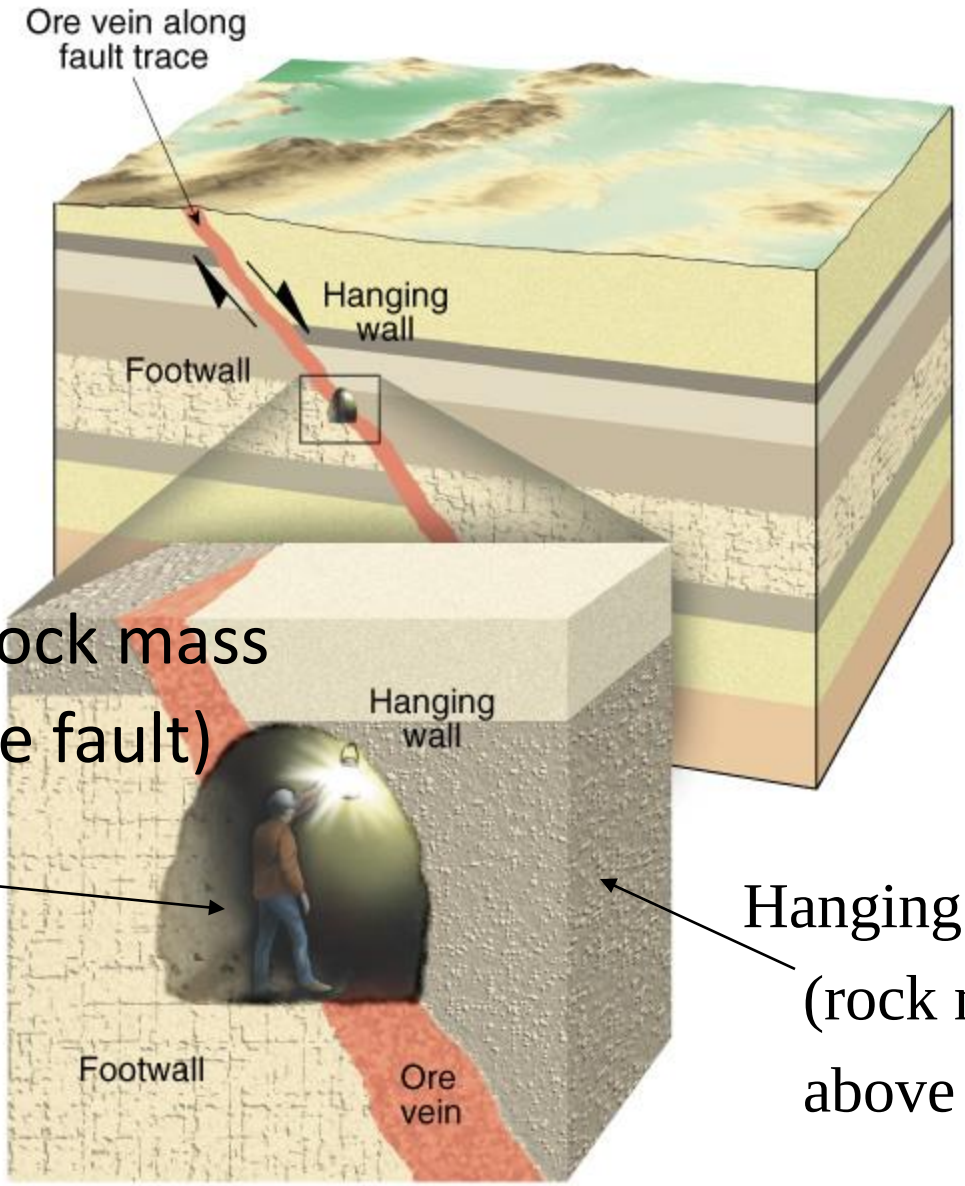
- Faults occur when brittle rocks fracture and there is an offset along the fracture.
- When the offset is small, the displacement can be easily measured, but sometimes the displacement is so large that it is difficult to measure.



Fault Terminology

- A **fault line** is the surface trace of a fault, i-e the line of intersection between the fault plane.
- A clearly seen line is formed by the intersection of faulted surfaces and can be observed even on satellite image.
- Hanging wall: fault block above the fault plane is called as hanging wall.
- Foot wall: fault block below the fault plane is called as foot wall.

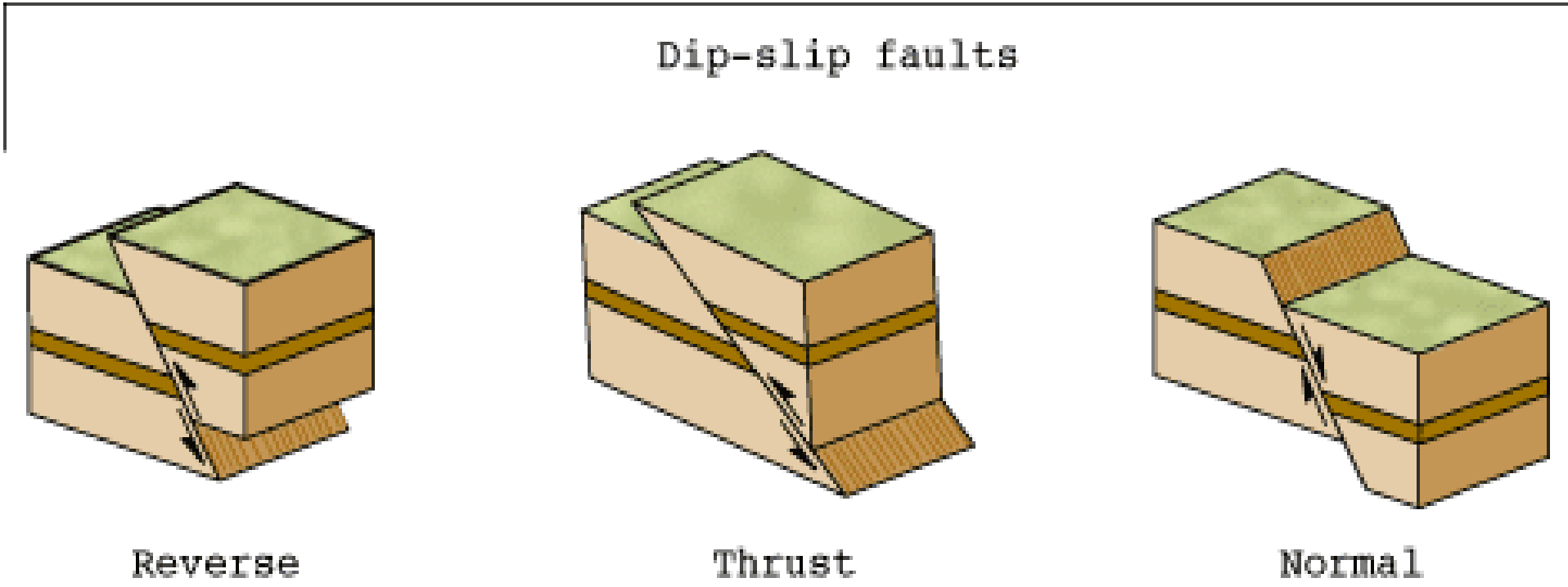
- **Fault blocks classified as**

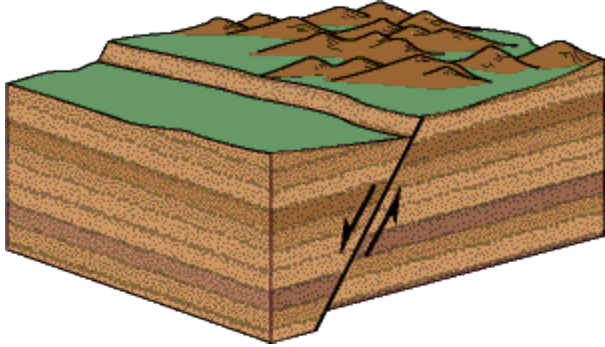


Footwall (rock mass below the fault)

Hanging wall (rock mass above the fault)

- Three dominant types
  - Normal fault
  - Reverse Fault
  - Thrust (a low angle reverse fault)
  - Strike Slip Fault

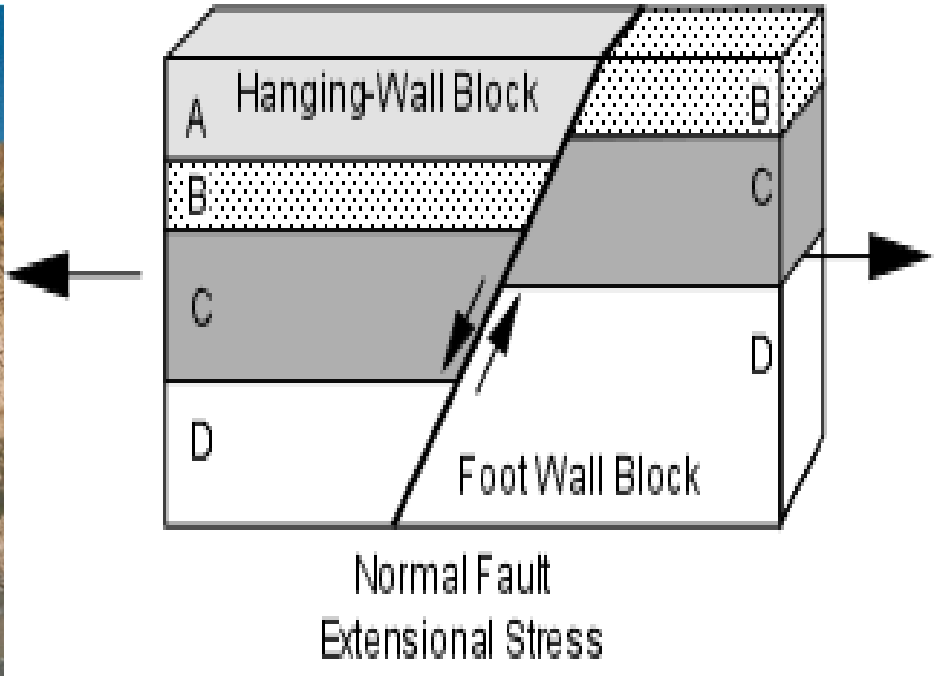




Normal fault

- Hanging wall moves down relative to the footwall.
- Accommodate lengthening or extension of the crust.
- Exhibit a variety of scales



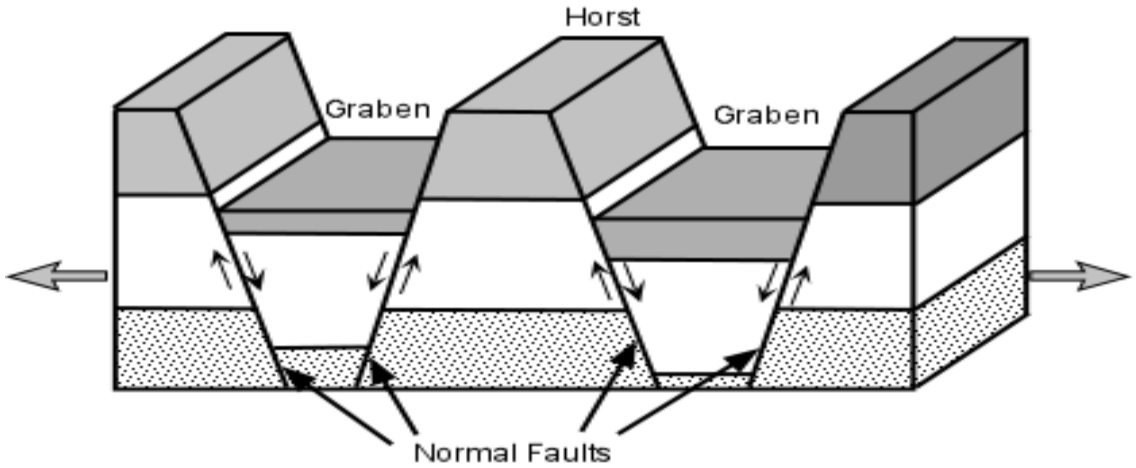


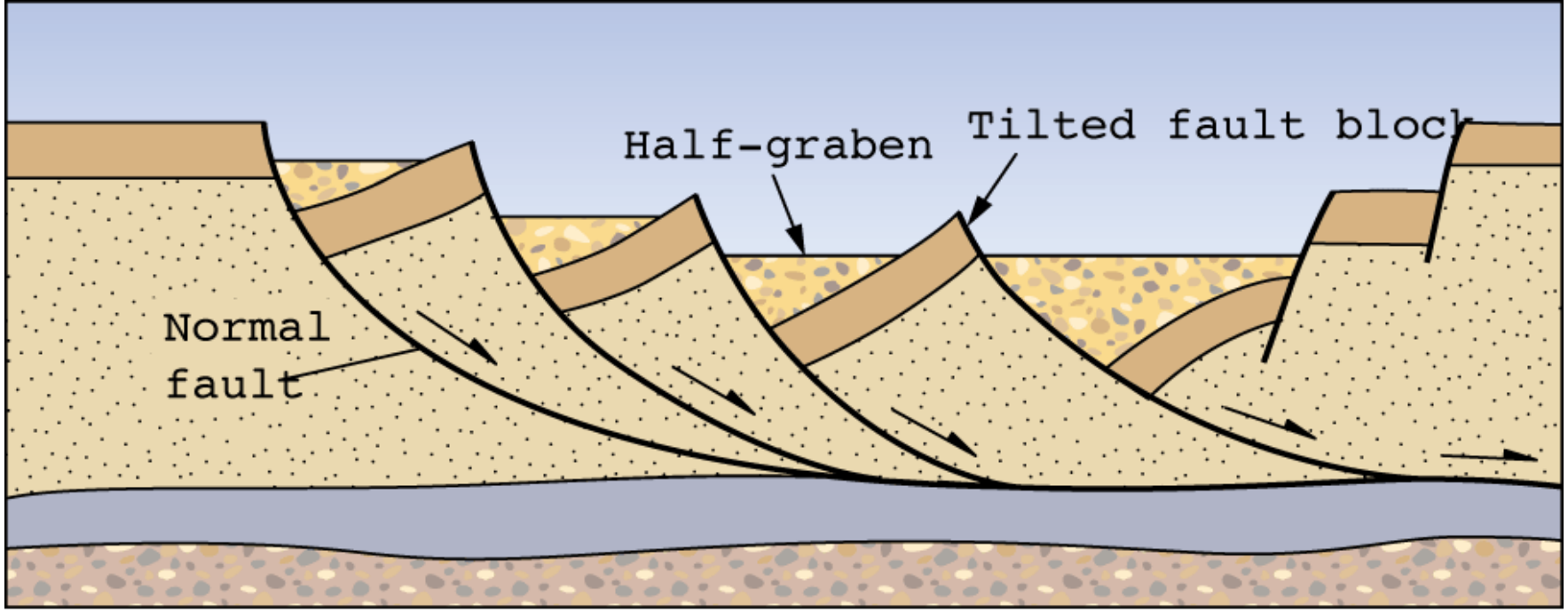
Normal Fault

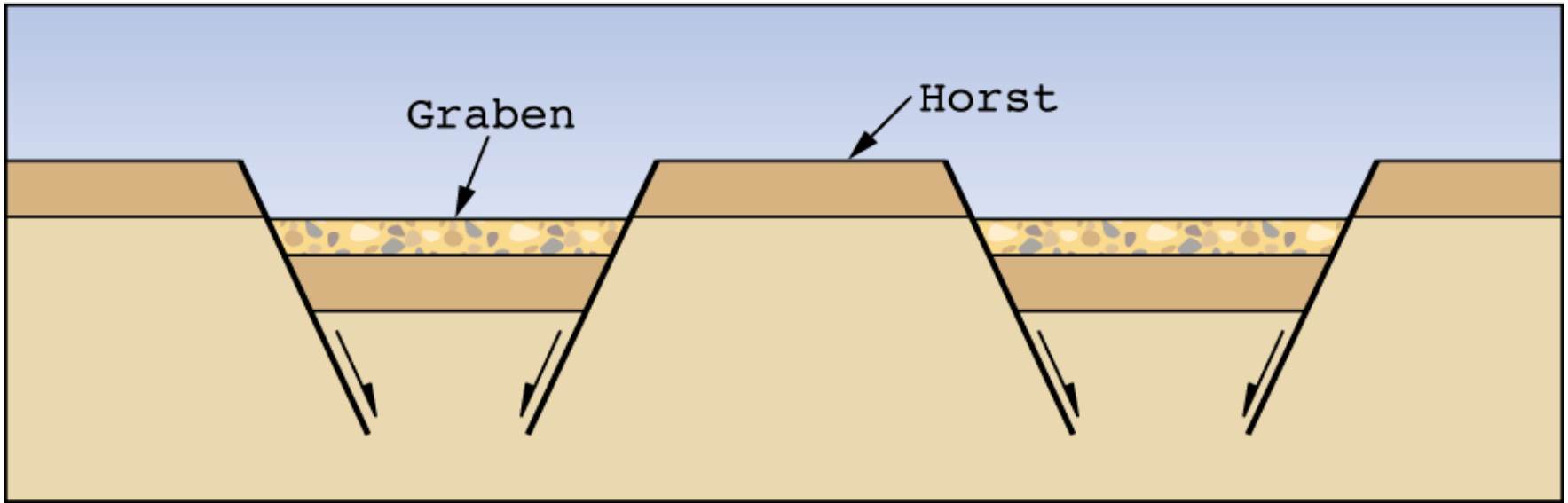
- Larger scale normal faults are associated with fault-block mountains (Basin and Range of Nevada).

