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سلايدات

جيولوجيا

م. حسين الديكي

Introduction to Physical Geology

Introduction

Hussien Aldeeky

Course Syllabus

Instructor:

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Time: Sun ,Tue 8:00-9:00

Course Information:

: Introduction to Physical Geology,
Course Number:1804011231
Department: Civil Engineering
Designation: Compulsory

Course Syllabus

Course Description:

- **Introduction** : { course objectives and relevance to engineering}
- **Structure and composition of earth**
- **Minerals:** properties, compositions, forms
- **Rocks:** Igneous, Sedimentary, Metamorphic
- **Engineering Properties of rocks** (foundation and materials as aggregates)
- **Geological structures:** Folds, Faults, Joint,

Course Syllabus

- **Mass movements and slope processes**
- **Site investigation**
- **Subsurface geology**, condition of stress at depth (for excavation, tunneling highways, …)
- **Earthquakes,** (interpreting earthquakes, effect of earthquakes on structures)
- **Topographic Maps**

Course Syllabus

Course Materials

Text book
Supplementary books
PowerPoint slides
Lab Work

Course Textbook:

Principles of Engineering Geology, by: Rebert B … , John Wiley & Sons Topics covered:

Other Book:

A Geology for Engineers, F. Blyth and M.Freitas, 7^{th} Seventh Edition
Principals of Physical Geology, D Holms
Foundations of Engineering Geology, T. Waltham, 2^{nd} Edition

Course Syllabus

Course work:

First exam	20%
Second exam	20%
Lab Assignment	20%
Final exam	40%

No make up exam

Introduction to Physical Geology

Aims:

1.To introduce civil engineering aspects of geology

2.To show how basic geological features can affect the performance of engineering construction and the means by which such effects may be predicted and evaluated.

3.Introducing the geological maps and plotting simple maps using software.

4.Predicting any geological hazards and the engineering solutions to minimize their effects

Introduction to Physical Geology

Geology is the science concerned with the Earth and the rocks of which it is composed, the processes by which they were formed during geological time, and the modelling of the Earth's surface in the past and at the present day.

It is divided into two major groups.
Physical Geology deals with the materials that constitute the Earth (soils and rocks), the structures and surface features of the Earth, and the processes that created these structures.

Historical Geology deals with the history of the Earth.

Introduction to Physical Geology

Geology Branches

Petrology: study of rocks and their origin. It consists of **Petrography:** (identification, description, and classification of rocks) & **Petro genesis** (origin of rocks)

Mineralogy : study of rock constituents or minerals

Geochemistry: chemistry of rocks

Geomorphology :landforms, their origin and development

Introduction to Physical Geology

Geophysics : application of principles of physics to the study of the Earth.: **Geomagnetic** (study of Earth's magnetic field) and **Seismology** (earthquakes);

Engineering Geology : geology and engineering

Hydrology : study of underground and surface water

economic geology, agricultural geology, mining geology, petroleum

Introduction to Physical Geology

Geologists

- Study problems
- Qualitative analysis emphasized (traditionally)
- See earth as complex (heterogeneous & anisotropic)

Engineers

- Solve problems
- Quantitative analysis emphasized
- Models often simplified/simplistic

Introduction to Physical Geology

Engineering geology is the application of geological data, techniques and principles to the study of rock and soil surficial materials, and ground water. This is essential for the proper location, planning, design, construction, operation and maintenance of engineering structures. Engineering geology complements environmental geology, or hydrogeology

Introduction to Physical Geology

Engineering Geology study :

- Engineering Geology study{**Rock, soil, water}, the interaction among these three constituents, as well as with engineering materials and structures**

Introduction to Physical Geology

Why Engineering Geology matter? □

•Serve civil engineering to provide information in 3 most □ important areas:

1–Resources for construction; □

•Aggregates, fills and borrows. □

2–Finding stable foundations; □

•Present is the key to the past –geology □

•Past is the key to the future -engineering □

3–Mitigation of geological hazards □

•Identify problems, evaluate the costs, provide □ information to mitigate the problem

Importance of engineering geology to in Civil engineering

1. The investigation of foundations for all types of major structures, (dams, bridges, airports, large buildings, and towers.)
2. The evaluation of geologic conditions along tunnel, pipeline, canal, railway, and highway routes.
3. The exploration and development of sources of rock, soil and sediment for use as construction material.
4. The investigation and development of surface and groundwater resources.

Importance of engineering geology to in Civil engineering practices

- 5.The evaluation of geologic hazards such as landslides, faults and earthquakes, radon, asbestos, subsidence, expansive and collapsible soils, expansive bedrock, cavernous rock, and liquefaction.
- 6.Evaluation of geologic conditions (including groundwater) affecting residential, commercial, and industrial land use and development.
- 7.Construction geology, including slope stability, dewatering, sub-drains, grouting considerations, and excavatability.
- 8.Safe siting and geologic design considerations for waste management and disposal facilities and to in establishing the bases for remedial actions for mitigation of related environmental threats from un-engineered and uncontrolled waste disposal

Introduction to Physical Geology

- The Engineering Geology was established in US after the St. Francis Dam near Los Angeles, CA failed on March 12, 1928. Engineering community realized the importance of Geology factor in civil engineering

Introduction to Physical Geology

Role of Engineer in Geological Hazards

- Assessing Risks
- Avoiding Risks
- Preventing damage
- Predicting Impact

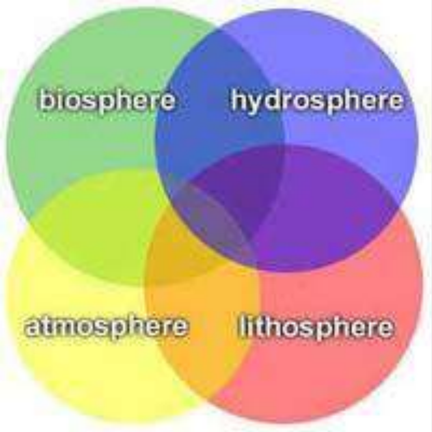
Introduction to Physical Geology

January 10, 2005: A 25-foot boulder blocks Topanga Canyon Blvd. near Malibu, southern California, after a massive mudslide killed 3 and had up to 21 missing (AP)

Earth Structure

- Hussien aldeeky

Introduction to Physical Geology



Earth major spheres

1. Hydrosphere

• Ocean is the most prominent feature of the hydrosphere.

- Is nearly 71% of Earth's surface
- Holds about 97% of Earth's water

• Fresh water found in streams, lakes, and glaciers, underground water

2. Atmosphere

• Thin, blanket of air

• One half lies below 5.6 kilometers (3.5 miles)

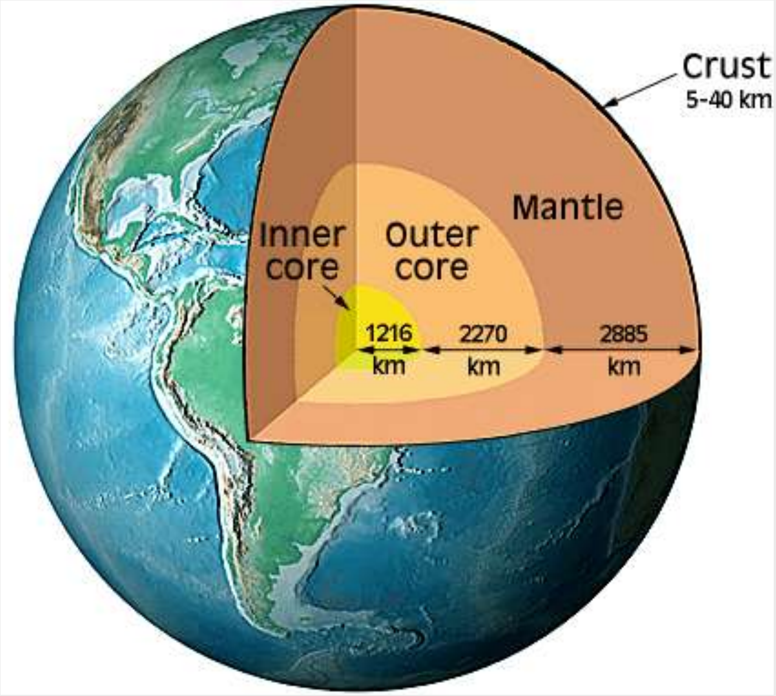
3. Biosphere

• Includes all life

• Concentrated near the surface in a zone that extends from the ocean floor upward for several kilometers into the

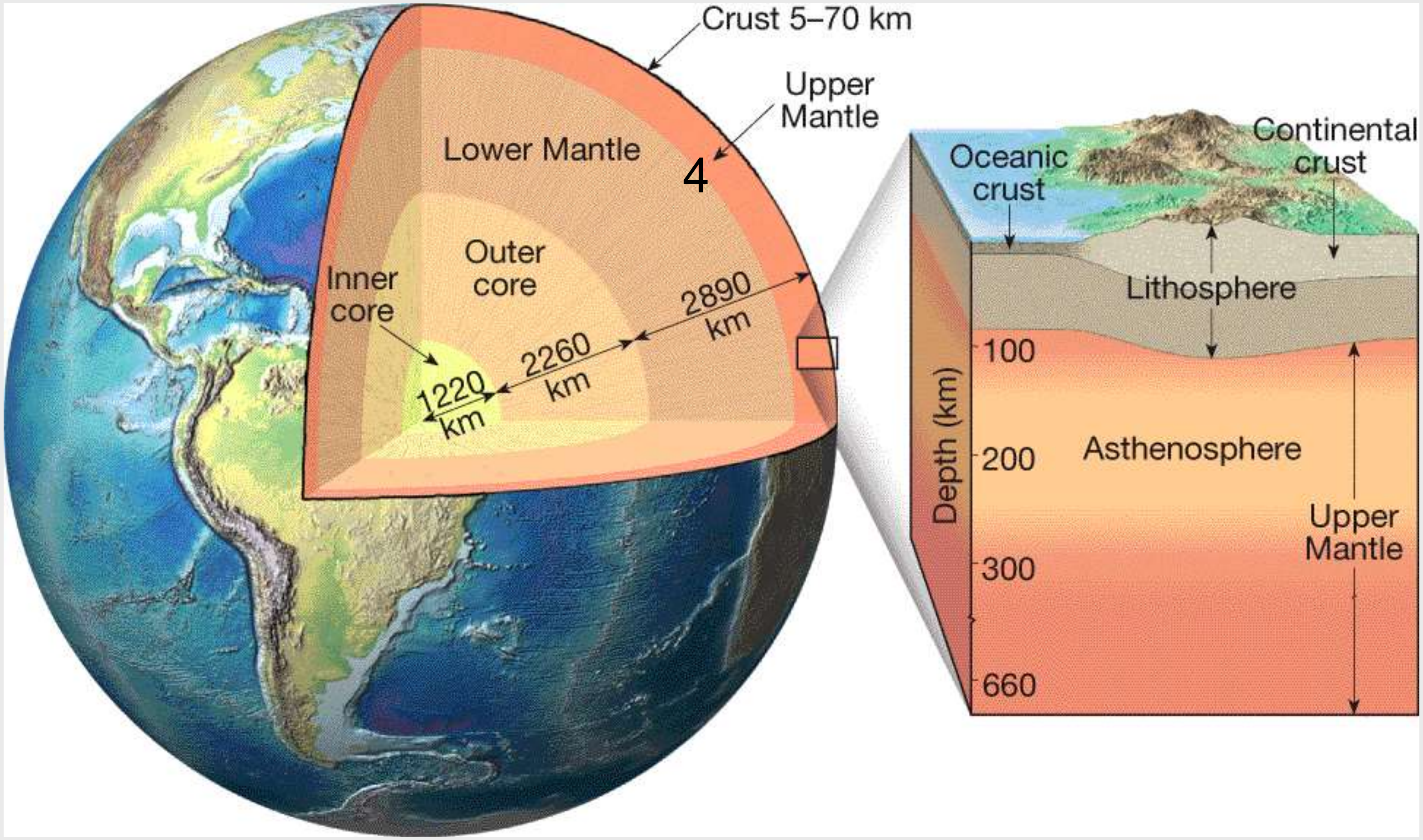
4. Geosphere

To the engineer interested in earthquake effects, the Geospere is a sphere having the layered structure of a boiled egg. It has a crust (the shell), a mantle (the egg white), and a core (the yolk.)

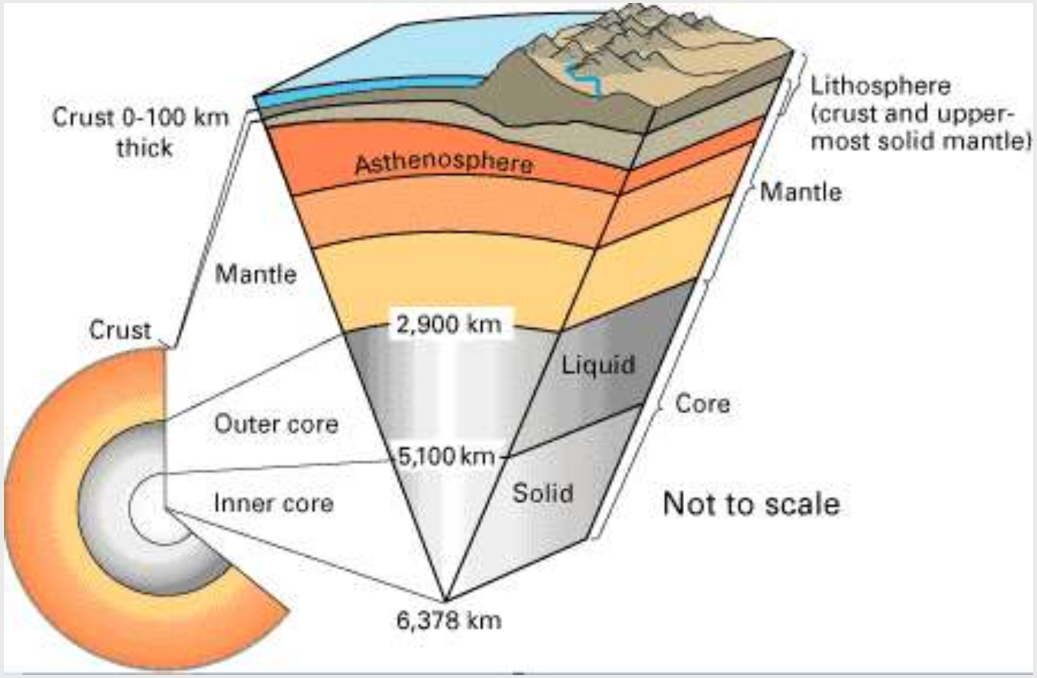


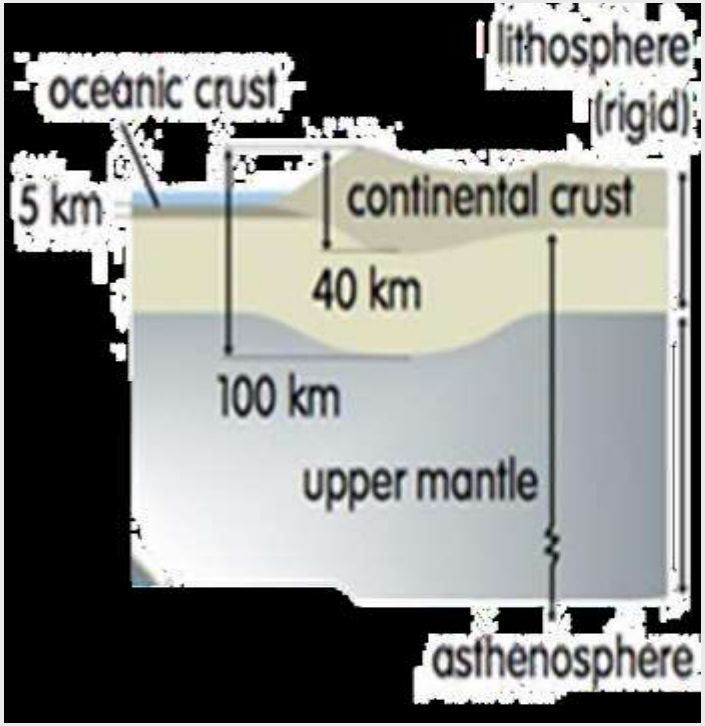
- Crust:
  - Continental crust (25-40 km*)
  - Oceanic crust (~6 km)
- Mantle
  - Upper mantle (650 km)
  - Lower mantle (2235 km)
- Core
  - Outer core: liquid (2270 km)
  - Inner core: solid (1216 km)

Interior Structure of the Earth



Interior Structure of the Earth





Layers of the Earth

- It is important to note that there has been, so far, no drill that has penetrated the surface of the earth more than a few kilometers.

- Almost all information about the internal structure of the earth is inferred from observed characteristics and propagation (travel rates and reflections) of seismic waves.

- Magnetic and gravitational observations also help complete the picture.

The earth is divided into three main layers: (**Inner core, outer core), mantle** and **crust**.

- The core is composed mostly of iron (Fe) and is so hot that the outer core, with about 10% sulphur (S). The inner core is under such extreme **pressure** that it remains solid.
- Most of the Earth's mass is in the mantle, which is composed of iron (Fe), magnesium (Mg), aluminum (Al), silicon (Si), and oxygen (O) **silicate** compounds. At over 1000 degrees C, the mantle is solid but can deform slowly in a **plastic** manner.

THE CRUST

- The crust is much thinner than any of the other layers, and is composed of the least dense calcium (Ca) and sodium (Na) aluminum-silicate minerals. Being relatively cold, the crust is rocky and **brittle**, so it can fracture in **earthquakes**.

- The shell of the earth, the crust, can be said to have two different thicknesses.

- Under the oceans, it is relatively thin. It varies in thickness from 5 to 8 km. Under the land masses, it is relatively thick. The thickness of the continental crust varies from 10 to 65 km.

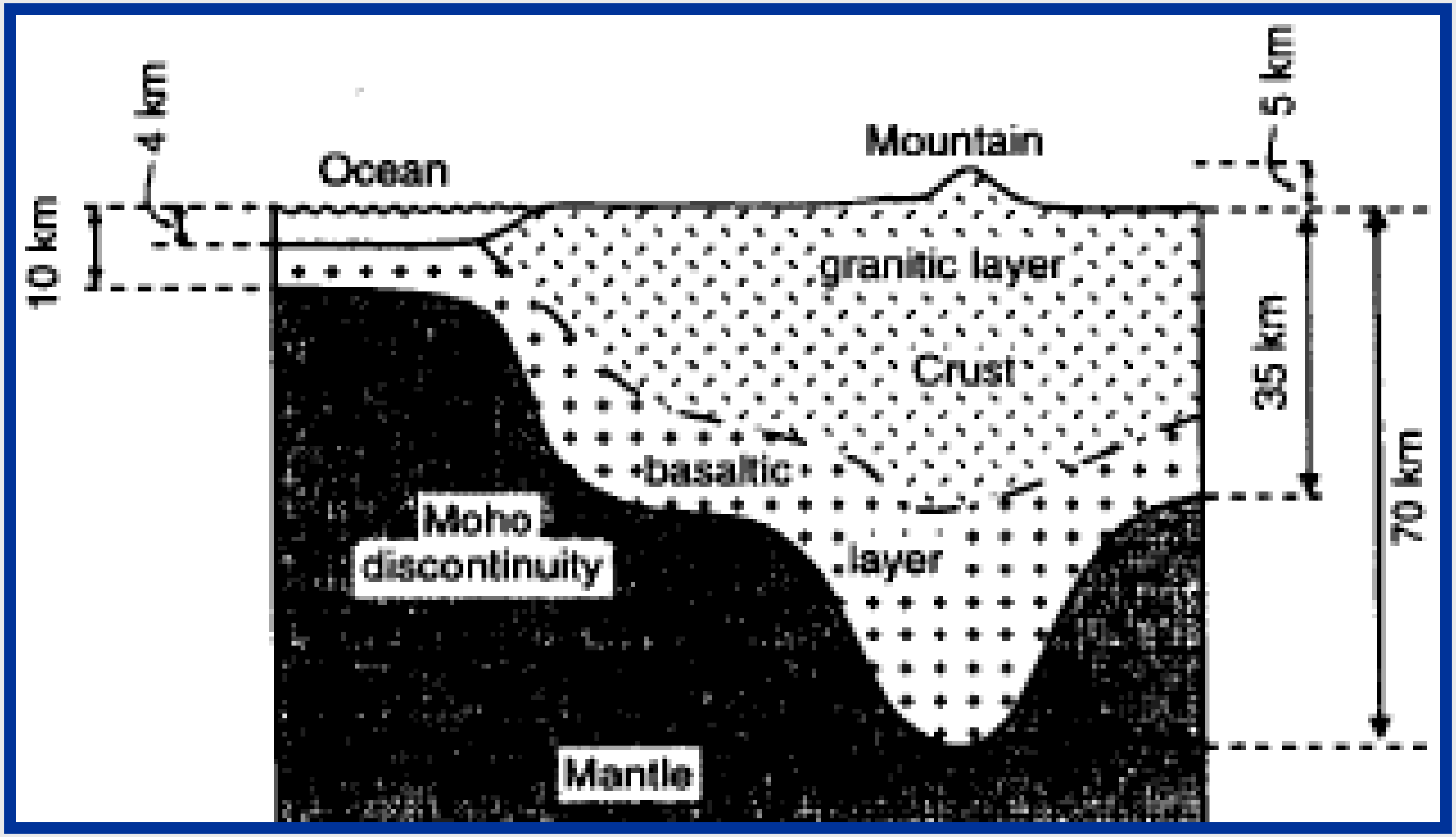
- The egg shell analogy for the crust is not an exaggeration(مبالغة). It is paper thin compared with the radius of the earth which is approximately 6400 km.
- The total weight of the continental crust is less than 0.3% of the weight of the earth.
- Variations in the crust thickness are compensated by the weight of the water and the differences in the specific gravities of the crust under the oceans (3.0 to 3.1) and under the continents(2.7 to 2.8).

Materials of the earth crust

Basic knowledge of earth materials (rocks) is essential to the understanding of all geologic phenomena The crust is composed of two basic rock type: **granite and basalt**. The crust is also the source of many of the minerals and other substances that we use in industry and other fields. **The continental crust is composed mostly of granite. The oceanic crust consists of volcanic lava rock called basal**t. Basaltic rocks of the ocean plates are much denser and heavier than the granitic rock of the continental plates. Because of this the continents rides on the denser oceanic plates.

THE MOHO

➢The Moho, refers to a zone or a thin shell below the crust of the earth that varies in thickness from 1 to 3 km.



Introduction to Physical Geology

- In seismology, the term "discontinuity" is used in its general sense. It refers to a change over a short distance of a material property. In this case, the "short distance" may be as long as 3 km, a trifle compared with the radius of the earth.

- In that zone, the P-wave velocity has been observed to increase from approximately 6 to approximately 8 km/sec.

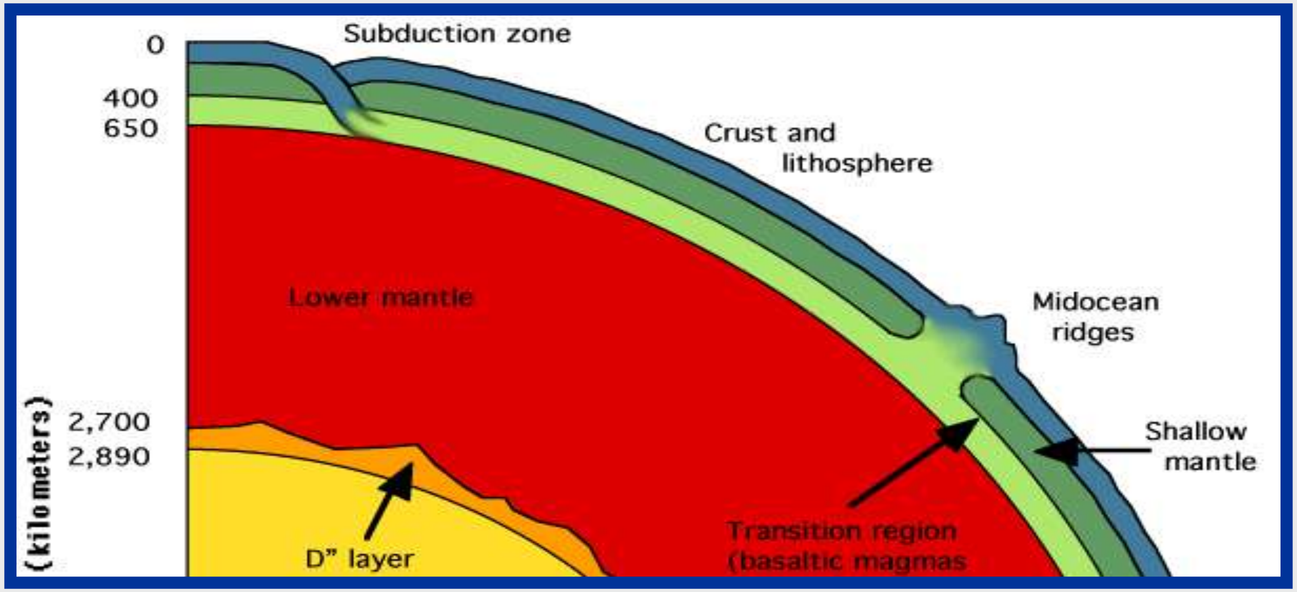
- The Moho is considered to be the boundary between the crust and the mantle.

- The increase in P-wave velocity is ascribed to change in composition of the medium. Rocks of the mantle are poorer in silicon but richer in iron and magnesium

THE MANTLE

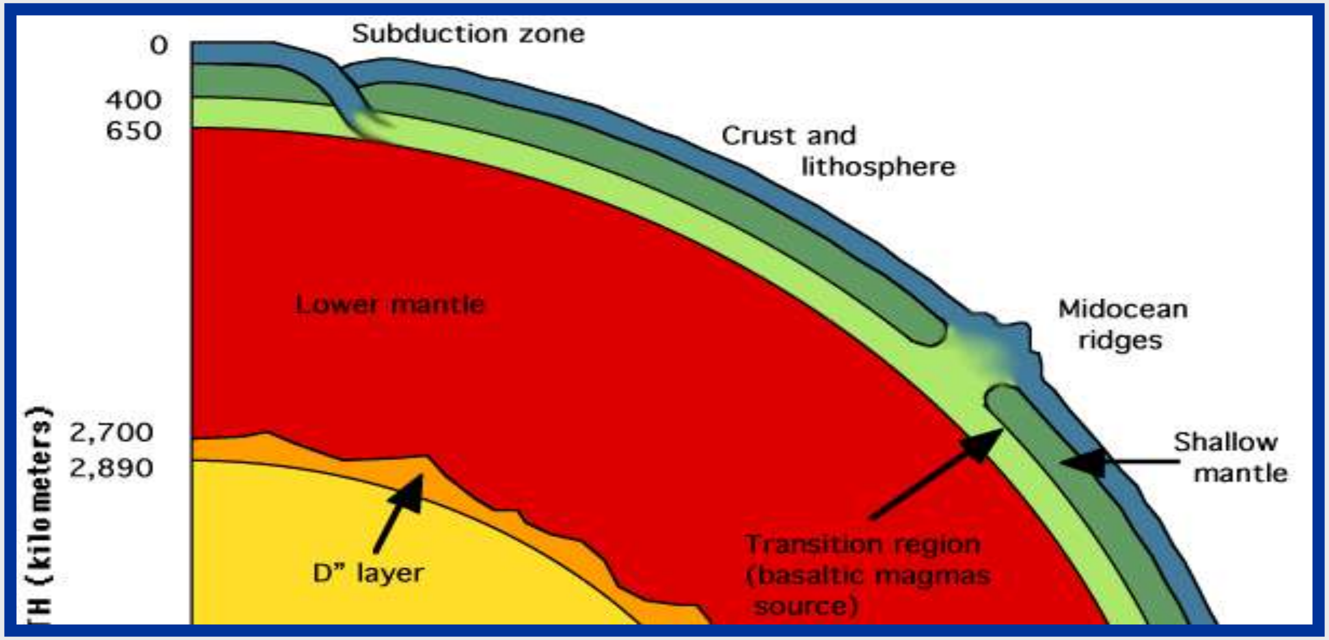
The mantle can be thought of having three different layers. The separation is made because of different deformational properties in the mantle inferred from seismic wave measurements.

(1) The upper layer is stiff. It is presumed that if the entire mantle had been as stiff, the outer shell of the earth would have been static. This stiff layer of the mantle and the overlying crust are referred to as the ***lithosphere***. The lithosphere is approximately 80-km thick



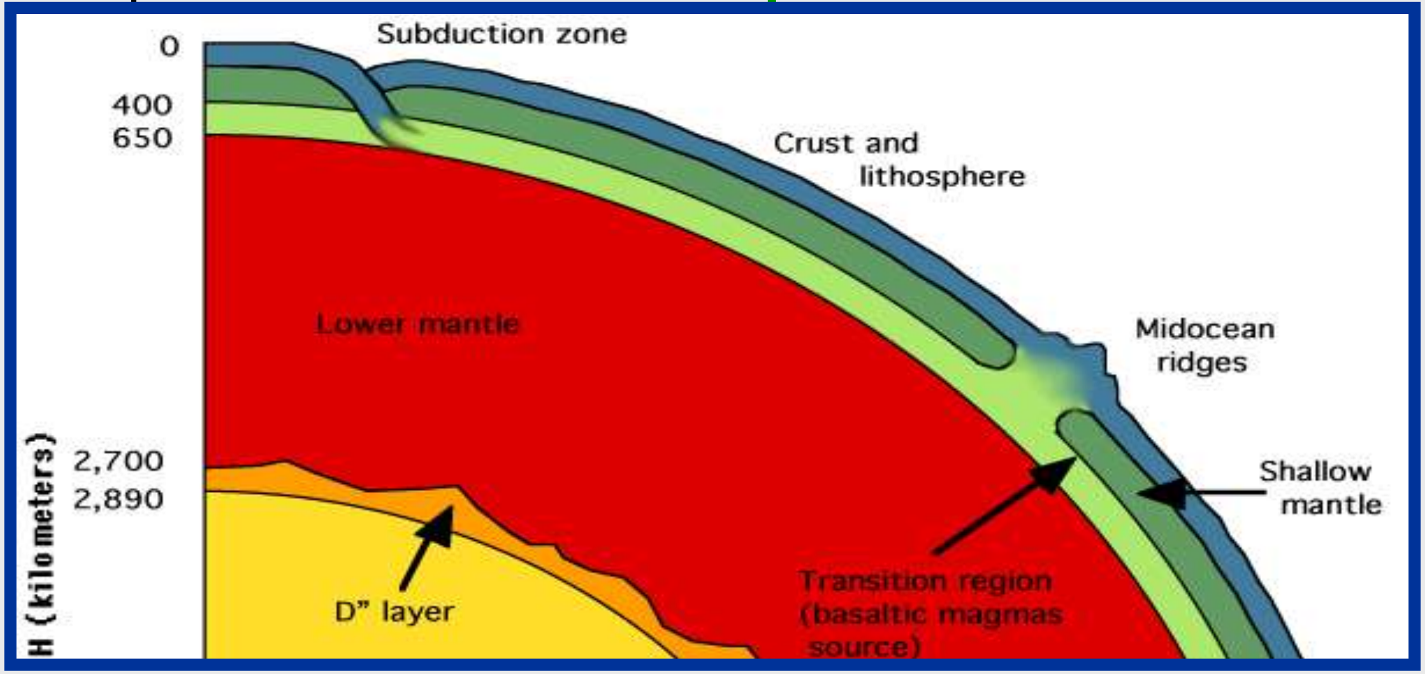
(2) Beneath the **lithosphere** is a soft layer of mantle called the ***asthenosphere*.**

- Its thickness is inferred to be several times that of the **lithosphere**.
- One may think of this as a film of lubricant although film is not exactly the word for something so thick. It is assumed that the lithosphere, protruding ***(meaning: extending beyond)*** parts and all, can glide over the **asthenosphere** with little distortion of the lithosphere



(3) The *mesosphere* is the lowest layer of the mantle.

- Considering the vagueness(غموض) in defining the lower boundary of the **asthenosphere** it would be expected that the thickness and material properties of the mesosphere are not well known.
- It is expected to have a stiffness somewhere between those of the lithosphere and the **asthenosphere.**

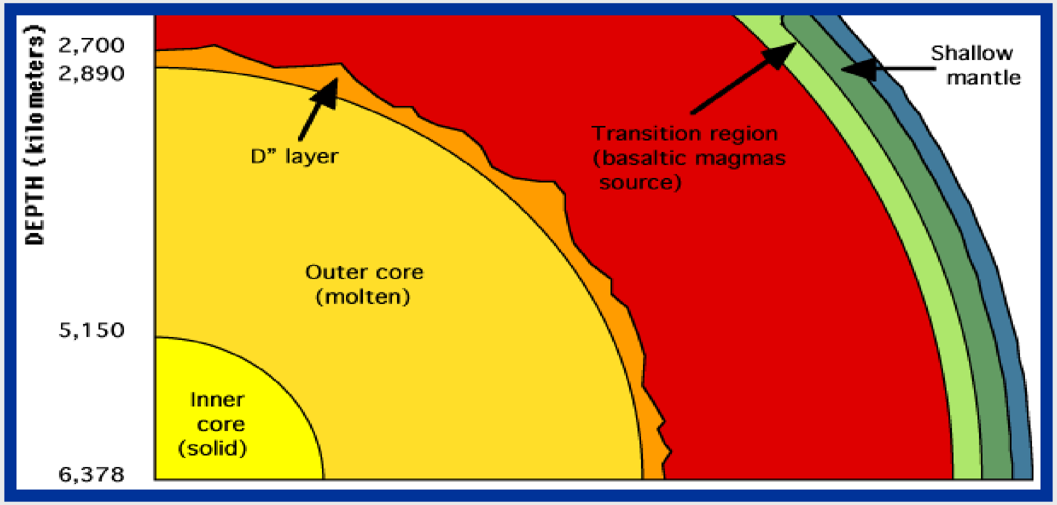


Introduction to Physical Geology

➢At a depth of approximately 2900 km, there is a large reduction (on the order of 40%) in the measured velocity of seismic waves. The boundary between the mantle and the core is assumed to be at this depth.