- Normal fault bounded valleys are called graben

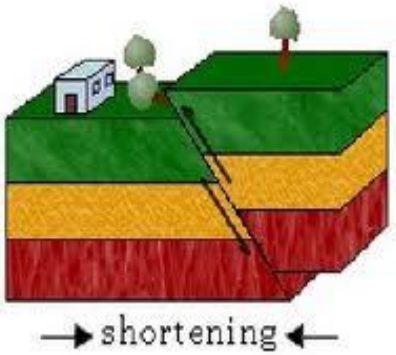
- Normal fault bounded ridges are called horsts.
- Basin area has a series of horsts and grabens.




Half-graben
Tilted fault block
Normal
fault


Graben
Horst

Reverse faults

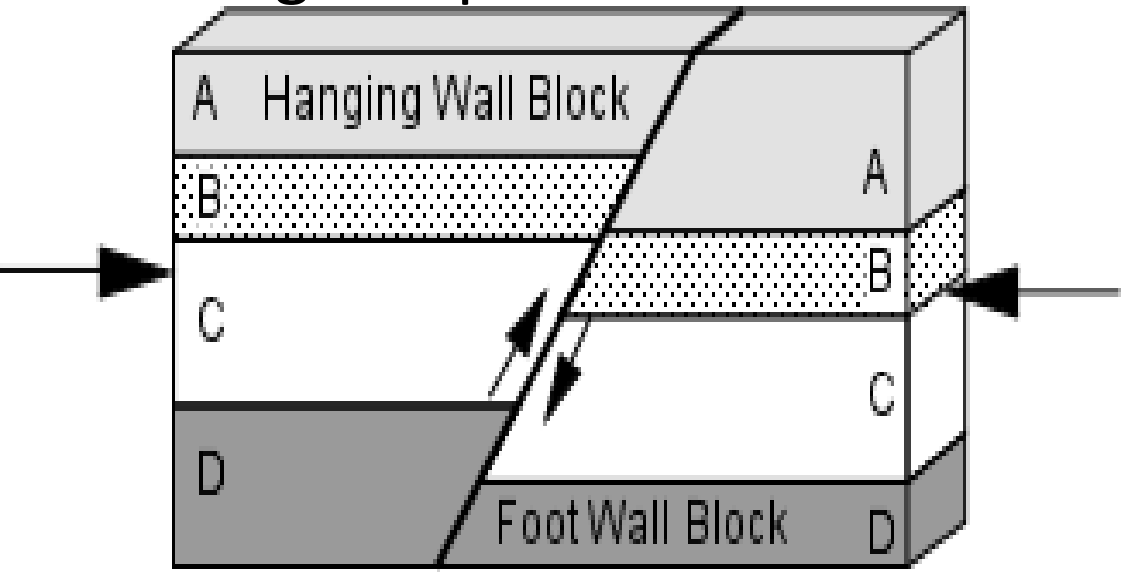


– Hanging wall block moves up relative to the footwall block

– Reverse faults have dips greater than 45°

– Accommodate shortening of the crust

– Strong compressional forces



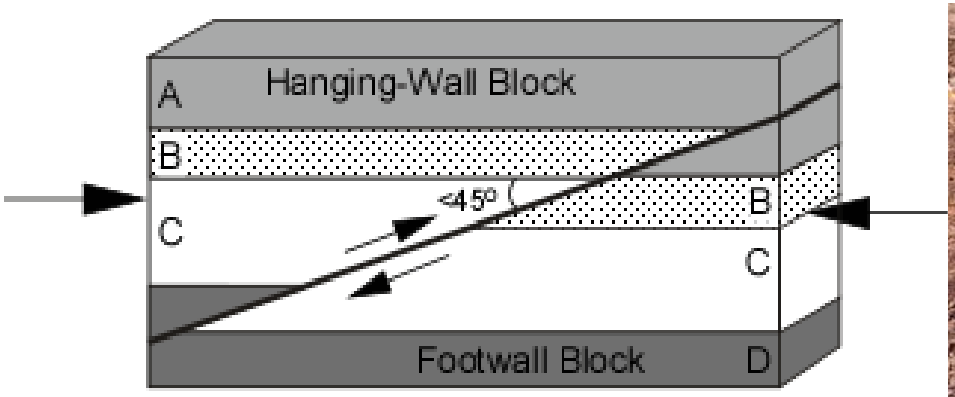
Reverse Fault
Compressional Stress



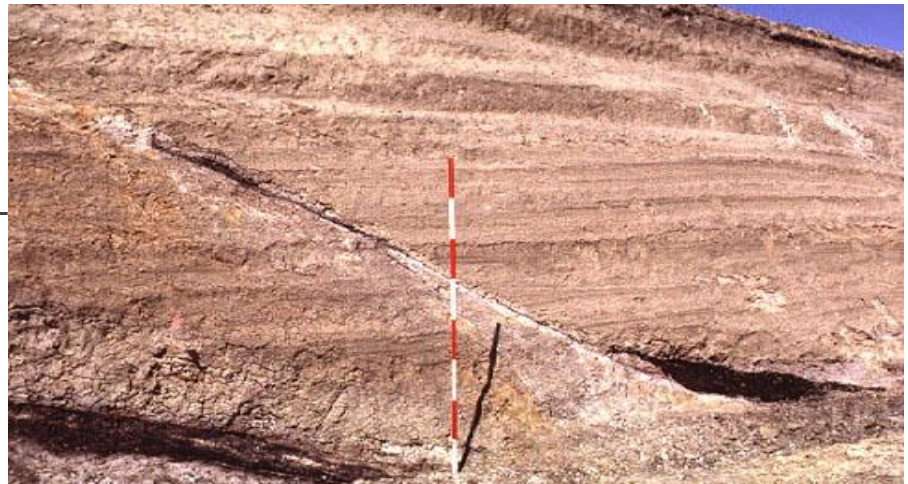
Reverse faults in shale layers, Trail to the Base of the Torres, Parque Nacional Torres de Paine, Chile

Thrust fault

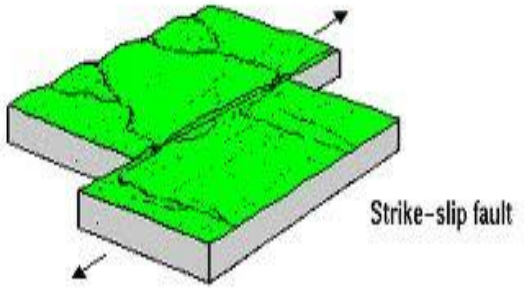
- A special case of reverse fault.
  - Hanging wall block moves up relative to the footwall block
  - Thrust faults are characterized by a low dip angle (less then 45$^{o)}$.
  - Accommodate shortening of the crust
  - Strong compressional forces



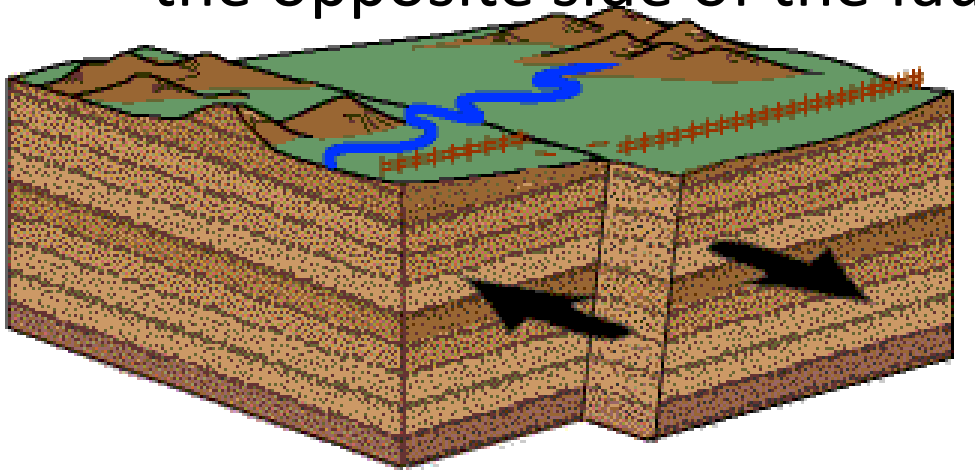
Thrust Fault
Compressional Stress

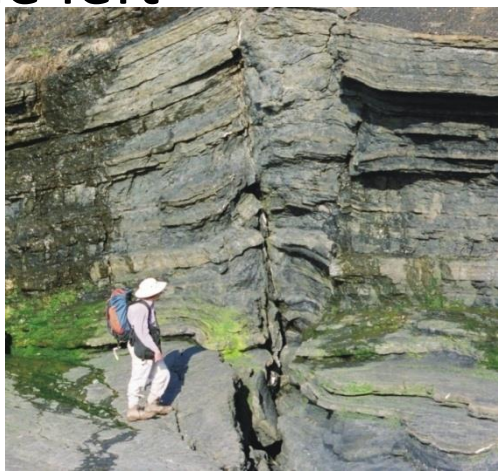


Strike-Slip Faults

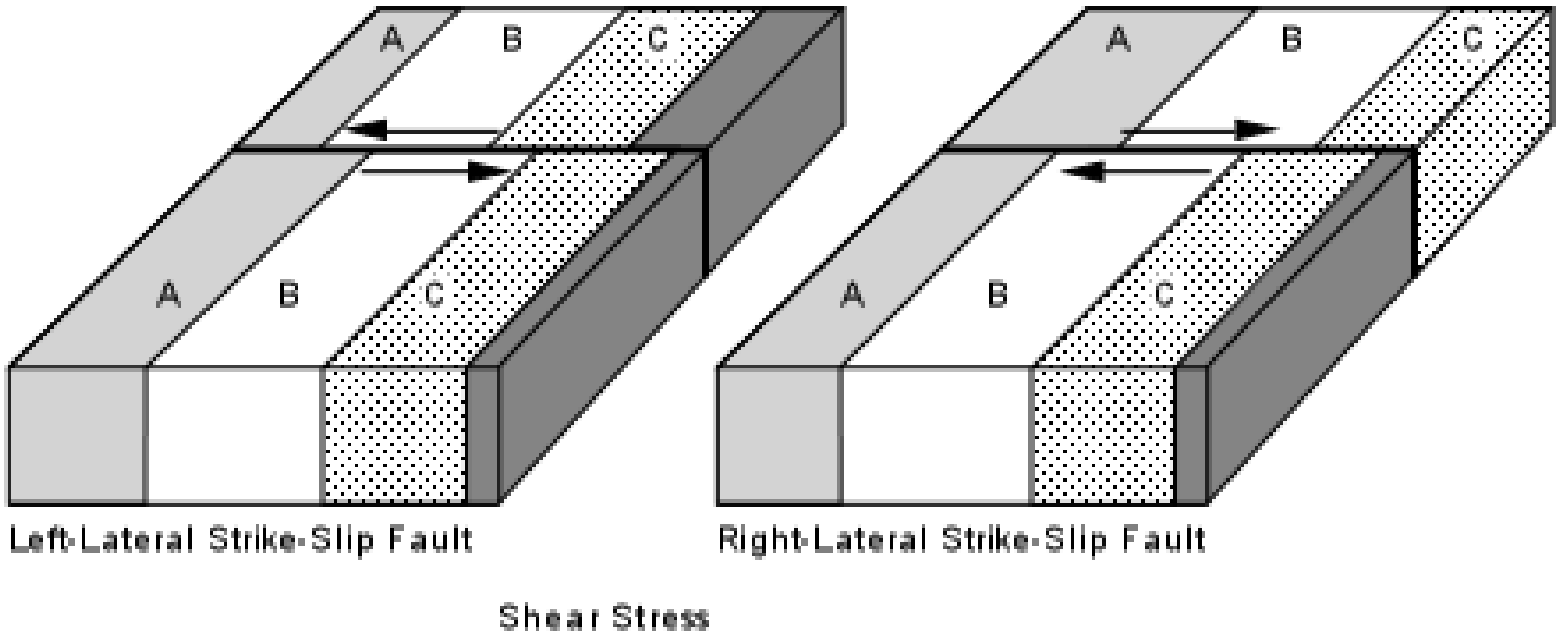


- Dominant displacement is horizontal and parallel to the strike of the fault
- Types of strike-slip faults
  - Right-lateral – as you face the fault, the block on the opposite side of the fault moves to the right
  - Left-lateral – as you face the fault, the block on the opposite side of the fault moves to the left





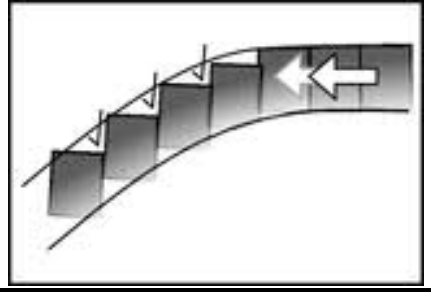
Types of Strike Slip Fault

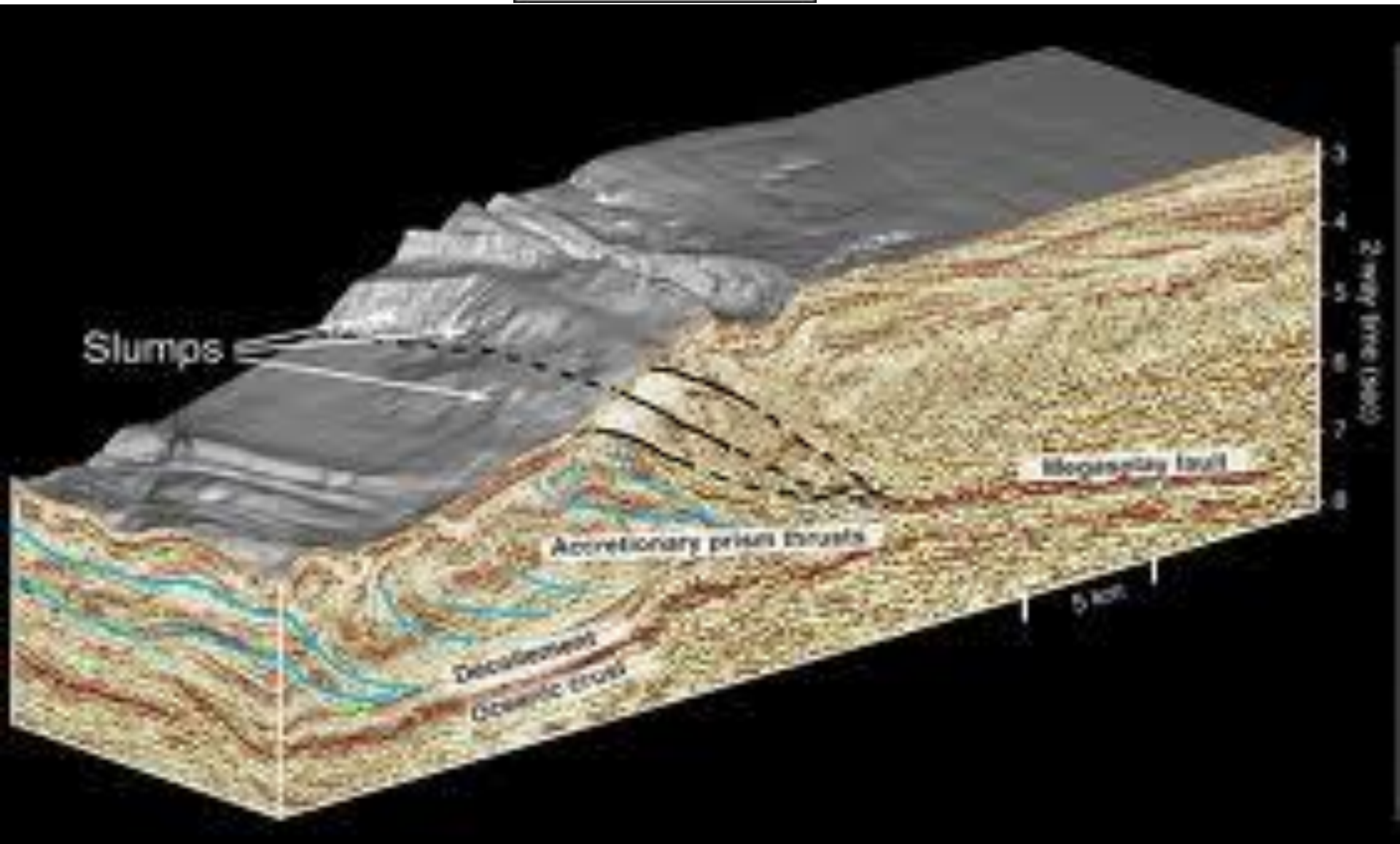


- **Fault Splays:** Fault is segments into many small faults.

Sometimes, A big fault initiate many small other fault known as fault splays or implication.





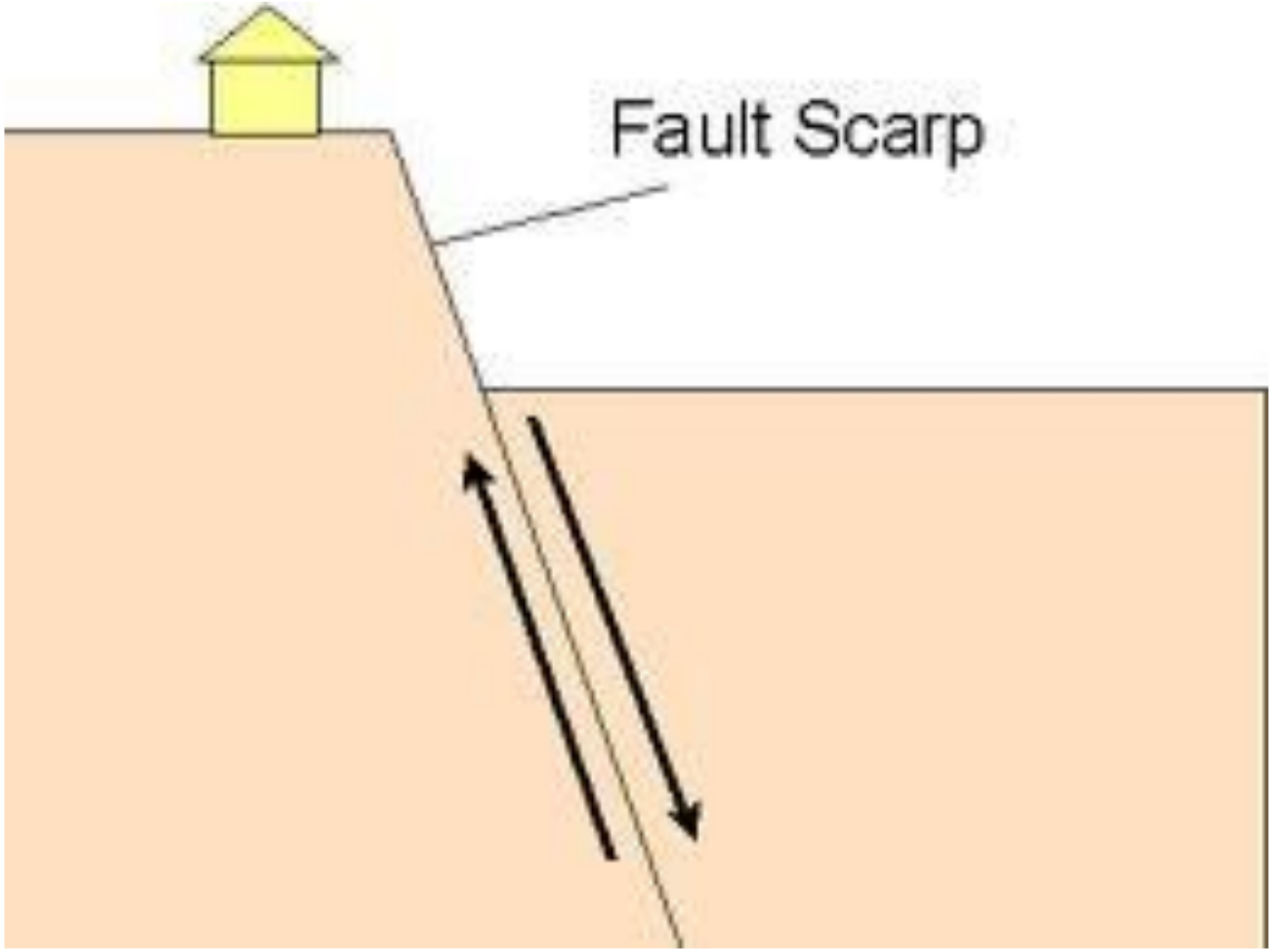

Slumps
Megasplay fault
Accretionary prism thrusts
Décollement
Oceanic crust
5 km


Sierra Nevada mountains

Criteria to identify the faults

Fault scarp

- A fault scarp is the topographic expression of faulting attributed to the displacement of the land surface by movement along faults.
- During faulting, one block may rise and appear as a raised ridge and shows steep bedding.


Fault Scarp

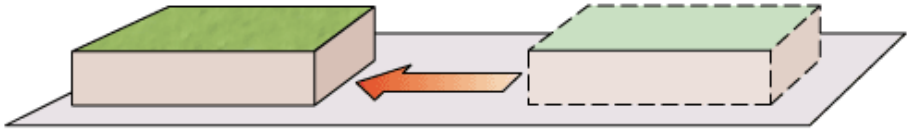
Thank you

Strength behavior of rocks

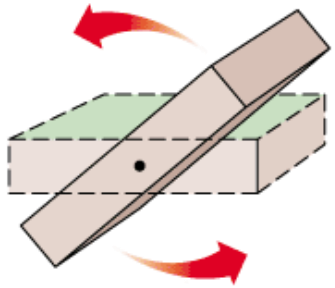
Stresses in rock

Deformation of Rocks

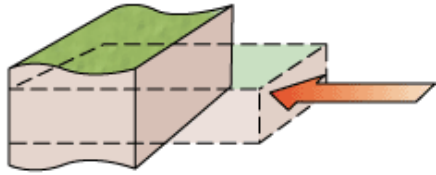
- Within the Earth rocks are continually being subjected to forces that tend to bend them, twist them, or fracture them. When rocks bend, twist or fracture we say that they deform (change shape or size).
- Deformation common at plate margins.
- Deformation concepts…
  - Force
  - Stress
  - Strain



Changing location



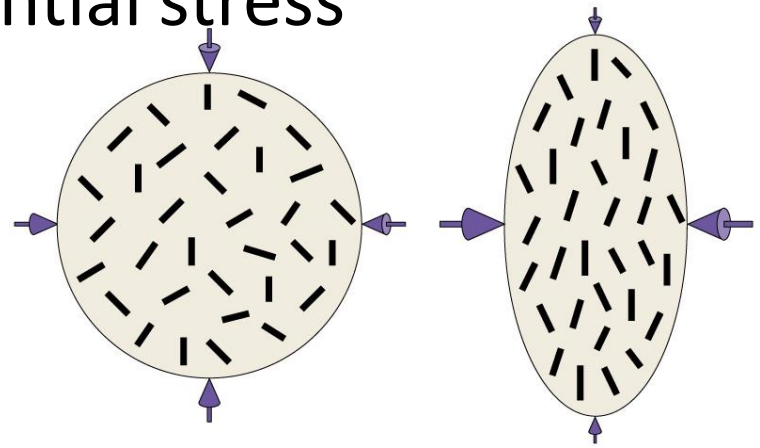
Changing orientation



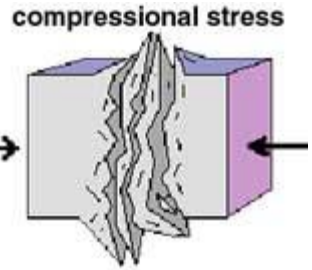
Changing shape

Stress

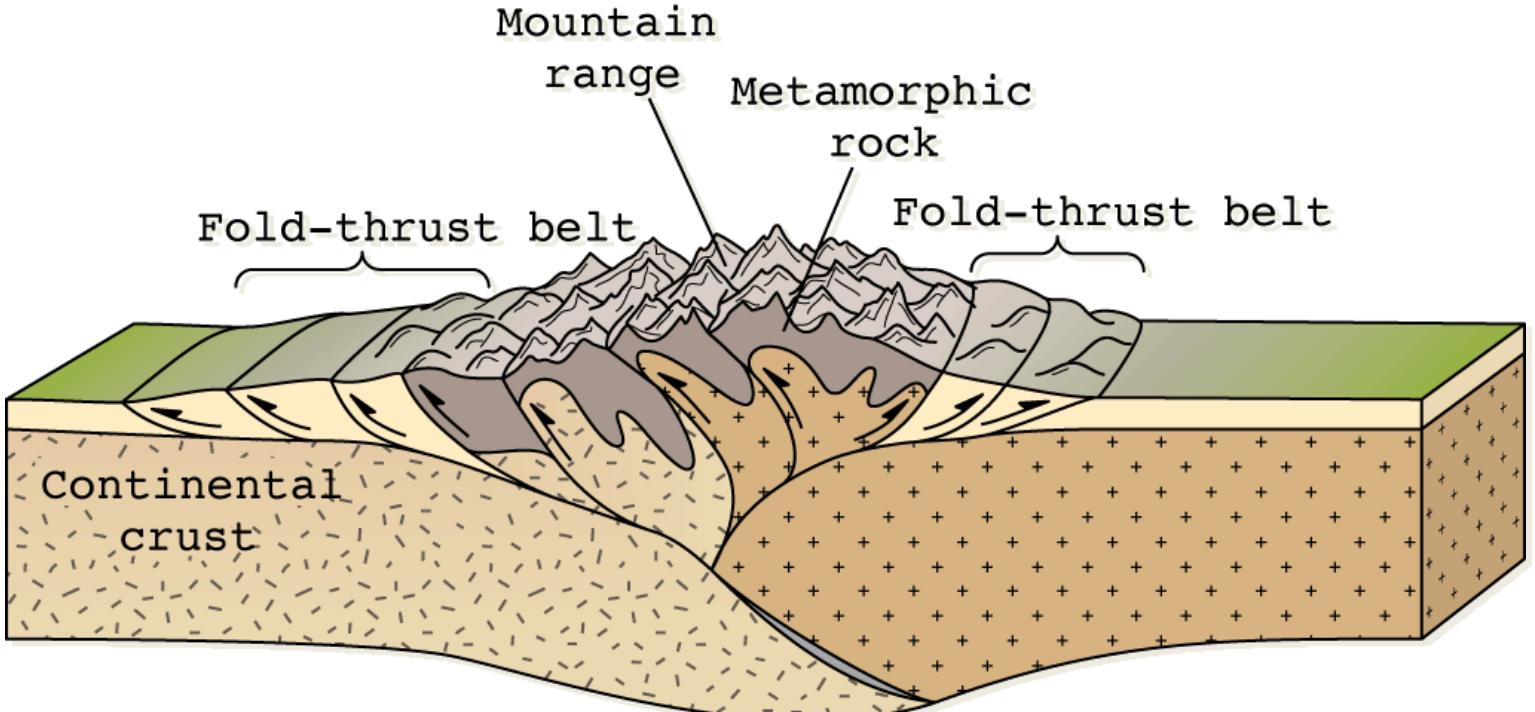
- The forces that cause deformation of rock are referred to as stresses (Force/unit area).
- Differential Stress – Unequal in different directions.
- A uniform stress is a stress wherein the forces act equally from all directions.
- 3 major types of differential stress
  - Compressional stress
  - Tensional stress
  - Shear stress

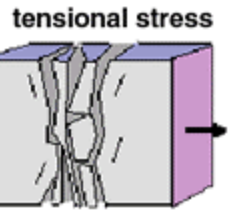


Compressional Stress



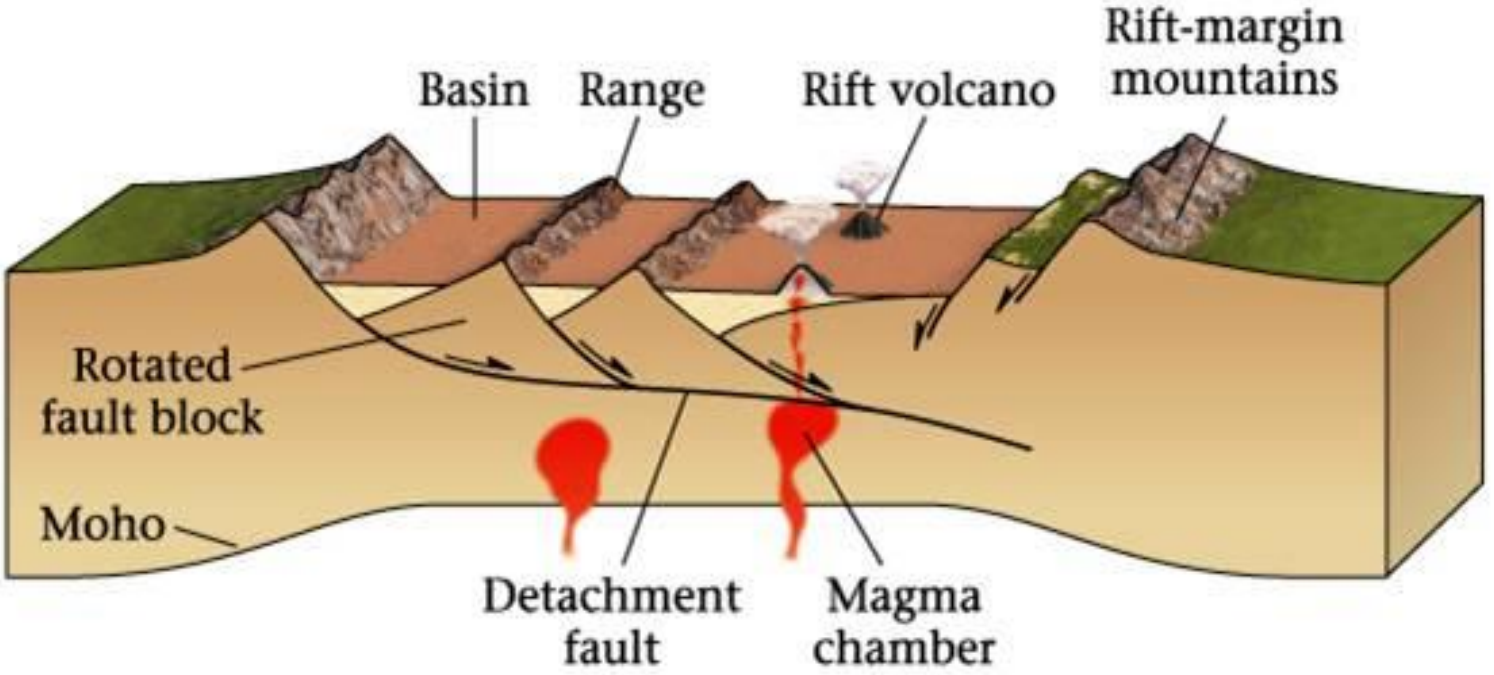
- Push Together stress.
- Shortens and thickens crust.
- which squeezes rock.