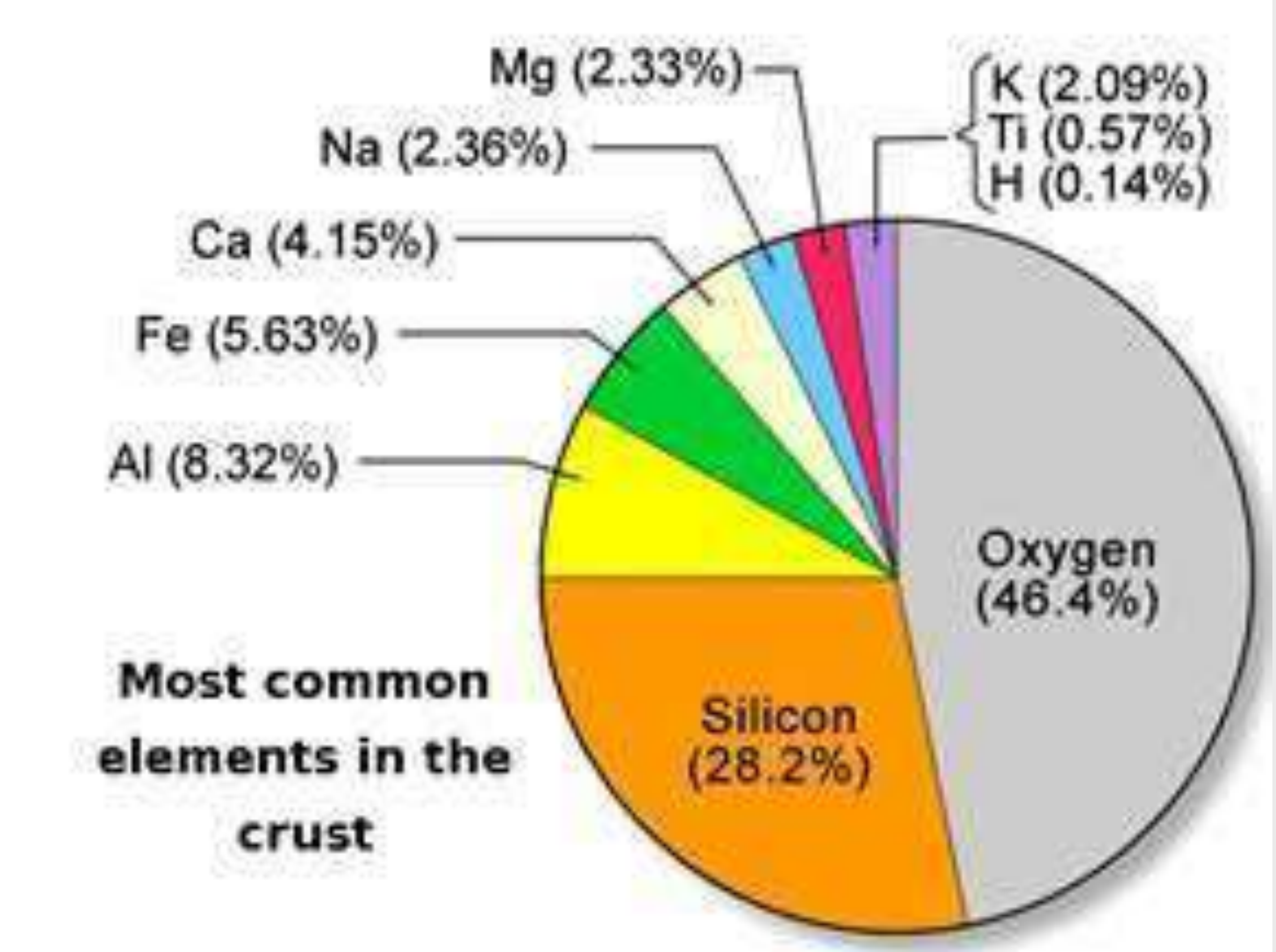
➢Because no S-wave has been observed to travel through the material below this boundary for a thickness of approximately 2300 km, it has been inferred that the core comprises two layers.

➢The 2300-km thick outer layer which is in a molten state and an 1100-km thick inner layer which is solid.



THE CORE

It is known that the pressure increases toward the center of the earth. So does the temperature. The liquid outer layer versus the solid inner layer is rationalized by recognizing that the melting point of the material increases (with pressure) at a faster rate than the temperature as the center of the earth is approached.


Mg (2.33%)
K (2.09%)
Ti (0.57%)
H (0.14%)
Na (2.36%)
Ca (4.15%)
Fe (5.63%)
Al (8.32%)
Oxygen (46.4%)
Most common elements in the crust
Silicon (28.2%)

Introduction to Physical Geology

Structure		Chemical Composition	Physical Composition
Crust	Oceanic	Basalt: O_2, Si, Mg, Fe	Lithosphere (cool, rigid)
	Continental	Granite: O_2, Si, Al	
Mantle	Uppermost	O_2, Fe, Mg, Si	
	Asthenosphere		Asthenosphere (hot, flowing)
	Mantle		Mantle (hotter, denser)
Core	Outer	Fe, Ni	Outer (hottest, viscous liquid, 4x denser than crust)
	Inner		Inner (hottest, solid, 6x denser than crust)

=> Earth's Crust

Stony-Iron Meteroites

=> Earth's Mantle

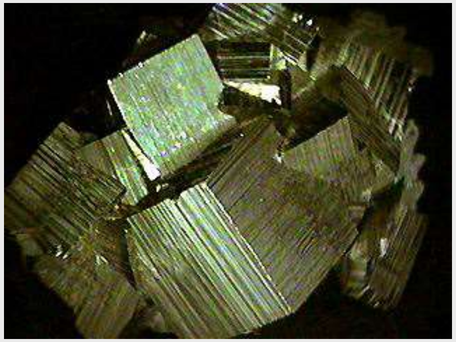
Iron Meteorites

=> Earth's Core

Engineering Geology

Minerals

Hussien al deeky



Engineering Geology

Definition of mineral and rock

Element : A form of matter that cannot be broken down into simpler form by heating, cooling, or chemical reactions

Mineral : is naturally occurring crystalline, inorganic, homogenous solid with a chemical Composition , a characteristic internal structure and physical properties

- **Rock:** A consolidated or unconsolidated aggregate of mineral grains consisting of one or more mineral species and having some degree of chemical and miner alogic constancy

Engineering Geology

A mineral characeristics

1) A naturally occurring chemical element or compound;
2) Formed by inorganic processes;
3) With an ordered arrangement or pattern for its atoms –crystalline structure;
4) Possesses a definite chemical composition or range of compositions.
5) Solid Substance

How Minerals Form: 1. Crystallization from magma 2. Precipitation 3. Pressure and temperature 4. Hydrothermal solutions

The opposite of mineral property is amorphous, i.e., the property of non-crystal, order-less property possessed by glass, volcanic glass, etc.; oil or coal can neither be regarded as minerals by their organic involvement

Engineering Geology

Basic Mineralogy of Rocks (cont.)

So we can simply express the mineral as

Mineral = composition + crystalline structure

For two minerals if the composition are the same but the structures are different, they can be called a pair of polymorphs. The common examples for polymorphs include

1) pyrite/marcasite(FeS_2 , isotropic vs anisotropic iron atom spacing);
2) diamond/graphite (C, the same composition of carbon but different structure);
3) Calcite/aragonite ($CaCO_3$);
4) quartz/cristobolite(SiO_2).

Engineering Geology

Mineralogy Identification for Engineering Purposes

From an engineering point of view, certain properties of minerals, especially when they are introduced into or encountered with another mineral, are of special concern to engineers.

For example

1-Gypsum in a limestone can become swelling when water presents

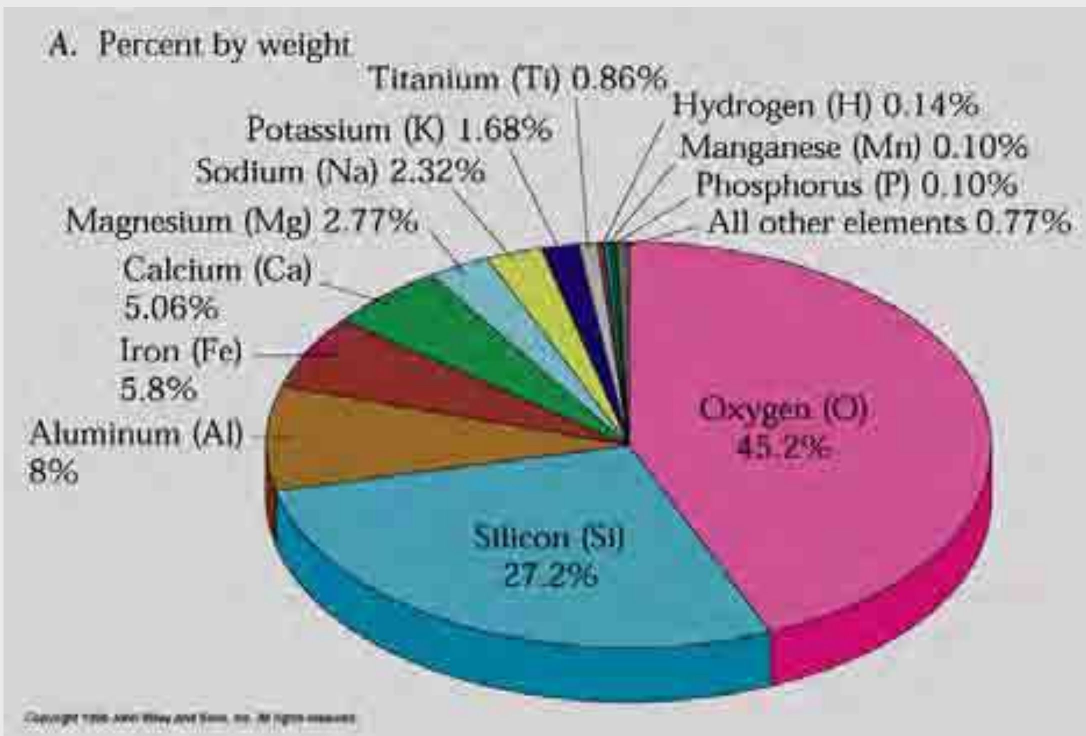
2- Pyrite (the fool's gold) in shale can be deteriorated by acid water

3- swelling clays in shale can become wetting and cause instability problem of a slope .

Thus, **fundamental mineralogical acknowledge is needed when identifying engineering material is needed**.

Mineral Groups

• Thousands of mineral species have been
Identified • Only ~20 make up 99% of the earth's crust



Elemental Abundance

• Given that oxygen is so abundant it is hardly surprising that it is present in many minerals

• 1-**It occurs as oxides (compounds that contain the O^{-2} anion)**

2- **as silicate anions (SiO^{-4})**

• **in silicate minera**ls

3- **Less commonly it occurs as carbonates ($CO3^{-2}$)**

4- **sulfates ($SO4^{-2}$)**

5- **a phosphates ($PO4^{-3}$)**

Engineering Geology

Rock forming Minerals

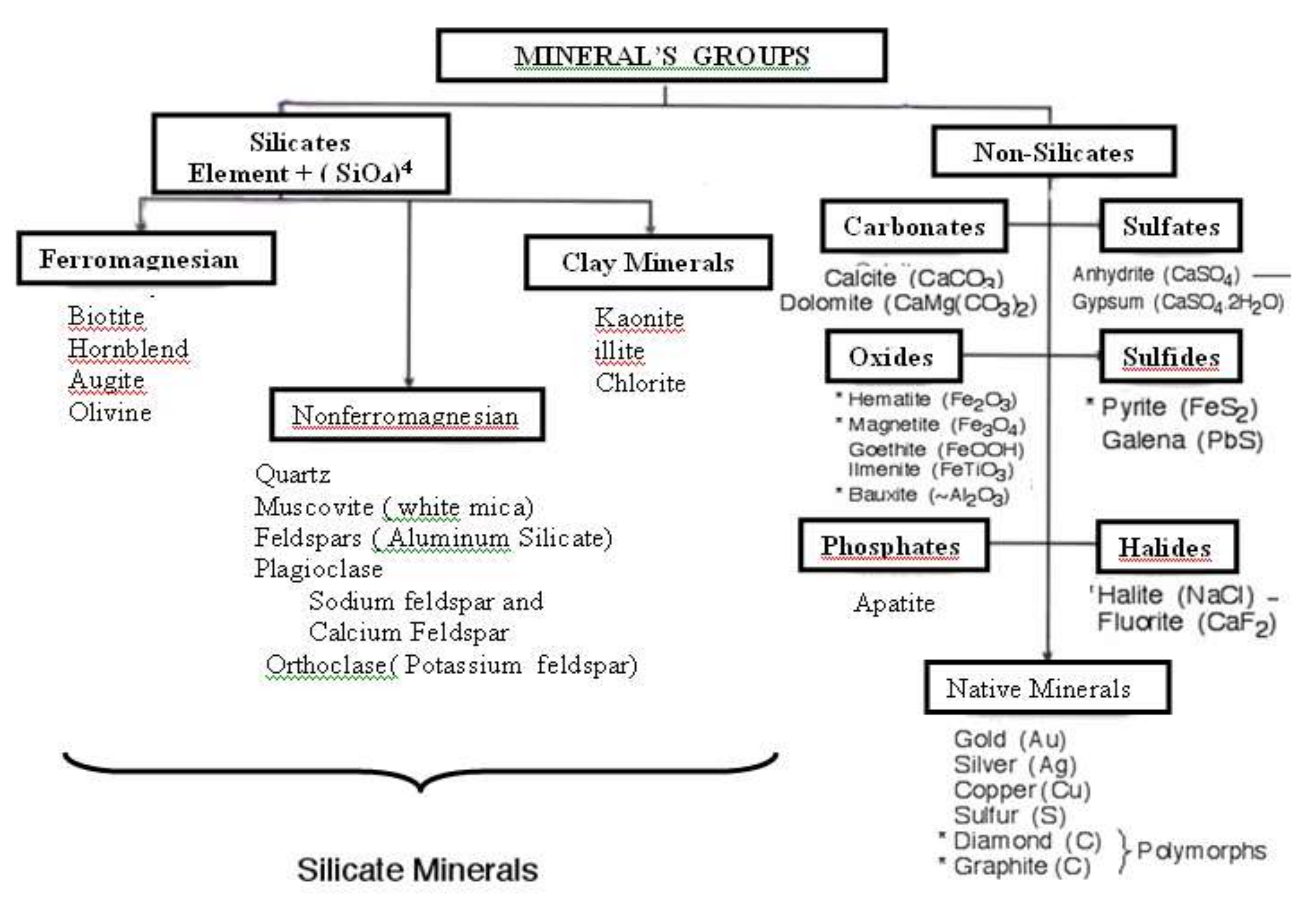
• A few silicates and oxides in conjunction with calcium sulphate and calcium carbonate comprise the majority of the Earth's crust These are the rock forming minerals Found in rocks, soils, sediments and construction materials • Quartz and feldspar = ~75% of the Earth's

Accessory Minerals

• These are present in common rocks but at low abundances • They do not determine the property of the rock but may be important sources of metals • Trace minerals occur at even lower abundances but are also important, ex. zircon or diamond

Engineering Geology

Mineral Groups



Engineering Geology

Mineral Groups

MINERAL GROUP	REQUIRED ION	EXAMPLES	COMPOSITION
Carbonate	CO3) $^{-2}$	Calcite	CaCO3
Halide	Cl^{-1}, F^{-1}	Halite	NaCl
Native Elements	not appl.	Gold	Au
Oxide	O^{-2}	Hematit	Fe2O3
Silicate	$(SiO4)^{-4}$	Quartz	SiO2
Sulfate	$(SO4)^{-2}$	Anhydrite	CaSO4
Sulfide	S^{-2}	Pyrite	FeS2

Oxide Minerals

Hematite: Fe_2O_3 Causes staining and pop outs on the concrete surface

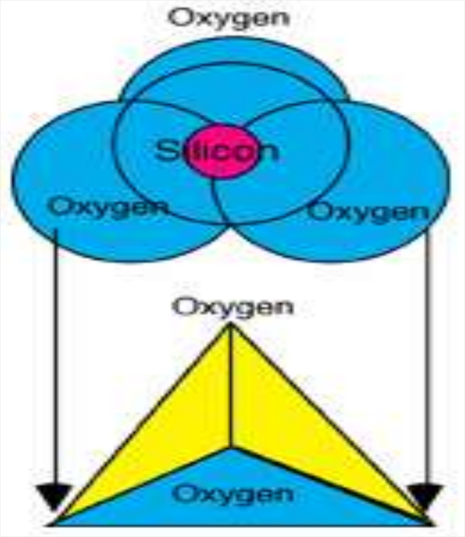
Chromite: -resistant to the altering affects of high temperatures and pressures-component in the bricks and linings of blast furnaces-major constituent in stainless steel

Ilmenite: -major ore of titanium (aluminum-like metal; light weight, non-corrosive, able to withstand temperature extreme, has many applications in high tech airplanes, missiles, space

Silicates

● Most important of all mineral classes because:

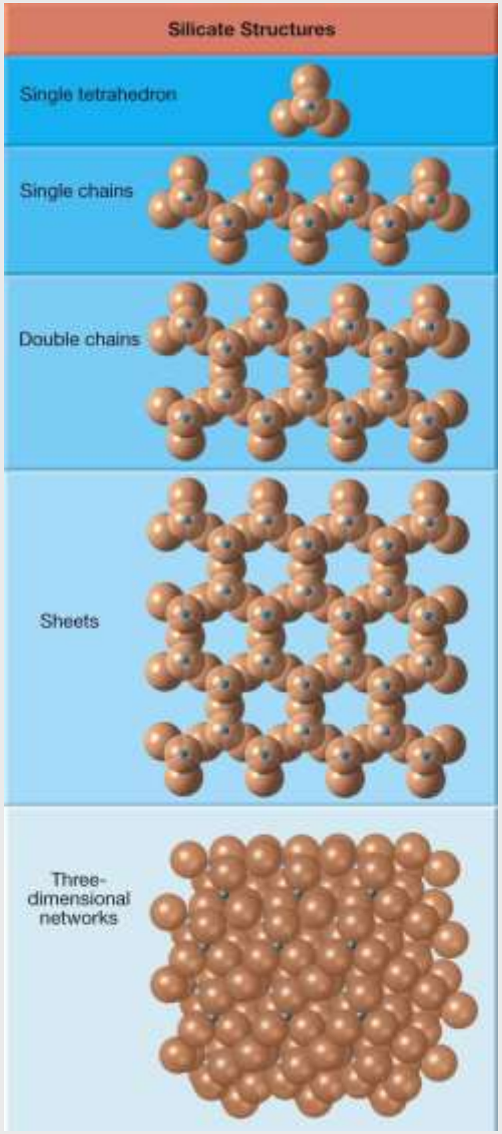
1- 25% of the known minerals and nearly 40% of the common ones are silicates
2- Nearly 90% of the igneous rock-forming minerals are silicates, which means that they make up over 90% of the Earth's crust
3 -Bricks, stones, concrete and glass are either silicates or derived from silicates• Important silicate groups: Ferromagnesians, non ferro mganesians, feldspar (orthoclase, plagioclase), Quartz **Silicon-**



Silicate structures

Single Chain - The pyroxenes group
Double Chain - The amphiboles
Hexagonal Sheets - Micas, chlorites, and clay minerals
Three-dimensional frameworks - feldspars and quartz

Type of structure	Si:O ratio	Repeated pattern	Mineral group
Separate SiO_4-groups	1:4	SiO_4	Olivine
Single chain	1:3	Si_2O_6	Pyroxenes
Double chain	1:2.75	Si_4O_{11}	Amphiboles
Sheet	1:2.5	Si_4O_{10}	Micas
Framework	1:2	$(Al,Si)_nO_{2n}$	Feldspars
		SiO_2	Quartz



Engineering Geology

Ferromagnesians

•Contain Fe or Mg
•**Olivine's: Olivine: $(Mg, Fe)_2SiO_4$**
-found mostly in igneous rock
-olivine's variety, peridot, has same chemical composition as molten magma in Earth's mantle. Thus, peridot is considered the most common mineral by volume in the Earth
-industrial uses as refractory sands and abrasives, an ore of magnesium
•**Pyroxenes: Augite**
•**Amphibole: Hornblende**

•**Micas: biotite**

Non ferromagnesians

- Contain Ca, K, Na
- Soft, flaky, platy, one prominent cleavage minerals
- **Serpentine**: many industrial applications, including brake linings and fireproof fabrics and as an ornamental stone.

- **Muscovite**: used in heat and electrical insulator for industrial purposes

Feldspars (Si3O8)

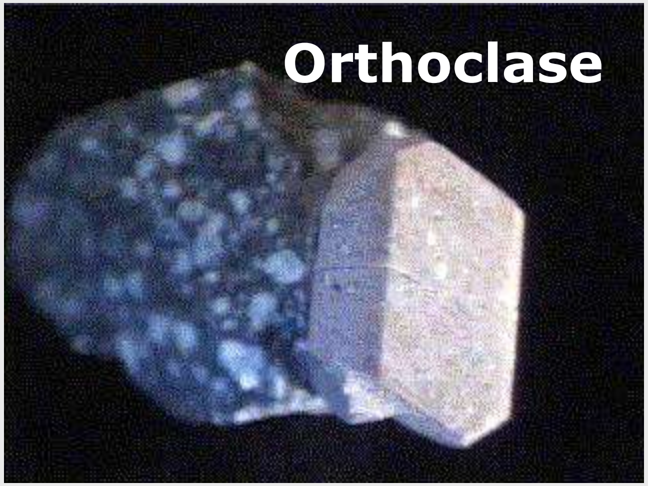
•By compositions, feldspars is the most common rock-forming silicates

•**Orthoclase**: -contains K

-used in porcelain industry

•**Plagioclas**e: -contains Ca, Na

-Industrially important in glass and ceramic industries; soaps; abrasives; bond for abrasive wheels; cements and concretes; insulating compositions; fertilizer; poultry grit; tarred roofing materials; and as a sizing (or filler) in textiles and paper.



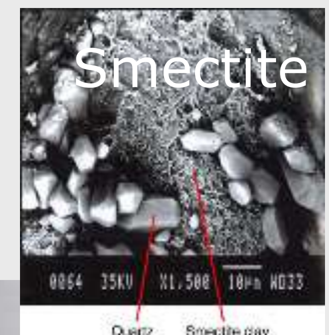
Quartz Minerals (SiO2group)

•Second common rock-forming mineral • silica for glass, electrical components, optical lenses, abrasives, building stone, etc.
•Chert: -variety of Quartz, -found in sedimentary rock-when used as an aggregate material, it easily breaks and pop out when exposed to freezing and thawing. Thus, it reduces the strength of

Engineering Geology

Clay Minerals

•Very fine-grained minerals, common in soil
•Clay = kaolinite, halloysite, illite (non swelling clays), vermiculite, smectite (swelling clays)
•**Smectite**: used in drilling mud since it has property of swelling when exposed to water
•**Kaolinite**: made up high-grade clay, used in manufacture of ceramic products, rubber industry, refractories
•**Illite**: chief constituent in shales

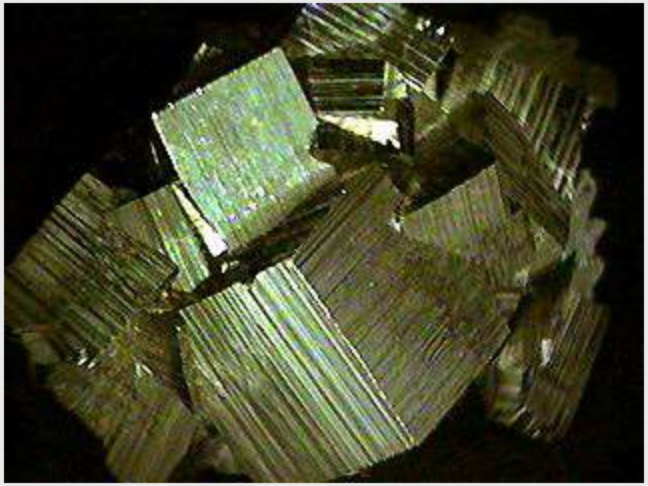


Sulfide Minerals

•**Pyrite** : "Fool's gold", minor ore of sulfur for sulfuric acid, causes staining on surface of concrete due to oxidation or presence of sulfate ions.

•**Molybdenite** : Nearly 50% of all molybdenum is used in making steel.

•**Sphalerite** : The most important ore mineral of zinc which is usedto make brass, electric batteries, and zinc white.



Carbonate minerals (CO3group)

•**Calcite**: -fizzes with acid-Primary component in cave formation, react with carbon dioxide in sea and air, thus, acts like carbon dioxide filter for the planet-used in cements and mortars, production of lime, limestone is used in the steel industry; glass industry, ornamental stone, chemical and optical use

•**Aragonite**: minor constituent of limestone which is used in cement and in steel production, ornamental carvings

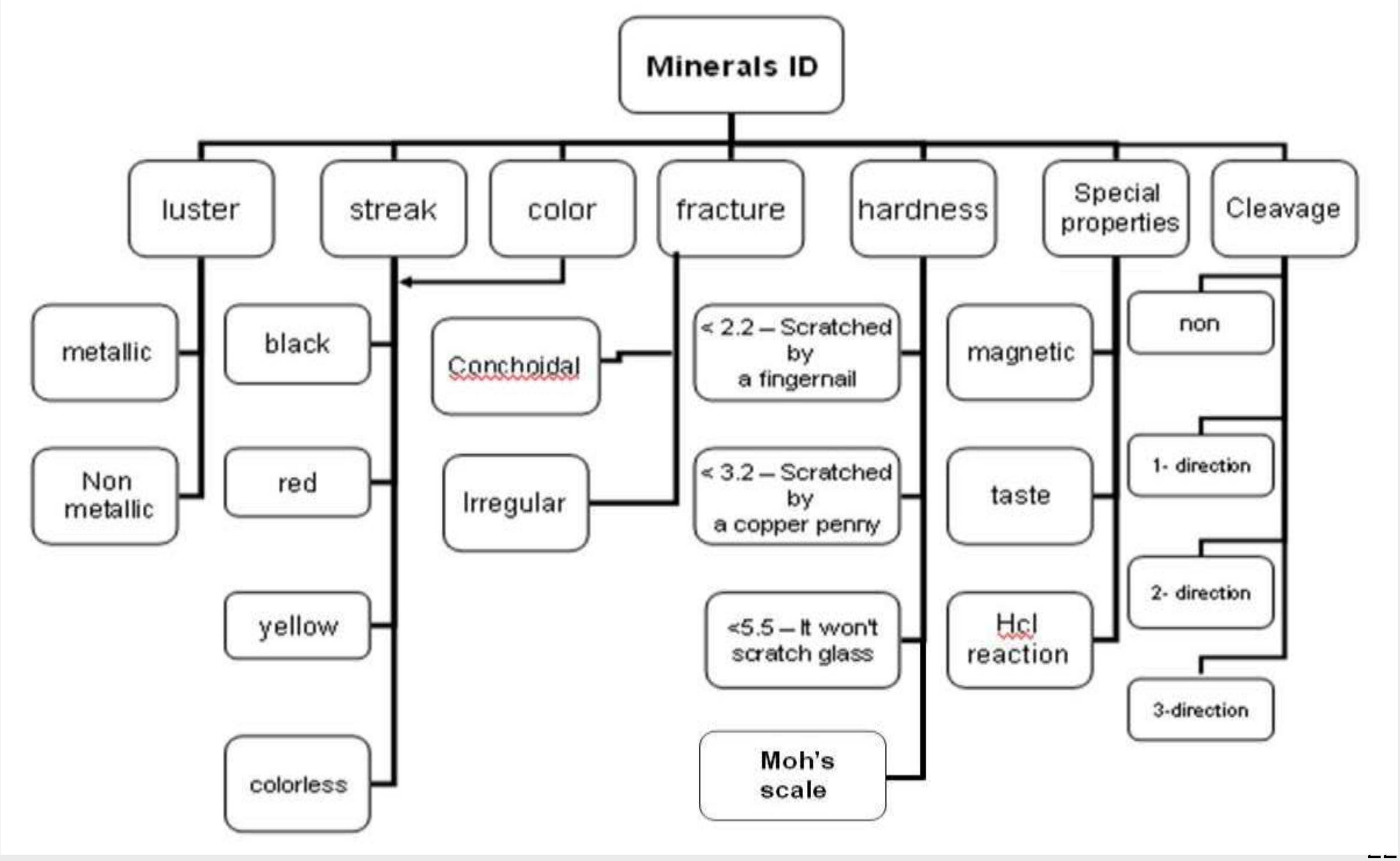
•**Dolomite**: “Dolomite problem”

Sulfate Minerals (SO_4group)

- **Gypsum:** -common in sedimentary rock in high saline water. –used in plaster, wall board, some cements, fertilizer, paint filler, ornamental stone

- **Anhydrite**: -water-free form of gypsum -in the manufacture of some cement, a source of sulfate for sulfuric acid-causes cracks in structure due to property of swelling when wetted

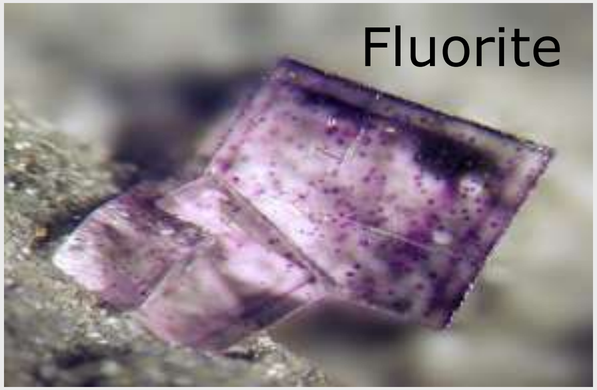
Physical Properties of Minerals



Physical Properties of Minerals

1-Color

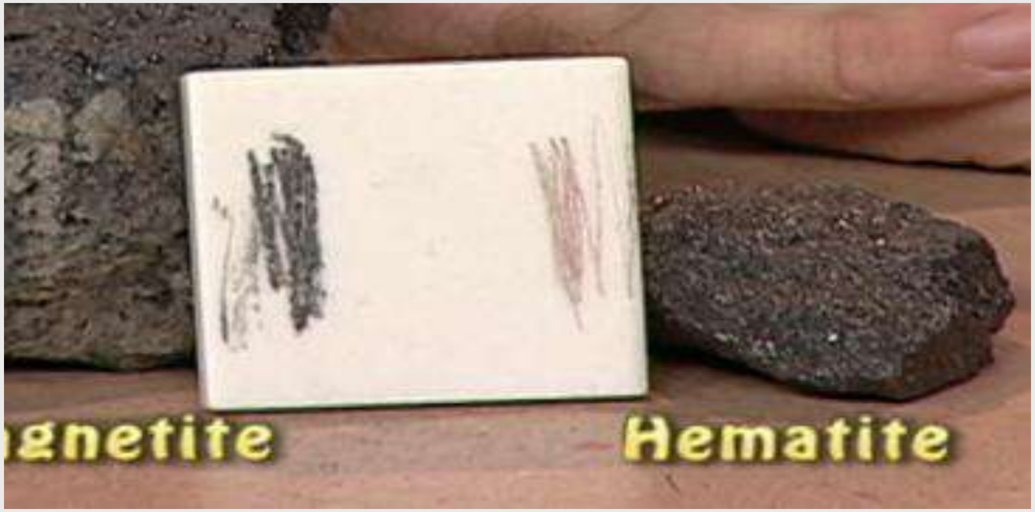
•Minerals are colored because certain wave lengths of light are absorbed, and the color results from a combination of those wave lengths that reach the eye.
•Some minerals show different colors along different crystallographic axes.



2-Streak

•The streak of a mineral is the color of the powder left on a streak plate(piece of unglazed porcelain) when the mineral is scraped across it Color of the streak may differs from color of mineral:

color of pyrite is brass yellow and its streak is dark green.
lead ore, galena, has a metallic grey color but a black streak.



3-Luster

•Luster refers to how light is reflected from the surface of a mineral.The two main types of luster are metallic(galena and pyrite) and nonmetallic(. vitreous, pearly, greasy, silky, earthy)

4-Cleavage

- **Cleavage** is the ability of a mineral to break along preferred planes
- Minerals tend to break along certain planes where atomic bonds are weak
- **Minerals can have one, two plane or three plane cleavages**.