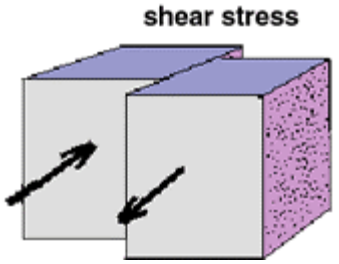




Tensional Stress

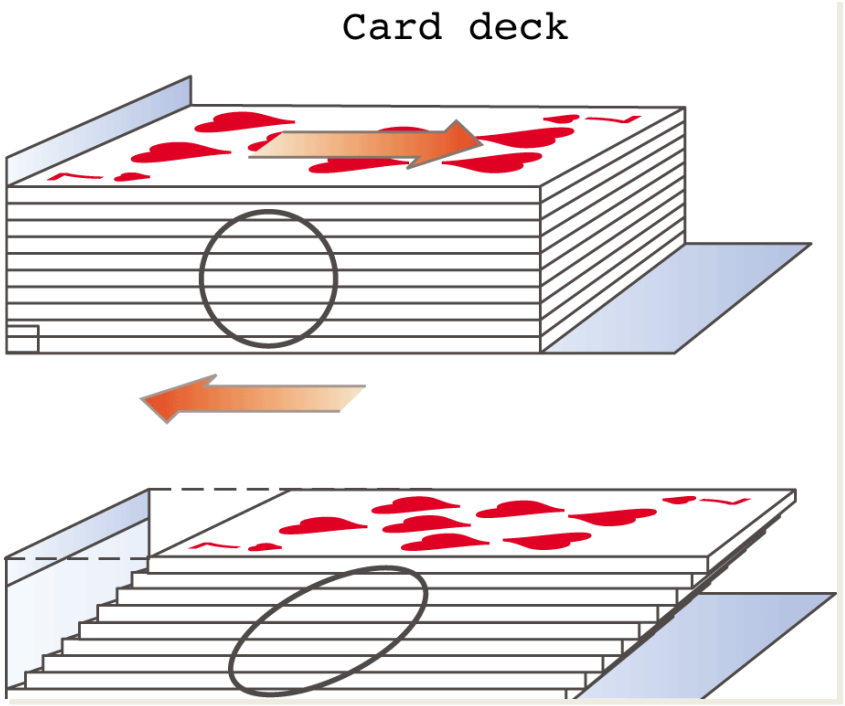
- “Pull-apart” stress.
- Thins and stretches crust.

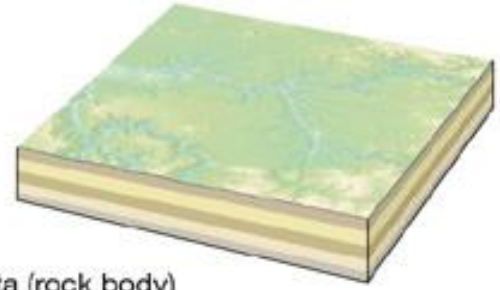




Shear Stress

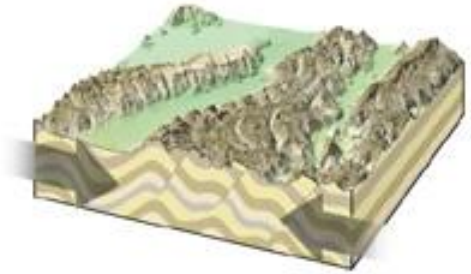
- Slippage of one rock mass past another.
- In shallow crust, shear is often accommodated by bedding planes.





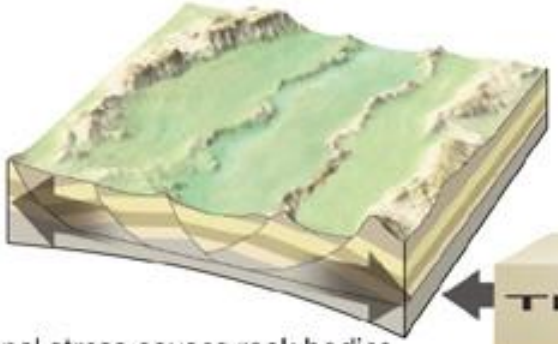


A. Undeformed strata (rock body)



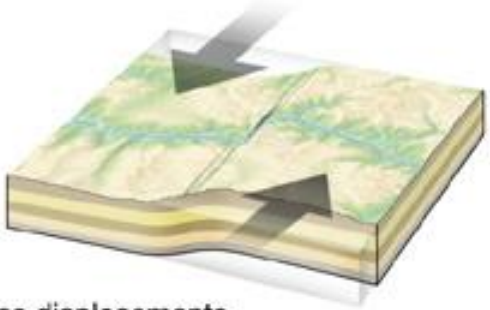


B. Horizontal compressional stress causes rock bodies to shorten horizontally and thicken vertically





C. Horizontal tensional stress causes rock bodies to lengthen horizontally and thin vertically





D. Shear stress causes displacements along fault zones or by ductile flow

Strain

- Changes in the shape or size of a rock body caused by stress.
- Strain occurs when stresses exceed rock strength.
- Strained rocks deform by folding, flowing, or fracturing

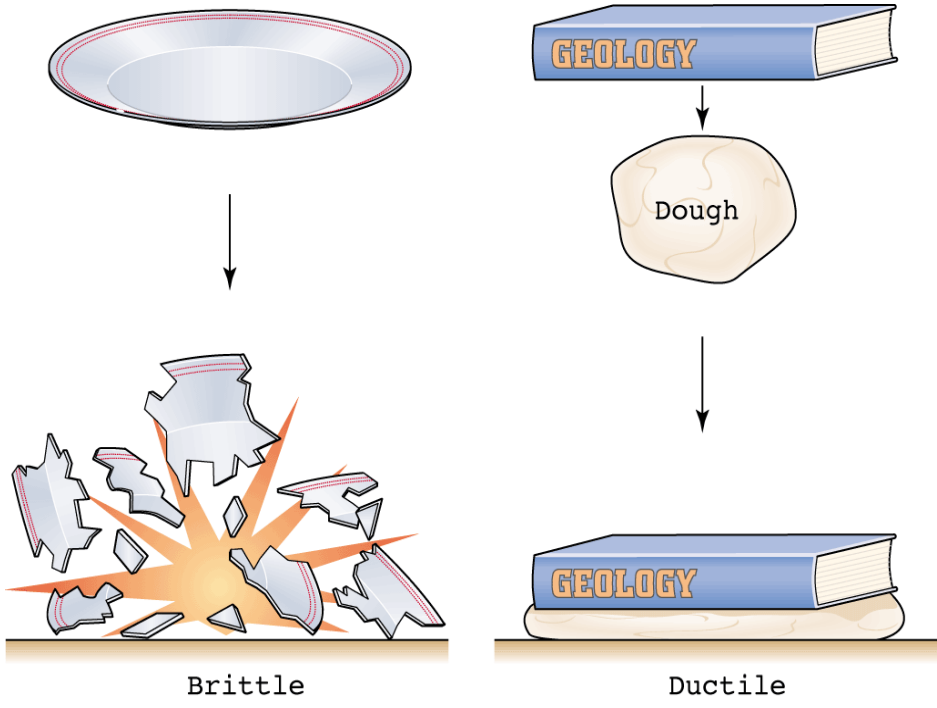


How Rocks Deforms

- Elastic deformation – The rock returns to original size and shape when stress removed.

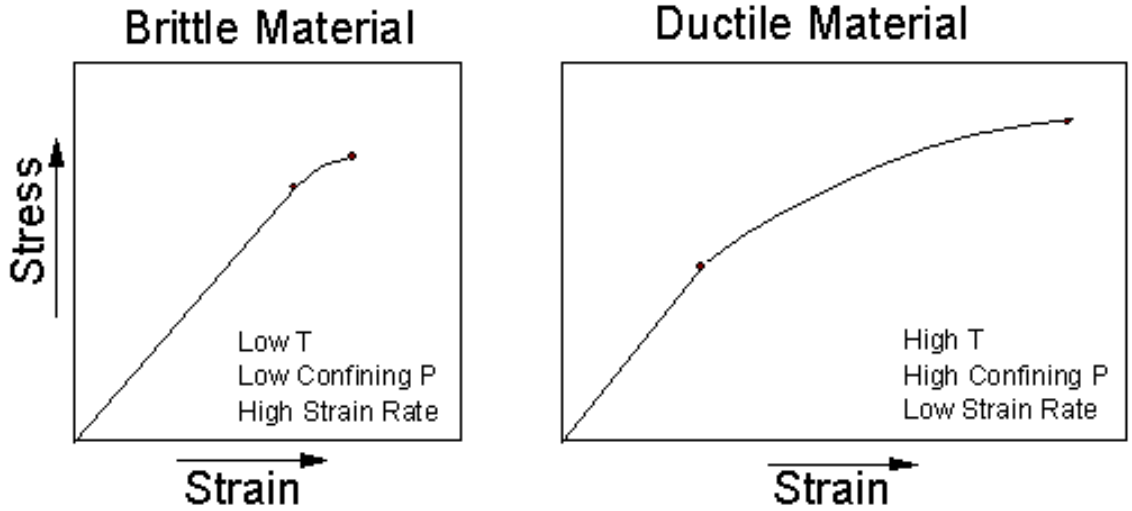
- When the (strength) of a rock is surpassed, it either flows (ductile deformation) or fractures (brittle deformation).

- Brittle behavior occurs in the shallow crust; ductile in the deeper crust.



We can divide materials into two classes.

- Brittle materials have a small or large region of elastic behaviour but only a small region of ductile behaviour before they fracture.
- Ductile materials have a small region of elastic behaviour and a large region of ductile behaviour before they fracture.



How a material behaves will depend on several factors

- **emperature - At high temperature molecules and their bonds can stretch and move, thus materials will behave in more ductile manner. At low Temperature, materials are brittle.**
- **onfining ressure - At high confining pressure materials are less likely to fracture because the pressure of the surroundings tends to hinder the formation of fractures. At low confining stress, material will be brittle and tend to fracture sooner.**
- **train rate -- At high strain rates material tends to fracture. At low strain rates more time is available for individual atoms to move and therefore ductile behaviour is favoured.**
- **omposition -- Some minerals, like quartz, olivine, and feldspars are very brittle. Others, like clay minerals, micas, and calcite are more ductile This is due to the chemical bond types that hold them together.**
- **Another aspect is presence or absence of water. Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place. Thus wet rock tends to behave in ductile manner, while dry rocks tend to behave in brittle manner.**

Thank you

Geological Hazards

Module 5

Mass Movement

- In mass movement superficial masses may leave their original positions abruptly or extreme slowly.
- Mass movement divided into three group: Flowage, Sliding and subsidence.

Flowage

- By flowage is understood a downgrade movement of mass along no definite surface of failure.
- Mass involved in this type of failure is primarily unconsolidated or loosely packed.
- Flowage is further distinguished into slow and rapid flowage.
- Rapid flowage means few meter or more a day and slow flowage means few centimeter a year.

Sliding

- In land sliding superficial mass fails by moving as a whole along a definite surface of failure.
- The surface of failure may be planar (Hard, brittle etc. rock) or curved (loose, unconsolidated etc. rock).
- Landslides are of types: translational slides, rotational slides, rock toppling and falls

Subsidence

- It is sinking or settling of the ground in almost vertically downward direction which may occur because of removal of natural support from the underground or due to compaction of the weaker rocks.

Cause of Mass movement

- Internal factors
  - The nature of slope
  - The role of water
  - Composition of mass
  - Geological structure
- External Factors
  - Vibration from natural and artificial causes

Soil creep

- It is type of slow flowage and consists of gradual, almost imperceptible downslope transit of soil and may sometimes take place even under the cover of vegetation with rate of 1 mm to several cm a year.
- It is surface phenomenon and common in cold humid slope, where frost action favors.

Solifluction

- Slow flowage type movement bsedon freeze thaw phenomenon.
- Solifluction differs from soil creep in water content.
- Solifluction occurs in saturated soil and in pefmafrost region where soil at some depth below the surface remains in permanently frozen state.
- Porous, unconsolidated soils are particularly susceptible to failure of solifluction.

Earth and Mudflows

- Rapid mass movement confined to open-textured soils or unconsolidated rocks which takes place usually after heavy melting of snow and ice.
- Clay and silt are most likely to fail.
- Earth flow and mud flow differs in terms of water content.
- In mudflows water content is high and can flow in slope between 1-25 degree.
- Both phenomenon are seasonal.

Monitoring and control of mass movement

- Monitoring help to detect the mass movement condition in time and helps in controlling it.
- Monitoring can be achieved by conventional surveying techniques or by the help of electronic equipment, laser equipment, settlement gauge and extensometers.
- Based upon cost-benefit ration desired method is adopted.

Controlling method

- Providing drainage
- Constructing retaining walls
- Providing reinforcement by rock bolting or rock anchors
- Slope treatment like; flattening, decreasing the load.
- Afforestation

Earthquake

Introduction

Earthquakes constitute one of the worst natural hazards which often turn into disaster causing widespread destruction and loss to human life.

The effects of earthquake vary upon the magnitude and intensity. Earthquakes occur every now and then all round the world, except in some places where earthquakes occur rarely. The devastation of cities and towns is one of the effects of earthquake.

What is Earthquake?

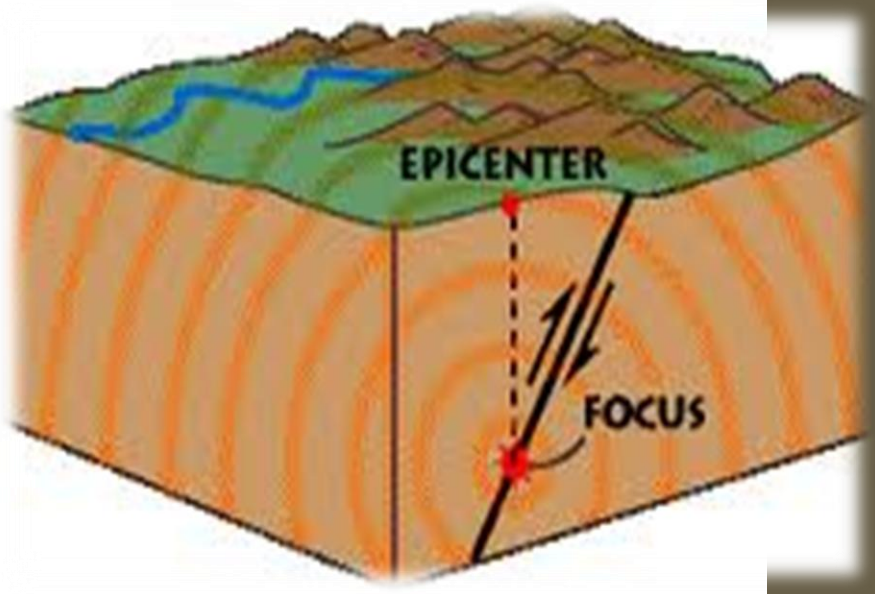
- An Earthquake is the result of a sudden release of energy in the earth's crust that creates seismic waves.
- The seismic activity of an area refers to the frequency,type and size of earthquakes experienced over a period of time



Terms Related To Earthquake

Focus(Hypocenter):

Focus is the point on the fault where rupture occurs and the location from which seismic waves are released.



Epicenter:

Epicenter is the point on the earth's surface that is directly above the focus ,the point where an earthquake or underground explosion originates.

Cont…

Fault Line:

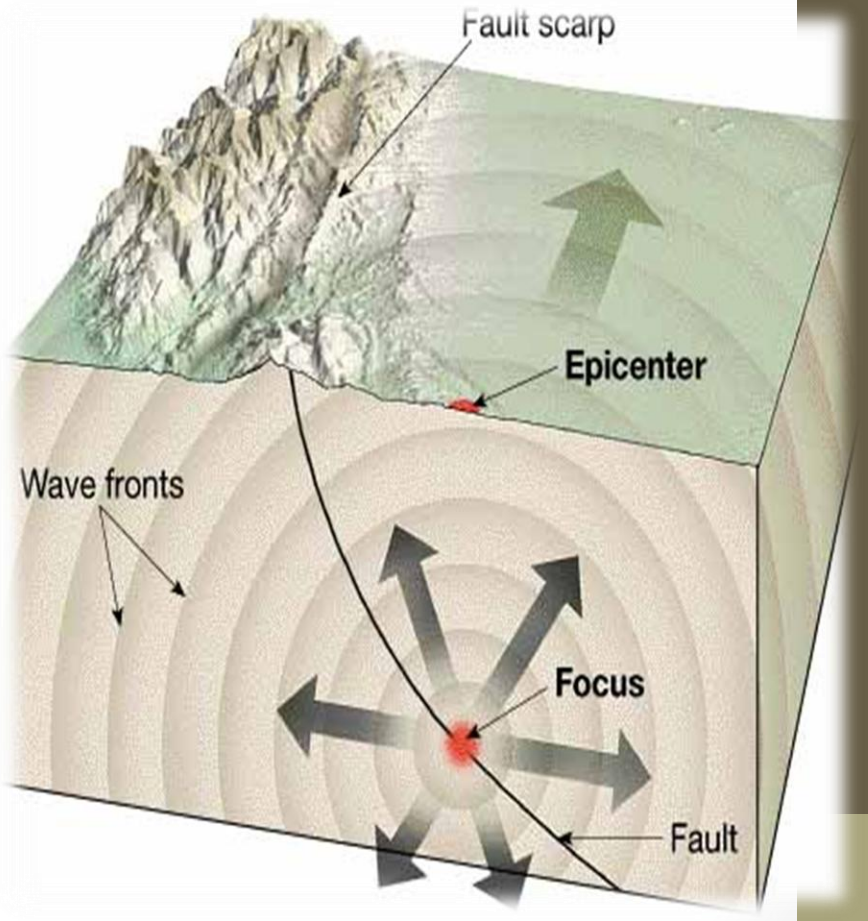
A Fault line is the surface trace of a fault, the line of intersection between the earth's surface.