Minerals break with ease producing smooth surfaces is called **perfect cleavage**.

quartz and garnet, possess no cleavages

mica : have perfect cleavage in one direction.

feldspars, have two cleavages.

galena: three directions

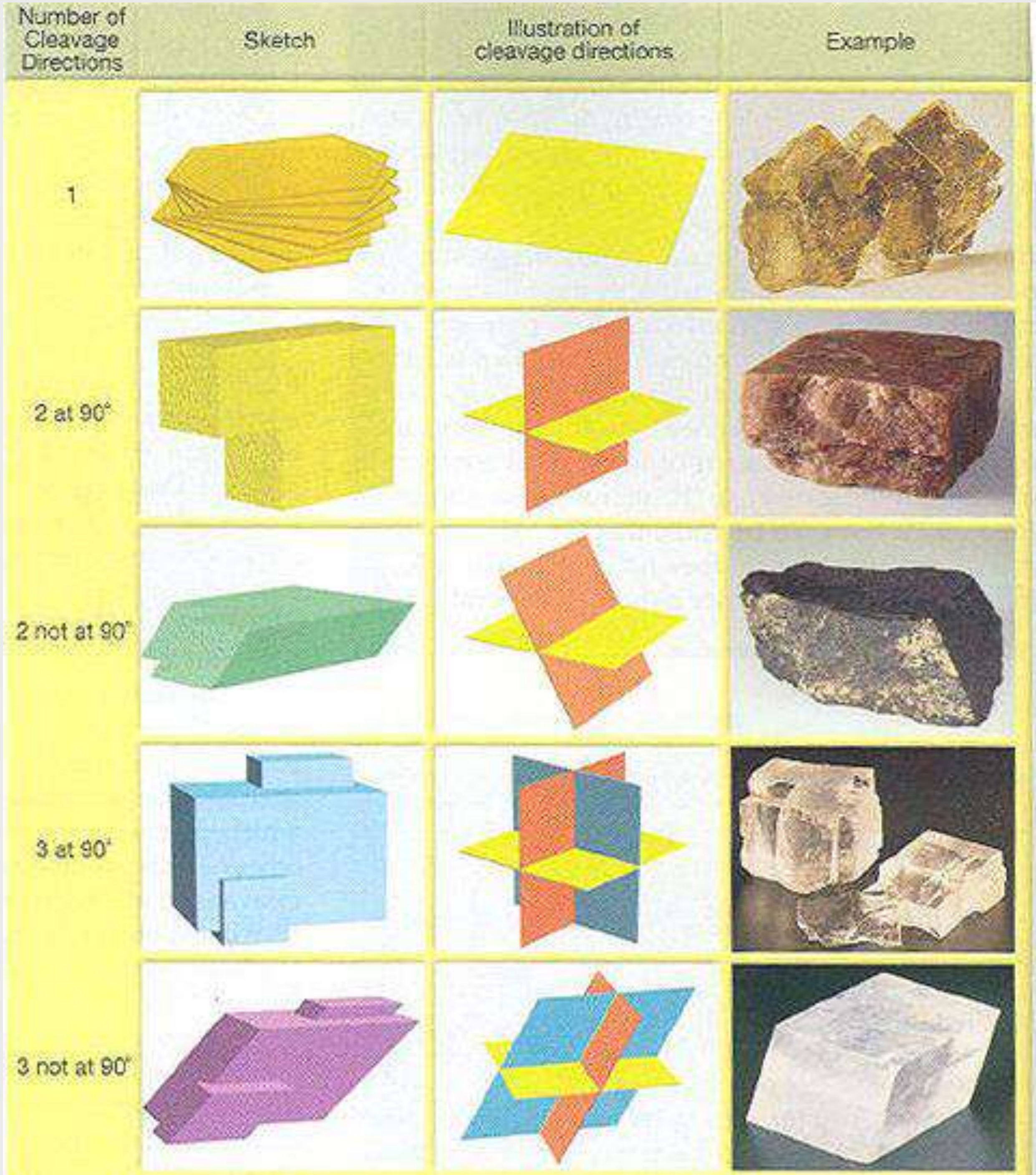
fluorite: four directions

When a cleavage is poorly developed it is **called a parting.**

5-Fracture

A surface formed by breaking the mineral along a direction which is not a cleavage is called a fracture and is usually more irregular than a cleavage plane.

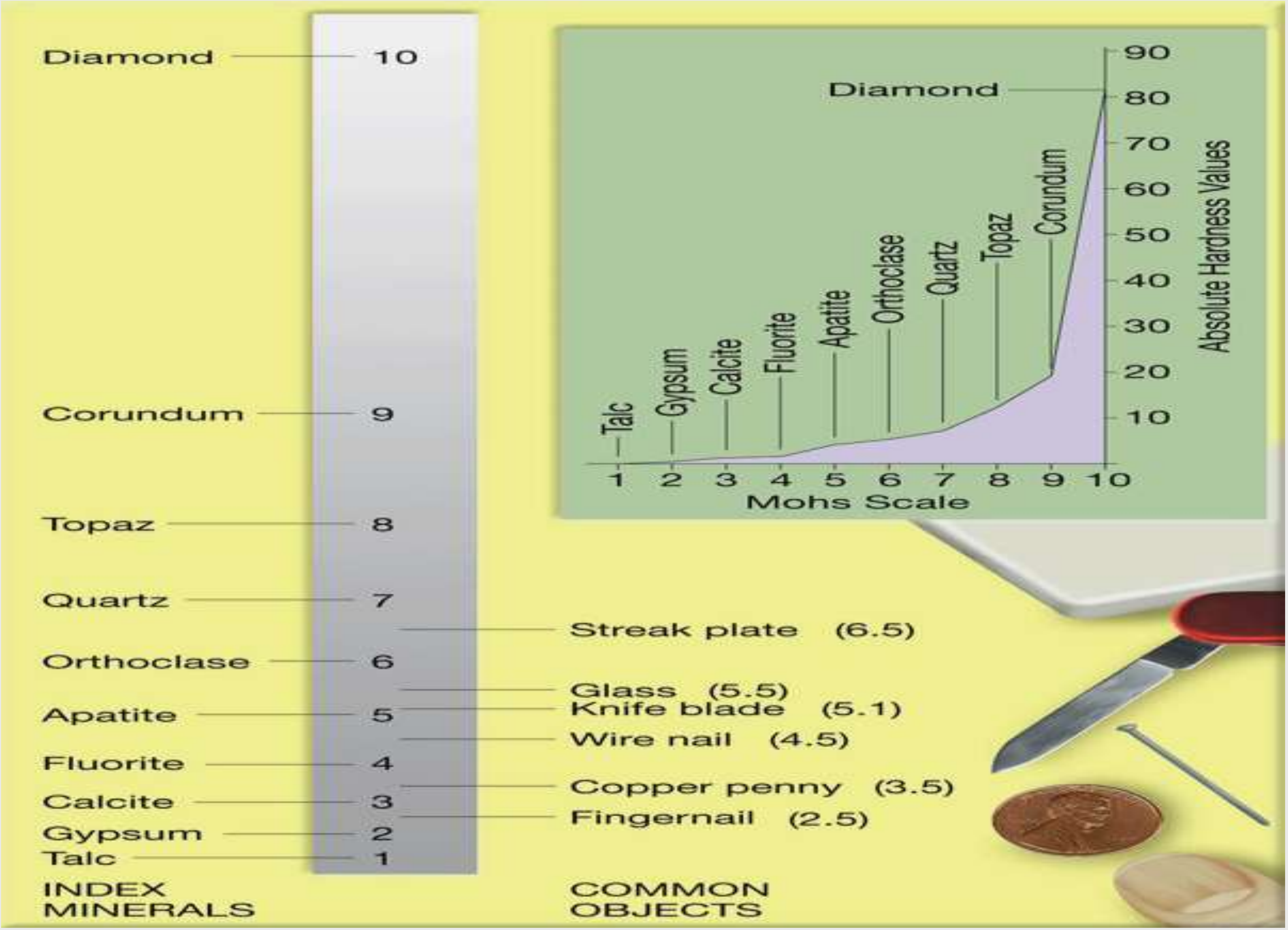
A curved, rippled fracture is termed conchoidal


Number of Cleavage Directions
Sketch
Illustration of cleavage directions
Example
1
2 at 90°
2 not at 90°
3 at 90°
3 not at 90°

6-Hardness

•The hardness of a mineral is its "scratch ability", determined by Moh's hardness scale. The hardest mineral known, diamond, was assigned the number 10.

Minerals	Level of Hardness	Tools
Talc	1	
Gypsum	2	Finger (2.5) nail
Calcite	3	
Fluorite	4	Copper penny (3.0)
Apatite	5	
Orthoclase	6	Glass(5.5)
Quartz	7	porcelain streak plate (7.0)
Topaz	8	
Corundum	9	
Diamond	10	



Diamond 10
Corundum 9
Topaz 8
Quartz 7
Streak plate (6.5)
Orthoclase 6
Glass (5.5)
Knife blade (5.1)
Apatite 5
Wire nail (4.5)
Fluorite 4
Copper penny (3.5)
Calcite 3
Fingernail (2.5)
Gypsum 2
Talc 1
INDEX MINERALS
COMMON OBJECTS
Diamond
Corundum
Topaz
Quartz
Orthoclase
Apatite
Fluorite
Calcite
Gypsum
Talc
90
80
70
60
50
40
30
20
10
Absolute Hardness Values
1 2 3 4 5 6 7 8 9 10
Mohs Scale

7-Specific Gravity

•Specific gravity is the "heaviness" of a mineral. It is defined as a number that expresses the ratio of the weight of a mineral and the weight of an equal volume of water. The specific gravity depends on:

•the kind of atoms that comprise the mineral

•how the atoms are packed together

•Common rock-forming minerals (quartz, feldspar, calcite, etc.) have specific gravity near 2.70

8- Magnetism :A few minerals are attracted by a magnet. Of these minerals, magnetite, and pyrrhotite

- **9-Taste** (Rock Salt, NaCl)
- **10-Odor** (Sulfur, Sphalerite ZnS)
- **11-Feel** (talc is greasy ,hornblende is rough)

•12- **Chemical reaction with** HCL Some minerals are known to react with acid. This can be a very diagnostic test for some minerals.

13-Crystal forms

Crystal forms are displays of well-formed crystal faces by a mineral
•Crystal faces formed during crystallization process vs. cleavage faces formed when mineral breaks.

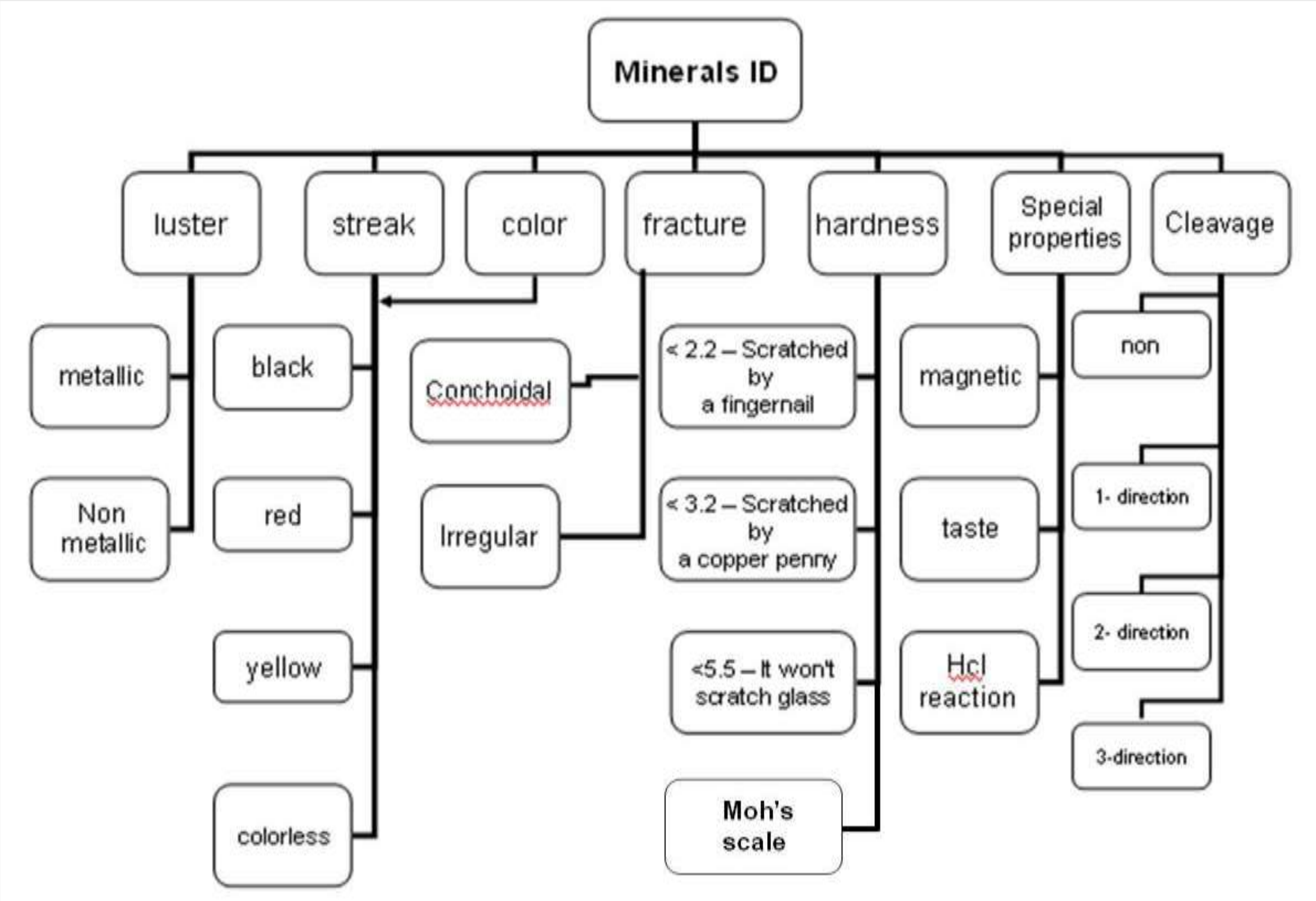
Beryl -hexagonal-Diamond-octahedron

Beryl Photo from MII. courtesy of the Smithsonian Institution

14-Tenacity

is a measure of how the mineral deforms when it is crushed or bent

brittle	shatters easily
flexible	can be bent, but will not return to original position af ter pressure is released
elastic	can be bent, and returns to original position after pressure is released
malleable	can be hammered into thin sheets
sectile	can be cut by a knife e
ductile	can be drawn into thin wires


Minerals ID
luster
streak
color
fracture
hardness
Special properties
Cleavage
metallic
Non metallic
black
red
yellow
colorless
Conchoidal
Irregular
< 2.2 – Scratched by a fingernail
< 3.2 – Scratched by a copper penny
<5.5 – It won't scratch glass
Moh's scale
magnetic
taste
Hcl reaction
non
1- direction
2- direction
3-direction

Mineral Physical Properties Chart

PHYSICAL PROPERTY	Definition*	Testing Method
Cleavage	Breakage of a mineral along planes of weakness in the crystal structure.	Examine the mineral for areas where the mineral is broken.
Color	Visible light spectrum radiation reflected from a mineral.	Look at the sample and determine its color - white, black, green, clear, etc.
Crystal Form	Geometric shape of a crystal or mineral.	Examine and describe the geometric shape of the mineral - cubic, hexagonal, etc. Not commonly seen in most introductory lab samples.
Fracture	Breakage of a mineral, not along planes of weakness in the crystral structure.	Examine the mineral for areas where the mineral is broken. Describe the breakage as either irregular or conchoidal (has the appearance of broken glass)
Hardness	Resistance to scratching or abrasion.	Use minerals of known hardness from the Mohs Hardness Kits. Scratch the unknown mineral with a known hardness to determine which mineral is harder. Continue doing this with harder or softer minerals from the kit until the hardness is determined.
Luster	Character of the light reflected by a mineral	Look at the sample to determine if the mineral is metallic in appearance (looks like a chunk of metal) or non-metallic (doesn't look like a chunk of metal).
Magnetism	Electromagnetic force generated by an object or electrical field.	Use a magnet to determine if the magnet is attracted to the sample.
Reaction to HCl	Chemical interaction of hydrochloric acid and calcium carbonate ($CaCO_3$).	Place one small drop of HCl on a sample a watch for a reaction - effervesces (bubbles).
Specific Gravity	Ratio of the mass of a mineral to the mass of an equal volume of water.	Generally not determined in an introductory lab. Look this information up in your lab manual once the mineral has been identified.
Streak	Color of the mineral when it is powdered.	Grind a small amount of a mineral into a powder on a porcelain streak plate and determine the color of the powder.
Taste	Nerve ending reaction in the tongue to different chemicals.	Lick the mineral (not recommended in an introductory lab - you don't know who has handled or licked the sample before you).
Other Properties	Fluorescence, Radioactivity	Requires special equipment such as a UV lamp and geiger counter. These are not commonly tested for in an introductory lab.

* Definitions simplified or modified from Bates, R.L. and J.A. Jackson (eds.), 1987, Glossary of Geology. American Geological Institute, Alexandria, VA. 788 p.

GYPSUM
clear color usually, 3 cleavages, hardness of 2.5, cleavages are perfect(meet at 90 degree angles), calcite scratches this mineral,

TALC:is common used as filler in paints, rubber and plastics too
0-1 cleavage plane, light apple green/grey/white color, pearly luster, hardness of 1, may have light grey streak, greasy feel.

GALENA: is the most important ore of lead.
-PbS (lead sulfide 3 excellent cleavages, metallic luster, hardness of 2.5, black/grey streak,

QUARTZ
clear, milky (many colors), hardness of 7, no cleavage, conchoidal fracture, vitreous luster

Engineering Geology

FELDSPAR
salmon-pink/white/gray/green, vitreous luster, hardness of 6, 2 cleavages that meet at nearly right angles, no striations POTASSIUM

PLAGIOCLASE FELDSPAR
white/dark grey, vitreous luster, hardness of 6, 2 cleavages meet at nearly right angles, some have perfect striations which you can see in reflected light

PYRITE- FeS2 (iron sulfide) metallic luster, a streak of greenish black to black, a hardness of 6-6.5 - cubic crystals, high gravity (5) – no Cleavage: specific

Hematite- Fe2O3 (iron oxide)
No Cleavage- Hardness: 6.0 red-brown streak, high specific gravity (5), commonly associated with limonite, granular or massive aggregates

Dolomite, $CaMg(CO_3)_2$, is common enough to be considered a rock-forming mineral. It is formed underground by alteration of calcite Dolomite is harder than calcite (Mohs hardness 4). It often has a light pinkish color, and if it forms crystals these often have a curved shape. It commonly has a pearly luster ,uses : sources of Mg

Fluorite, calcium fluoride or CaF2, belongs to the halide mineral group Thus fluorite is not an evaporite mineral
Nonmetallic luster, Color = colorless or variable Hardness = 4 Characteristics = cleaves in four directions Uses = hydroflouric acid

Halite is sodium chloride, NaCl, the same mineral you use as table salt. It is the most common halide mineral

GRAPHITE Metallic luster , Hardness = 1-2 Color = silver to gray black streak, greasy feel Uses = pencil lead, lubricants

MAGNETITE Metallic luster Hardness = 5.5 - 6.5 Fracture Color = black to silver black streak, attracted by magnet Uses = ore of iron

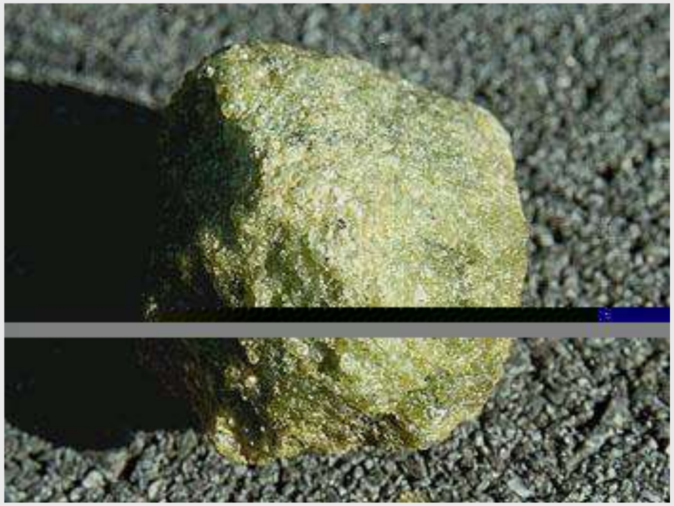
HEMATITE Metallic , either Hardness = 1-6.5 Fracture Color = metallic silver or earthy red red-brown streak Uses = ore of iron

SULFUR Nonmetallic luster Hardness = 2 Fracture Color = yellow to amber Characteristics = easily melted, may smell Uses = vulcanize rubber, sulfuric acid

BIOTITE Nonmetallic luster Hardness = 2.5 - 3 Cleavage Color = black to dark brown Characteristics = flexible in thin sheets Uses = electrical insulator

QUARTZ Nonmetallic luster Hardness = 7 Fracture Color = colorless or variable Characteristics = glassy luster, may form hexagonal crystals Uses = glass, jewelry, and electronics

OLIVINE Nonmetallic luster Hardness = 6.5 Fracture Color = green to gray or brown Characteristics = commonly light green and granular Uses = furnace bricks and jewelry



PLAGIOCLASE FELDSPAR
Nonmetallic luster Hardness = 6 Cleavage Color = white to gray Characteristics = cleaves in 2 directions, striations visible Uses = ceramics and glass

POTASSIUM FELDSPAR Nonmetallic luster Hardness = 6 Cleavage Color = white to pink Characteristics = cleaves in 2 directions at 90o Uses = ceramics and glass

Rock Forming Minerals

1-**Feldspa**r is the most abundant minerals. There are two types. Orthoclase feldspars contain potassim (KalSi3O8) and usually range from white to pink. Plagioclase feldspars contain sodium (NaAlSi3O8), calcium (CaAl2Si2O8) or both, and range from white to gray to black,. Feldspars have moderate. hardness

2. **Quartz**: It is silicate (SiO2), and usually has a translucent to milky white color. The luster is vitreous. Quartz is harder than most minerals (hardness 7), and thus is very resistant to weathering.

Chert is a type of quartz sometimes found in sedimentary rocks.

3. Mica: thin sheets or flakes. There are two common varieties.

Muscovite: is potassium aluminium silicate of colorless or silvery tint, pearly luster and especially one very perfect cleavage, thin elastic sheets that when bent spring back to shape.

Biotite, is a complex silicate of potassium, magnesium and iron and aluminum.

Mica, Biotite and muscovite are similar in physical properties. Both are soft, 2.5-3, with one perfect cleavage

Rock Forming Minerals

4. Ferromagnesian minerals: A class of minerals, all of which contain both iron and magnesium. This class includes pyroxene, amphibole, hornblende and olivine. These minerals are dark color and a moderate hardness.

5. Calcite: A mineral made of calcium carbonate ($CaCO_3$). It is usually white, pink or gray. It is soluable in water, and thus can be transported by ground water into cracks in rock where it precipitate out of solution. It also can precipitate in soil, becoming a cementing agent. Calcite is much softer then quartz or feldspar. The hardness is 3. Have vigorous reaction to hydrochloric acid.

6. Dolomite: Similar to calcite with magnesium added. Less vigorous reaction to dilute hydrochloric acid.

7. Iron Oxides: Another class of minerals, all of which contain iron (FeO_3). The most common iron oxides are hematite, Fe_2O_3 ; hydrous iron oxide that are often called limonite and magnetite. The compact varieties have a hardness of 5.5-6, but earthy form are soft. The luster is sub-metallic.

8. Gypsum: A soft minerals often occurring as a precipitate in sedimentary rocks. It is colorless to white and has economic value when found in thick deposits.. Gypsum is water soluble and thus can dissolve under the action of ground water, which can lead to other problems.

Properties of Common Minerals

LUSTER	HARD-NESS	CLEAVAGE	FRACTURE	COMMON COLORS	DISTINGUISHING CHARACTERISTICS	USE(S)	MINERAL NAME	COMPOSITION*
Metallic Luster	1–2	✓		silver to gray	black streak, greasy feel	pencil lead, lubricants	**Graphite**	C
Metallic Luster	2.5	✓		metallic silver	very dense (7.6 g/cm³), gray-black streak 	ore of lead	**Galena**	PbS
Metallic Luster	5.5–6.5		✓	black to silver	attracted by magnet, black streak	ore of iron	**Magnetite**	Fe_3O_4
Metallic Luster	6.5		✓	brassy yellow	green-black streak, cubic crystals 	ore of sulfur	**Pyrite**	FeS_2
Either	1–6.5		✓	metallic silver or earthy red	red-brown streak	ore of iron	**Hematite**	Fe_2O_3
Nonmetallic Luster	1	✓		white to green	greasy feel	talcum powder, soapstone	**Talc**	$Mg_3Si_4O_{10}(OH)_2$
Nonmetallic Luster	2		✓	yellow to amber	easily melted, may smell	vulcanize rubber, sulfuric acid	**Sulfur**	S
Nonmetallic Luster	2	✓		white to pink or gray	easily scratched by fingernail	plaster of paris and drywall	**Gypsum** (Selenite)	$CaSO_4{\bullet}2H_2O$
Nonmetallic Luster	2–2.5	✓		colorless to yellow	flexible in thin sheets 	electrical insulator	**Muscovite Mica**	$KAl_3Si_3O_{10}(OH)_2$
Nonmetallic Luster	2.5	✓		colorless to white	cubic cleavage, salty taste 	food additive, melts ice	**Halite**	NaCl
Nonmetallic Luster	2.5–3	✓		black to dark brown	flexible in thin sheets 	electrical insulator	**Biotite Mica**	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
Nonmetallic Luster	3	✓		colorless or variable	bubbles with acid 	cement, polarizing prisms	**Calcite**	$CaCO_3$
Nonmetallic Luster	3.5	✓		colorless or variable	bubbles with acid when powdered	source of magnesium	**Dolomite**	$CaMg(CO_3)_2$
Nonmetallic Luster	4	✓		colorless or variable	cleaves in 4 directions	hydrofluoric acid	**Fluorite**	CaF_2
Nonmetallic Luster	5–6	✓		black to dark green	cleaves in 2 directions at 90° 	mineral collections	**Pyroxene** (commonly Augite)	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
Nonmetallic Luster	5.5	✓		black to dark green	cleaves at 56° and 124° 	mineral collections	**Amphiboles** (commonly Hornblende)	$CaNa(Mg,Fe)_4(Al,Fe,Ti)_3Si_6O_{22}(O,OH)_2$
Nonmetallic Luster	6	✓		white to pink	cleaves in 2 directions at 90°	ceramics and glass	**Potassium Feldspar** (Orthoclase)	$KAlSi_3O_8$
Nonmetallic Luster	6	✓		white to gray	cleaves in 2 directions, striations visible	ceramics and glass	**Plagioclase Feldspar** (Na-Ca Feldspar)	$(Na,Ca)AlSi_3O_8$
Nonmetallic Luster	6.5		✓	green to gray or brown	commonly light green and granular	furnace bricks and jewelry	**Olivine**	$(Fe,Mg)_2SiO_4$
Nonmetallic Luster	7		✓	colorless or variable	glassy luster, may form hexagonal crystals 	glass, jewelry, and electronics	**Quartz**	SiO_2
Nonmetallic Luster	7		✓	dark red to green	glassy luster, often seen as red grains in NYS metamorphic rocks	jewelry and abrasives	**Garnet** (commonly Almandine)	$Fe_3Al_2Si_3O_{12}$

*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

Engineering Geology

Igneous rocks

Hussien Al - deeky

Engineering Geology

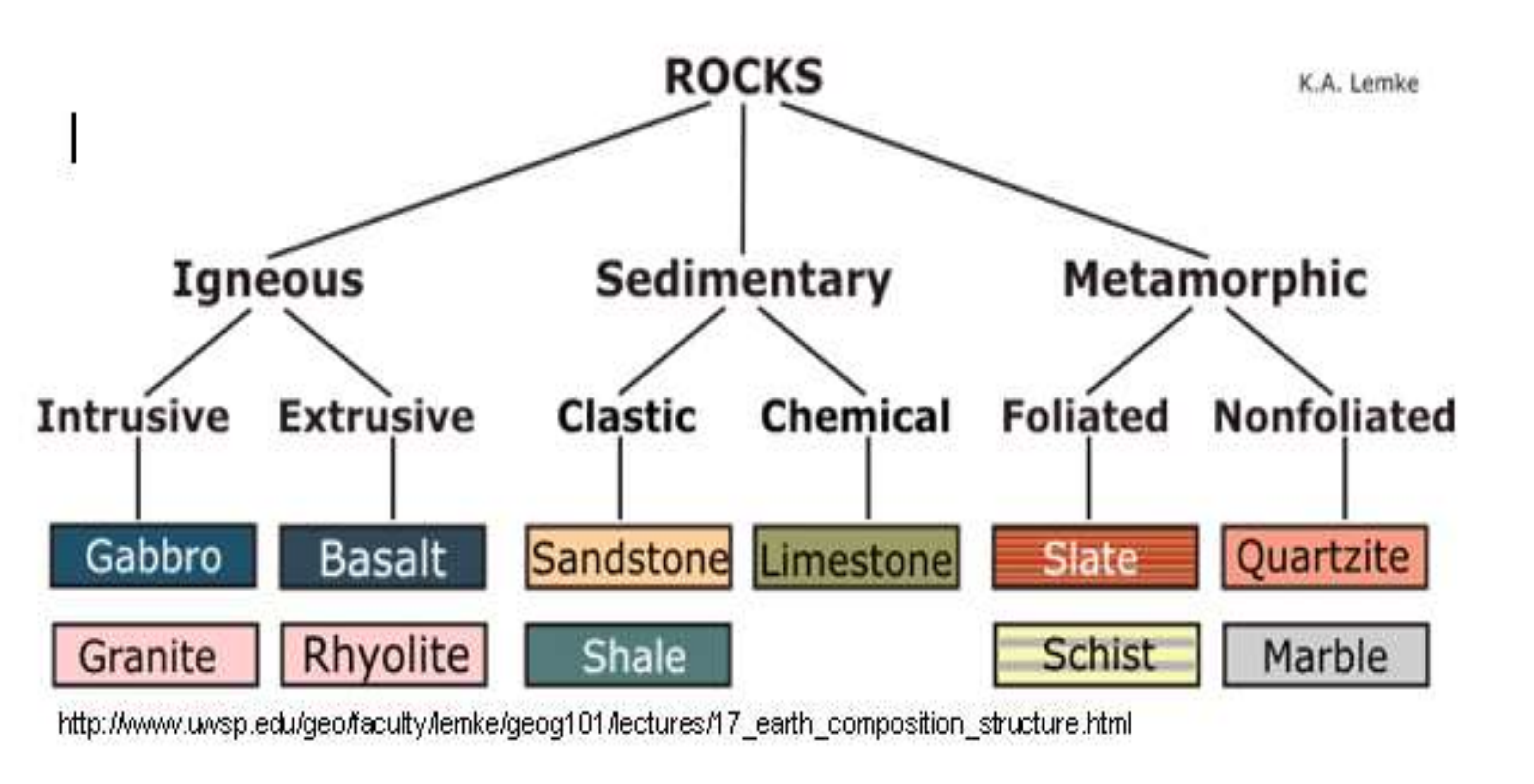
The Geology Definition of Rocks

In Geology Rock is defined as **the solid material forming the outer rocky shell or crust of the earth.**
There are three major groups of rocks by its origin:

(**1)Igneous rocks**: cooled from a molten state ; e.g., granite, basalt

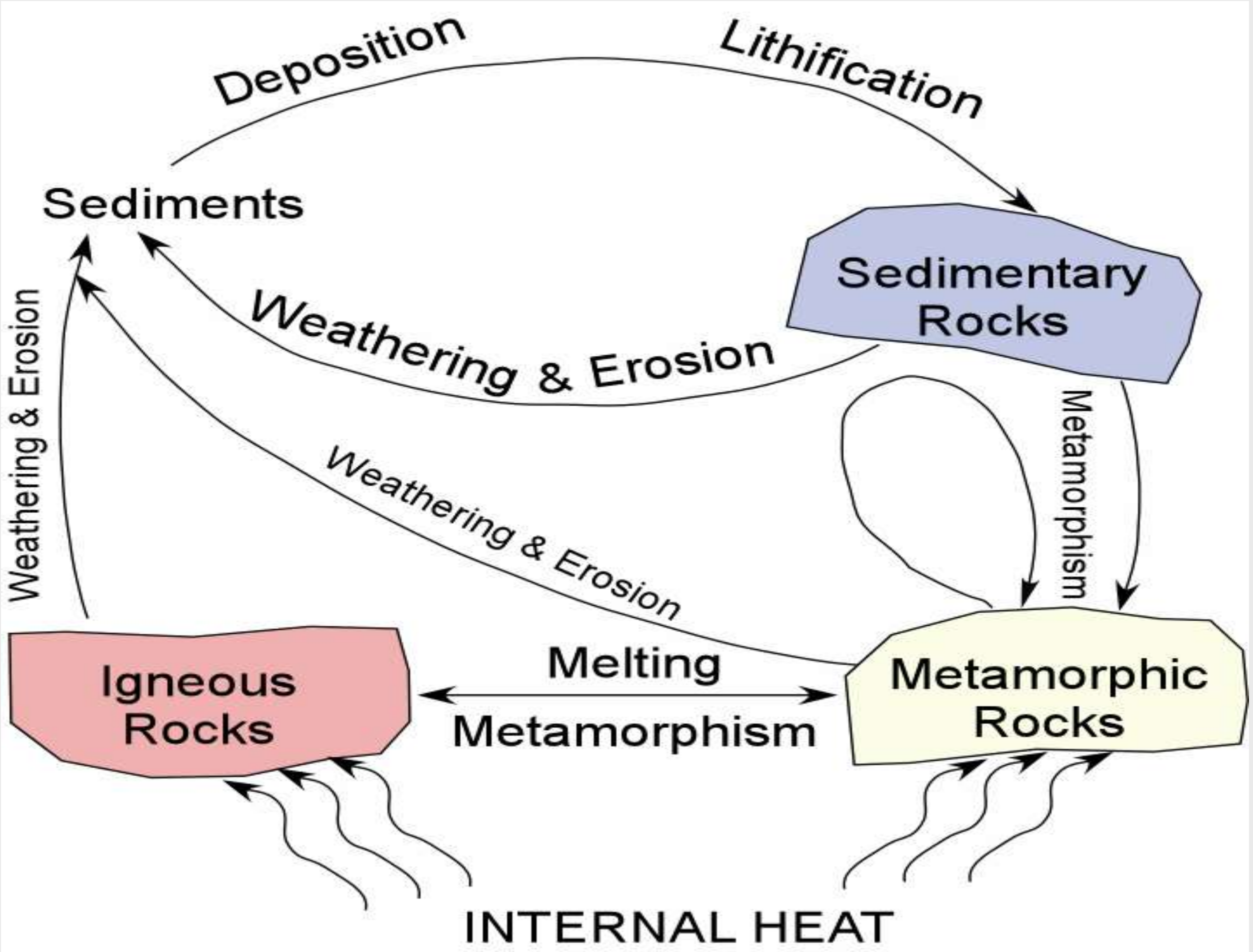
(2)Sedimentary rocks: deposited from fluid medium; the products of weathering of other rocks in water ; e.g., sandstone, mudstone…;

(3)Metamorphic rocks : formed from pre-existing rocks by the action of heat and pressure . e.g., dolomite, marble …;


ROCKS
K.A. Lemke
Igneous
Sedimentary
Metamorphic
Intrusive
Extrusive
Clastic
Chemical
Foliated
Nonfoliated
Gabbro
Basalt
Sandstone
Limestone
Slate
Quartzite
Granite
Rhyolite
Shale
Schist
Marble
http://www.uwsp.edu/geo/faculty/lemke/geog101/lectures/17_earth_composition_structure.html

Engineering Geology

Rock Cycles



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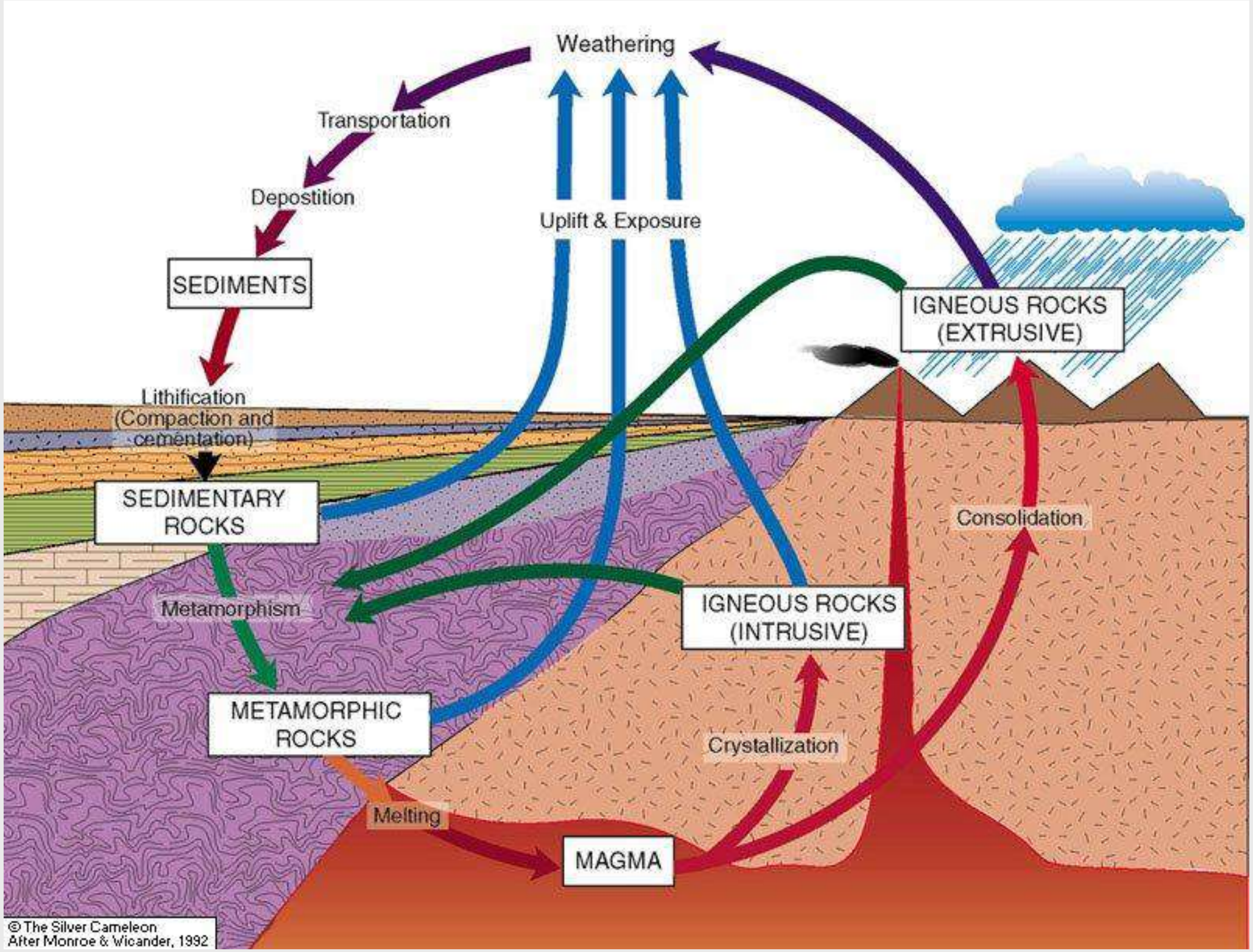


Engineering Geology

The Engineering Definition of Rocks

Thus, in pure geological sense rock is defined as the essential part of the earth's crust. Geologists concern about the origin, classification, history, and the spatial aspects of rocks. So, geologically speaking, ice, sand, marble, coal, basalt, can be simply regarded as rocks

. However, the Engineering Geologists have a different, and relatively narrower view of rocks. The Engineering Definition of Rocks Rock **is the hard and durable material**

By an excavation point of view, Rocks are the earth materials that cannot be excavated without blasting . This definition clearly excludes other kinds of earth materials such as soils, and glacial till s, etc. Here is another engineering definition of rocks : **The earth materials that do not slake when soaked into water** . For example, a thick loess deposit is regarded as rock geologically and regarded as soil in engineering.

Engineering Geology

Igneous rocks

• Igneous rocks form by cooling and crystallization of molten rock

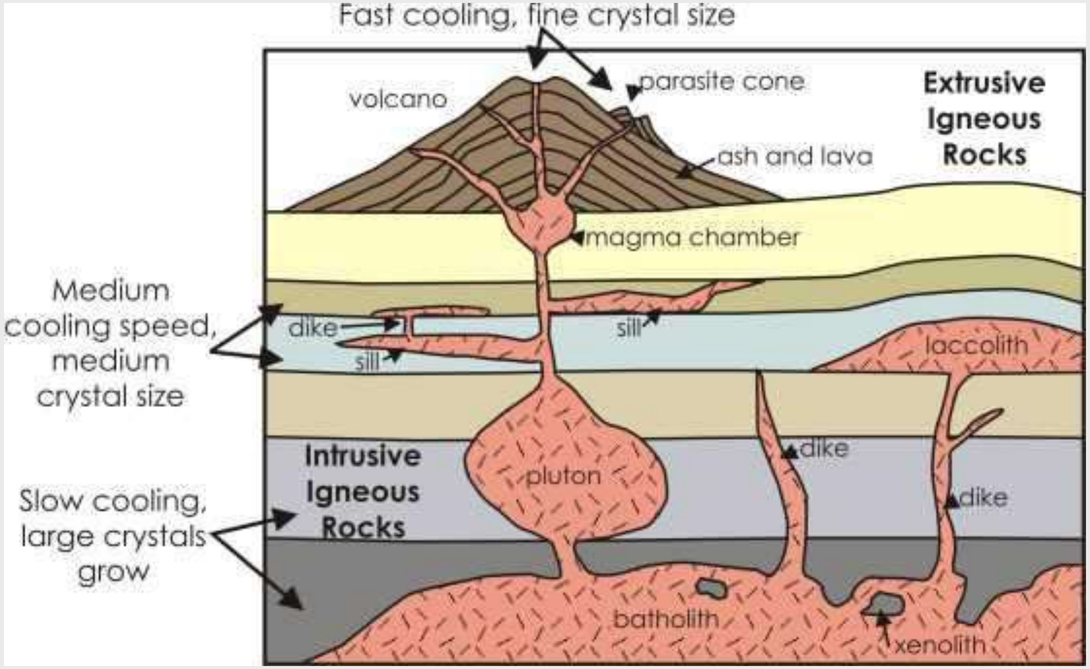
• Molten material residing below Earth's surface is known as **magma**, whereas the same material at the surface is **called lava.**

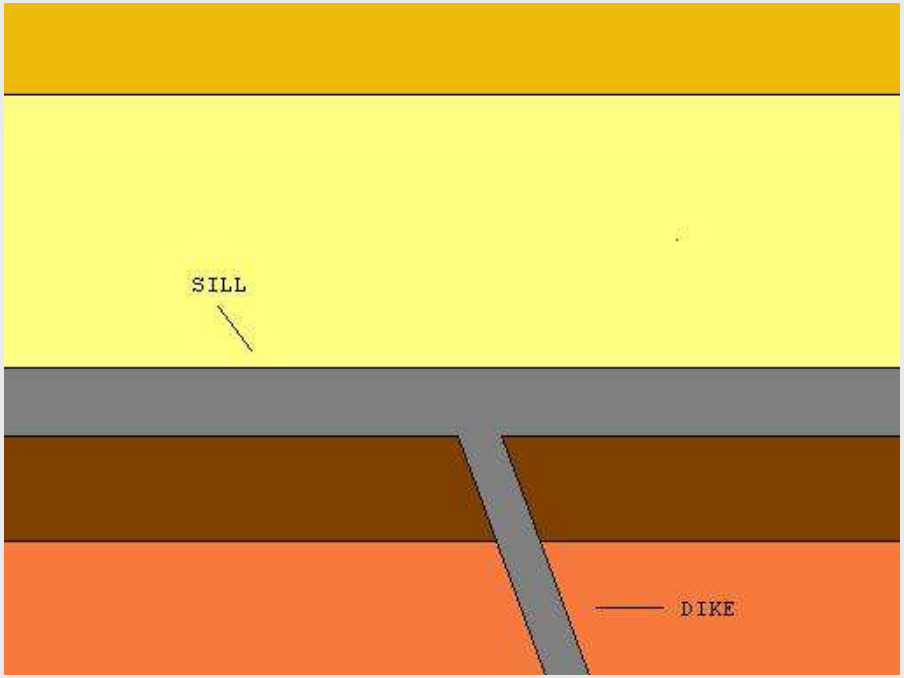
• Igneous rocks formed of cooled lava or volcanic ejected are common, but most molten material cools below Earth's surface,
producing bodies of
igneous rock known
As
-plutons.
- Intrusive and Extrusive
- Dikes and sell

Igneous rocks types:

Classification based on mode of occurrence: two major Groups

Extrusive (Volcanic): occurred on the earth surface.
Intrusive (Plutonic): occurred within the earth crust
Massive intrusive bodies : such as batholiths have relatively 3-D homogenous composition and texture.
Dikes and sills: may create more construction or rock- utilization problems than massive intrusive because of the inherent lack of the 3-D continuity.




SILL
DIKE

Properties of Magma and Lava

• All igneous rocks derive either directly or indirectly from magma. **Lava is magma that has reached Earth's surface.**

• **Plutonic (intrusive) igneous rocks form as magma cools and crystallizes within Earth.**

• **Volcanic (extrusive) igneous rocks form by cooling and crystallization of lava** or by consolidation of pyroclastic material, such as volcanic ash, ejected from volcanoes

It is not possible to study magma directly

• However, studying lavas can tell us a lot

• **Magmas have a range of compositions**

• **Characterized by high temperatures**

• **Have the ability to flow**

Magma Composition

• Silicate minerals are by far the most abundant minerals in the crust and silica is the most abundant constituent of magma. • The bulk chemical composition of magma is dominated by the most abundant minerals Si - Al - Fe - Ca - Mg - Na - K - H - O

• These major elements occur as oxides (SiO_2) • SiO_2 = ~45 to 75% of rocks • Water and CO_2 make up 0.2 - 3 %

• Minor and trace elements make up the remainder

How hot are magma and lava?

• Erupting lavas range in temperature from **1000° to 1200° C**. Magma must be even hotter, but direct measurements are not possible.

• Rock is a poor heat conductor.

Mineralogical Contents

•Common major igneous rock-forming minerals are: quartz, K-feldspars, plagioclase, biotite, amphiboles, pyroxenes and olivine.

•Minor minerals constituents of igneous rocks: magnetite, pyrite, zircon, apatite, chlorite, muscovite, etc.

•Combination of minerals forming the igneous rocks is controlled by the magma chemistry. The crystals formed early have a higher specific gravity than the remaining liquid of the magma

The content of silica (as SiO2) in igneous rocks classifies the rocks into four groups rocks containing much silica were originally called acid, and those with less silica and correspondingly more of the metallic oxides were called basic

Rock composition	Amount of SiO_2 (%)	Minerals
acid	65	quartz, orthoclase, Na-plagioclase, muscovite, biotite (±hornblende)
intermediate	55–65	plagioclase, biotite, hornblende, quartz, orthoclase (±augite)
basic	45–55	Ca-plagioclase, augite (±olivine, ±hornblende)
ultrabasic	45	Ca-plagioclase, olivine (±augite)

Main Rock Forming Minerals

1. Feldpars: is the most abundant minerals. There are two types. Orthoclase feldspars contain potassim ($KalSi_3O_8$) and usually range from white to pink. Plagioclase feldspars contain sodium ($NaAlSi_3O_8$), calcium ($CaAl_2Si_2O_8$) or both, and range from white to gray to black, Feldspars have moderate hardness.

2. Quartz : very common ingredient in many kinds of rock. It is silicate (SiO_2), and usually has a translucent to milky white color. The luster is vitreous. Quartz is harder than most minerals (hardness 7), and thus is very resistant to weathering. Chert is a type of quartz sometimes found in sedimentary rocks. It can cause problem when used as concrete aggregate.

3. Mica: Translucent thin sheets or flakes. Muscovite is potassium aluminium silicate of colorless or silvery tint, pearly luster and especially one very perfect cleavage Biotite, other common variety, is a complex silicate of potassium, magnesium and iron and aluminum. The sheets of mica have very low coefficient of friction, which can produce shear failure in certain rocks, such as schist.

4. Ferromagnesian minerals: A class of minerals, all of which contain both iron and magnesium. This class includes pyroxene, amphibole, hornblende and olivine. These minerals are dark color and a moderate hardness.

5. Calcite: made of calcium carbonate ($CaCO_3$). It is usually white, pink or gray. It is soluble in water, and thus can be transported by ground water into cracks in rock where it precipitate out of solution. It also can precipitate in soil, becoming a cementing agent. Calcite is much softer then quartz or feldspar. The hardness is 3. Have vigorous reaction to hydrochloric acid.

6. Dolomite: Similar to calcite with magnesium added. Less vigorous reaction to dilute hydrochloric acid.

7. Iron Oxides: class of minerals, all of which contain iron (FeO_3). The most common iron oxides are hematite, Fe_2O_3 ; hydrous iron oxide that are often called limonite and magnetite. Although less common, these minerals give a distinctive rusty color to some rocks and soils and can act as cementing agents. The compact varieties have a hardness of 5.5-6, but earthy form are soft.

8. Gypsum: It is colorless to white and has economic value when found in thick deposits. Gypsum is water soluble

Engineering Geology

Cooling rates

• Intrusive (plutonic) rocks cool slowly while extrusive (volcanic) rocks cool quickly

• The cooling rate determines whether or not crystals form

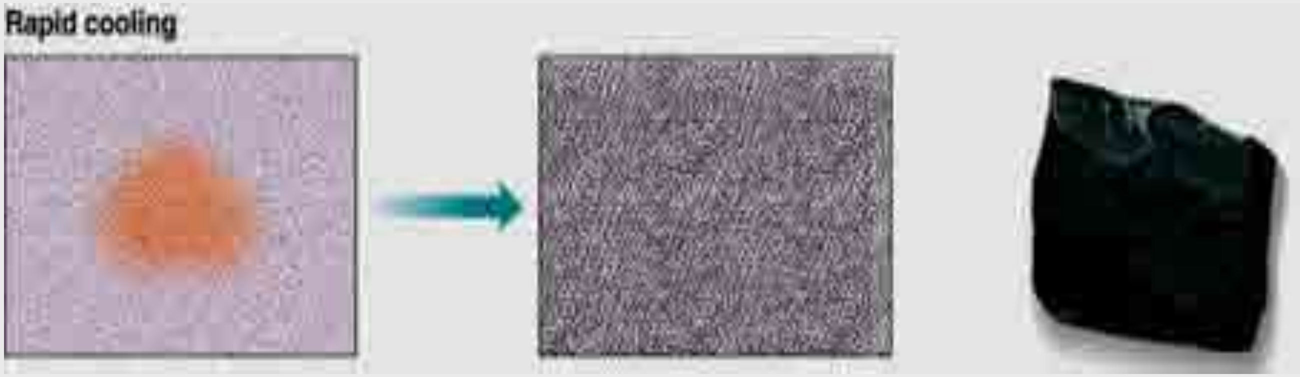
• **So cooling and crystallization determine the texture of the rock**

Engineering Geology

Texture

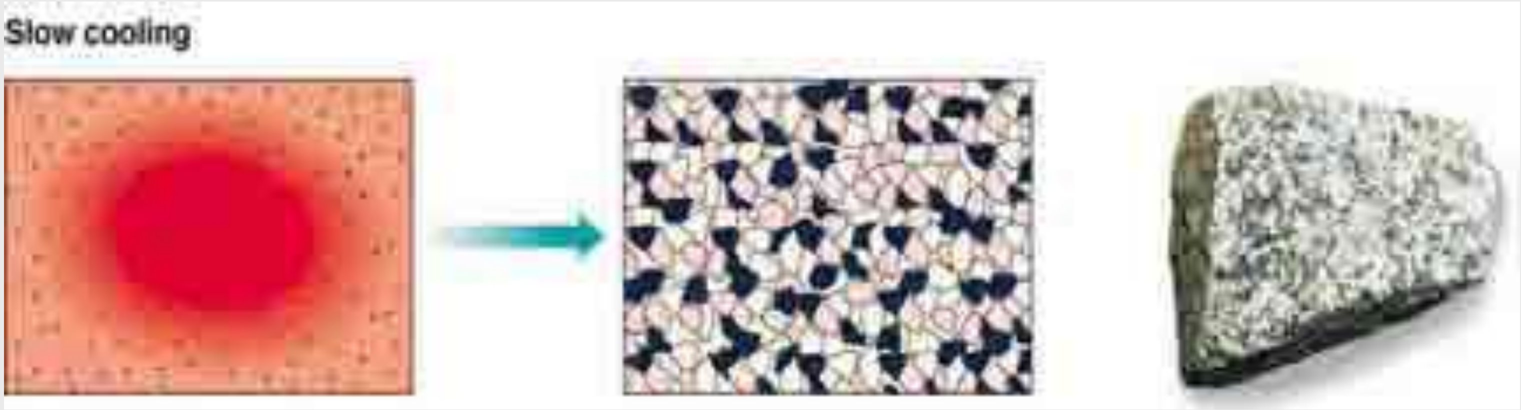
• Texture refers to the size, shape and arrangement of minerals' grains and is an important characteristic of igneous rocks. Grain size records cooling history.

• 1-**An aphanitic** texture consists of an aggregate of **very small mineral grains**, too small to be seen clearly with the naked eye. Aphanitic textures record rapid cooling at or very near Earth's surface and are characteristic of extrusive (volcanic) igneous rocks.



2-Plutonic textures: Phaneritic

• A phaneritic texture consists of an **aggregate of large mineral grains**, easily visible without magnification . Phaneritic textures record slow cooling within Earth and are characteristic of intrusive (plutonic) igneous rocks



3-Glassy texture

- Very rapid cooling of lava produces a “glassy texture”. The lava cools so quickly that atoms do not have time to arrange in an ordered three dimensional network typical of minerals. The result is natural **glass, or obsidian**

4-Vesicular textures

• Gases trapped in cooling lava can result in numerous small cavities, vesicles, in the solidified rock.

5-Pyroclastic texture (fragmental textures)

• Igneous rocks formed of mineral and rock fragments ejected from volcanoes by explosive eruptions have Pyroclastic (**fragmental) textures**. The ejected ash and other debris eventually settles to the surface where it is consolidated to form a Pyroclastic igneous rock. • Much of this material consists of angular pieces of volcanic glass measuring up to 2mm

6-Porphyritic texture

• Igneous rocks comprised of minerals of two or more markedly different grain sizes have a porphyritic texture. The coarser grains are called phenocrysts and the smaller grains groundmass. Porphyritic textures result from changes in cooling rate and include both aphanitic porphyrys and phaneritic porphyrys.

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Classifying Igneous Rocks

• Most igneous rocks can be classified on the basis of **Texture ,mineral composition and color.**

		Granitic	Andesitic	Basaltic	Ultramafic
Chemical Composition		Granitic	Andesitic	Basaltic	Ultramafic
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
TEXTURE	Coarse-grained	**Granite**	**Diorite**	**Gabbro**	**Peridotite**
TEXTURE	Fine-grained	**Rhyolite**	**Andesite**	**Basalt**	**Komatiite** (rare)
TEXTURE	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts.			Uncommon
TEXTURE	Glassy	**Obsidian** (compact glass) **Pumice** (frothy glass)			Uncommon
Rock Color (based on % of dark minerals)		0% to 25%	25% to 45%	45% to 85%	85% to 100%

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Texture	Color	Description	Rock
Coarse Grained (Phaneritic; crystals seen by eye)	Light Color	White, Gray, Pink; black minerals rare	Granite
	Intermediate Color	Salt and Pepper white/black ≃ 50/50	Diorite
	Dark Color	No light minerals; dark gray to black	Gabbro
	Light Green; granular; some black	Olivine and/or Pyroxene; no feldspar	Peridotite
Fine Grained (Aphanitic; no crystals visible; uniform)	Light Color	White, Gray, Pink	Rayolite
	Light / Intermediate Color		Felsite (A light to intermediate colored rock which cannot be positively identified.)
	Intermediate Color	Dark gray typical but other colors too	Andesite
	Dark Color	Dark gray to black	Basalt
Large Crystals (Phenocrysts) in groundmass	Light Color	Phenocrysts of orthoclase and/or quartz	Rayolite Porphory
	Intermediate Color	Phenocrysts of amphibole and/or plagioclase	Andesite Porpyry
	Dark Color	Phenocrysts of olivine	Basalt Porphyry
Glassy	Black, red, brown	conchoidal fracture; breaks along smooth curving surfaces	Obsidian
Vesicular (Cellular; full of holes; often light wieght)	Light Color and light weight	White to gray; spun glass look	Pumiice
	Dark Color and light weight	Black, brown red	Scoria
	Dark Color and heavy	Black, gray to brownish	Vesicular Basalt
Frag-mental	Any color; volcanic fragments cemented together	small, welded volcanic fragments; often stretched out	Volcanic Tuff
		angular volcanic fragments larger than 64 mm	Volcanic Breccia

Engineering Considerations of Igneous Rocks

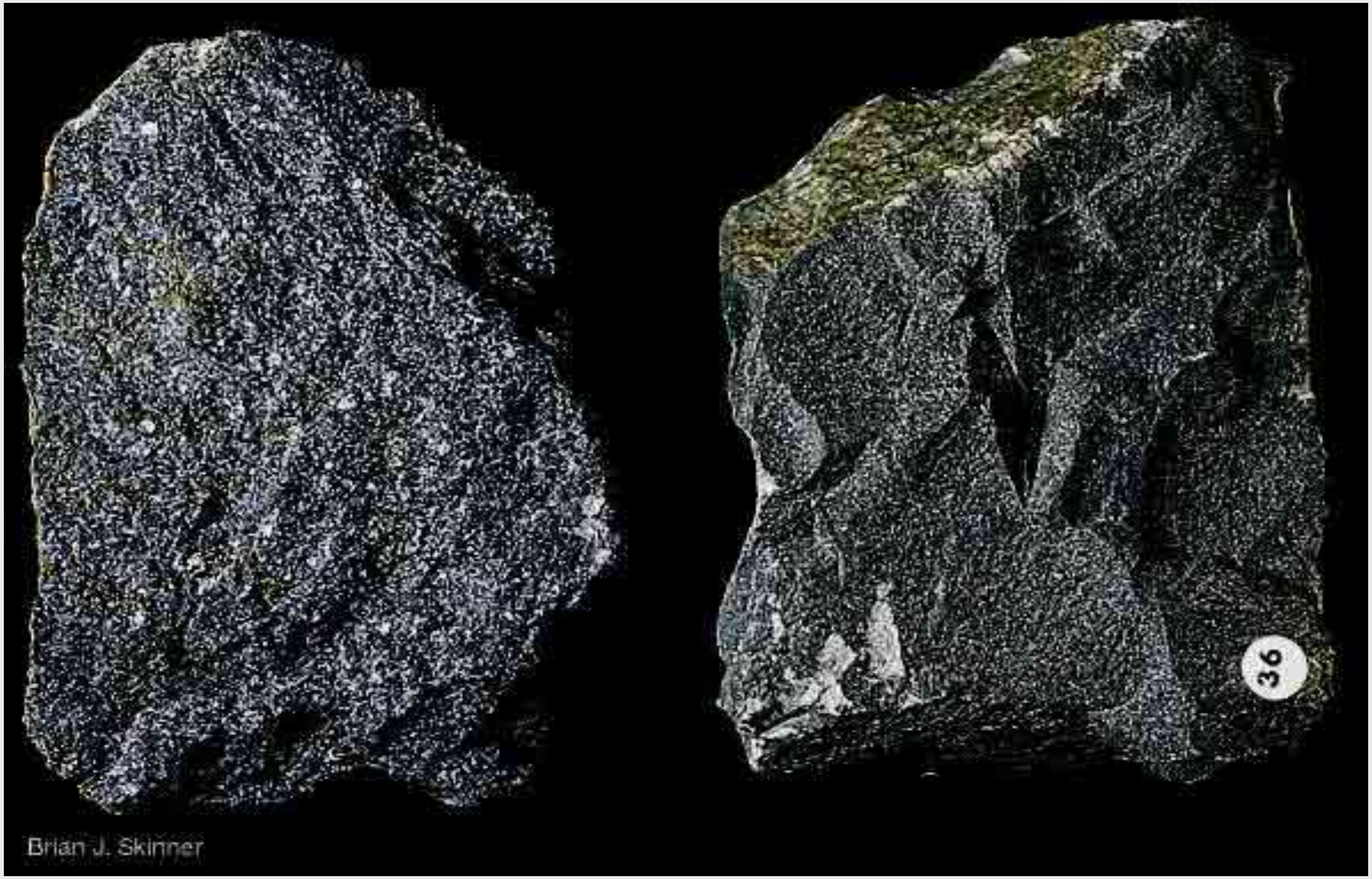
(1)Fine-grained igneous rocks cannot be used as aggregates in Portland cement due to volume expansion caused by the Alkali-silica reaction. Solutions include:(a)Can be used in low alkali cement;(b)Non-reactive aggregates go with the high alkali cement;(c)Add pozzolans, coal-ashes, etc. in the aggregate-cement mixture to minimize the reaction.

(2)Coarse-grained igneous rocks (e.g., granite, syenite, etc.) are not for aggregates for constructions because its low abrasion resistance; but fine-grained igneous rocks (e.g., basalt) are good for aggregates (e.g., basalt as paving aggregates goes with asphalt.