Fault plane:

Fault plane are the crackes or sudden slips of the land .

Fault Scrap:

A Fault scrap is the topographic expression of faulting attributed to the displacement of the land surface by movement along faults.



Causes Of Earthquake

The primary cause of an earthquake is **faults** on the crust of the earth.

"A Fault is a break or fracture b/w two blocks of rocks in response to stress."

- This movement may occur rapidly, in the form of an **earthquake** or may occur slowly, in the form of **creep.**

- Earth scientists use the **angle of the fault** with respect to the surface (known as the dip) and the **direction of slip** along the fault to classify faults.

Some major causes of earthquakes on basic of its causes are:

- Surface causes
- Volcanic causes
- Tectonic causes

Surface cause:

Great explosions, landslides, slips on steep coasts, dashing of sea waves , avalanches , railway trains, heavy trucks, some large engineering projects cause minor tremors. some of them are man made, other are natural.

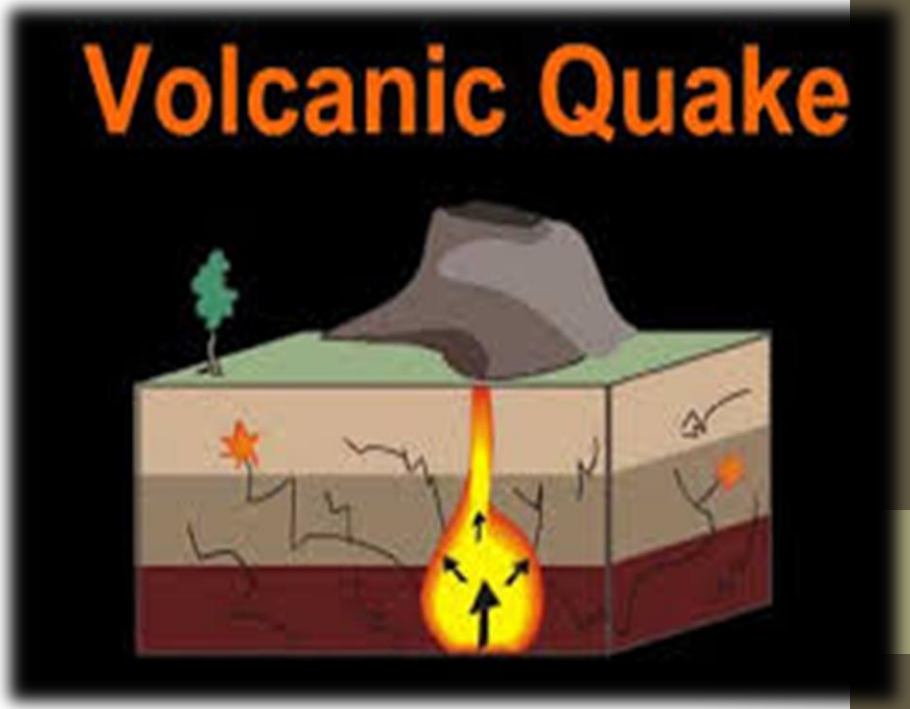
Volcanic cause:

Volcanic eruptions produce earthquakes. Earthquakes may precede, accompany and frequently follow volcanic eruptions.

They are caused by sudden displacements of lava within or beneath the earth crust.

There are two general categories of earthquakes that can occur at a volcano:

- volcano-tectonic earthquakes
- long period earthquakes.



Tectonic cause:

Structural disturbances resulting in the parts of the lithosphere is the main cause of this type of earthquake.

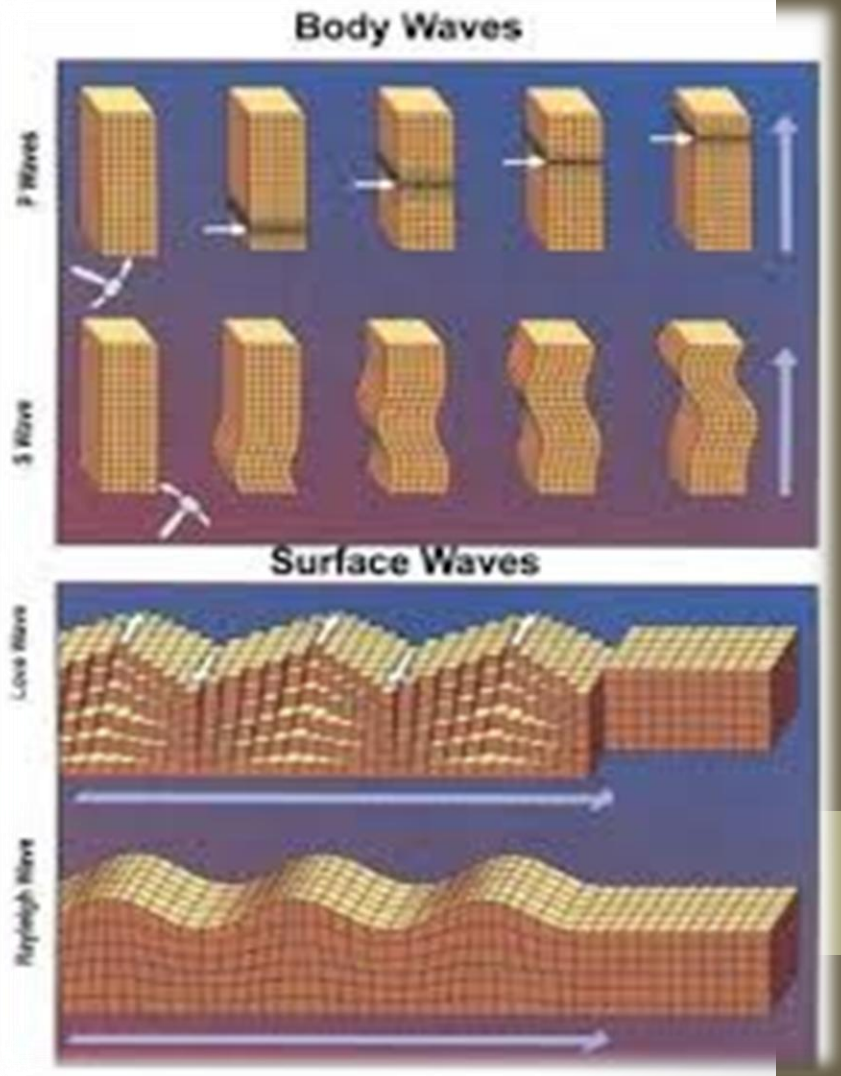
Most of the disastrous earthquakes belong to this category and occur in areas of great faults and fractures. Sudden yielding to strain produced on the rocks of accumulating stress causes displacements especially along old fault zones known as great transform faults.

Plate Boundary Overview.flv

Waves produced due to Earthquake

Seismic waves produced due to earthquake are basically divided into two major types:

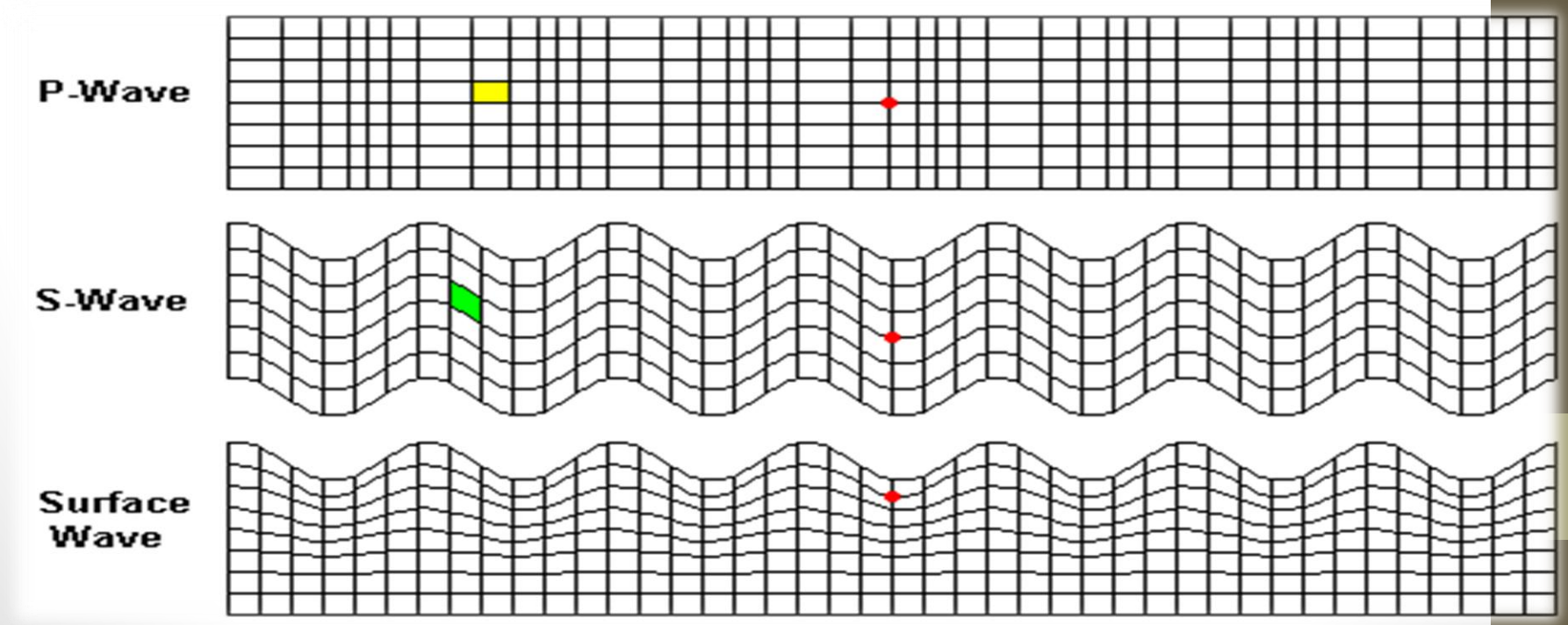
- Body waves
- Surface waves



Body waves:

Body waves travels through the interior(body) of earth as they leave the focus. Body waves are further divided into following types:

- Primary (P) waves
- Secondary(S) waves

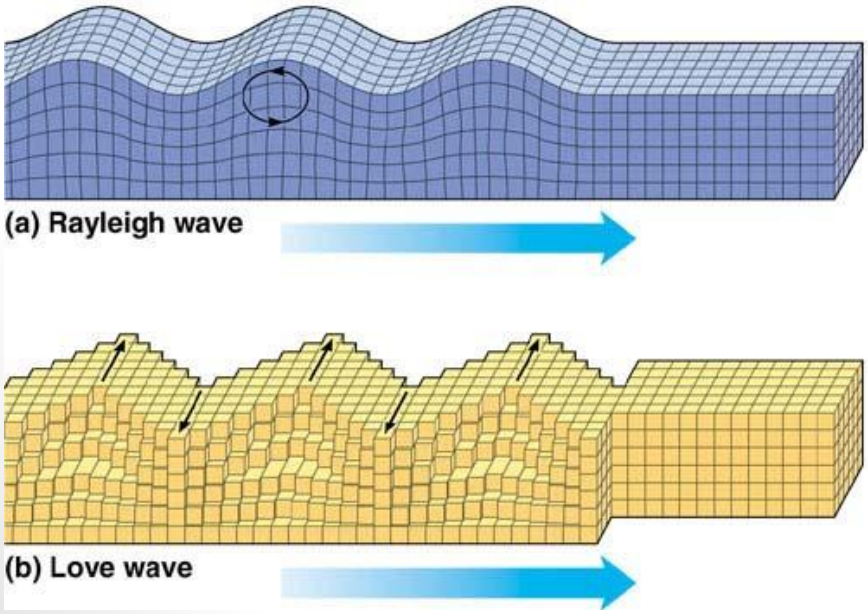


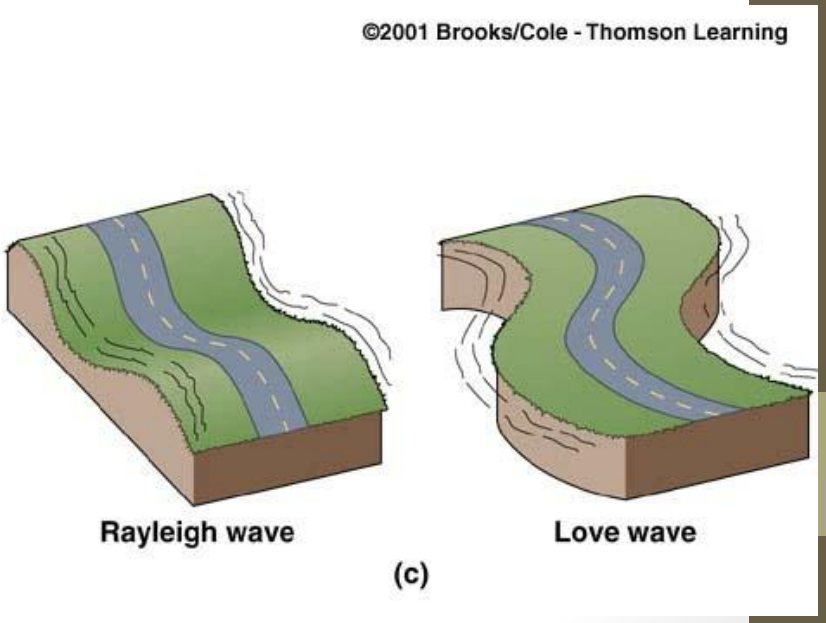
Primary Waves (P-waves)	Secondary Waves(S-wave)
High frequency	High frequency
Short Wavelength	Short Wavelength
Longitudinal waves	Transverse waves
Pass trough both solids and liquids	Can not move through liquids
Move forwards and backwards as it compressed and decompressed	Move in all direction from their source
P-wave is faster	S-wave is more slower than P-wave
First P-wave arrive	After P-wave,S-wave is arrive

Surface Wave:

Surface waves travels parallel to the earth's surface and these waves are slowest and most damaging. Surface wave are divided into following types:

- Love waves
- Rayleigh waves





Love Waves	Rayleigh wave
Guided waves	Guided waves
Displacement is parallel to the free surface	Displacement is perpendicular to love-wave displacement
Love wave is faster	Rayleigh wave is slower
Causes horizontal shifting of the earth surface.	Ground move in circular motion.

Strength Of Earthquake

The intensity and strength of an earthquake is measured on Richter scale,the scale invented by Charles Richter California ,USA in 1935.which categories earthquake on the basis of energy released.

Defintion:

"The **Richter magnitude scale** (also **Richter scale**) assigns a magnitude number to quantify the energy released by an earthquake. The Richter scale is a base-10 logarithmic scale, which defines magnitude as the logarithm of the ratio of the amplitude of the seismic waves to an arbitrary, minor amplitude.."

Scientists measure the strength of earthquakes using machines known as **seismographs.**

- **Seismology** is the scientific study of earthquakes and the propagation of elastic waves through the Earth.

- $M_L = \log_{10}A - \log_{10}A_o$

Where, A = maximum amplitude obtained from seismograph

Ao = empirical function (depends upon distance from the epicenter.

- One increment represent 10 times improvement of amplitude.
- Each whole no. represent 31.6 times amount release of energy and 0.2 represent 2 times release of energy.
- expression of energy $E = 6.3 \times 10^4 \times 10^{(3M/2)}$
- These formulae are an alternative method to calculate Richter magnitude instead of using Richter correlation tables based on Richter standard seismic event (=0, A=0.001mm, D=100 km).