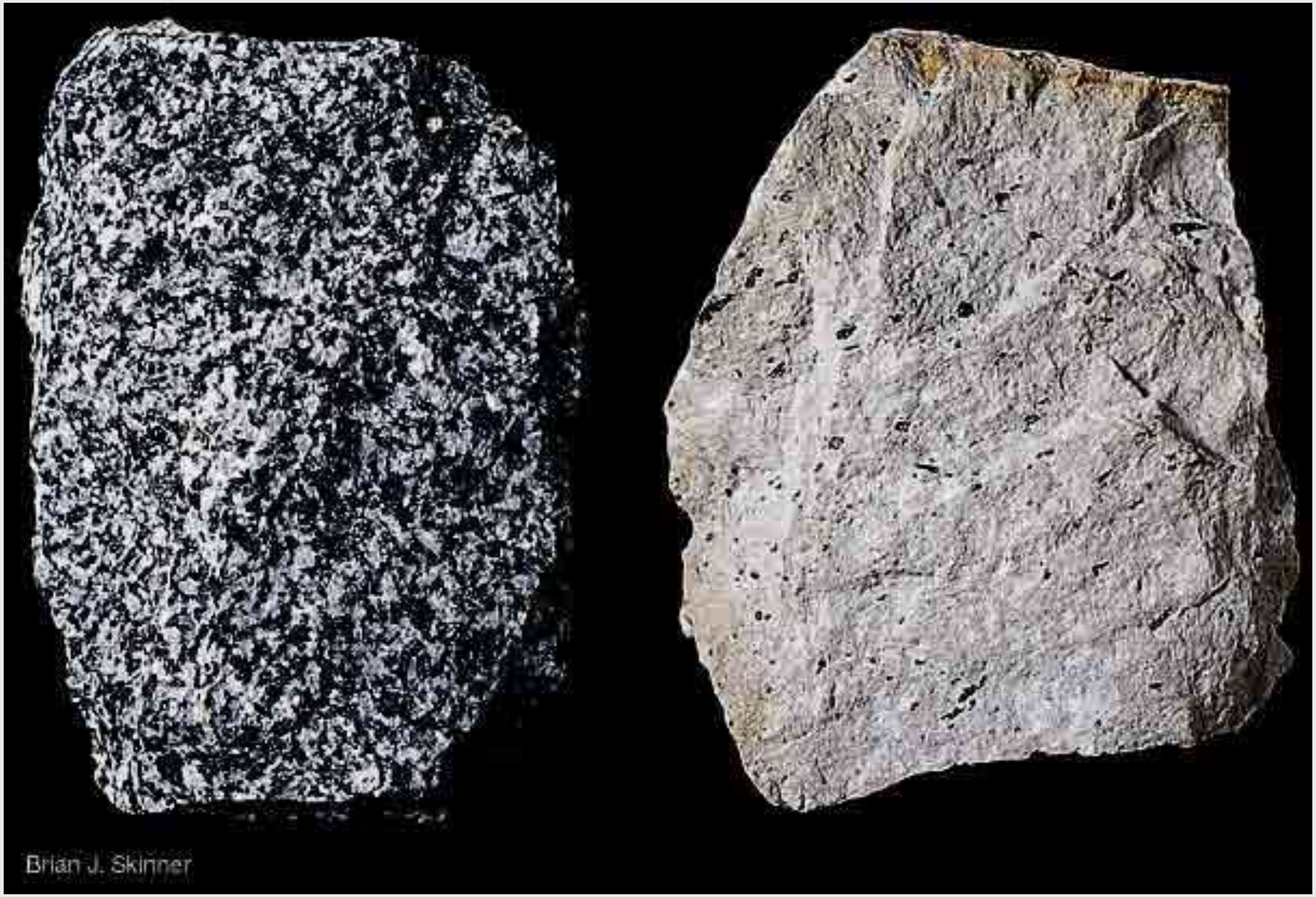
(3)Sitting of foundations needs to avoid weathered rocks (e.g., dams, bridge piers, etc.);

(4)Igneous rocks are good for dimension stone (tombstone etc.) because their resistance to weathering but need avoid fractures

Gabbro and basalt



Diorite and Andesite



Granite and Rhyolite

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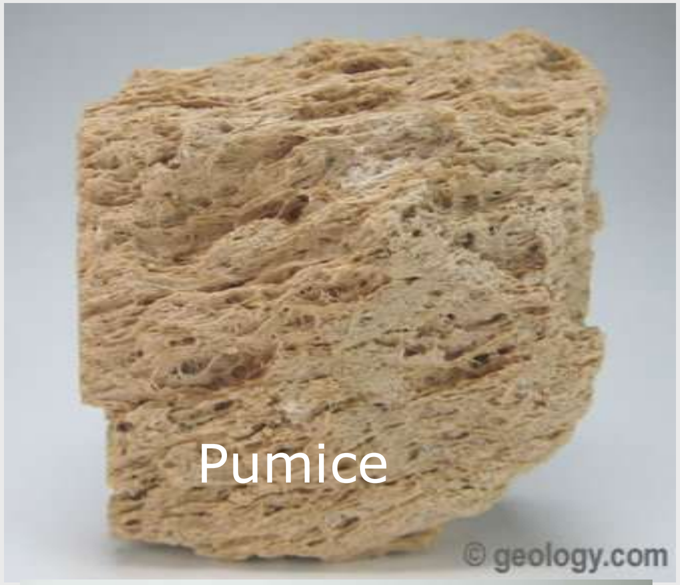
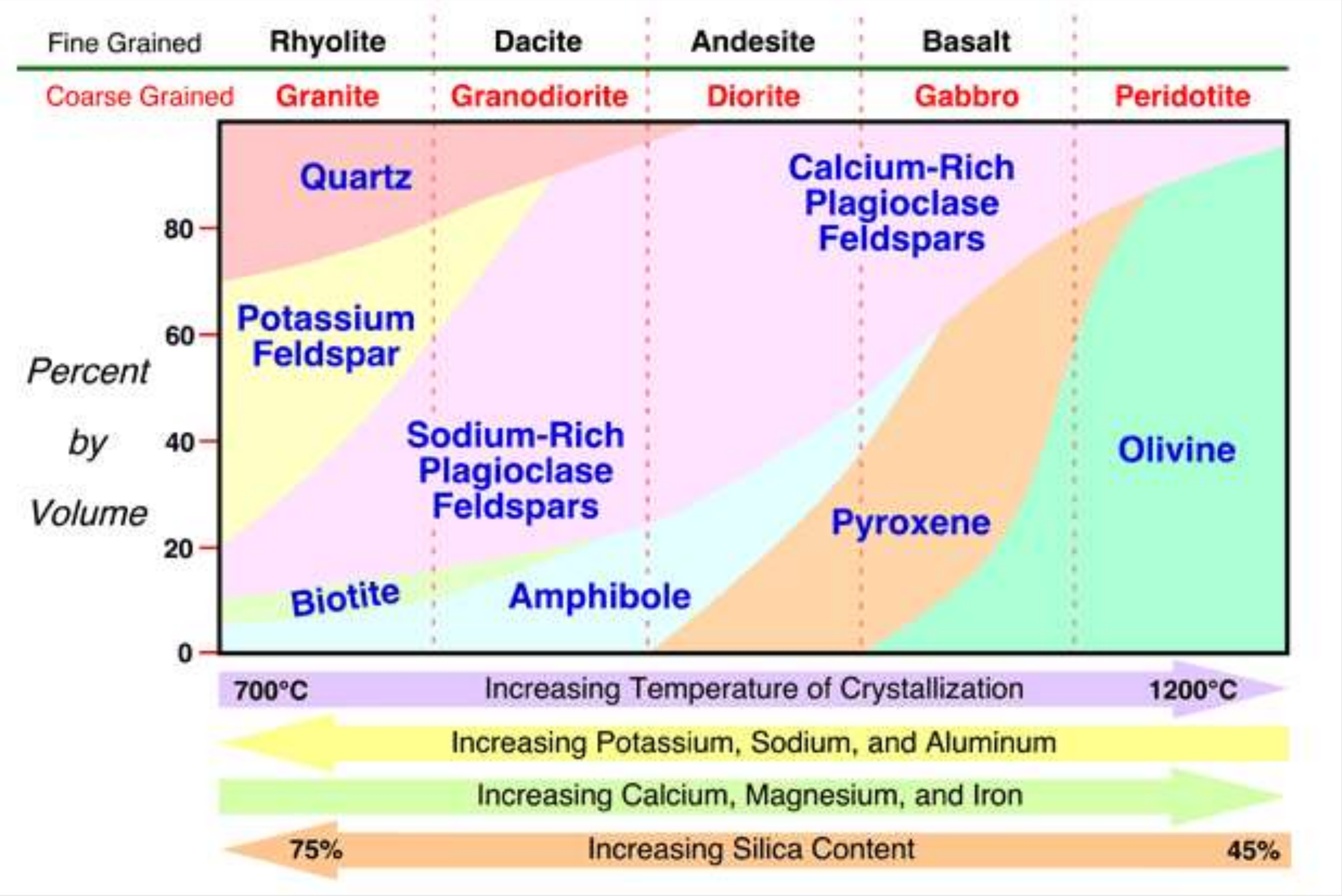
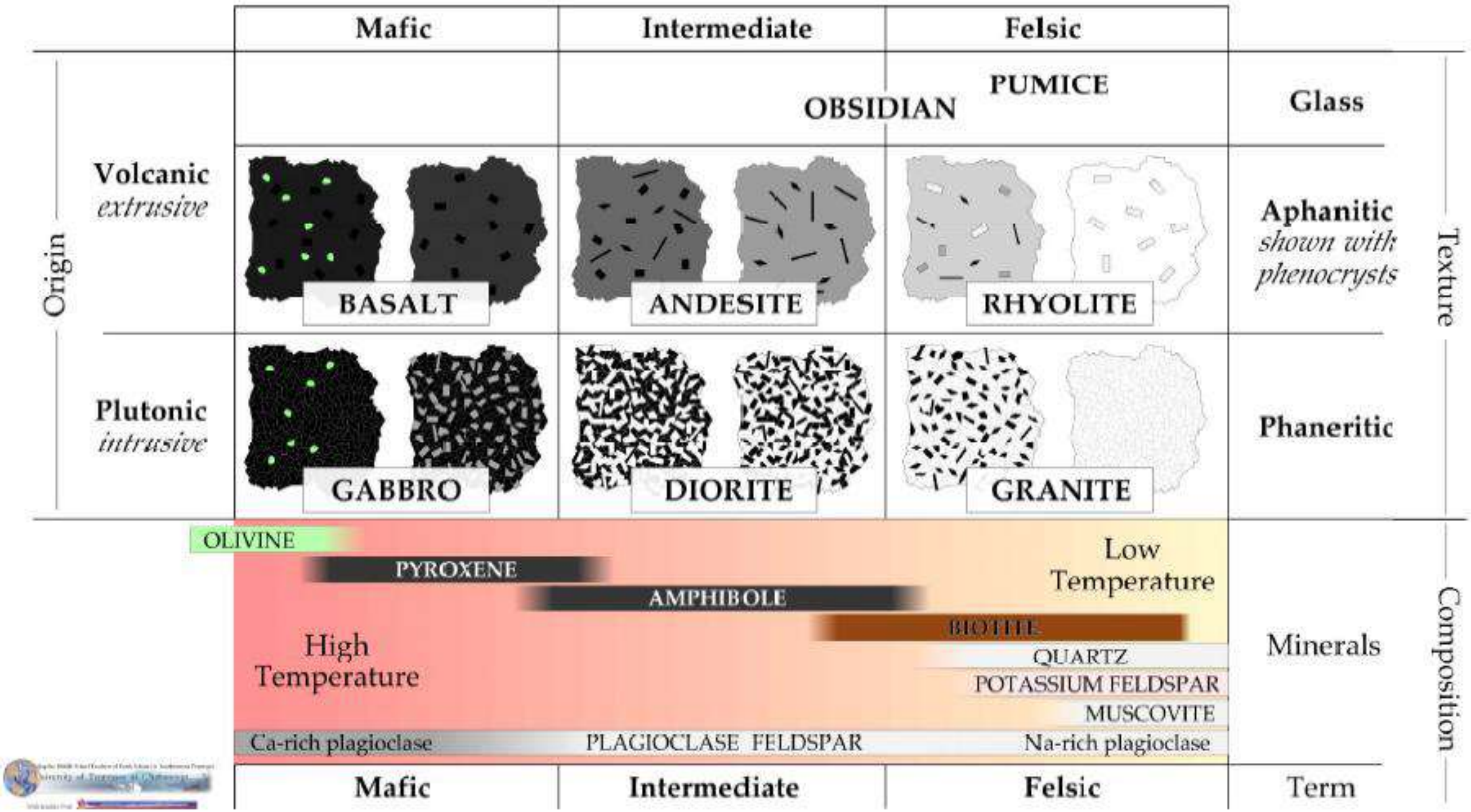



Fine Grained
Rhyolite
Dacite
Andesite
Basalt
Coarse Grained
Granite
Granodiorite
Diorite
Gabbro
Peridotite
Percent by Volume
80
60
40
20
0
Quartz
Potassium Feldspar
Sodium-Rich Plagioclase Feldspars
Calcium-Rich Plagioclase Feldspars
Biotite
Amphibole
Pyroxene
Olivine
700°C
Increasing Temperature of Crystallization
1200°C
Increasing Potassium, Sodium, and Aluminum
Increasing Calcium, Magnesium, and Iron
75%
Increasing Silica Content
45%

Igneous Rocks



Basalt occurrence in Jordan (natural recourses authority)

Rock Wool Industry

As Aggregates and Building Stones

The uses of basalt as aggregates is still weak due to the available of alternative and cheap material such as limestone,

although the physical engineering specifications of basalt are much better than limestone, therefore it consider a good investment opportunity to use basalt in this field, also basalt can be used as a dimension stones for building.

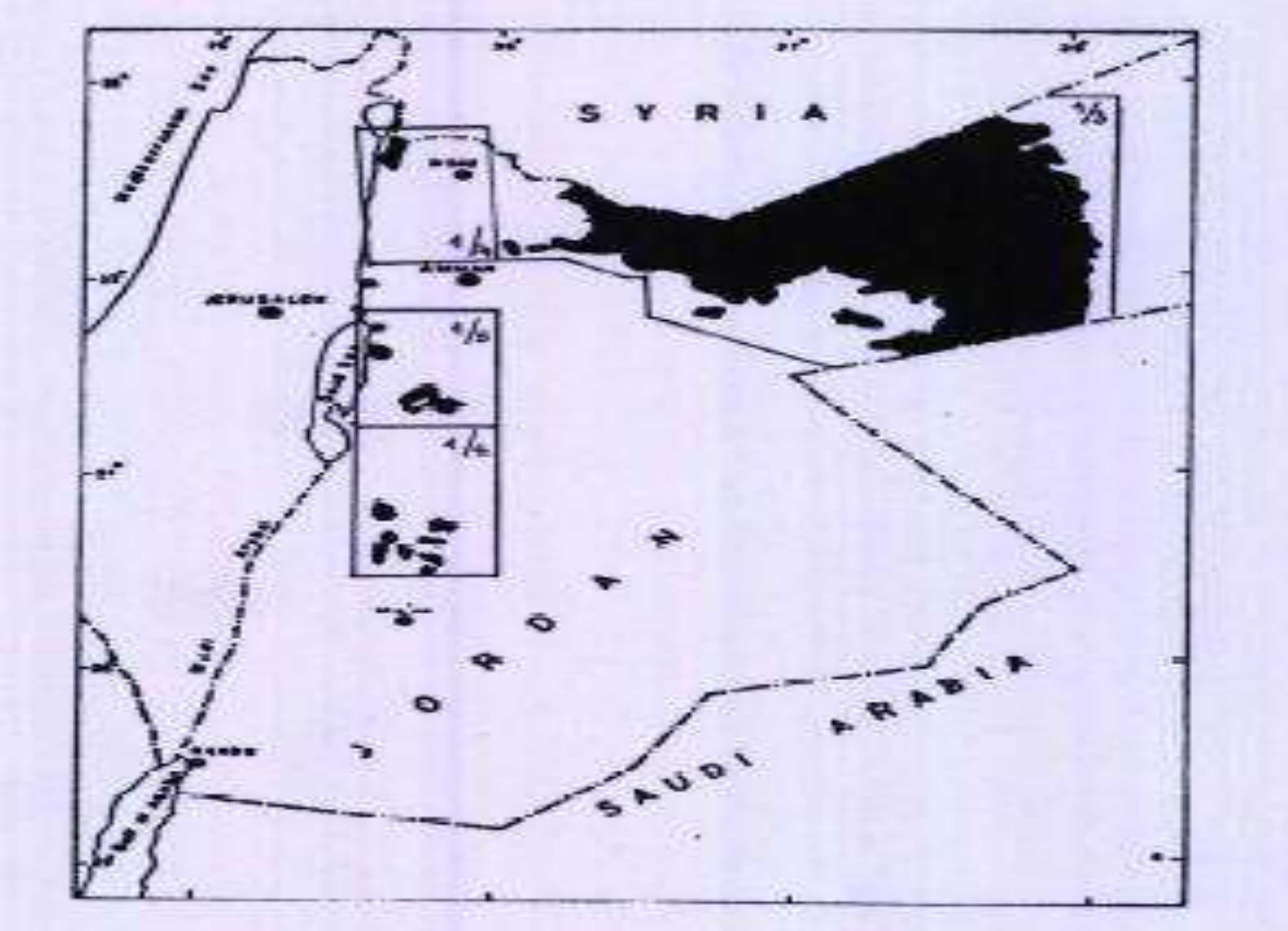
Mold Casting

Basalt fibers: It has a similar chemical composition as glass fiber but has better strength characteristics, and unlike most glass fibers is highly resistant to alkaline, acidic and salt attack making it a good candidate for concrete, bridge and shoreline structures.

Crushed basalt rock: is the only raw material required for manufacturing the fiber. It is a continuous fiber produced through igneous basalt rock melt drawing at about 1,500° C. Though the temperature required to produce fibers from basalt is higher than glass

Basalt When crushed: it is used for many construction purposes. It can be used for the base of a roadway, as an aggregate of concrete, as an aggregate of asphalt, ballast for railroads, in monuments and even as thin slices of floor tile

Pumice: is porous in nature and is used to make lightweight concrete and low density blocks.


SYRIA
JORDAN
SAUDI ARABIA
JERUSALEM

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Sedimentary Rocks

Hussien Al - deeky

Definition

Sedimentary rock is a type of rock that is formed by sedimentation of material at the Earth's surface and within bodies of water.

Sedimentation is the collective name for processes that cause mineral and/or organic particles (detritus) to settle and accumulate or minerals to precipitate from a solution.

Particles that form a sedimentary rock by accumulating are called **sediment.** Before being deposited, **sediment was formed by weathering and erosion in a source area**, and then transported to the place of deposition by water, wind, mass movement or glaciers.

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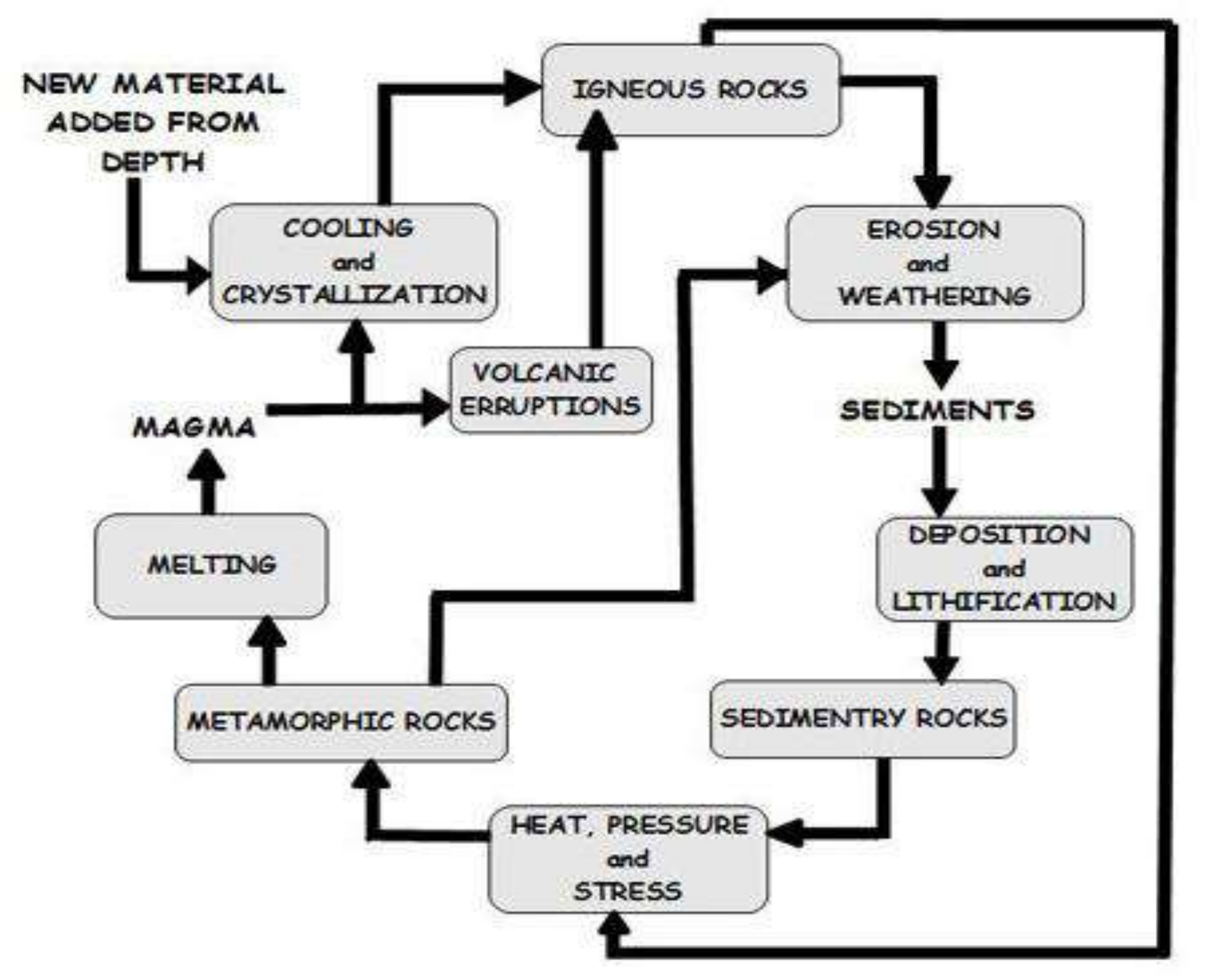
- Sedimentary rock is formed by deposition and consolidation of minerals and organic materials and from precipitation of minerals from solution. The processes that form sedimentary rock occur at the surface of the earth and within bodies of water.

-Rock formed from sediments covers 70-80 % of the earth's land area, and includes common types such as limestone, chalk, sandstone, conglomerate and shale.

-Sedimentary rocks are only a thin veneer over a crust consisting mainly of igneous and metamorphic rocks and constitute a total of 5% of the earth crust volume.

-Sedimentary rocks are deposited in layers as strata, forming a structure called bedding. The study of sedimentary rocks and rock strata provides information about the subsurface that is useful for civil engineering, for example in the construction of roads, houses, tunnels canals or other constructions. Sedimentary rocks are also important sources of natural resources like coal, fossil fuels, drinking water.

Rock Cycle Diagram



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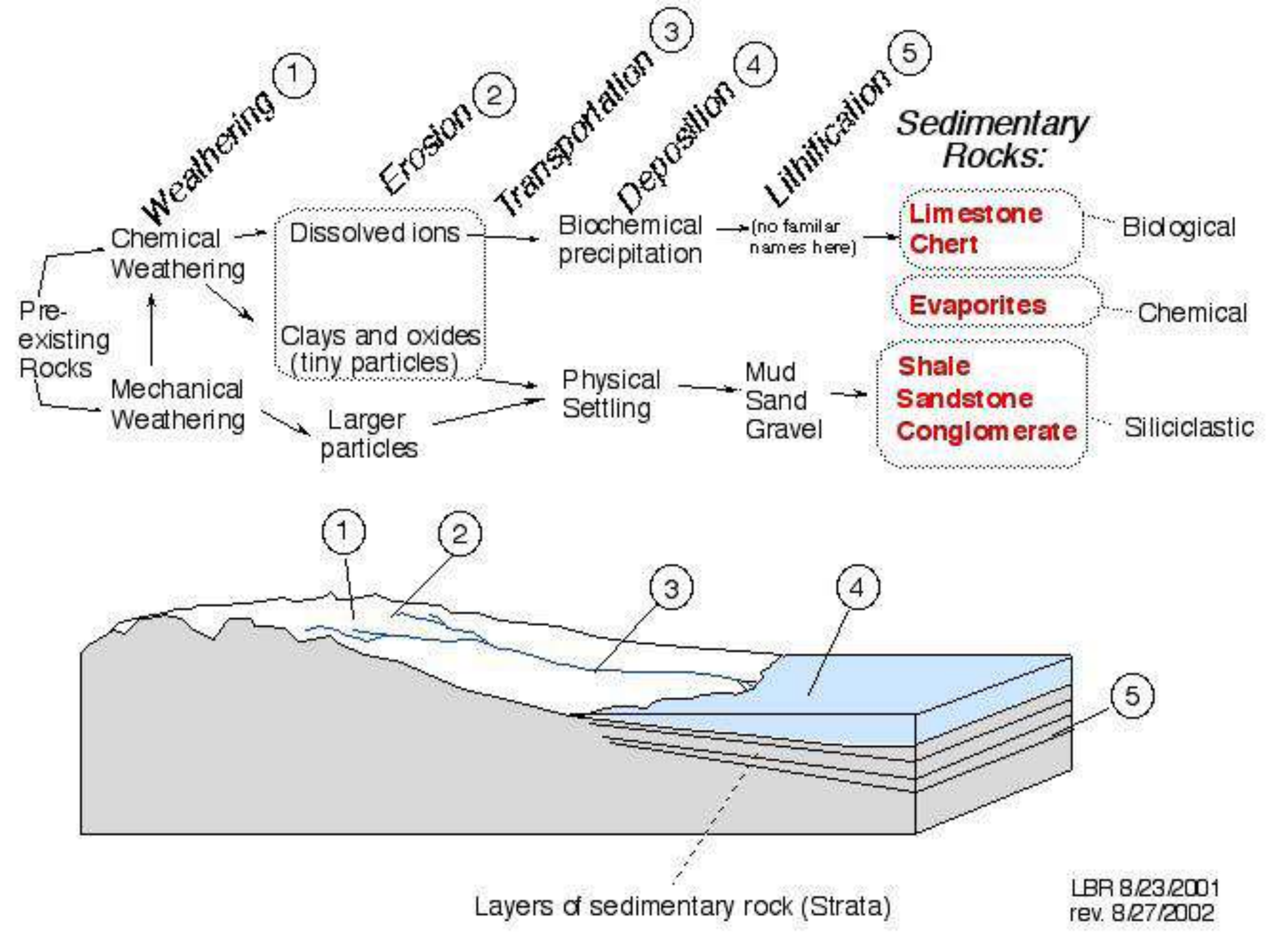

Weathering

Weathering Changes that take place in a rock exposed the earth's surface:

1.Mechanical weathering : breaking larger pieces into smaller pieces (clasts), with no change of chemical composition (clastic Rocks)

2. **Chemical weathering** : original minerals partially dissolve, and new minerals form that are more stable at the lower temperature and pressure, and more moist environment at the earth's surface

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Sediments

• Sediments: **are particulate matter derived from physical or chemical weathering of the earths crust which are subsequently transported by wind, water or ice**.

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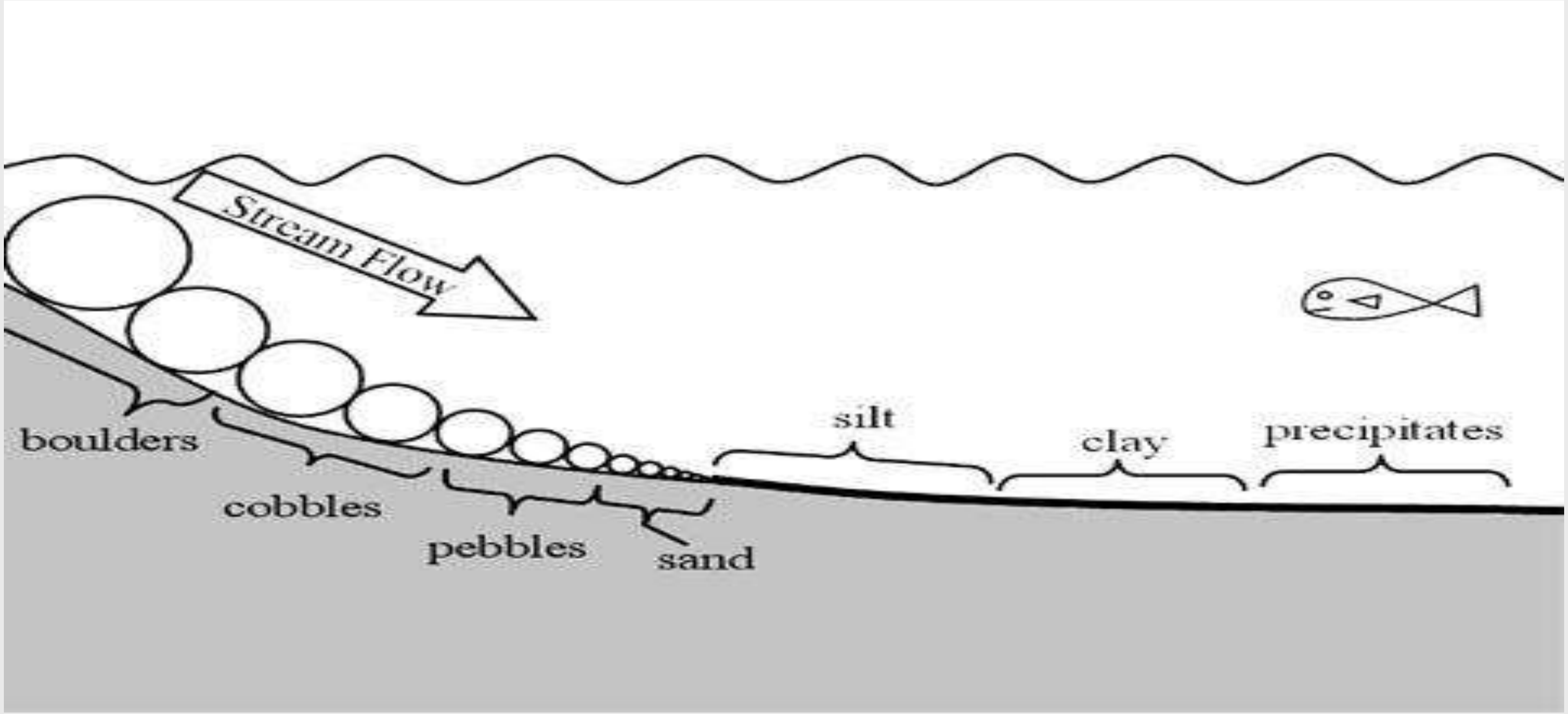
Sediment transport & deposition

- Sediment is transported by wind, water and ice. Ice is a solid and so can carry sediment particles of any size, but wind transports only sand and smaller particles. The most prolific transport agent is running water. The larger the particle size, the more vigorous the current required for transport.
- Whether transported by water, wind, or ice, sediment eventually accumulates in a geographic area known as a depositional environment.



Weathering products are separated by transportation.

•The quartz settles quickly and form rocks such as sandstone and siltstone.

•The clay stays in suspension until it settles to form shale and mudstone.

•The dissolved $CaCO_3$ precipitates to form limestone or dolomite

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- Abrasion during transport reduces particle size and smoothes sharp corners, a process known as rounding.
- Transport & depositional processes influence sorting, which refers to the variety of particle sizes present in a sediment or sedimentary rock. Sorting and rounding provide information that can help decipher the history of a sedimentary deposit

Lithification.

Lithification :is a process by which soft and loose sediments are converted into hard and firm rocks. Consolidation is of three types:

1. **Compaction and Dehydration**: The squeezing out of water from the pores of the sediments and its changing to solid mass by cohesion between the particles and pressure from overlying rock is called compaction and dehydration.
2. **Cementation:** Many coarse grained sediments are consolidated by cementation, which is the process of precipitation of some cementing materials, for example, silica, calcium carbonate, iron oxides and clay minerals.
3. **Crystallization:** Chemically formed sedimentary rocks such as limestone, dolomites, gypsum etc are consolidated chiefly by the crystallization of their constituents.

Structural features

Structural features of sedimentary rocks are of great value in determining their origin. The main structures are as follows:

1-Stratification: The deposition of sediments into layer or beds is called stratification. The thickness of a single bed may vary from a few centimeters to many meters. The stratification is formed due to the following.

I. Difference in the kinds of materials deposited for example shale and lime stone
II. Difference in the size of particles deposited for example coarse grained and fine grained sandstone beds
III. Difference in the color of the materials deposited for example light grey and dark grey layers of limestone

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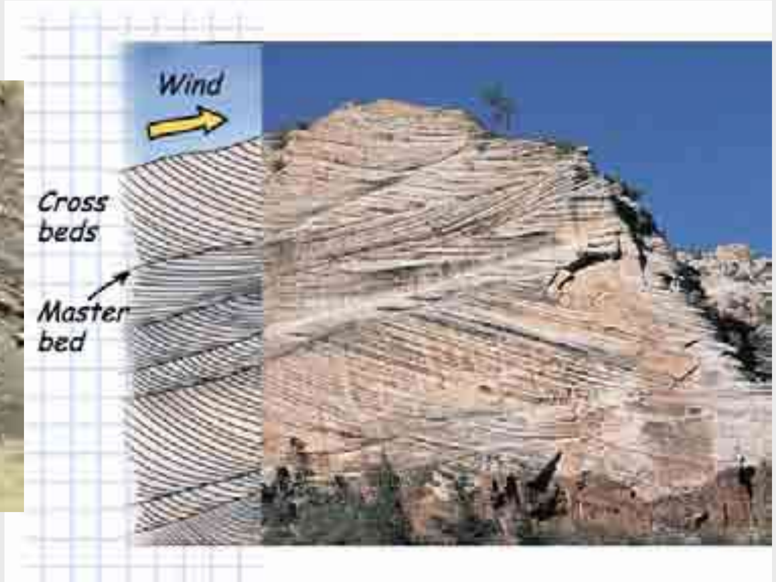
Lamination: Thin bedding, less than one centimeter in thickness, are called lamination. It is usually fined grained sedimentary rocks like shales.

Cross-bedding: It is also called current bedding or false bedding. Cross-bedding are the minor bedding or lamination which lie at an angle to the planes of general stratification. This structure is found in shallow water and wind formed deposits.



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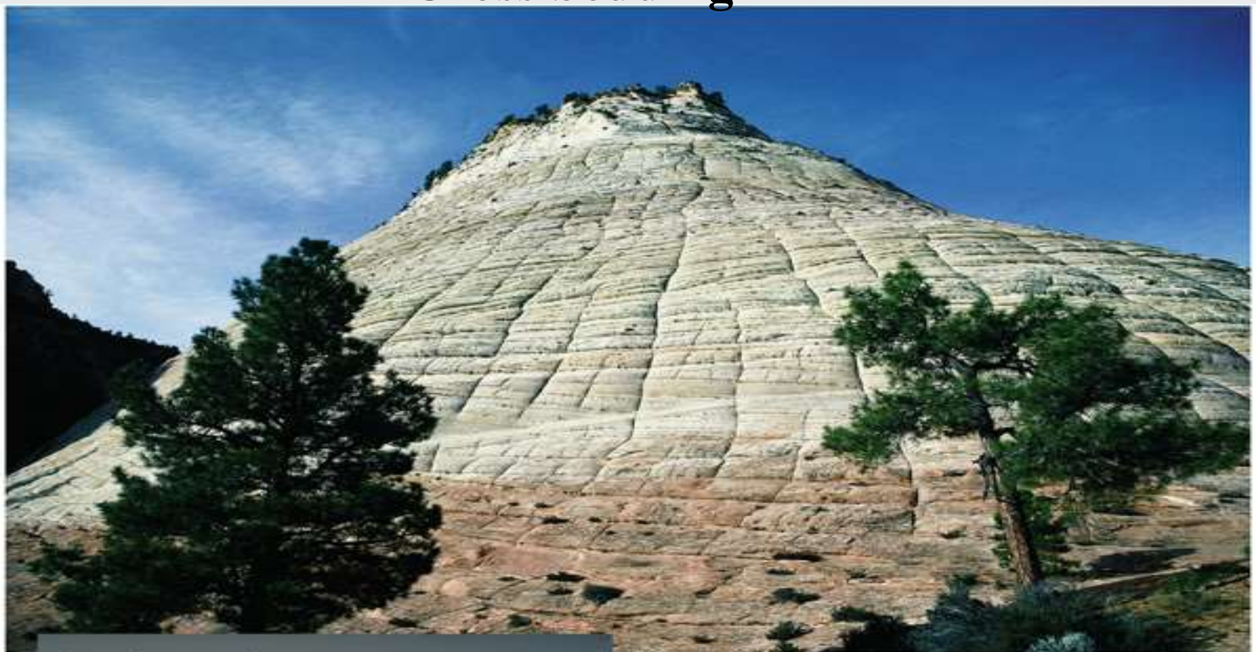
Strata- Bedding Planes

Cross bedding



Close up

Classification of Sedimentary Rocks

1-Clastic sedimentary rocks: are formed from the mechanical break up of other rocks and are classified based on the particle size, e.g. sandstone. Closer to the source the grains will tend to be larger and more angular These rocks are classified by the size of their constituent particles

Sediment Name &	Size Description	Rock Name
gravel (>2 mm)	rounded gravel angular gravel	Conglomerate breccia
sand (1/16-2 mm)	>25% feldspar mostly quartz	Arkose sandstone
silt (1/16-1/256 mm)	mostly silt	siltstone
clay (<1/256 mm)	mostly clay	Claystone

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Conglomerate and composed of round gravel

breccia are composed angular gravel

2-Chemical sedimentary rocks : are formed of ions taken into solution by chemical weathering of parent material. Many have crystalline texture of interlocking mineral grains. These rocks are classified based on their mineral composition.

Texture	Compostion	Rock Name
Varies	calcite ($CaCO_3$)	*limestone
Varies	dolomite [$CaMg(CO_3)_2$]	**dolostone
Crystalline	gypsum ($CaSO_4 . 2H_2O$)	rock gypsum
Crystalline	halite (NaCl)	rock salt

** most limestone is biochemical*

*** dolostone is chemically altered limestone*

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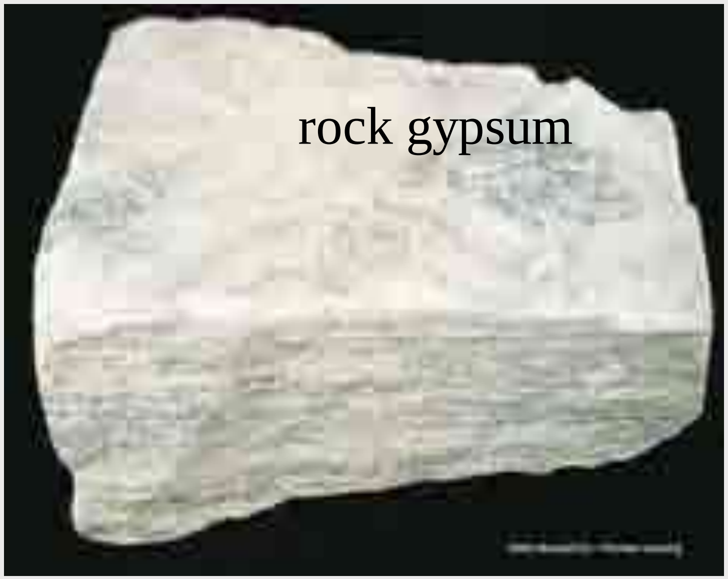


3-Biochemical sedimentary rocks are formed of ions taken into solution by chemical weathering of parent material, as are chemical sedimentary rocks. Organisms aid in the precipitation of biochemical sedimentary rocks

Texture	Composition	Rock Name
*clastic	calcite ($CaCO_3$ shells, etc.)	limestone
Crystalline	altered microscopic shells	chert
	carbon from altered plant remains	coal

* composed of individual particles or grains, fragments of shells or similar grains in the case of biochemical limestone


Chert


Coal


Limestone

Engineering Considerations of Sedimentary Rocks

(1)The sedimentary rocks also have the Alkali-silica reaction problem when used as aggregates with Portland cement. The sedimentary rocks with this problem are chert and graywacke

.(2)Fine-grained sedimentary rocks like limestone and dolomite are the best for being used as aggregates; siltstone, shale, conglomerate, and quartz sandstone are not acceptable;

(3)Stream and terrace gravel contains weak pieces, they are not good for aggregates in concrete. Weathered chert , shale, and siltstone can cause pop-outs at the concrete surface after freeze-thaw cycles;

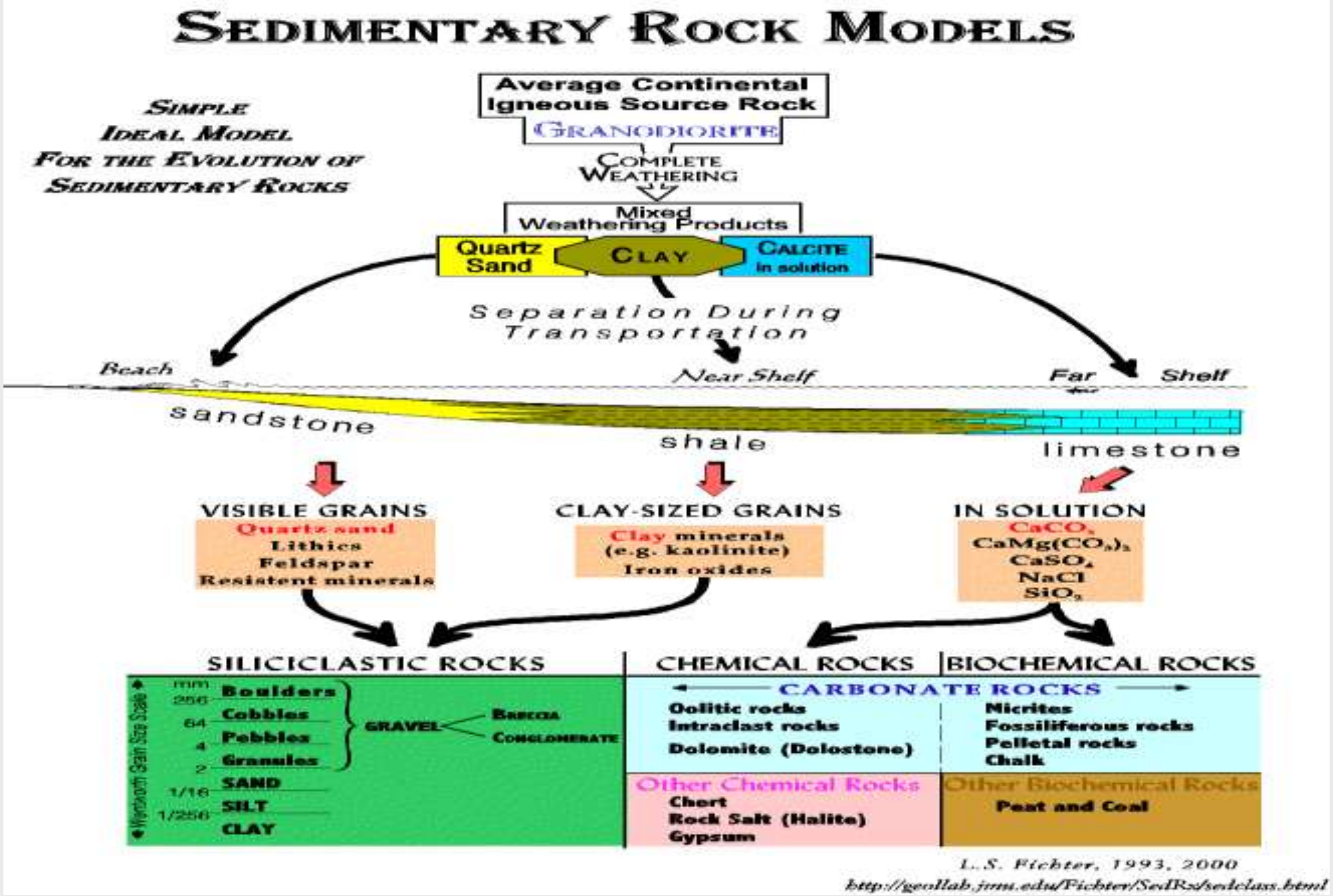
(4)Coarse-grained limestone is not good for aggregates by reducing particle size;

(5)Sinkhole problem in carbonate terrains due to the high dissolvability of limestone and dolomite

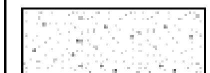
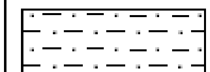
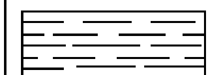
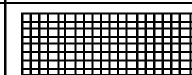
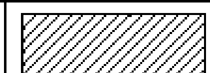
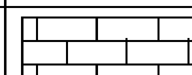
Scheme for Sedimentary Rock Identification

INORGANIC LAND-DERIVED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SY**
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate	
			Angular fragments	Breccia	
	Sand (0.2 to 0.006 cm)		Fine to coarse	Sandstone	
	Silt (0.006 to 0.0004 cm)		Very fine grain	Siltstone	
	Clay (less than 0.0004 cm)		Compact; may split easily	Shale	

CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SY**
Crystalline	Varied	Halite	Crystals from chemical precipitates and evaporites	Rock Salt	
	Varied	Gypsum		Rock Gypsum	
	Varied	Dolomite		Dolostone	
Bioclastic	Microscopic to coarse	Calcite	Cemented shell fragments or precipitates of biologic origin	Limestone	


SEDIMENTARY ROCK MODELS
SIMPLE IDEAL MODEL FOR THE EVOLUTION OF SEDIMENTARY ROCKS
Average Continental Igneous Source Rock
GRANODIORITE
COMPLETE WEATHERING
Mixed Weathering Products
Quartz Sand
CLAY
CALCITE in solution
Separation During Transportation
Beach
Near Shelf
Far Shelf
sandstone
shale
limestone
VISIBLE GRAINS
Quartz sand
Lithics
Feldspar
Resistent minerals
CLAY-SIZED GRAINS
Clay minerals
(e.g. kaolinite)
Iron oxides
IN SOLUTION
CaCO3
CaMg(CO3)2
CaSO4
NaCl
SiO2
SILICICLASTIC ROCKS
CHEMICAL ROCKS
BIOCHEMICAL ROCKS
Wentworth Grain Size Scale
mm
256
64
4
2
1/16
1/256
Boulders
Cobbles
Pebbles
Granules
SAND
SILT
CLAY
GRAVEL
BRECCIA
CONGLOMERATE
CARBONATE ROCKS
Oolitic rocks
Intraclast rocks
Dolomite (Dolostone)
Micrites
Fossiliferous rocks
Pelletal rocks
Chalk
Other Chemical Rocks
Chert
Rock Salt (Halite)
Gypsum
Other Biochemical Rocks
Peat and Coal
L.S. Fichter, 1993, 2000
http://geollab.jmu.edu/Fichter/SedRx/sedclass.html

Scheme for Sedimentary Rock Identification

INORGANIC LAND-DERIVED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SYMBOL**
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate	
			Angular fragments	Breccia	
	Sand (0.2 to 0.006 cm)		Fine to coarse	Sandstone	
	Silt (0.006 to 0.0004 cm)		Very fine grain	Siltstone	
	Clay (less than 0.0004 cm)		Compact; may split easily	Shale	
CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS					
TEXTURE	**GRAIN SIZE**	**COMPOSITION**	**COMMENTS**	**ROCK NAME**	**MAP SYMBOL**
Crystalline	Varied	Halite	Crystals from chemical precipitates and evaporites	Rock Salt	
	Varied	Gypsum		Rock Gypsum	
	Varied	Dolomite		Dolostone	
Bioclastic	Microscopic to coarse	Calcite	Cemented shell fragments or precipitates of biologic origin	Limestone	
	Varied	Carbon	From plant remains	Coal	

Conglomerate is a clastic sedimentary rock that contains large (>2 mm in diameter) rounded particles. The space between the pebbles is generally filled with smaller particles and/or a chemical cement that binds the rock together

Breccia is a clastic sedimentary rock that is composed of large (over two millimeter diameter) angular fragments. The spaces between the large fragments can be filled with a matrix of smaller particles or a mineral cement which binds the rock together

Sandstone is a clastic sedimentary rock made up mainly of sand-size (1/16 to 2 mm diameter) weathering debris. Environments where large amounts of sand can accumulate include beaches, deserts, flood plains and deltas

Shale is a clastic sedimentary rock that is made up of clay-size (less then 1/256 mm in diameter) weathering debris. It typically breaks into thin flat pieces

Siltstone is a clastic sedimentary rock that forms from silt-size (between 1/256 and 1/16 mm diameter) weathering debris

Limestone : composed primarily of calcium carbonate. It can form organically from the accumulation of shell, coral, algal and fecal debris. It can also form chemically from the precipitation of calcium carbonate from lake or ocean water. Limestone is used in many ways. Some of the most common are: production of cement, crushed stone

Rock Salt is a chemical sedimentary rock that forms from the evaporation of ocean or saline lake waters. Known as "halite". It is often mined for use in the chemical industry or for use as a winter highway treatment. Some halite is processed for use as a seasoning for food

Coal : organic sedimentary rock that forms mainly from plant debris. The plant debris usually accumulates in a swamp environment. Coal is combustible and is often mined for use as a fuel

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Metamorphic Rocks


Hussien Al - deeky

Definition

Metamorphic rock is the result of the transformation of an existing rock type, the *protolith* (**parent rock**), in a process called metamorphism, which means "change in form".

When the pre-existing rocks (sedimentary or igneous rock) are subjected to increased temperature, pressure and action of chemically active fluids, metamorphic rocks are formed. During metamorphism re-crystallization of mineral constituent takes place, as a result new minerals and new texture are produced.

The metamorphic processes generally improve the engineering behavior of these rocks by increasing their hardness and strength. Nevertheless, some metamorphic rocks still can be problematic. Some metamorphic rocks are foliated, which means they have oriented grains similar to bedding plains in sedimentary rocks. These foliation is important because the shear strength is less for stresses acting parallel to the foliation

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for engineering works, and are similar to intrusive igneous rocks in their quality. However, some foliated rocks are prone to slippage along the foliation planes. Schist is the most notable in this regard because of its strong foliation ad the presence of mica. The 1928 failure St.Fancis Dam in California has been partially attributed to shearing in schist and the 1959 failure of Malpasset dam in France to shearing in a schistose gneiss.

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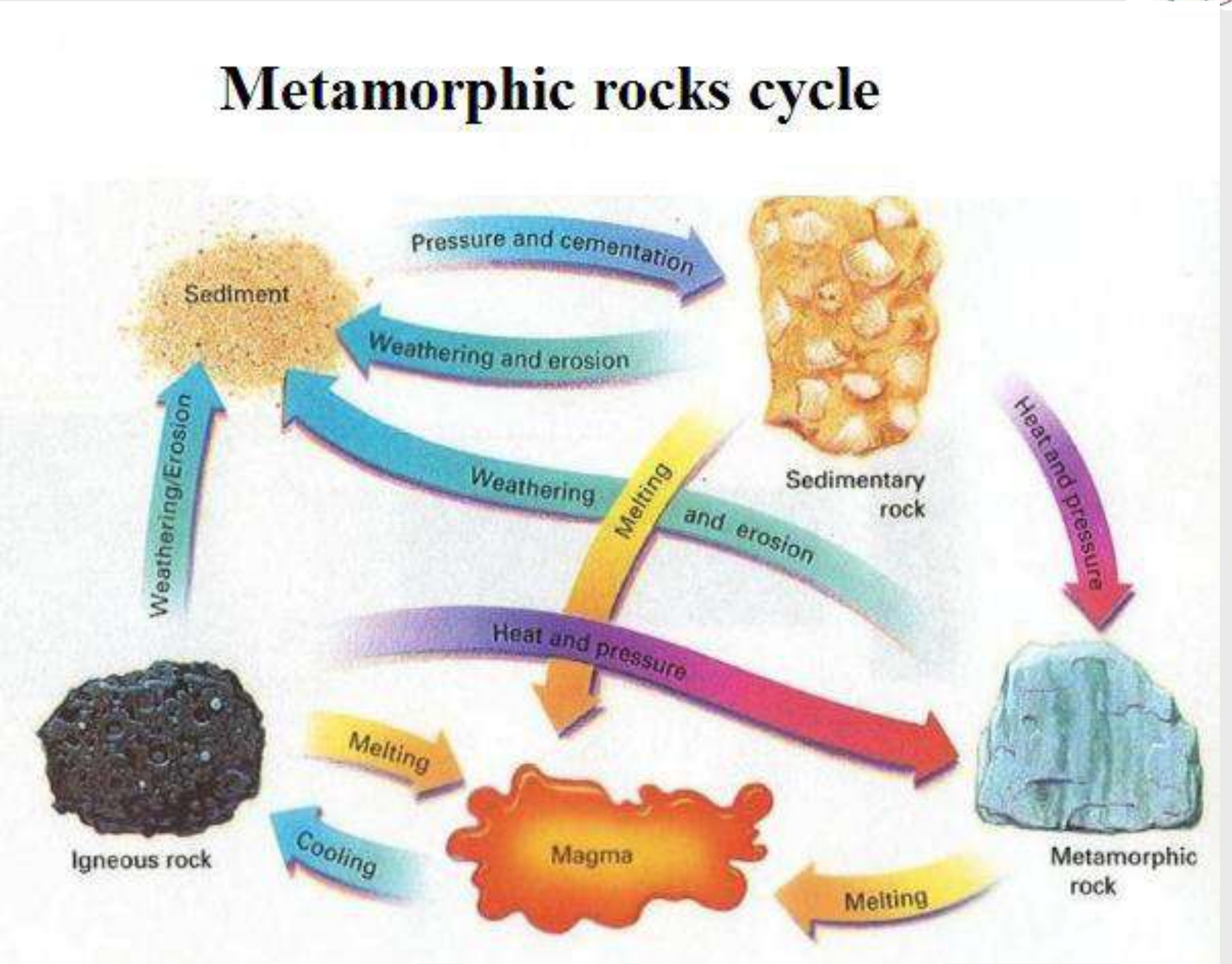
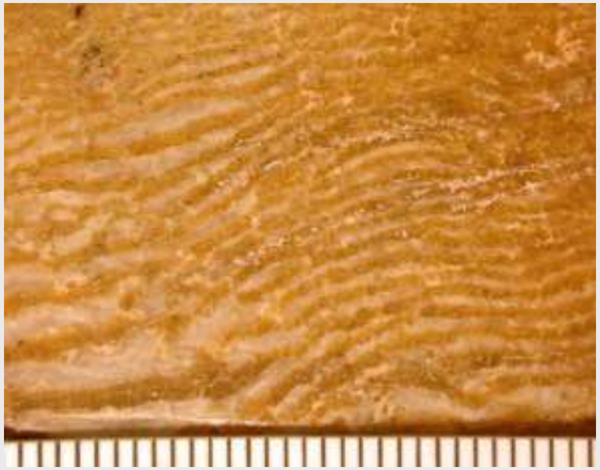


Types of Metamorphism

1-Contact metamorphism (Heat) is the name given to the changes that take place when magma is injected into the surrounding solid rock. The changes that occur are greatest wherever the magma comes into contact with the rock because **the temperature are highest** at this boundary and decrease with distance from it. Around the igneous rock that forms from the cooling magma is a metamorphosed zone called a contact metamorphism aureole.



-shale may become a dark argillaceous hornfels,

-Limestone may change to a grey, yellow or greenish lime-silicate-hornfels or siliceous marble,

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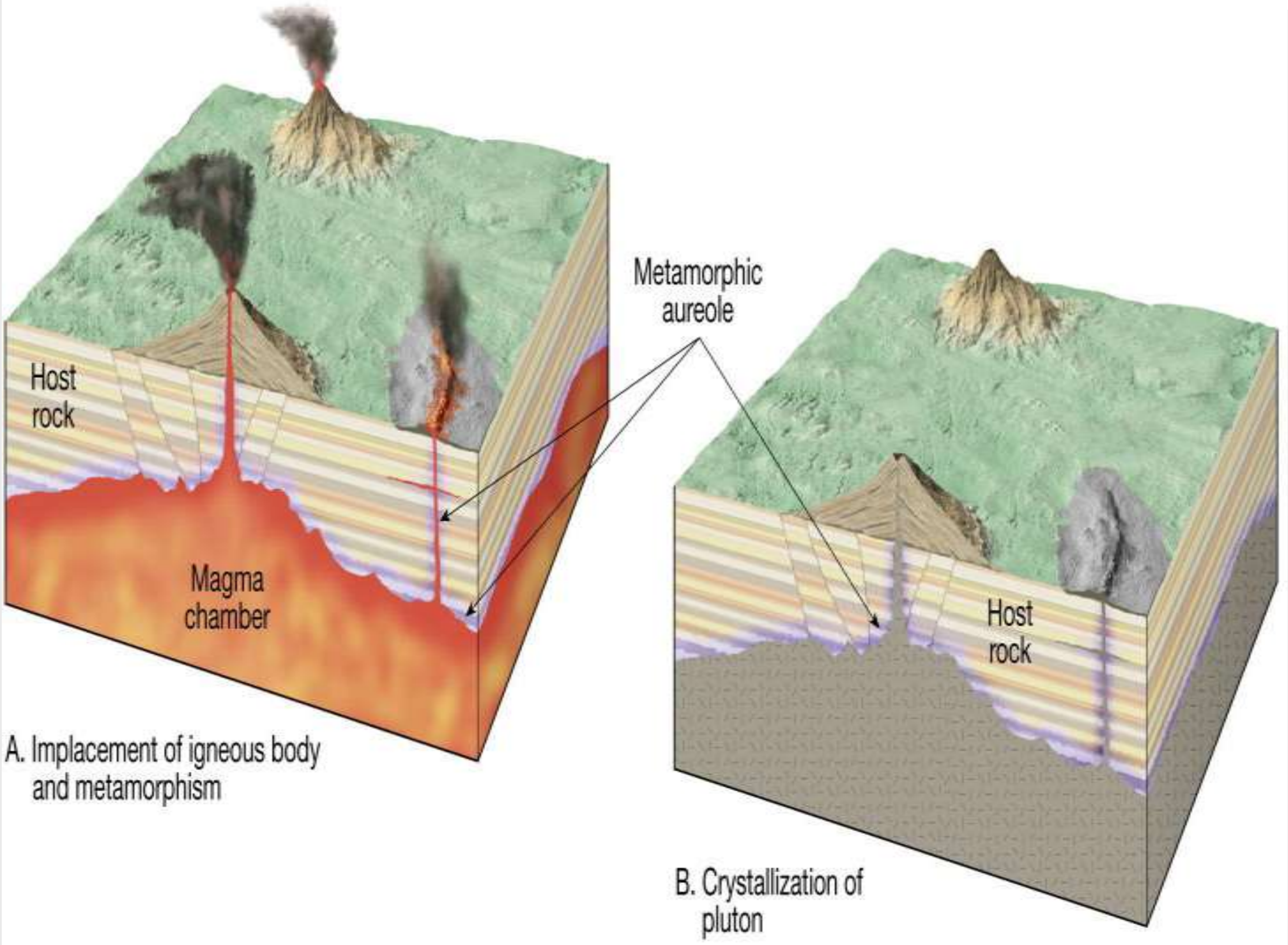

2-Regional metamorphism (heat &pressure)

is the name given to changes in great masses of rock over a wide area. Rock can be metamorphosed simply by being at great depths below the earth's surface, subjected to **high temperatures and the great pressure** caused by the immense weight of the rock layers above. Much of the lower continental crust is metamorphic.

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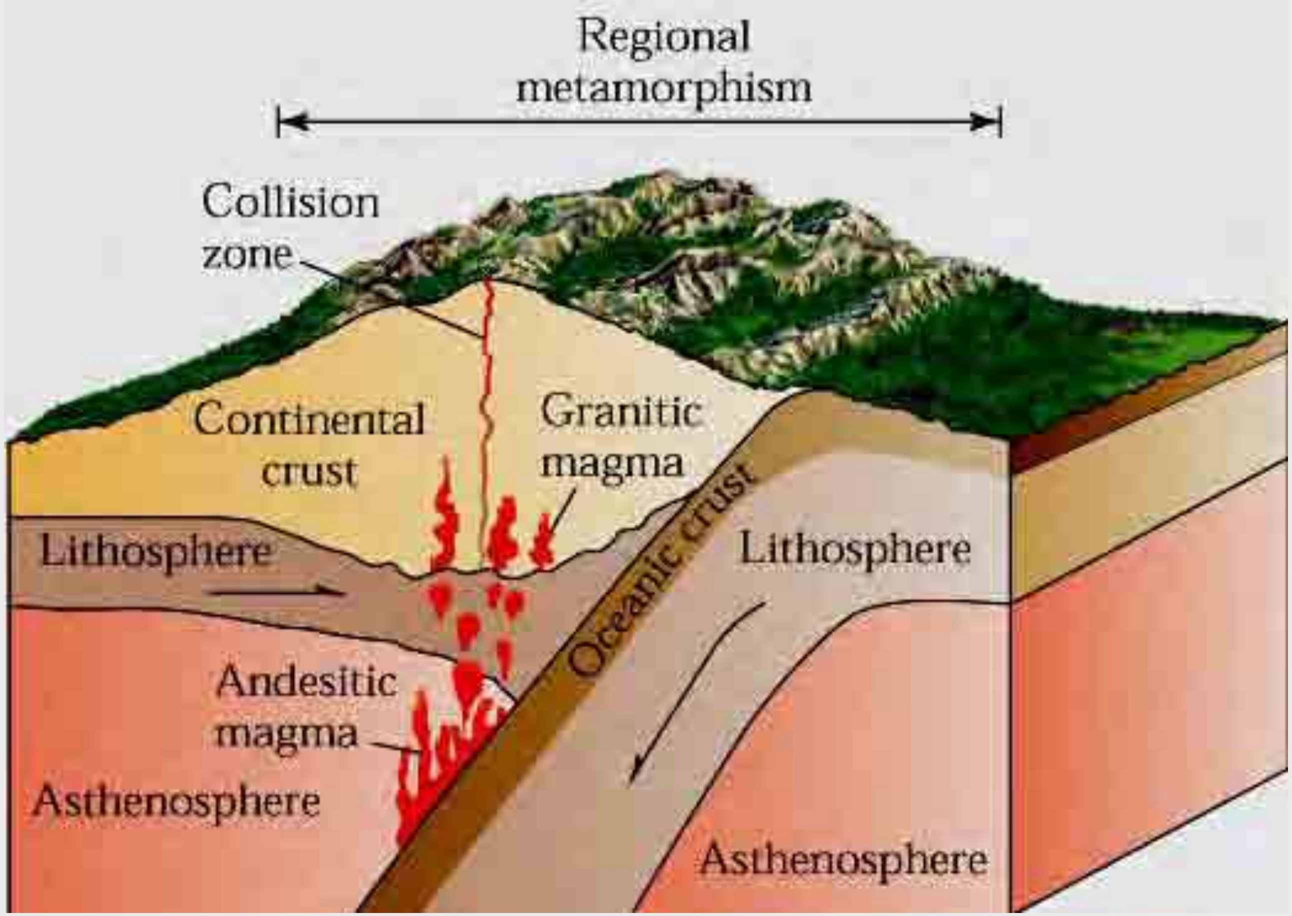
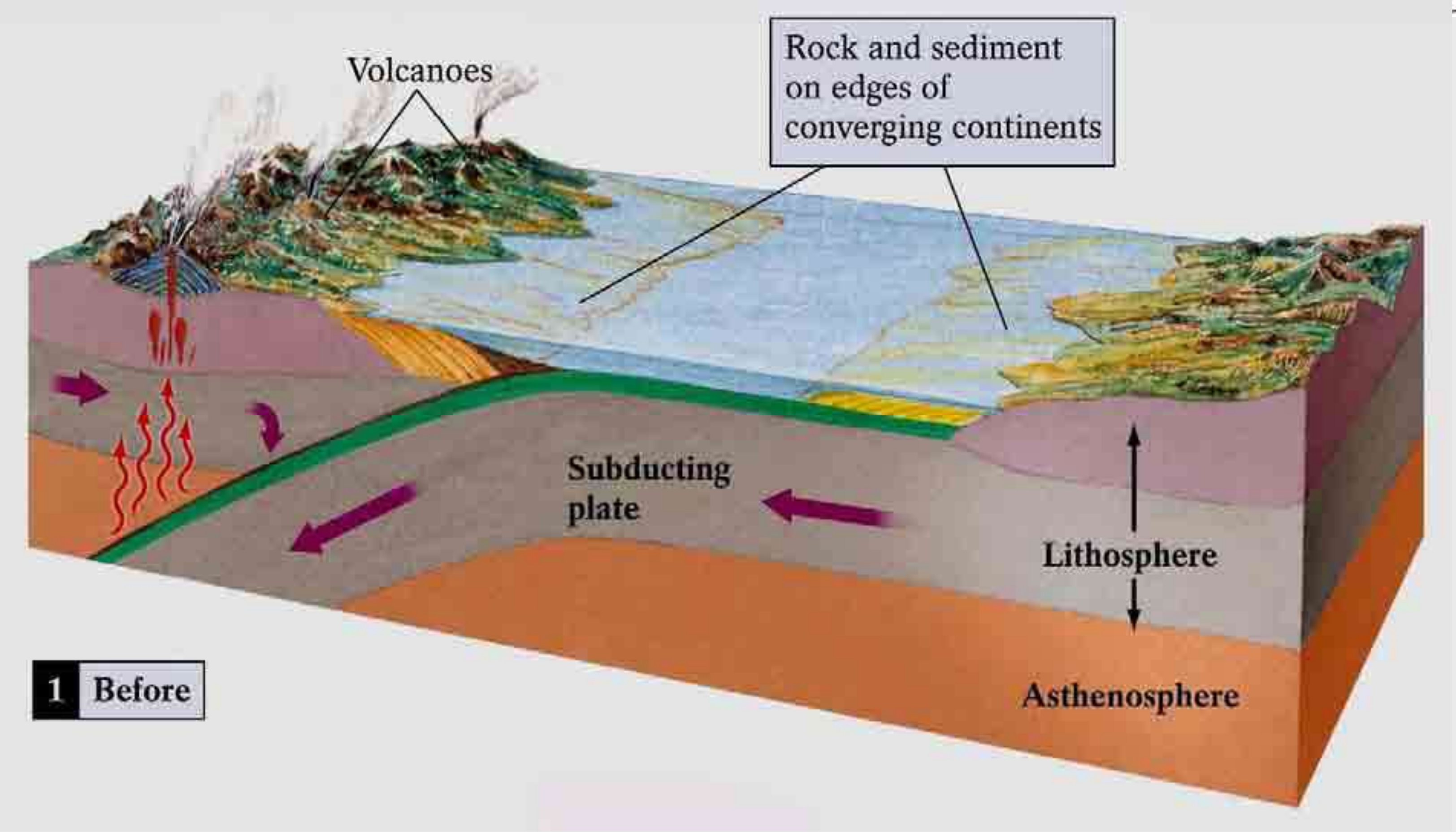


Engineering Geology



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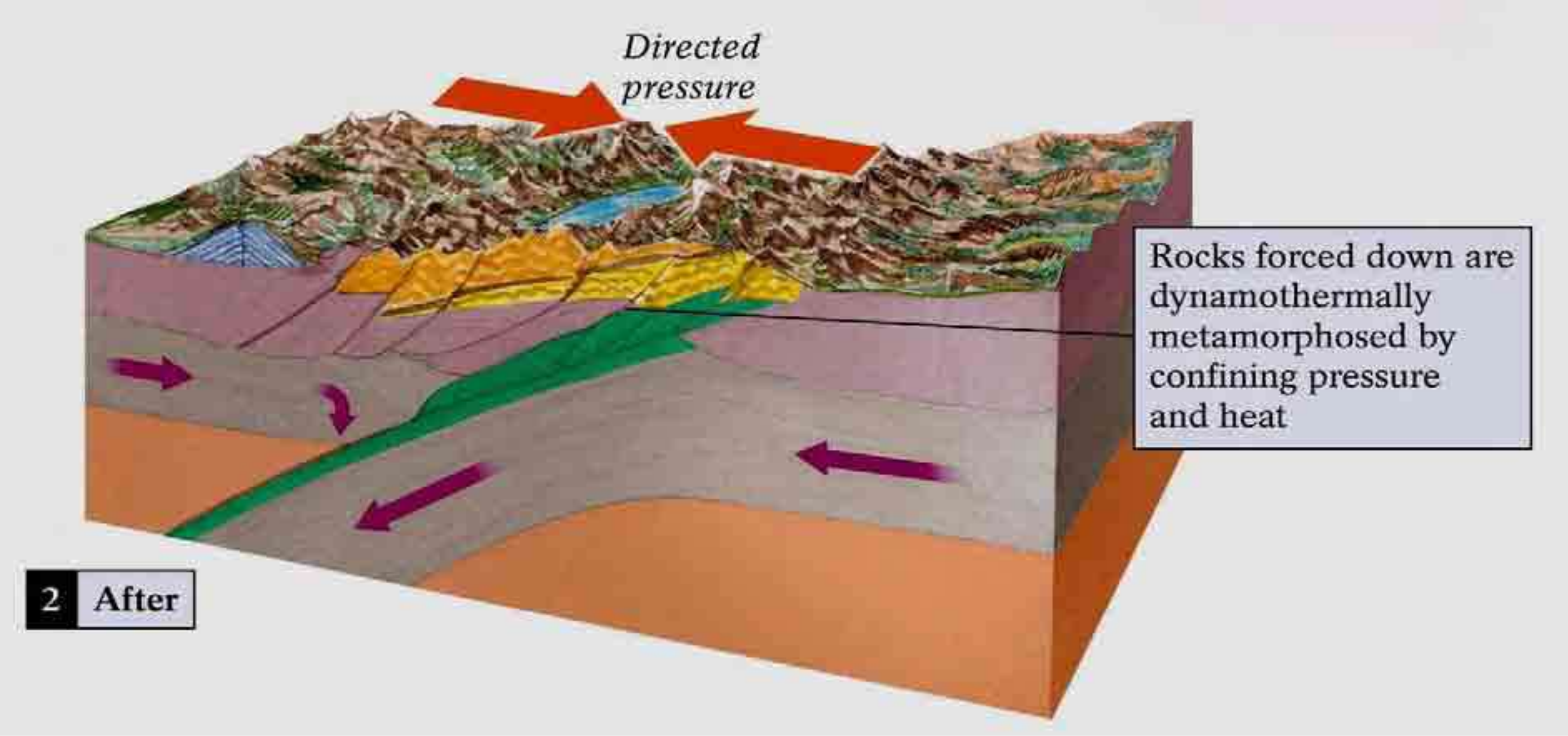

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3-Dynamic metamorphism (pressure)

Dynamic metamorphism occurs along fault zones where rocks have been altered by **high differential pressure**. Rocks formed by dynamic metamorphism are restricted to narrow zones adjacent to faults and are known as Mylonites . Mylonites are commonly hard, dense, fine-grained, and contain thin laminations.