- The Lillie empirical formula

$$M_L = \log_{10}A - 2.48 + 2.76\log_{10}\Delta$$

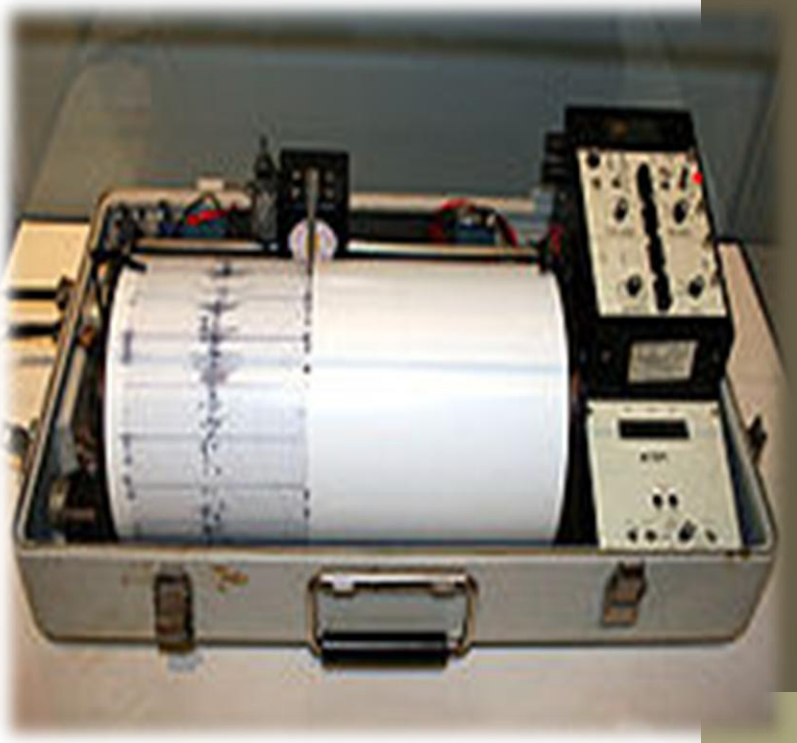
where, A→ amplitude of P-wave, in micrometer

Δ →epicenter distance in KM

Seismometers-The measurement of earthquake

- **Seismometers** are instruments that measure motions of the ground, including those of seismic waves generated by earthquakes, volcanic eruptions, and otherseismic sources.

- Seismometers may be deployed at Earth's surface, in shallow vaults, in boreholes, or underwater.



Types Of Zones

The earthquake zoning map of India divides India into 4 seismic zones Based on the observations of the affected area due to Earthquake india divided into four types of zones:

- Zone - II: This is said to be the least active seismic zone.
- Zone - III: It is included in the moderate seismic zone.
- Zone - IV: This is considered to be the high seismic zone.
- Zone - V: It is the highest seismic zone.

Effect Of Earthquake

- Loss of life and property
- Damage to transport system i.e. roads, railways, highways, airports, marine
- Damage to infrastructure.
- Chances of Floods – Develop cracks in Dams
- Chances of fire short-circuit.
- Communications such as telephone wires are damaged.
- Water pipes, sewers are disrupted
- Economic activities like agriculture, industry, trade and transport are severely affected.

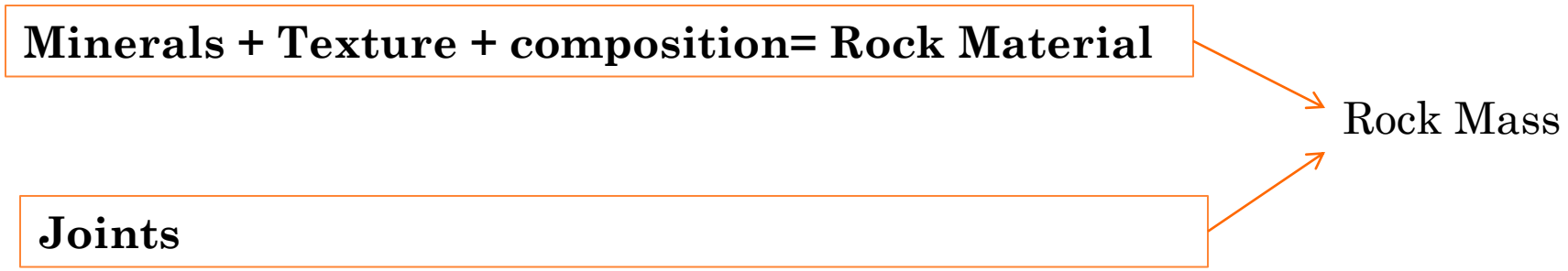
Thank You

Rock Masses as Construction

Module 6

Rock Masses

- Rock mass is heterogeneous and quite often discontinuous.
- Rock mass is composed of a system of rock blocks and fragments separated by discontinuities forming a material.



Quality of rock masses

- Quality of rock depends upon two main features:
  - The understanding and interpretation of the geological setting of the area of interest.
  - The way the rock mass at the site is described or measured.

- The first feature is important during pre construction phase
- The second feature is mainly connected to the present work.



Basic element	Size range	structures	Considered area
Crystal lattice	Angstrom size	Micro structures	Electron microscope
Mineral grain	m - cm	Grain structures in rock	Microscope, hand piece, test sample of rock
Rock material	cm - 10 m	Massive rock	Hand piece, stone ornaments, building stone, test of rock samples
Jointed rock	cm - 10 m	Joint pattern, rock mass	Foundations, small underground structures, test samples of rock masses, test pits/adits
Geological Tectonical Units	10 m - km	Rock mass volumes between large faults	Slopes, tunnels, large underground structures, mines (geological maps and sections)
Geological-Tectonical Large size units	Several km	Regional plates	Oil reservoirs, (general geological maps and sections)

Discontinuities in rock masses

- Length from less than a decimeter to several kilometers divide the bedrocks into units, volumes or blocks of different scales:
  - The regional pattern or first order fault blocks are bounded by the larger weakeness zones or faults
  - The second order blocks formed by singularities i.e. small weakness zones or seams.
  - The third order blocks formed by normal joints
  - The small joints in the appearance and smallest pattern from engineering point of view.
  - The micro cracks are responsible for making small fragment or grains in the rock .



Rock Mass characterization for design and construction purpose

- Selection of parameter of greater significance for actual type of design or construction is most important issue.
- Parameters related to discontinuities is important also if discontinuities are widely spaced or intact rock is weak, then parameters related to the intact rock is important.
- As per Kirkaldie (1988) mentioned a total of 28 parameters present in rock masses 10 rock material properties, 10 properties of discontinuities and 8 hydrogeological properties.



Parameters frequently applied in design

- Most frequently applied parametrs
  - The rock material (Rock type, Geological name, weathering and alteration, strength)
  - The degree of jointing (Joint spacing, block size, RQD)
  - In-situ stresses
- Other important features
  - Orientation of main discontinuities or Joint set
  - Joint Conditions
  - Block shape or Jointing pattern
  - Faults and Weakness zones and
  - Excavation features (Dimension, orientation etc.)



Rock and their main features

- Geologist use a classification, which reflects the origin, formation and history of a rock rather than its potential mechanical performance.

- Each particular rock type is characterized by its minerals, texture fabric, bonding strength and macro and micro structure.



Fresh rocks

- Igneous rocks tend to be massive rocks of generally high strength.
- Sedimentary rocks shows variation in strength and behavior. Softer than igneous. Show anisotropic behavior.
- The metamorphism often show formation of hard minerals and high intact rock strength.

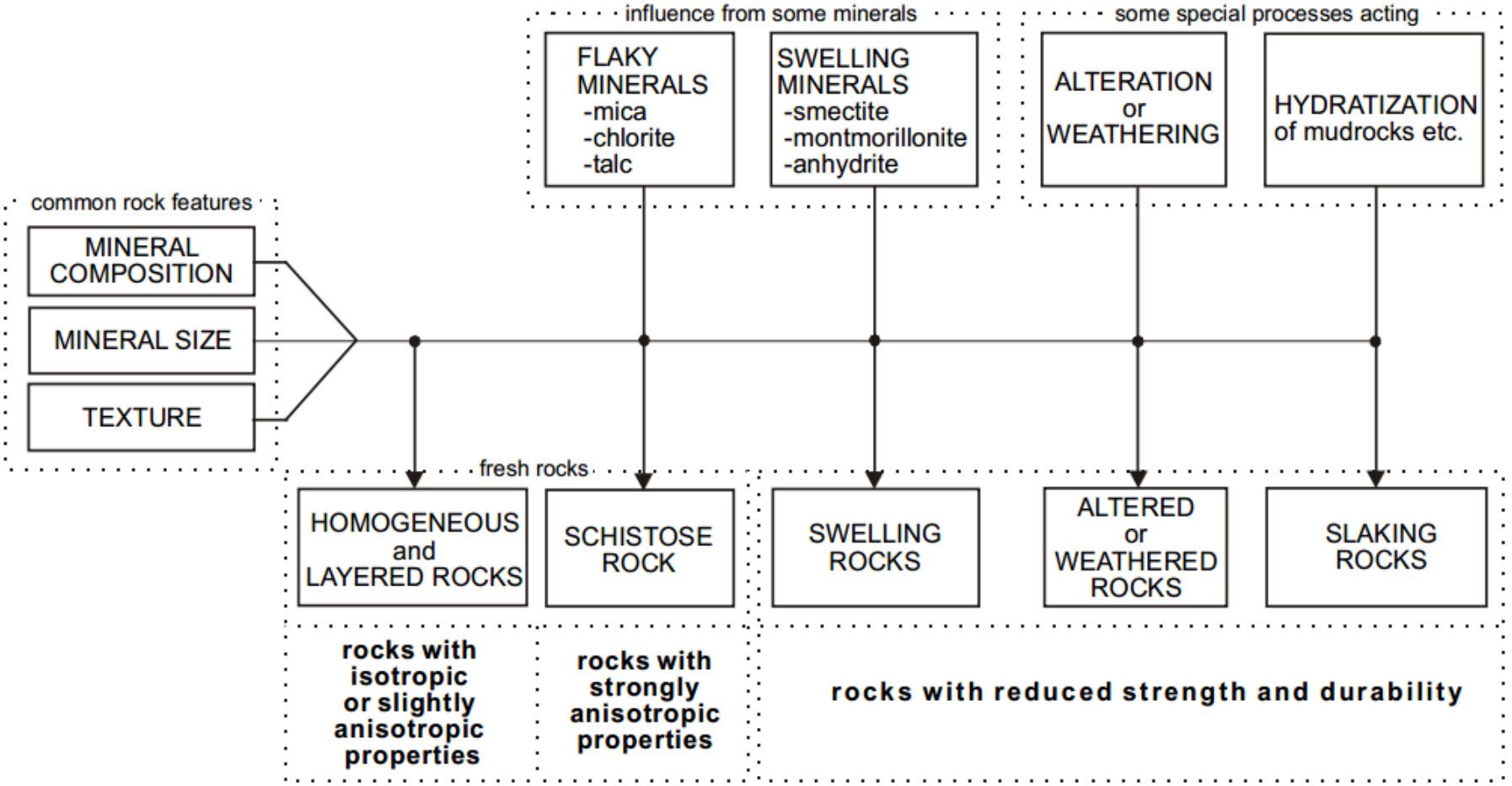


The influence from some minerals

- Minerals like: mica, amphiboles and pyroxenes have elastic and anisotropic behavior influence the mechanical properties of rocks.
- Swelling minerals like montmorillonite causes problem related to high swelling pressures.
- These minerals, occurring either as infilling or alteration products in seams or faults, have in addition to expansion, a low shear strength, which may contribute to rock falls and, in some cases, slides in underground openings and cuttings. Also some rocks may show swelling properties.



VARIABLES INFLUENCING ROCK PROPERTIES AND BEHAVIOR



- Brekke and Howard 1972

Effect of alteration and weathering

- Alteration and weathering of rock material reduces effect on strength and deformation properties of rock. Main results of rock weathering and alteration are:
  - Mechanical Disintegration
    - The opening up of joints
    - The formation of new joints by rock fracture, the opening up of grain boundaries
    - The fracture or cleavage of individual minerals grains
  - Chemical Decomposition
    - Discoloration of the rock
    - Decomposition of complex silicate minerals
    - Leaching or solution of calcite

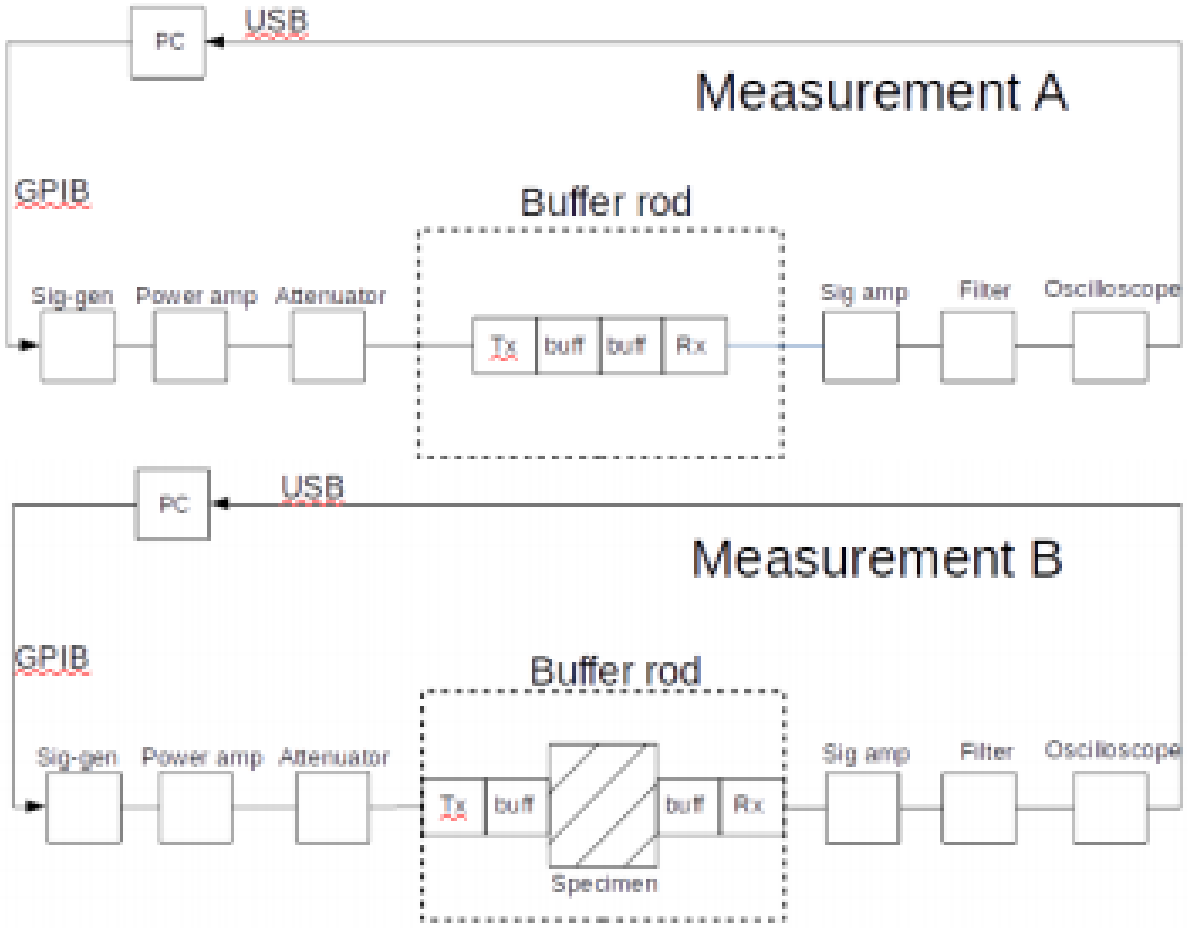


Measurement of sound wave in rock

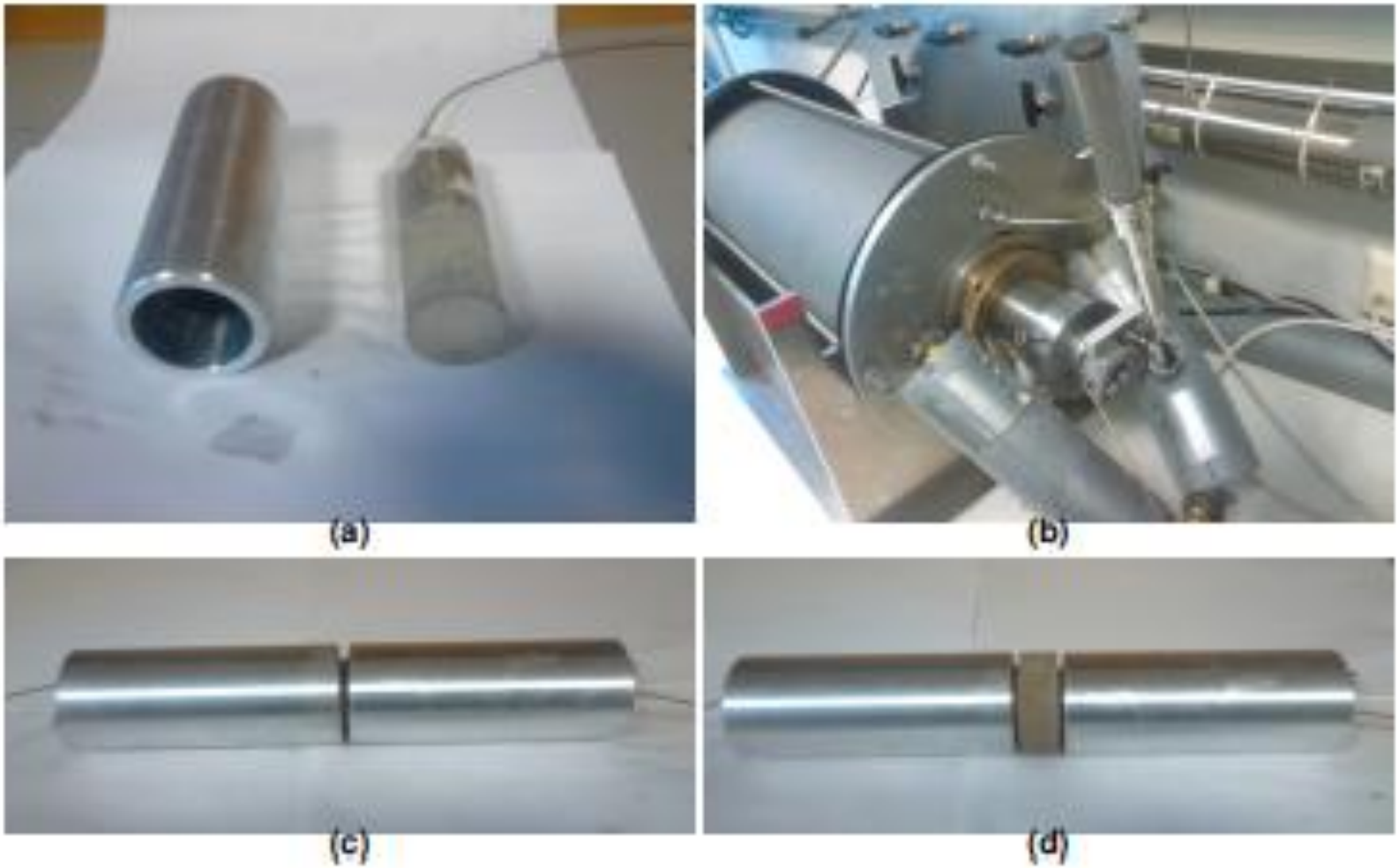
- Different methods of measurement of wave velocity in rocks are available.
- Solid buffer method and Immersion method are used for the measurement of the wave velocity in rock in laboratory.



Solid buffer method (Saether et al. 2016)



- In the solid buffer method two different measurements are used:
- Measurement A without specimen inserted,
- Measurement B with the specimen inserted into the wave propagation path.
- The compressional wave velocity in the specimen is found by taking the difference between the transit time in measurement A and the transit time in measurement B.
- The specimen are a plexiglas disc with 20 mm thickness and 50 mm diameter, a plexiglas cylinder with 60 mm thickness and 50 mm diameter, a Bentheim sandstone disc with 20 mm thickness and 50 mm diameter, and two Bentheim sandstone cylinders with 50 mm diameter and thicknesses 47 mm and 53 mm, respectively


(a)
(b)
(c)
(d)

Immersion Method

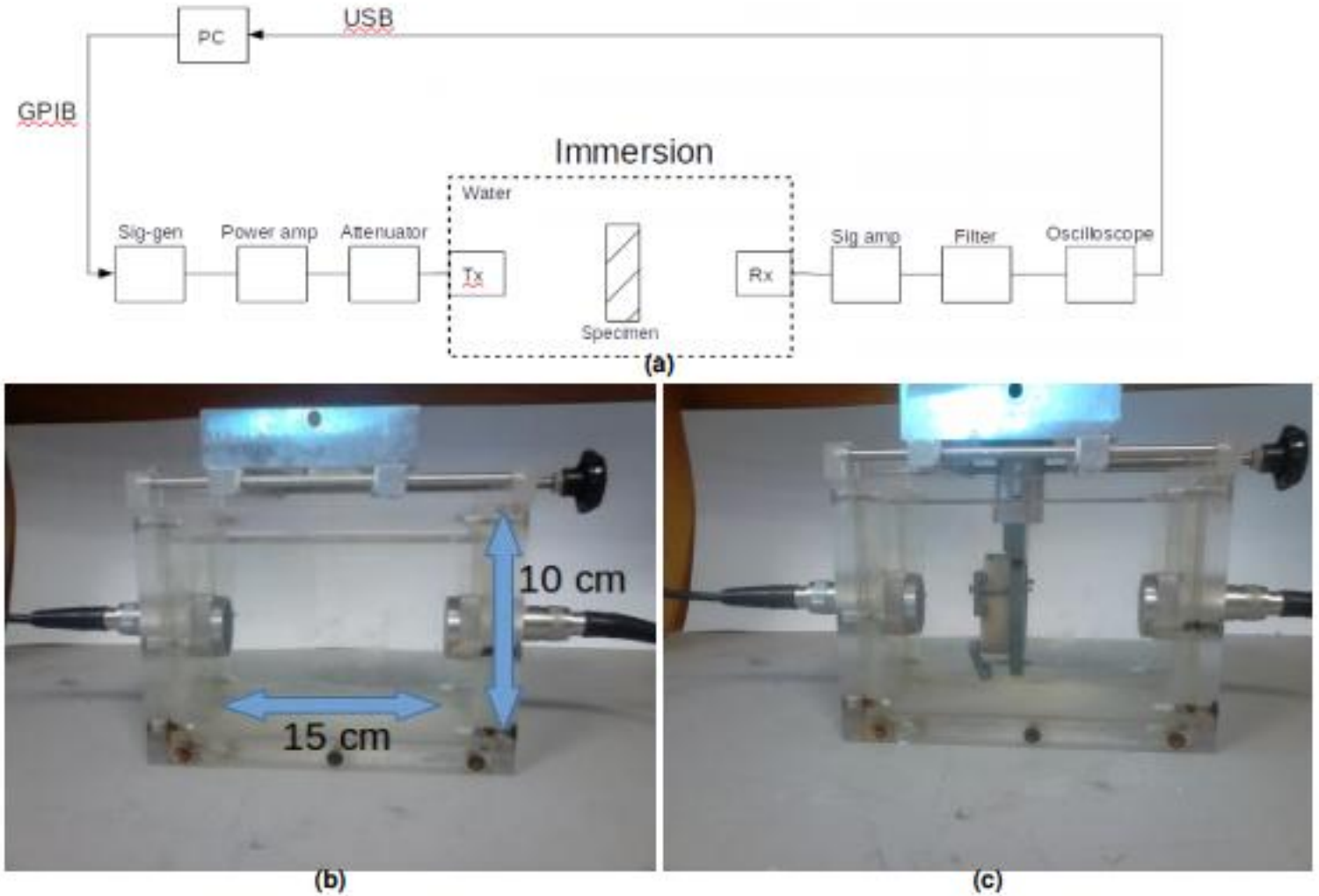
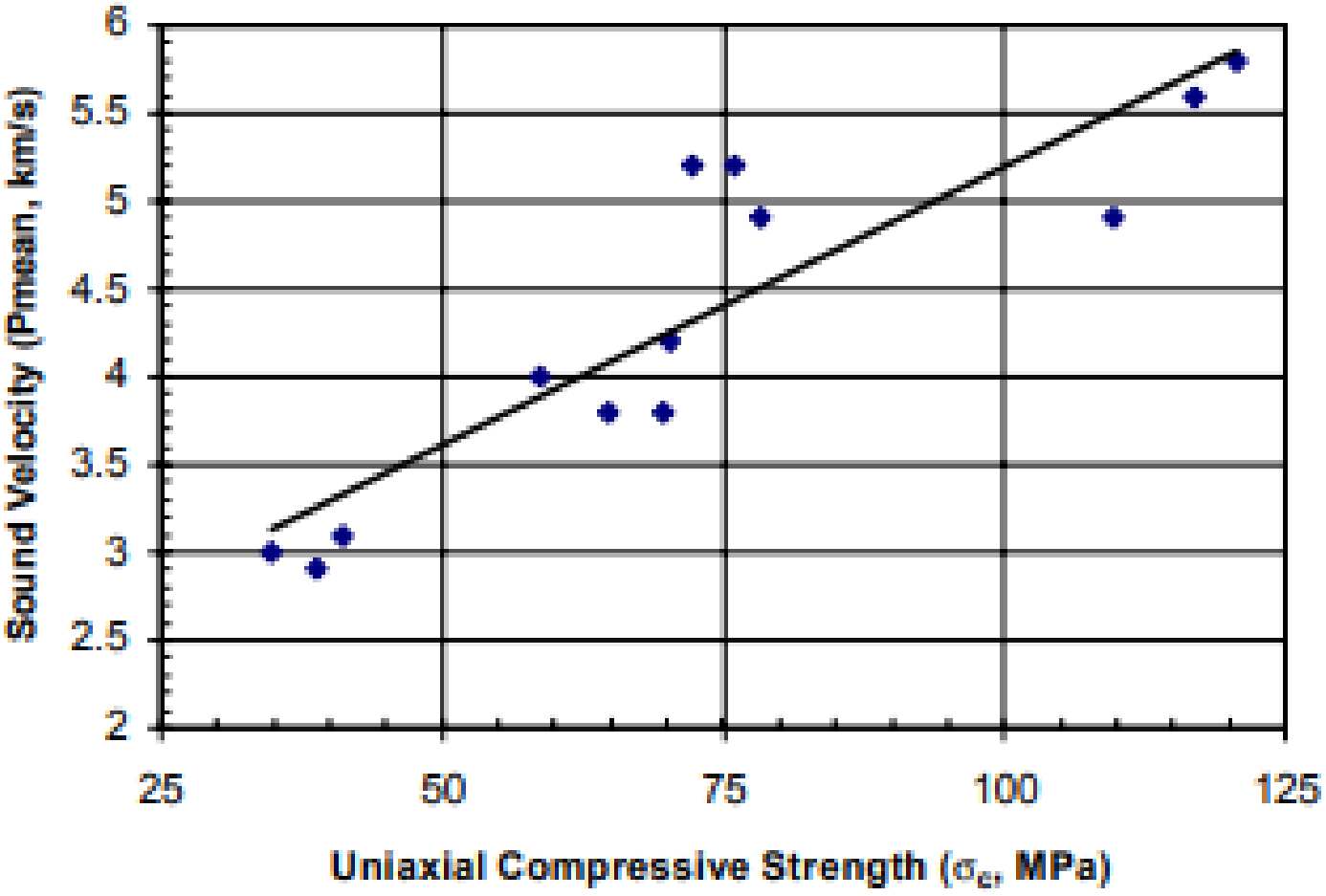


Figure 5: a) Schemeatics of the experimental setup of the immersion method, **b)** water immersion cell, measurement A, **c)** water immersion cell, measurement B.

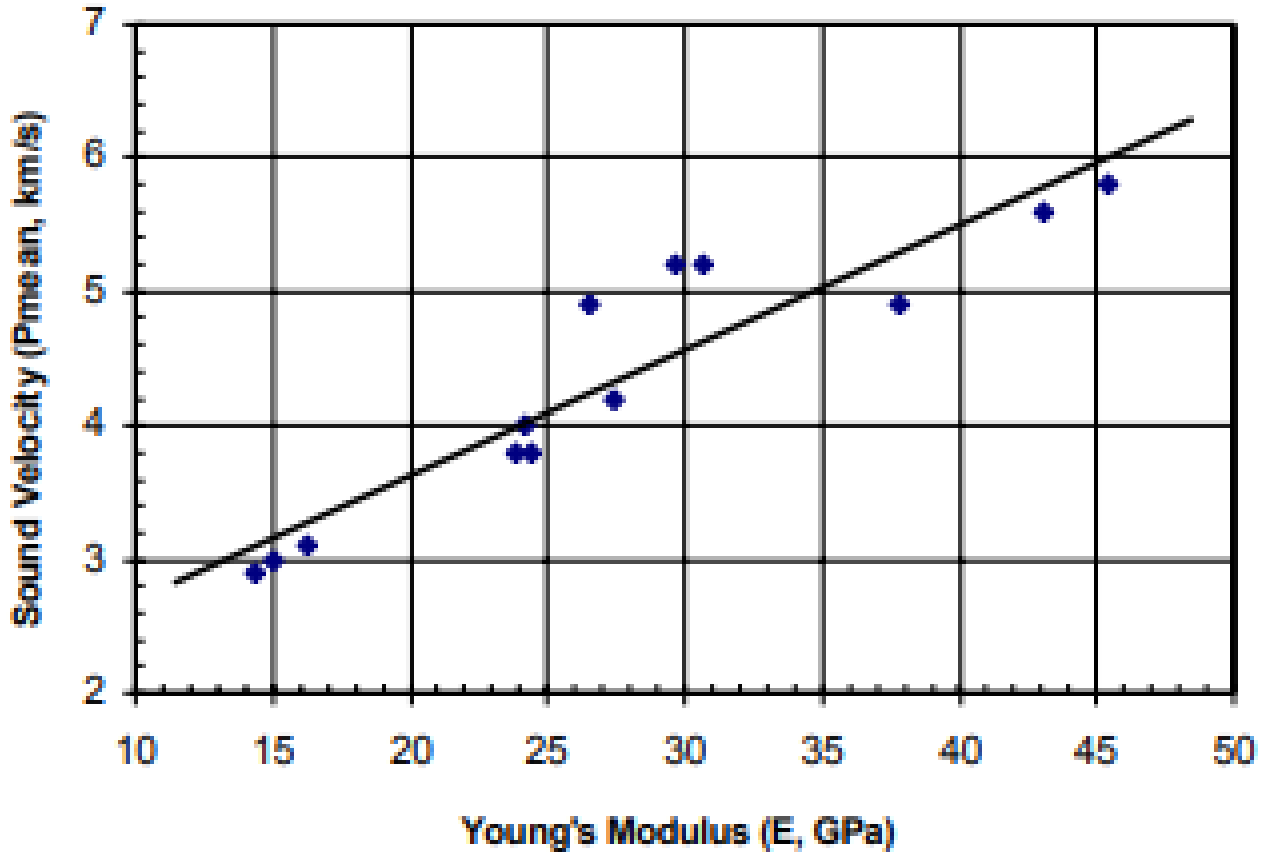
- In the immersion method it is assumed that no unwanted reflections are present and the method serves to be suitable as a reference measurement method for comparison with the solid buffer method.
- As for the solid buffer method, a transit time measurement A and a transit time measurement B are used.
- These transit time measurements are used to calculate the compressional wave velocity in the immersed specimen. When immersing the specimen in the water bath, an adapter is used to keep it steadily in-between the two transducers. The specimen are the same as used with the solid buffer method.