Factors Controlling Metamorphism

1-Heat Most important agent

•Two sources of heat

–Contact metamorphism – heat from magma

–An increase in temperature with depth due to the geothermal gradient 15-30o C increase per km

2-Pressure and differential stress

•Confining pressure applies forces equally in all directions; increases with depth

•Rocks may also be subjected to differential stress which is unequal in different directions

3-Chemically active fluids

•Mainly water with other volatile components

•Aids in re-crystallization of existing minerals

4-Sources of fluids

–Pore spaces of sedimentary rocks

–Fractures in igneous rocks

–Hydrated minerals such as clays and micas

Engineering Geology

the same Protoliths experience different conditions of temperature and pressure, they will yield different metamorphic rocks

Heat

Pressure

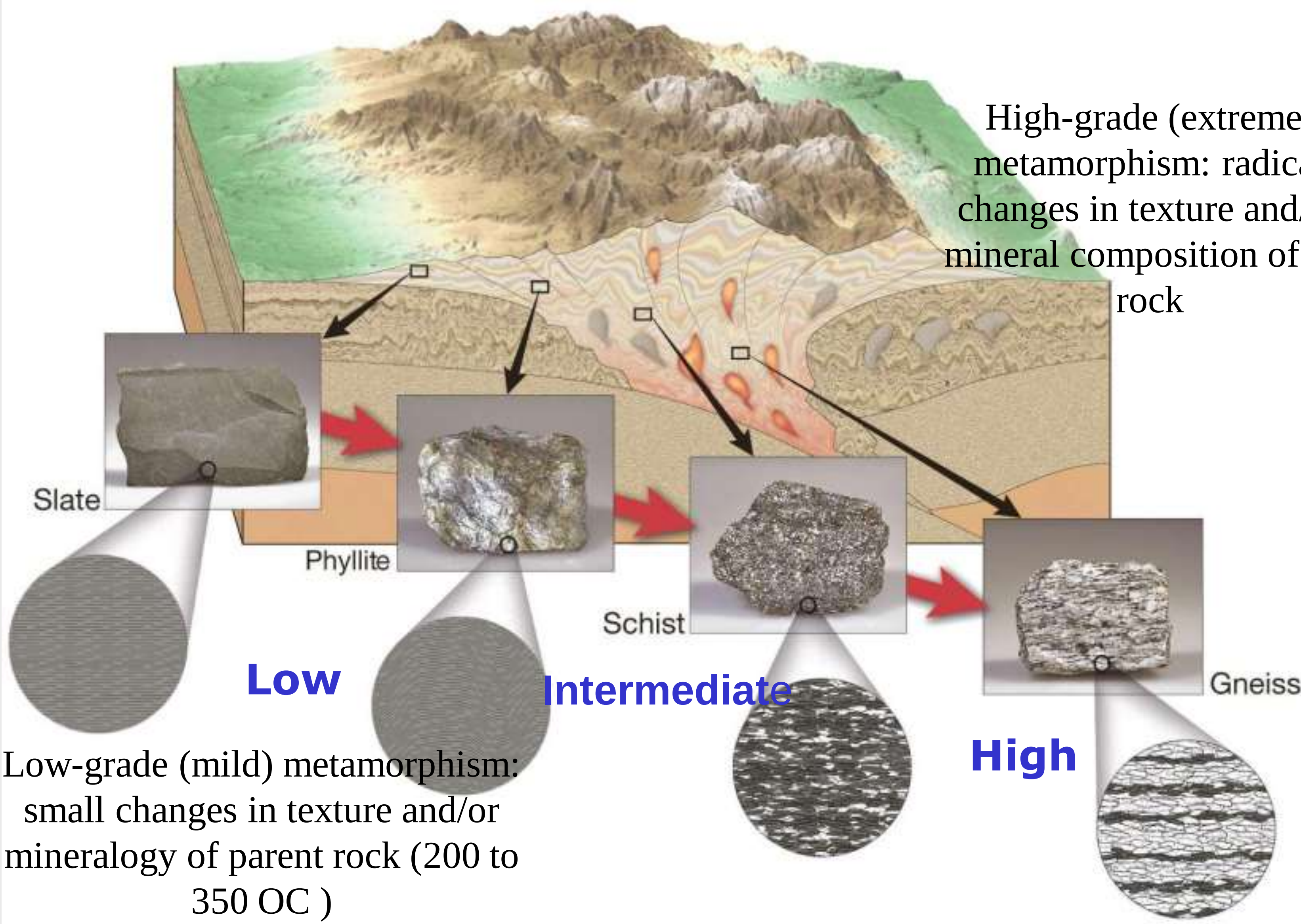
Greenschist

Eclogite

Engineering Geology

- Temperature & Pressure determine degree of metamorphism
- **Low-grade metamorphism- 200 to 350 C**
- **Intermediate-grade metamorphism-350 to 550 C**
- **High-grade metamorphism - very high temperatures, above 550C**

Metamorphic Grade



High-grade (extreme) metamorphism: radical changes in texture and/or mineral composition of the rock

Low-grade (mild) metamorphism: small changes in texture and/or mineralogy of parent rock (200 to 350 OC)

• CHANGES DURING METAMORPHISM

- Rock texture changes
- • Foliation: Parallel alignment of platy or elongate mineral
- grains (mica/amphibole) in a rock caused by directed stress.
- – slaty cleavage: parallel alignment of microscopic platy minerals (mainly mica). Low-grade Metamorphism
- – phyllitic texture: parallel, but wavy, foliation of fine-grained
- platy minerals (mainly mica and chlorite) exhibiting a shiny or
- glossy luster. Low-grade Metamorphism
- – schistosity: parallel to sub-parallel foliation of medium to
- coarse-grained platy minerals. Intermediate To High grade
- Metamorphism
- – gneissic layering: discontinuous light and dark layering due to
- mineral segregation. Intermediate To High-grade
- Metamorphism

- **•Mineralogy changes**
- –New minerals form that are stable under the new metamorphic conditions

Rock texture changes

1-Foliation: layering or banded appearance produced by exposure to heat and directed pressure

common foliated rock

Foliated: Slate
- Parallel orientation of grains
- Low grade metamorphic, slaty texture
- Protolith: shale/mudstone

Foliated: Phyllite
- Very fine grained mica
- Barely macroscopic
- Crenulated parallelism, sheen

Engineering Geology

Foliated: Chlorite Schist
- Mid-grade metamorphic rock
- Schistose texture

Foliated: Muscovite Schist

Foliated: Garnet Schist

Foliated: Gneiss

• High grade metamorphic
• Gneissic banding: 1mm to cm’s scale
• Protolith: Shale, mudstone, igneous rock

Non-Foliated and Foliated: Amphibolite

• Coarse grained, high grade
• Protolith : Mafic and Ultramafic igneous rocks

Non-Foliated: Marble

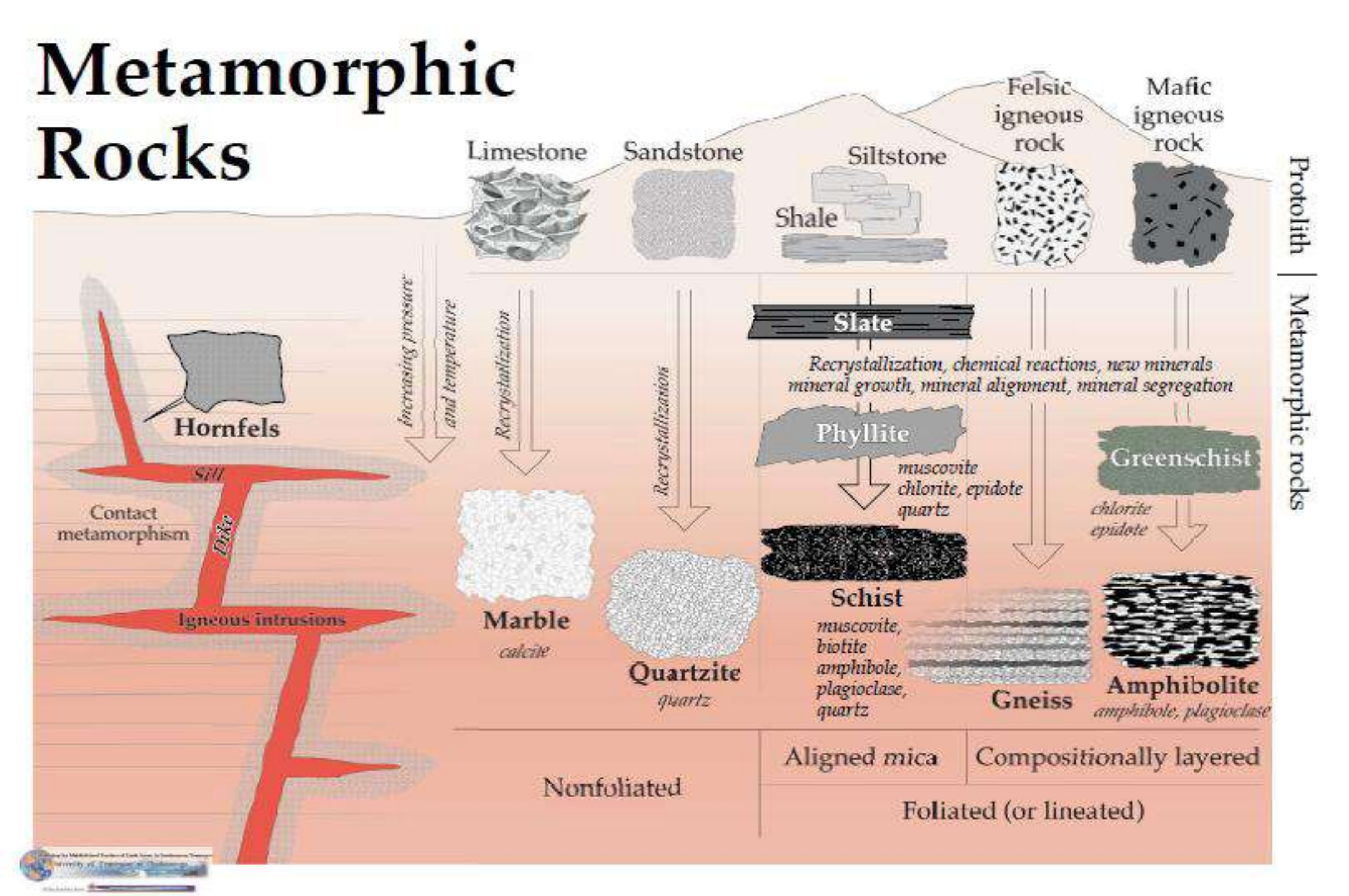
- $CaCO_3$
- Metamorphosed limestone!

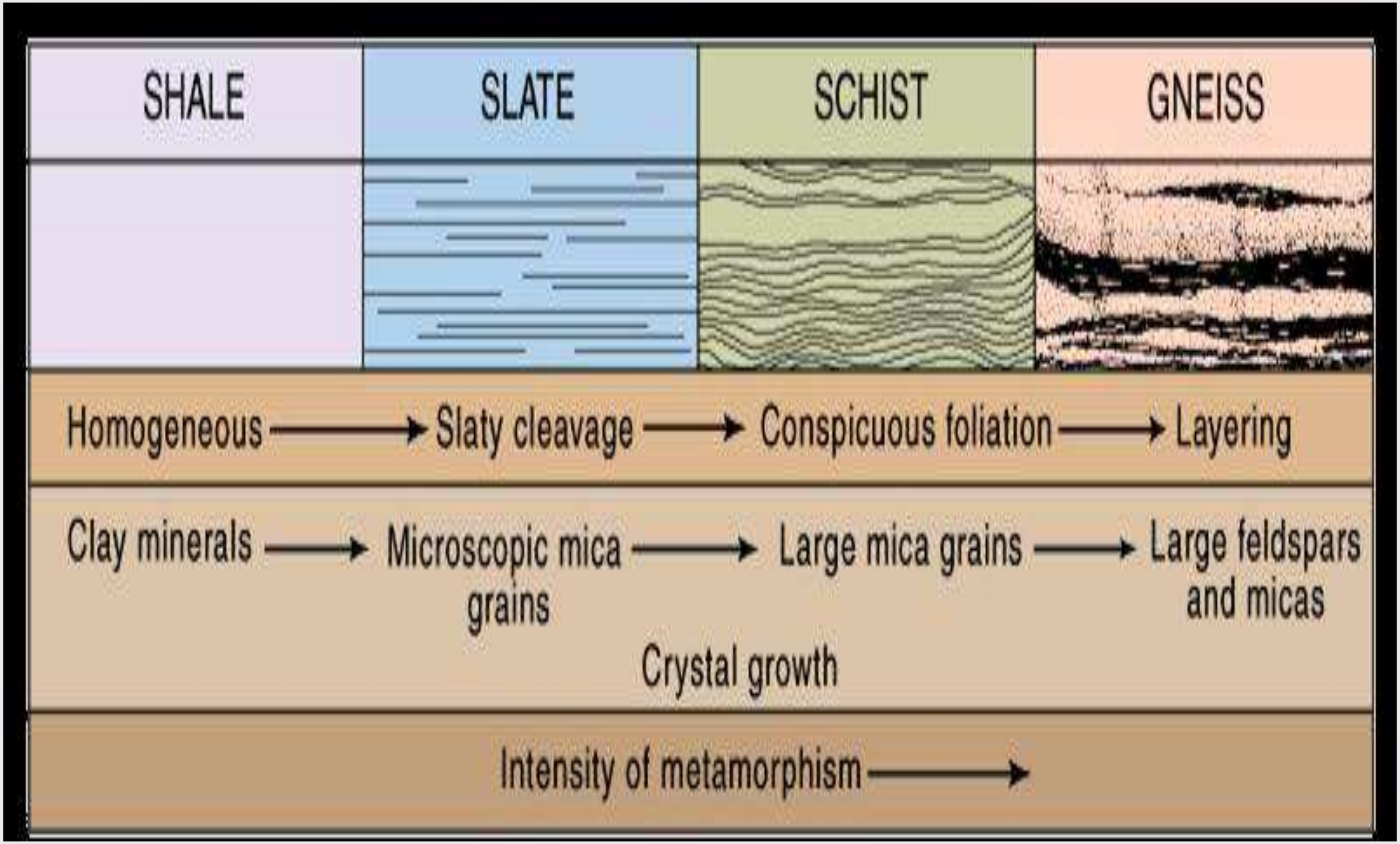
.

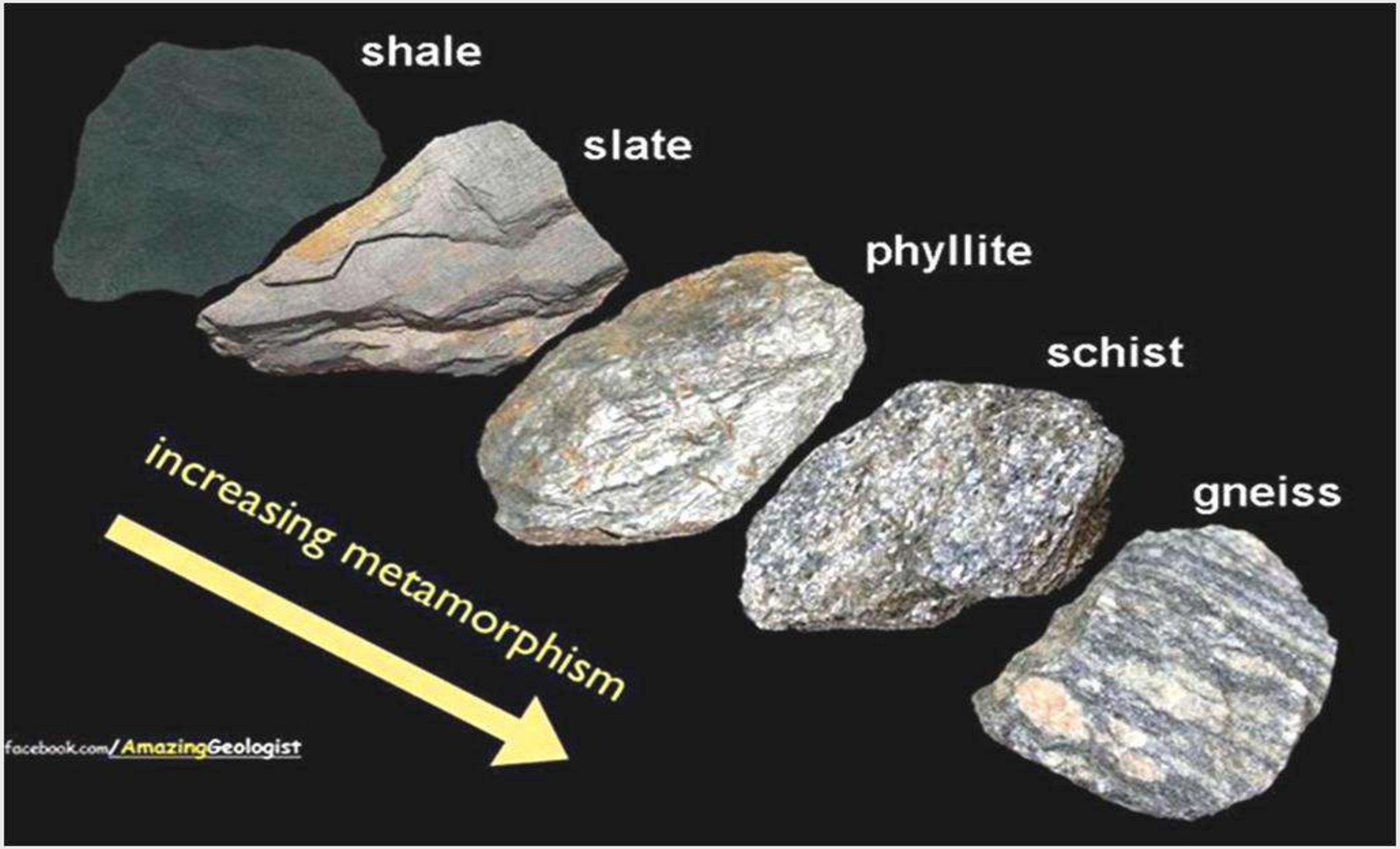
Non-Foliated: Quartzite

- Metamorphism of sandstone

Engineering Geology




SHALE
SLATE
SCHIST
GNEISS
Homogeneous → Slaty cleavage → Conspicuous foliation → Layering
Clay minerals → Microscopic mica grains → Large mica grains → Large feldspars and micas
Crystal growth
Intensity of metamorphism →


shale
slate
phyllite
schist
gneiss
increasing metamorphism
facebook.com/AmazingGeologist

Texture	Grain Size	Comments	Parent Rock	Rock Name
Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone	Slate
Foliated	Fine	Breaks along wavey surfaces, glossy sheen	Slate	Phyllite
Foliated	Medium to Coarse	Micaceous minerals dominate, scaly foliation	Phyllite	Schist
Foliated	Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite or volcanic rocks	Gneiss
Foliated	Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Gneiss, schist	Migmatite
Weakly Foliated	Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type	Mylonite
Weakly Foliated	Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate	Metaconglomerate
Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone	Marble
Nonfoliated	Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone	Quartzite
Nonfoliated	Fine	Usually, dark massive rock with dull luster	Any rock type	Hornfels
Nonfoliated	Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal	Anthracite
Nonfoliated	Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type	Fault breccia

Increasing Metamorphism (Slate → Phyllite → Schist → Gneiss → Migmatite)

Engineering Considerations of Metamorphic Rocks

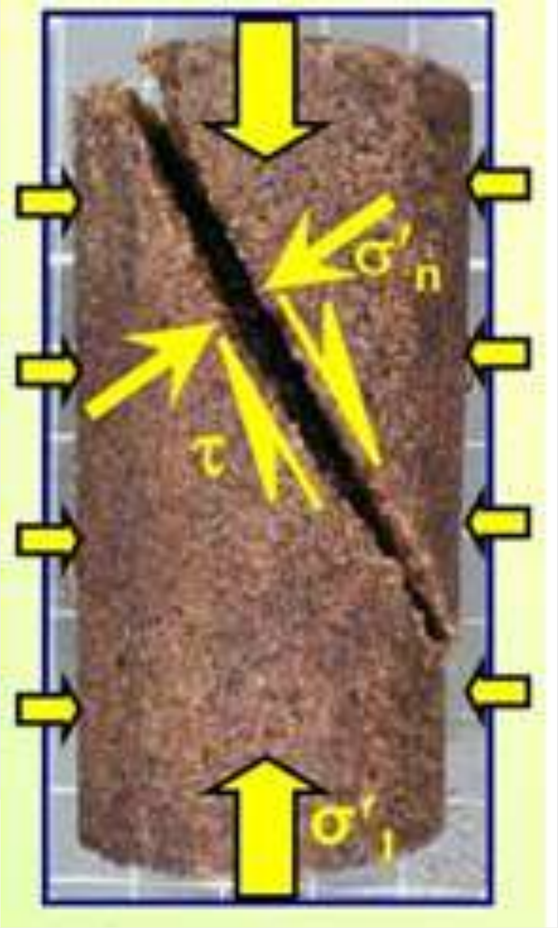
(1)The metamorphic rocks also have the Alkali-silica reaction problem when used as aggregates with Portland cement. The metamorphic rocks with this problem are argillite, phyllite, impure quartzite, and granite gneiss;

(2)Coarse-grained gneiss can be abraded severely when used as aggregates

(3)For metamorphic rocks the stability of rock mass greatly affected by the foliation orientation;

(4)Marble as a metamorphic rock from carbonate sedimentary rocks can cause similar problems, eg., leakage of reservoirs, sinkhile collapse, solution cavities, and channels

Rock Properties for Engineering



- Hussien aldeeky

Rock significant

Rock are significant for two major reasons in engineering:

(1)As building materials for constructions;

(2)As foundations on which the constructions are setting

For the consideration of rocks as construction material the engineers concern about:
(a)Density to some extent (for calculating the weight, load to the foundation, etc.);
(b)Strength;
(c)Durability;

For the consideration of rocks as the construction foundation the engineers concern about:

(a)Density
(b)Strength
(c)Compressibility

So the major difference is for material we want the durable (not have to be hard) rock, and for foundation we want hard rock (hard ones usually durable especially in a stable subsurface condition).

Engineering Geology

- **The rock type, the rock structure, any alteration to the rock, the in situ stress state and Hydro-geological regime will be important for all engineering**
- During Engineering planning, design and construction of works, there are many rock mechanics issues such as:
- • Evaluation of geological hazards;
- • Selection and preparation of rock materials;
- • Evaluation of cuttability and drillability of rock;
- • Analysis of rock deformations;
- • Analysis of rock stability;
- • Control of blasting procedures;
- • Design of support systems;
- • Hydraulic fracturing, and
- • Selection of types of structures

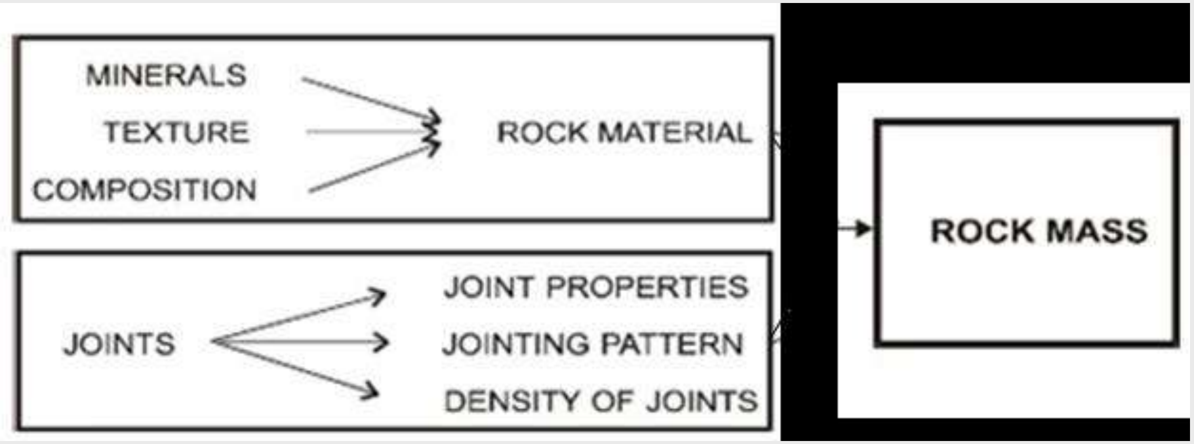
- **The same rock properties measured in lab and in field may have different values**
- **. This is because that in lab the rock properties are measured on small sized samples, but rocks in situ usually contains weakness planes (foliations, joints, cracks and fractures, etc.)**

4

- **In general the measured values on density, strength, seismic velocity, etc usually have a smaller value in field than in lab. Rock mass (*in situ) properties are fundamentally controlled by weakness planes* .**
- ***So it is a common practice to have a room for the variability when use lab measured value to field engineering projects.***

field-scale measures: 'rock mass properties' and are descriptions of the bulk strength properties of the rock mass. The nature of these properties are governed primarily by 'discontinuities', or planes of weakness, that are present in the rock mass. Examples of discontinuities are fractures, bedding planes, faults, etc.

The measured distance between fractures, bedding planes, and other structural features are also important when collecting field-scale data.



Factors influence the deformation and failure of rocks

- **1-Mineralogical composition and texture;**
- **2-Planes of weakness;**
- **3-Degree of mineral alteration;**
- **4-Temperature and Pressure conditions of rock formation;**
- **5-Pore water content**
- **6-Length of time and rate of changing stress that a rock experiences.**

1-Mineralogical composition and texture

-Very few rocks are homogeneous, continuous, isotropic (non directional) and elastic.
- Generally, the smaller the grain size, the stronger the rock.

-Texture influences the rock strength directly through the degree of interlocking of the component grains

2-Planes of weakness

-Rock defects such as micro fractures, grain boundaries, mineral cleavages, twinning planes and planar discontinuities influence the ultimate rock strength and may act as "surfaces of weakness" where failure occurs.

-When cleavage has high or low angles with the principal stress direction, the mode of failure is mainly influenced by the cleavage.

3-Degree of mineral alteration

- Anisotropy is common because of preferred orientations of minerals and directional stress history.
- Rocks are seldom continuous owing to pores and fissures (i.e. Sedimentary rocks).
- Despite this it is possible to support engineering decisions with meaningful tests, calculations, and observations.

4-Temperature and Pressure conditions of rock formation

- All rock types undergo a decrease in strength with increasing temperature, and an increase in strength with increasing confining pressure.
- At high confining pressures, rocks are more difficult to fracture as incipient fractures are closed

Engineering Geology

5-Pore water content

- The presence of moisture in rocks adversely affects their engineering strength.
-Reduction in strength with increasing H_2O content is due to lowering of the tensile strength, which is a function of the molecular cohesive strength of the material.

-6-Length of time and rate of changing stress that a rock experiences

- Most strong rocks , like granite show little time-dependent strain or creep.

Different degrees of rock weathering (from Johnson and DeGraff, 1988

Term	Description	Grade
fresh	no visible sign of rock material; perhaps slight discoloration on major discontinuity surfaces	I
slightly weathered	discoloration indicates weathering of rock material and discontinuity surfaces; all the rock material may be discolored by weathering.	II
moderately weathered	less than half of the rock is decomposed and /or disintegrated to a soil; fresh or discolored rock is present either as a continuous framework or as corestones.	III
highly weathered	more than half of the rock is decomposed and/or disintegrated to a soil; fresh or discolored rock is present either as a discontinuous framework or as corestones.	IV
completely weathered	all rock material is decomposed and/or disintegrated to soil; the original mass structure is still largely intact.	V
residual soil	all rock material is converted to soil; the mass structure and material fabric are destroyed; there is a large change in volume, but the soil has not been significantly transported.	VI

rock and rock mass properties can be divided into 5 groups:

1.physical properties (durability, hardness, porosity, etc.),

2. mechanical properties (deformability, strength),

3.hydraulic properties (permeability,)

4.thermal properties (thermal expansion, conductivity), a

5.in situ stresses

Since there are vast ranges in the properties of rocks, Engineers rely on a number of basic measurements to describe rocks quantitatively. These are known as Index Properties.

Index Properties of Rocks:

- **Porosity**- **Identifies the relative proportions of solids & voids;**

- **Density**- **a mineralogical constituents parameter;**

- **Sonic Velocity- evaluates the degree of fissuring;**

- **Permeability- the relative interconnection of pores;**

- **Durability**- **tendency for eventual breakdown of components or structures with degradation of rock quality,**

- **Strength**- **existing competency of the rock fabric binding components**

Engineering Geology

Density, specific gravity, porosity, and void ratio

Porosity: Proportion of void space given **by** $\mathbf{n = \upsilon_p / \upsilon_t}$, where υ_p is the pore volume and υ_t is the total volume. Typical values for sandstones are around 15%. In Igneous and Metamorphic rocks, a large proportion of the pore space (usually < 1-2%) occurs as planar "fissures". With weathering this increases to > 20%. Porosity is therefore an accurate index of rock quality.