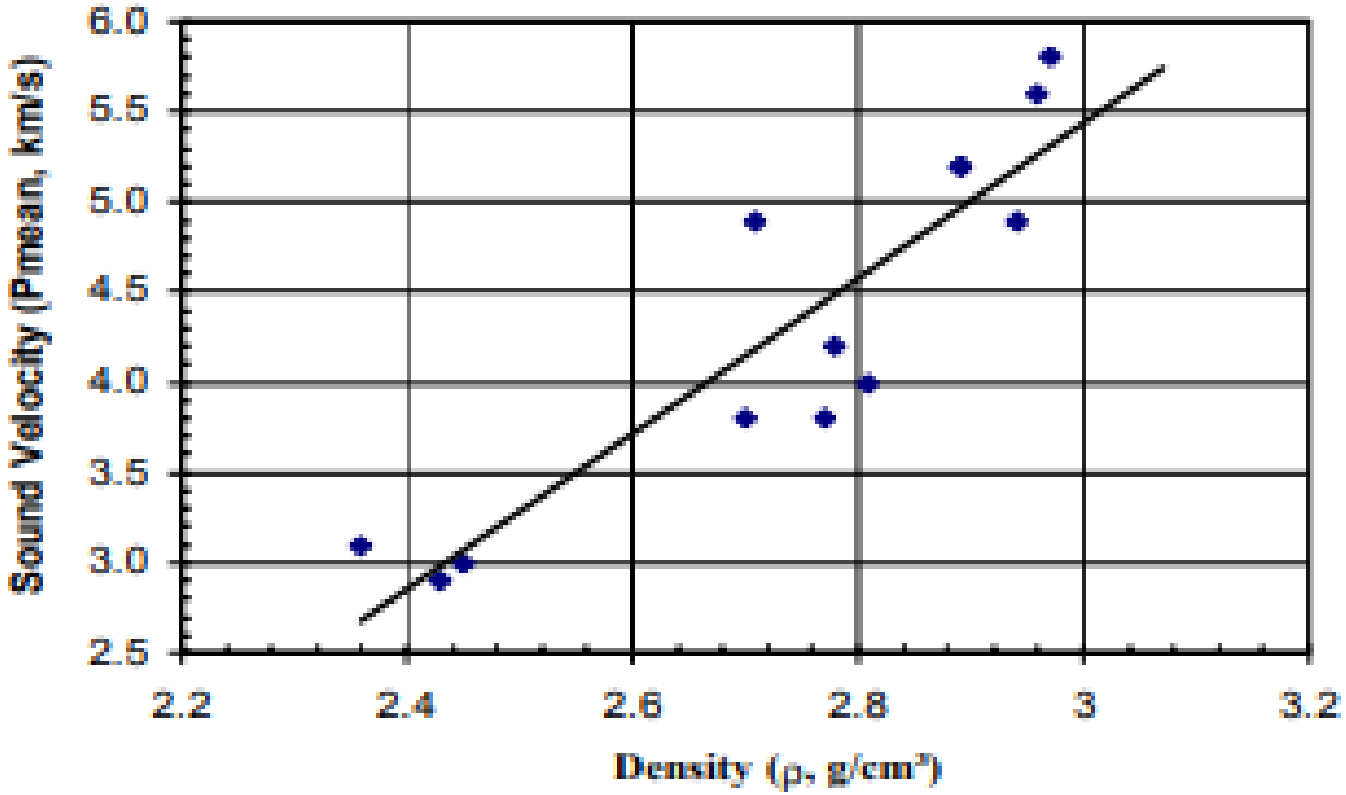
Relationship of sound wave with UCS (Yasar and Erdogan 2004)



Relationship between Sound velocity and Young's Modulus



Relationship between Sound velocity and Density



Classification of rock material strength

Class	Type Description	Uniaxial Compressive strength (kg/cm2)
A	Very high strength	More than 2240
B	High strength	1120-2240
C	Medium strength	560-1120
D	Low strength	280-560
E	Very low strength	Less than 280

Rock quality designation (RQD)

- Rock Quality Designation (RQD) represents the quality of rock core taken from borehole for testing or investigation.
- RQD also shows the degree of jointing or fracture in rock mass measured in percentage.
- RQD is calculated by taking a rock core sample from a borehole and length of all sound rock pieces which are minimum 100 mm long are summed up and are divided by length of core run.
- Only those pieces of rocks are considered which are hard and good quality.

RQD

Rock Quality	RQD (%)
Very poor (completely weathered rock)	<25
Poor (Weathered rock)	25-50
Fair (Moderately weathered rocks)	51-75
Good (Hard rock)	76-90
Very good (Fresh rocks)	91-100

Core recovery(CR)

- Core recovery(CR) = (total length of rock recovered/ Total core run length) x 100

- RQD = (sum of length of sound pieces >100 mm)/ total core run length) x 100
- RQD is used to evaluate quality of rocks such as degree and depth of weathering, zones of rock weakness and fracturing.
- This is used for determining the depth of foundations, bearing capacity of rocks, settlement and sliding possibilities of foundation.



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- Brekke T.L. and Howard T.R. (1972) Rock Masses as Construction Materials. PhD thesis Oslo Thesis, Norway.
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- Yasar E. and Erdogan Y. (2004). Correlating sound velocity with the density, compressive stremgth and Young's modulus of carbonate rocks. Rock Mechanics and Mining sciences, 41, 871-875.
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Geology of Dam and Reservoir Site

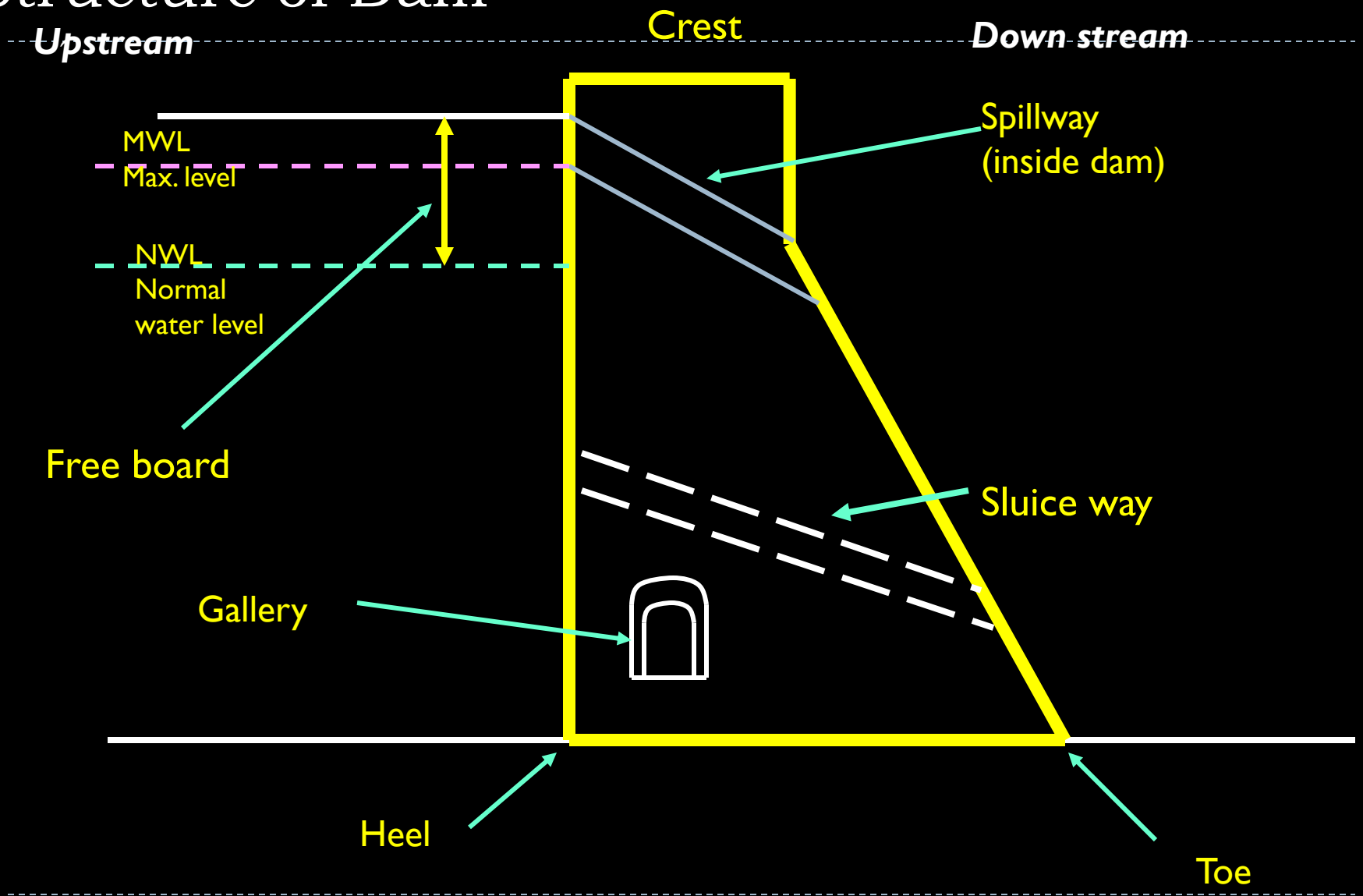
Module 7

DAM

- A Dam is barrier constructed at suitable location across a river valley for impounding water.
- Generation of energy, irrigation, for water supply system, fighting for droughts etc. are major objectives of the DAM.
- Hundreds of thousands kilometer long irrigational canals being fed by reservoirs created by around four thousand minor and major dams spread throughout the country.



Structure of Dam



- *Heel: contact with the ground on the upstream side*
- *Toe: contact on the downstream side*
- *Abutment: Sides of the valley on which the structure of the dam rest*
- *Galleries: small rooms like structure left within the dam for checking operations.*
- *Diversion tunnel: Tunnels are constructed for diverting water before the construction of dam. This helps in keeping the river bed dry.*
- *Spillways: It is the arrangement near the top to release the excess water of the reservoir to downstream side*
- *Sluice way: An opening in the dam near the ground level, which is used to clear the silt accumulation in the reservoir side.*



Types of Dams based upon purpose

- Storage Dam or Impounding Dam
- Detention Dam
- Diversion Dam
- Coffer Dam



Storage Dam

- It is to create reservoir to store water.
- Water stored is used for irrigation, power generation, water supply etc.

Detention Dam

- It is primarily constructed to temporarily detain all or part of the flood water in a river and to gradually release the stored water later at controlled rates.
- It protects the downstream side of the dam.
- It may also be used as a storage dam



Diversion Dam

- It is constructed to divert part of or all the water from river to other channel or conduit.
- For diverting water from a river into irrigation canal, mostly a diversion weir is constructed across the river

Coffer Dam

- It is a temporary dam constructed to exclude water from a specific area.
- It is constructed on the upstream side of the site where a dam is to be constructed so that the site is dry.
- In this case it behaves like a diversion dam.



Types of Dams based upon structure

- Gravity Dams
- Arch Dams
- Embankment Dams



Gravity Dams

- In such dam gravity essentially holds the dam to the ground. They are used to block rivers in wide valleys and must be built on a strong foundation of bed rock.
- Strength of the foundation rocks is most critical factor in the design of such dam.
- If properly design and constructed, it is considered safest type.



Arch Dams

- An arch dam, as the name implies is an arch-shaped solid structure mostly of concrete which is designed in such a way that a major part of thrust forces acting on the dam are transmitted by arch action.
- Arch dams are better for narrow valley, with strong and uniformly sloping walls or abutments.
- Wall of arch dam are thinner than gravity dam, Hence lighter than gravity dam.



Embankment Dams

- These include a variety of non-rigid structures which are built over wide valleys with varying foundation characteristics from easily available materials such as earth and rock fragments.
- In trapezoidal shape made of single or combination of more than one material.
- They can be constructed over weak foundation.
- Depending upon type of material used, the embankment dams may be an earth fill dam or rock fill dam or mixed-type embankment.



Geotechnical Considerations

- Following questions to be answered before construction of Dams.
  - The exact location where the dam should be placed against the river along its longitudinal profile
  - The type of dam that will be most suitable for that particular site
  - The availability cost and quality of materials required for the construction of the dam.



Geological considerations in the selection of Dam site

- Narrow river valley
- Occurrence of bedrock at a shallow depths
- Effect of associated geological structures
- Leakage below dams
- Competent rocks to offer stable foundations
  - Suitability of different types of rocks
  - Influence of weathering
  - Effect of occurrence of intrusions
  - Effect of fracturing



Selection of sites

- Topographically: a place is suitable like; narrow gorge or a small valley with enough catchment area available behind.
- Technically: site should be sound i.e. strong, impermeable and stable.
- Constructionally: the site should not be far off from deposits of materials and ease of construction should be considered.
- Economically: cost benefit aspects should be considered.
- Environmentally: environmental and ecological aspects should be considered.



Geological characters for investigation

- Geology of area
- Geology of site



Geology of area

- Preliminary geological surveys of entire catchment area followed by detailed geological mapping of the reservoir area have to be conducted. These should reveal
  - Main topographic features
  - Natural drainage pattern
  - General characters and structures of rock formations such as stratification, folding and faulting and igneous intrusions
  - The trend and rate of weathering and erosion in the area



Geology of the Site

- Lithology: The characteristics of the rock should be known. Complex lithology poses challenging design problems.
- Structures: Detailed mapping of planes of weakness like; bedding planes, shistosity, foliation, cleavage, joints, shear zones, faults and fault zones, folding etc. Resultant force normal to the bedding plane is most suitable.
- Dams founded on beds traversed by fault zones and on major fault plane are more liable to shock during an earthquake compared to dams on non-faulted rocks.
- Dams aligned along axial regions of folds would be resting on most unsound rocks in terms of strength. Similarly in synclinal bends dams placed on the upstream limbs would run the risk of leakage from beneath the dam.



Geology of the Site

- The geometry of joints, their intensity, nature and continuity with depth, all must be thoroughly established and their effects on he site rocks evaluated and remedial measures taken in advance.



Treatment associated with Dam sites

- Engineering problem associated with Dam site is stability, subsidence, settlement, slide, seepage, leakage, piping, uplift etc.
- Engineering geological investigation of a dam site is essential to evaluate its precise geological conditions before the site is taken up for construction.
- At the initial stage, photogeological study of the site is undertaken followed by reconnaissance of the site.
- Engineering geological mapping of the site is then prepared to identify and record the lithological and structural set-up including all the visible geologic defects at the surface.
- In the subsequent stages, exploratory drilling and sometimes geophysical works are done to identify the subsurface weakness of the site.



Treatment associated with Dam sites

- Problem faced in dam project (eastern India)
  - Weak structural
  - Thick mantle
  - Deep weathering of bed rock
  - Karstic condition and cavities
  - Permeable boulder bed
  - Soft sedimentary rock
  - Buried channel
  - Kaolinisation
  - Old slides
  - Reservoir siltation.



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Rock Mechanics

Module 8

Terzaghi Rock Mass Classification

- Terzaghi (1946) classification is based upon gravity driving force:
  - Intact rock
  - Stratified rock
  - Moderately jointed rock
  - Blocky and seamy rock
  - Crushed but chemically intact rock
  - Squeezing rock
  - Swelling rock

Cont…

- ***Intact rock**: It contains neither joints nor hair cracks. Dropping off in case of intact rock takes place spontaneously and violent.*
- ***Stratified rock:** It consists of individual strata with little or no resistance against separation along the boundaries between strata.*
- *Moderately jointed rock: It contains joints and hair cracks, but blocks between joints have interlocking, due to which lateral support is not required.*

- ***Blocky and Seamy rock:*** *In such rock blocks are chemically intact or imperfectly interlocked. In such rock vertical walls may required lateral support.*
- ***Crushed but chemically intact rock:*** *if most or all of the fragments are as small as fine sand grains.*
- ***Squeezing rock:*** *Squeezing rock slowly advances into the tunnel without perceptible volume increase. A prerequisite for squeeze is a high percentage of microscopic and sub-microscopic particles of micaceous minerals or clay minerals with low swelling capacity.*

- **Swelling rock:** Swelling rock advances inot the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks that contain clay minerals such as montmorillonite, with high swelling capacity.

Rock Quality Designation (RQD)

- $$core\ recovery = \frac{Length\ of\ core\ piece}{Total\ lenght\ of\ core\ run}\ X\ 100$$

- $$RQD = \frac{Total\ length\ of\ core\ piece}{total\ lenght\ of\ run} X100$$

Classification based upon RQD

RQD (%)	Rock quality
90-100	Excellent
75-90	Very good
50-75	good
25-50	poor
0-25	Very poor

Classification based on uniaxial compressive strength

- Commission on standardization, International society of Rock Mechanics, ISRM, 1978

Types of material	UCS (Mpa)
Soil	< 0.25 MPa
Extremely low strength	0.25 – 1 MPa
Very low strength	1 – 5 MPa
Low strength	5 – 25 MPa
Medium strength	25 – 50 MPa
High strength	50 – 100 MPa
Very high strength	100-250 MPa
Extremely high strength	>250 MPa

Slake Durability Test

- IS: 10050-1981
- **Objective:** This test is done to find out the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting in a slaking fluid usually water



Procedure

- Dry the sample to constant mass of placing it in oven, maintained at a temp of 105+-5 C. place the sample in the drum of the machine and record the weight of sample plus drum as 'A'.
- Fill the lid with the drum; mount the drum in the trough.
- Fill the trough with slakiing fluid to a level 20 mm below the drum axis. Rotate the drum at 20 rev/min for a period of 10 minutes.
- Remove the drum from trough and remove the lid from the drum
- dry the drum plus retained portion of the sample in an oven maintained at temp of 105+-5 C.
- Record the weight of drum plus retained portion of the sample as 'B'

- Repeat the steps from 2 to 5 for a further period of 10 minutes. Record the weight of drum plus retained portion of sample as ‘C’
- Clear the drum and record its weight as ‘D’
- $slake\ durability\ index\ (\%) = \frac{C-D}{A-D}\ x\ 100$

Gamble's slake durability classification

Group name	% retained
Very high durability	>99
High durability	98-99
Medium high durability	95-98
Medium durability	85-95
Low durability	60-85
Very low durability	<60