Density: Rocks exhibit a greater range in density than soils. Knowledge of the rock density is important to engineering practice. A concrete aggregate with higher than average density can mean a smaller volume of concrete required for a gravity retaining wall or dam. Expressed as weight per unit volume.

$$\rho = M \div V$$

$$Gs = \rho s \div \rho w$$

Density:

$$\rho = \frac{m}{v}$$

Specific gravity:

$$G_s = \frac{\rho_s}{\rho_w}$$

Porosity:

$$n = \frac{v_{pore}}{v_{total}}$$

Void ratio:

$$e = \frac{v_{pore}}{v_{skeleton}}$$

Rock with higher density usually corresponds to higher strength and better material for engineering construction.

porosity, and void ratio

The limits of the value of porosity:

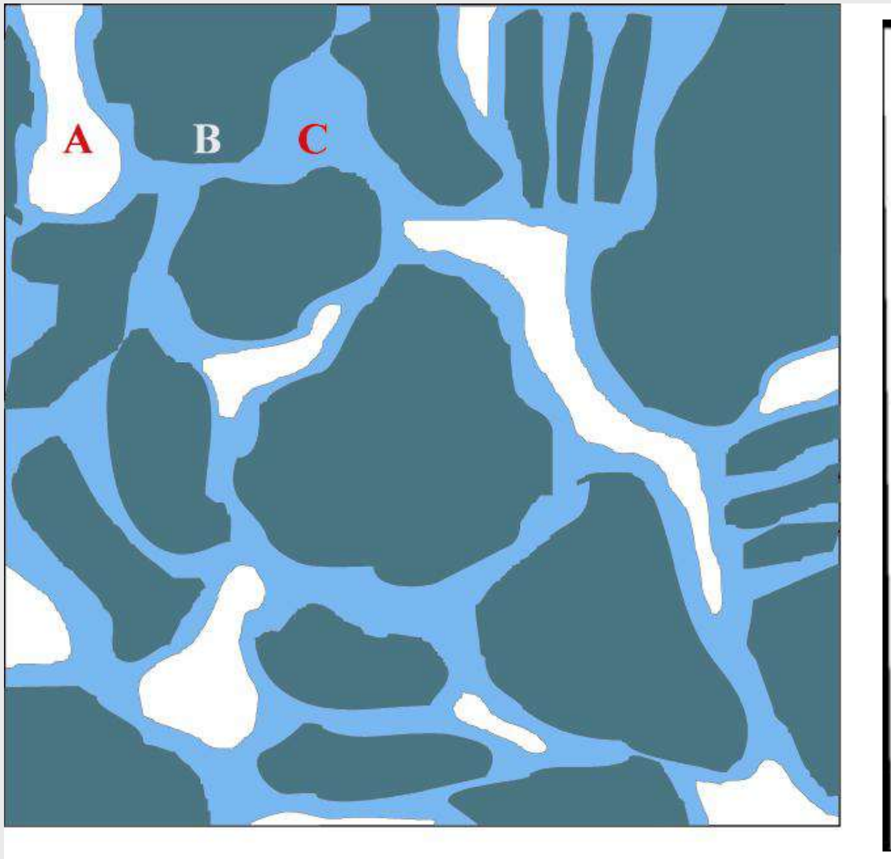
$$\max(n) = \frac{v_{pore}}{v_{total}} = 1, \qquad \min(n) = \frac{v_{pore}}{v_{total}} = 0$$

The limits of the value of Void ratio:

$$\max(e) = \frac{v_{pore}}{v_{skeleton}} \to \infty, \qquad \min(e) = \frac{v_{pore}}{v_{skeleton}} = 0$$

So

$$n = \frac{e}{1+e}, \qquad e = \frac{n}{1-n}$$



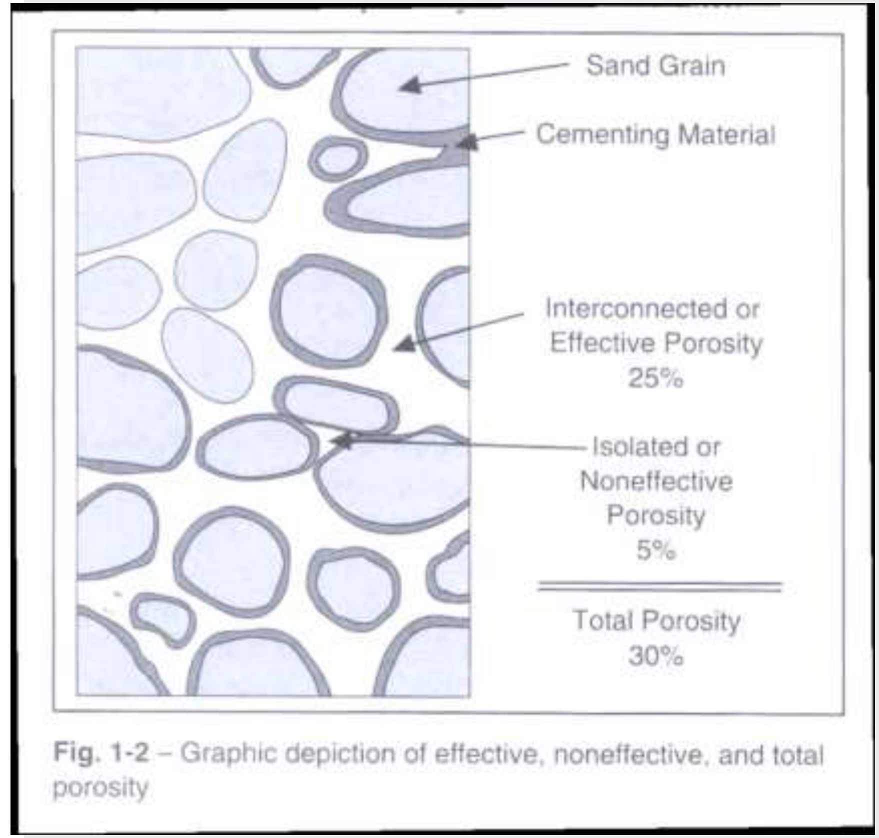
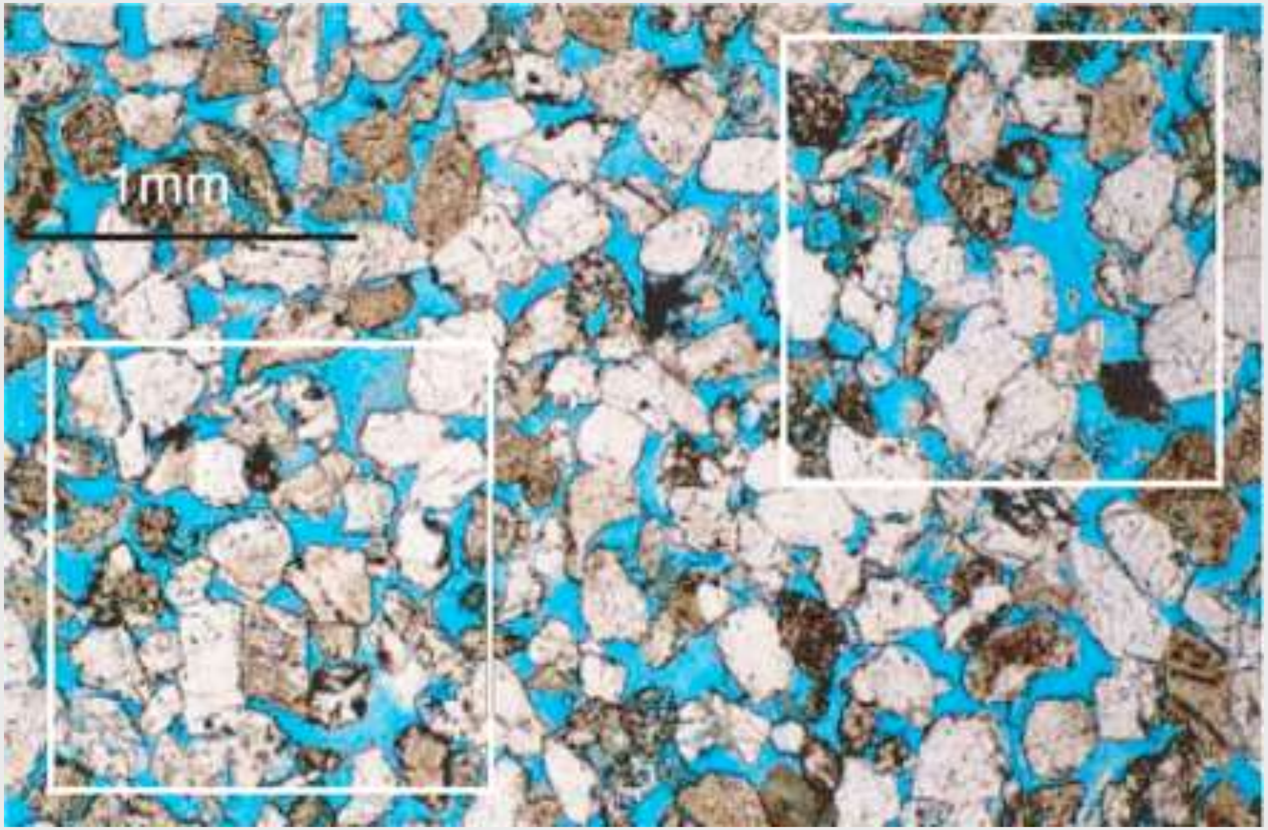


Fig. 1-2 – Graphic depiction of effective, noneffective, and total porosity

Schematic representation of porous medium indicating relationship between air (A), solid skeleton (B) and water (C).

Porosity types



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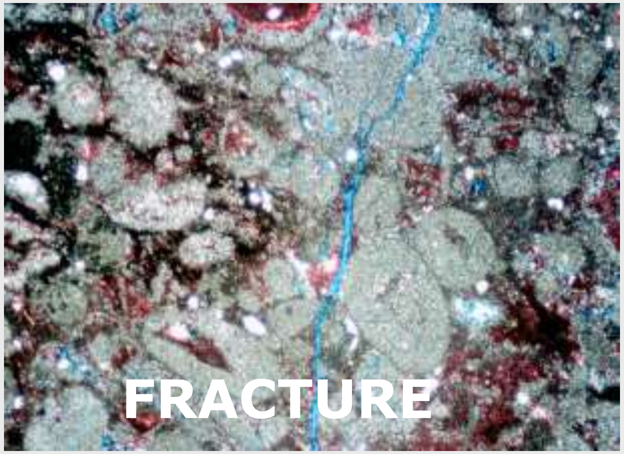
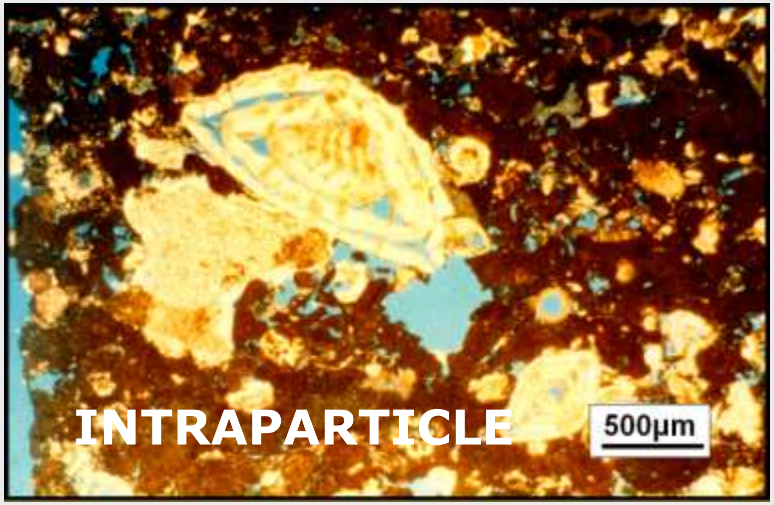
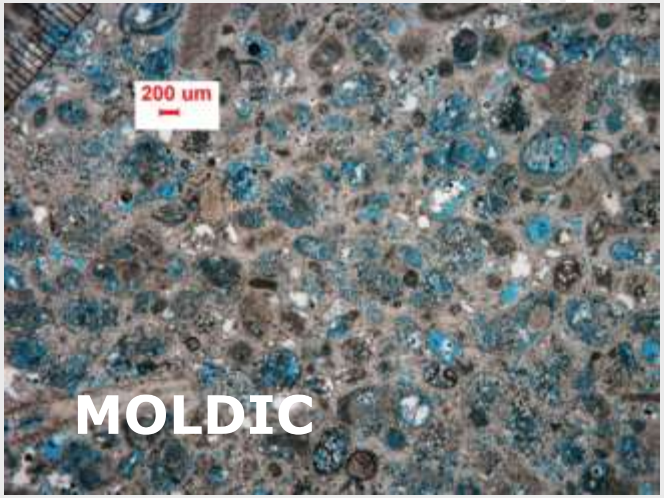






Porosity does not give any information about

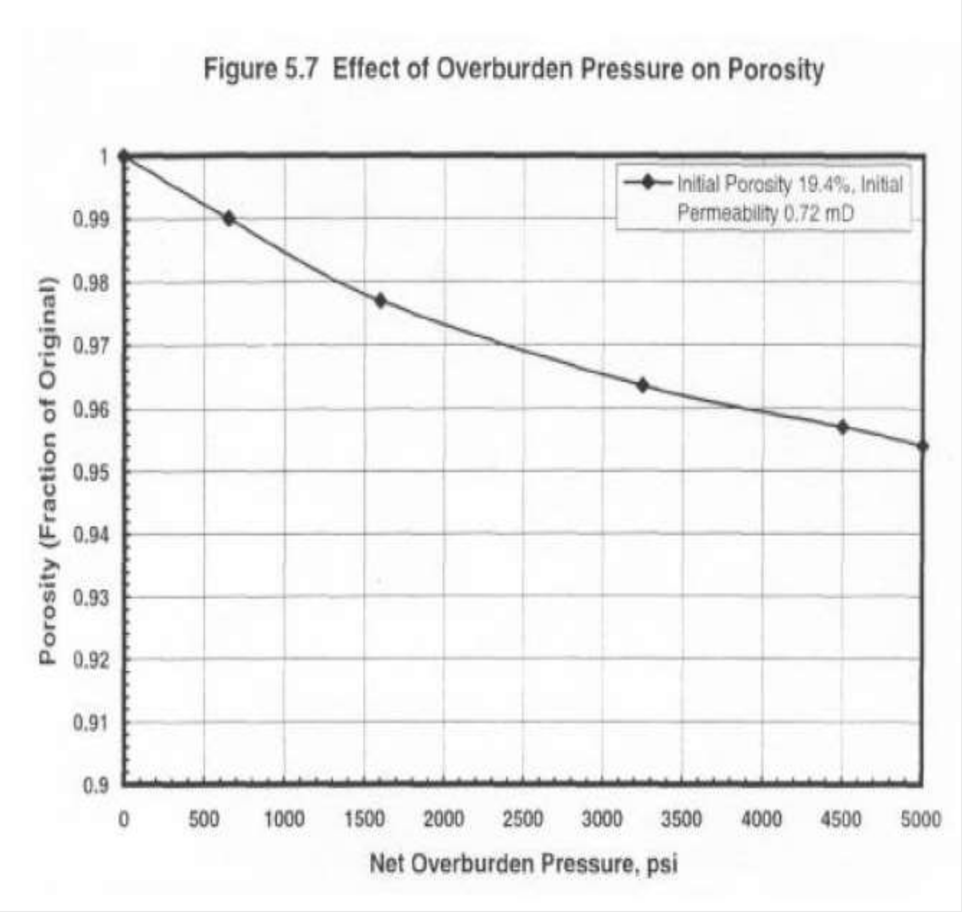
1- Pore size

2-pore distribution

3- pore connectivity

Pock of the same porosity can have widely different physical properties

Porosity depends on stress conditions

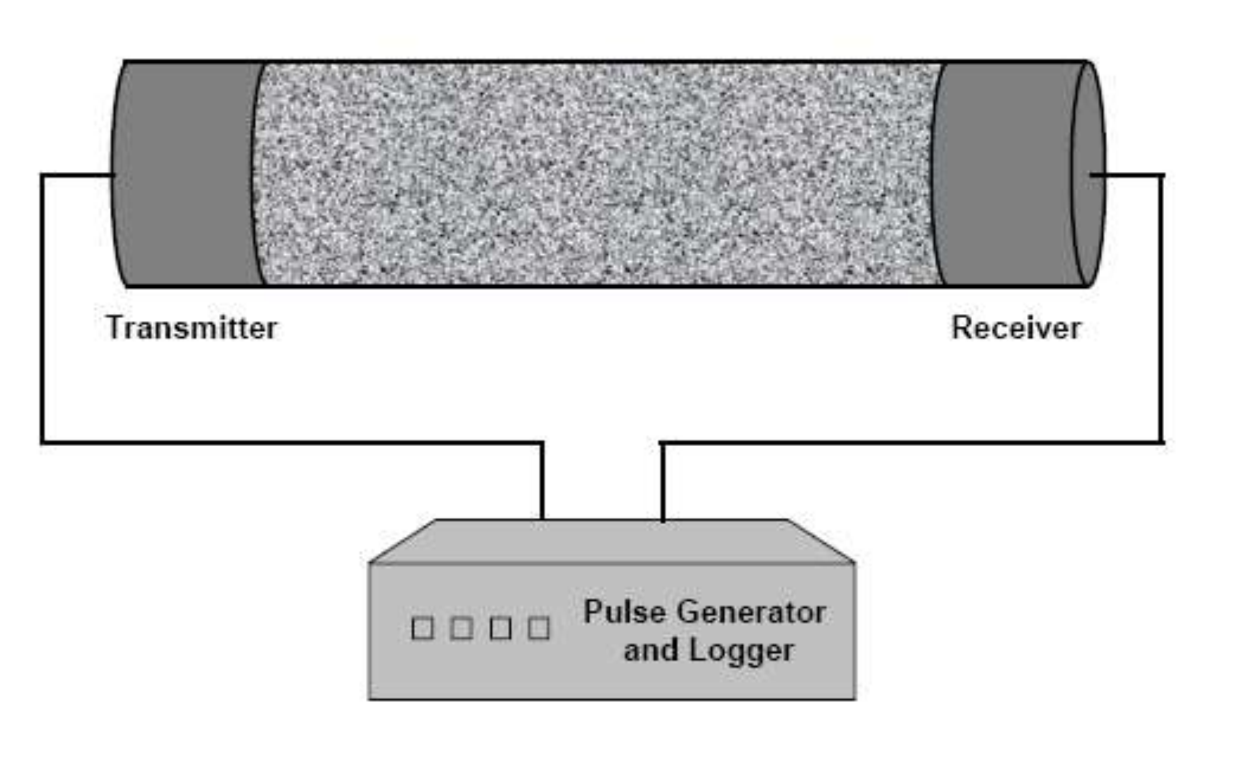


Rock Type	Porosity %
Granite	0.4-4.0
Andesite	0.1-11
Gabbro,Diorite, Diabase	0.1-1.0
Basalt	0.2-22
Limestone	0.2-4.4
Sandstone	1.6-26
Chert	4
Gneiss	0.3-2.2
Marble	0.3-2.1
Quartzite	0.3-0.5
Slate	0.1-1.0

Pulse Sonic Velocity

Sonic Velocity: Use longitudinal velocity V_l measured on rock core. Velocity depends on elastic properties and density, but in practice a network of fissures has an overriding effect. Can be used to estimate the degree of fissuring of a rock specimen by plotting against porosity (%).

The value of the compressional wave velocity can serve as an indicator of the degree of weathering. For instance, **Dearman et al. (1978**) have tabulated ranges of velocity for various degrees of weathering in granites and gneisses: fresh, 3050-5500 m/s; slightly weathered, 2500- 4000 m/s; moderately weathered, 1500-3000 m/s; highly weathered, 1000-2000 m/s; completely weathered to residual soil, 500-1000 m/s. Note that an empirical upper limit for the velocity of 2000 m/s is often used in practice to define geologic materials that can be ripped without difficulty.


Transmitter
Receiver
Pulse Generator
and Logger

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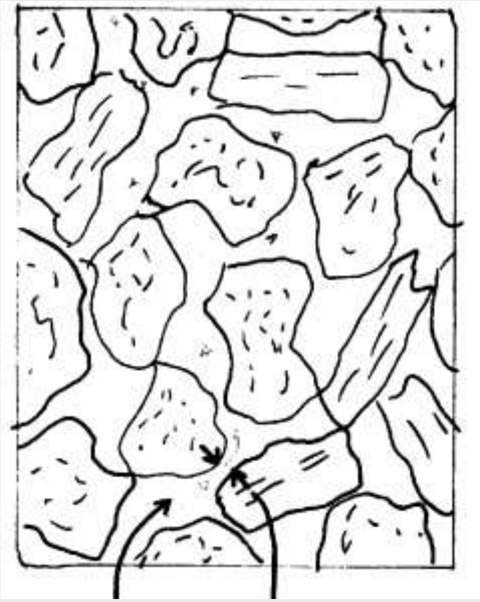
Rock	Dry Density (g/cm^3)	Porosity (%)	Schmidt Hardness Index	Cerchar Abrasivitiy Index	P-Wave Velocity (m/s)	S-Wave Velocity (m/s)	Coefficient of Permeability (m/s)
Igneous							
Granite	2.53 – 2.62	1.02 – 2.87	54 – 69	4.5 – 5.3	4500 – 6500	3500 – 3800	$10^{-14} – 10^{-12}$
Diorite	2.80 – 3.00	0.10 – 0.50		4.2 – 5.0	4500 – 6700		$10^{-14} – 10^{-12}$
Gabbro	2.72 – 3.00	1.00 – 3.57		3.7 – 4.6	4500 – 7000		$10^{-14} – 10^{-12}$
Rhyolite	2.40 – 2.60	0.40 – 4.00					$10^{-14} – 10^{-12}$
Andesite	2.50 – 2.80	0.20 – 8.00	67	2.7 – 3.8	4500 – 6500		$10^{-14} – 10^{-12}$
Basalt	2.21 – 2.77	0.22 – 22.1	61	2.0 – 3.5	5000 – 7000	3660 – 3700	$10^{-14} – 10^{-12}$
Sedimentary							
Conglomerate	2.47 – 2.76			1.5 – 3.8			$10^{-10} – 10^{-8}$
Sandstone	1.91 – 2.58	1.62 – 26.4	10 – 37	1.5 – 4.2	1500 – 4600		$10^{-10} – 10^{-8}$
Shale	2.00 – 2.40	20.0 – 50.0		0.6 – 1.8	2000 – 4600		
Mudstone	1.82 – 2.72		27				$10^{-11} – 10^{-9}$
Dolomite	2.20 – 2.70	0.20 – 4.00			5500		$10^{-12} – 10^{-11}$
Limestone	2.67 – 2.72	0.27 – 4.10	35 – 51	1.0 – 2.5	3500 – 6500		$10^{-13} – 10^{-10}$
Metamorphic							
Gneiss	2.61 – 3.12	0.32 – 1.16	49	3.5 – 5.3	5000 – 7500		$10^{-14} – 10^{-12}$
Schist	2.60 – 2.85	10.0 – 30.0	31	2.2 – 4.5	6100 – 6700	3460 – 4000	$10^{-11} – 10^{-8}$
Phyllite	2.18 – 3.30						
Slate	2.71 – 2.78	1.84 – 3.64		2.3 – 4.2	3500 – 4500		$10^{-14} – 10^{-12}$
Marble	2.51 – 2.86	0.65 – 0.81			5000 – 6000		$10^{-14} – 10^{-11}$
Quartzite	2.61 – 2.67	0.40 – 0.65		4.3 – 5.9			$10^{-14} – 10^{-13}$

Permeability

due to open joints and fractures : As well as the degree of interconnection between pores / fissures, its variation with change in normal stress assesses the degree of fissuring of a rock. Dense rocks like granite, basalt, schist and crystalline limestone possess very low permeabilities as lab specimens, but field tests can show significant permeability

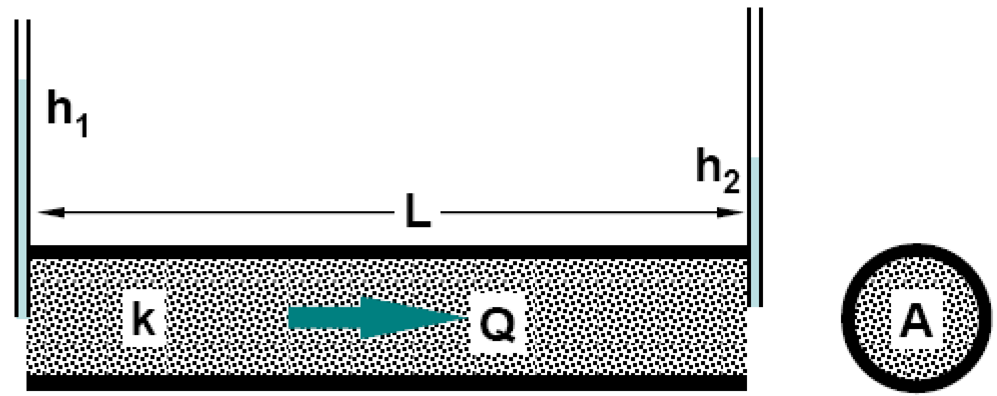


Permeability related to the following

- **volume of pores**
- **degree of openness or connection between pores and fractures**
- **Grain size**
- **Sorting of grains**

Permeability is a measure of the ability of a material to transmit fluids. It is given by the Darcy's law,

$$Q = A\,k\,(h_1 - h_2)/L$$



Q = Flow rate
k = Coefficient of permeability
A = cross section area
L = length
h_1, h_2 = hydraulic head

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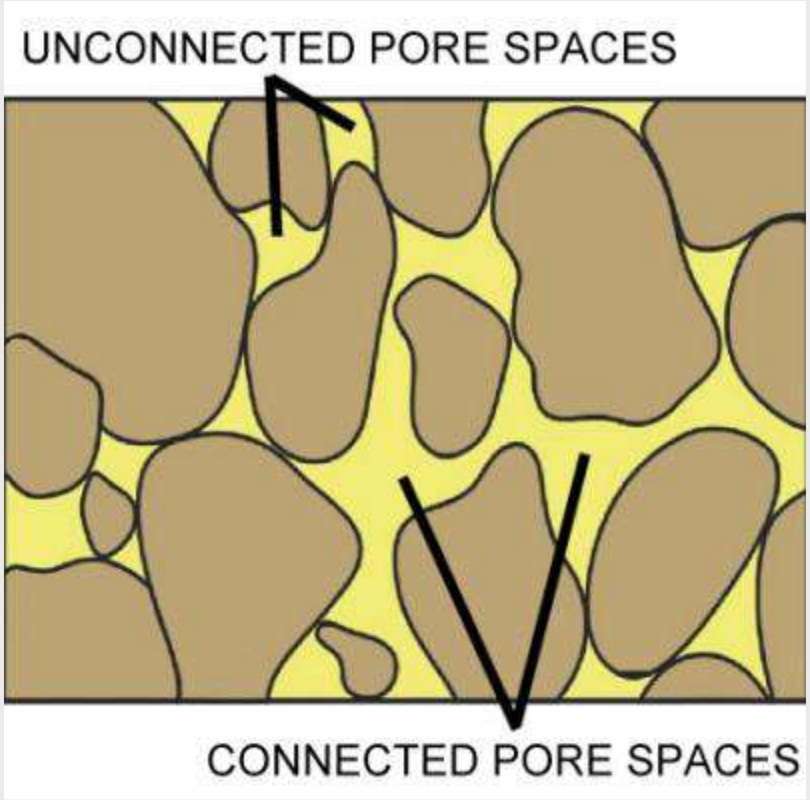
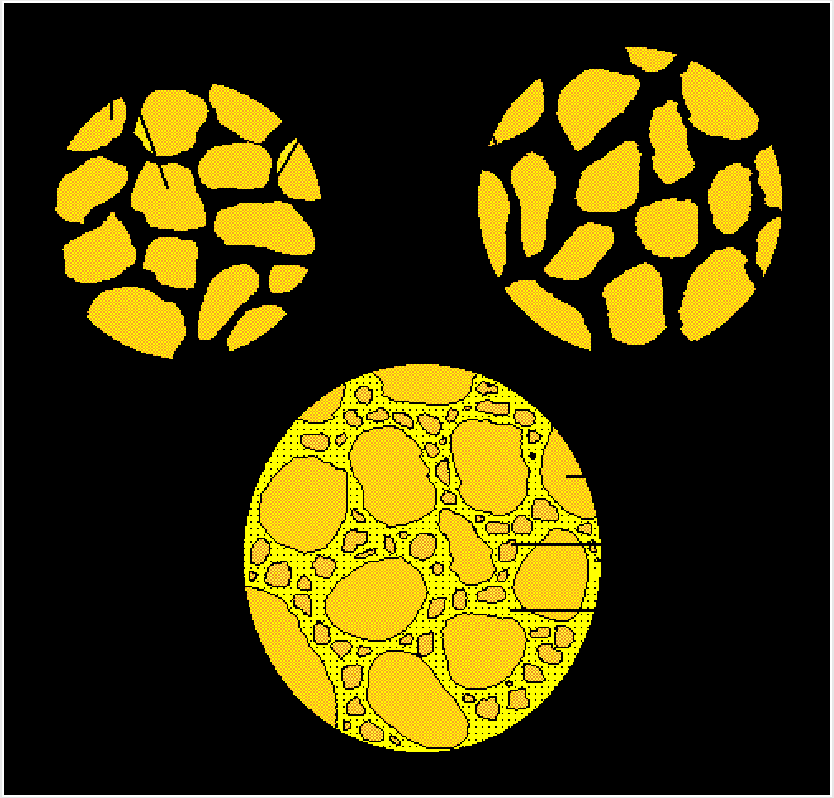
Permeability	Pervious				Semi-Pervious				Impervious				
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	
κ (cm^2)	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}
κ (millidarcy)	10^{+8}	10^{+7}	10^{+6}	10^{+5}	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001

Source: modified from Bear, 1972


UNCONNECTED PORE SPACES
CONNECTED PORE SPACES

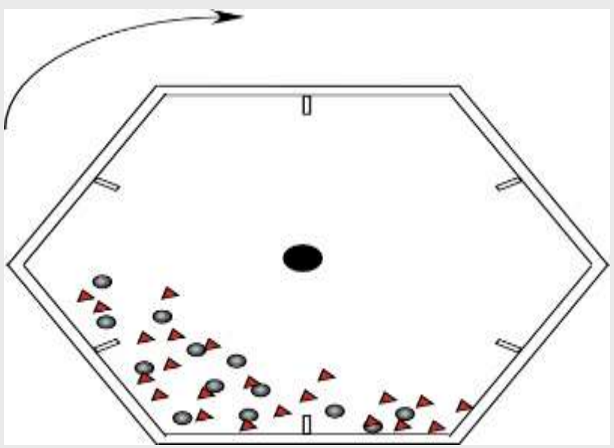


Abrasion resistance test:

Sample weight 5 kg, specific size gradation specific number of steel spheres, interior projecting shelf, 500 revolutions, then use #12 sieve with d=0.141 mm.

Percent loss = (material finer than #12 sieve) / (original weight)

For highway construction, we need percent loss less than 35 – 50 %.



A typical Los Angeles abrasion test values

Rock types	L.A abrasion loss
General values	
Hard , igneous rocks	10
Soft , limestone and sandstones	60
Range for specific rocks	
Basalt	10-17
Dolomite	18-30
Gneiss	33-57
Granite	27-49
Limestone	19-30
Quartzite	20-35

(Source :Bull. Mater. Sci., Vol. 31, No. 2)

Example:

Mass placed in abrasion machine 5,000 g
Mass of intact particles left after test 3,891 g
(1 pound = 454 grams)

$$\% \, loss = \frac{(5000 - 3891)}{5000} = 22\%$$

Common Values

Basalt » 14%
Limestone » 30%
Granite » 40%,
Marine Limestone » 53%

slake durability test

Approximately 500 g of broken rock lumps (~ 50 g each) are placed inside a rotating drum which is rotated at 20 revolutions per minute in a water bath for 10 minutes. The drum is internally divided by a sieve mesh (2mm openings) and after the 10 minutes rotation, the percentage of rock (dry weight basis) retained in the drum yields the "slake durability index (I_d)". A six step ranking of the index is applied (very high-very low). as shown in tables 1 and 2. Used to evaluate shales and weak rocks that may degrade in service environment.

D: the mass of the empty dry drum.

A: The initial dry mass of rock plus drum

C: dry mass of the drum and the rock after two cycles of wetting and drying, From a practical point of view, slaking of clay-bearing rocks requires protection of all outcrops. Shot crete or any other form of protective layers are usually adequate. After slaking for 10 minutes the rock samples were then dried in an oven at a temperature of 105 □C for up to 6 hrs

$$I_{d2} = \frac{(C-D)}{(A-D)}.100\%$$

Visual description of the rock samples retained in the test drum after the second cycle (after Franklin and Chandra. 1972).

Type	Description
I	Pieces remain virtually unchanged
II	Consist of large and small pieces
III	Exclusively small fragments

Slake durability index classification (after Franklin and Chandra. 1972).

ID_2 (%)	Durability classification
0 – 25	Very Low
26 – 50	Low
51 – 75	Medium
76 - 90	High
91 – 95	Very High
96 - 100	Extremely High

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Durability test

.

For durability test there are two major methods:

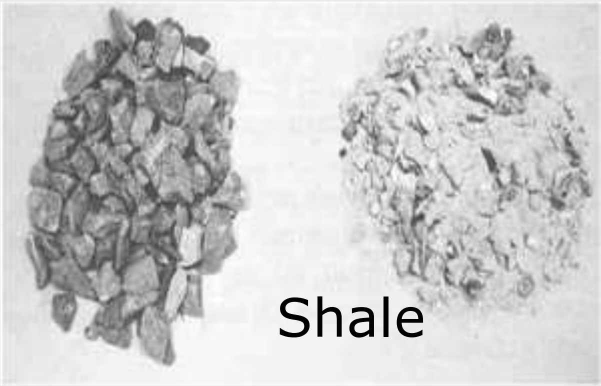
1) sulfate soundness: Example

-Soaking the material under test into sulfate solution and put it into oven for drying to crystal for 5 cycles, then use the same sieve and get the percent loss;

-Provides a measure of the aggregates durability when exposed to the elements

- measures resistance to rapid weathering
- important in frost-susceptible regions

Sulfate Soundness Test



Example

Original mass of sample = 2,175 g

Mass of particles after test = 1,847 g

$$\% \ loss = \frac{(2175 - 1847)}{2175} \times 100\% = 15.1\%$$

2) freezing-thawing test:

Freezing and thawing the material for 25 cycles, then use the same sieve and get the percent loss;

For highway construction material, the maximum loss for concrete aggregate is 12-15%, and for base course this number is 15-18%.

Tests and observations at the site

•**degree of cementation** – related to rock durability and permeability

•**stability of cementation** – is the cement soluble or reactive

•**moisture content** -

–poorly cemented/high moisture content

–well cemented/low moisture content

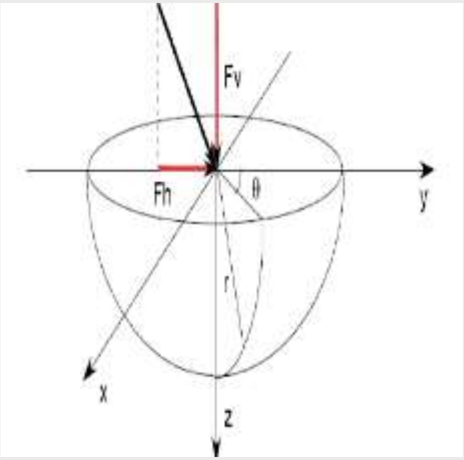
Rock characteristics

Class	Rock Type	Toughness	Hardness	Durability	Chemical Stability	Surface Character	Crushed Shape
Igneous	Granite Syenite	Good	Good	Good	Excellent	Fair to good	Good
	Gabbro-diorite	Excellent	Excellent	Excellent	Excellent	Excellent	Good
	Diabase Basalt	Excellent	Excellent	Excellent	Excellent	Excellent	Good
	Felsite	Excellent	Good	Good	Questionable	Fair	Fair
Sedimentary	Conglomerate Breccia	Poor	Poor	Poor	Variable	Good	Fair
	Sandstone	Variable	Variable	Variable	Good	Good	Good
	Shale	Poor	Poor	Poor	Questionable	Fair to good	Poor
	Limestone Dolomite	Good	Good	Fair to good	Good	Good	Good
	Chert	Good	Excellent	Poor	Poor	Fair	Poor
Metamorphic	Gneiss	Good	Good	Good	Excellent	Good	Good to fair
	Schist	Good	Good	Fair	Excellent	Poor to fair	Poor to fair
	Slate	Good	Good	Fair to good	Excellent	Good	Poor
	Quartzite	Excellent	Excellent	Excellent	Excellent	Good to fair	Fair
	Marble	Good	Fair	Good	Good	Good	Good

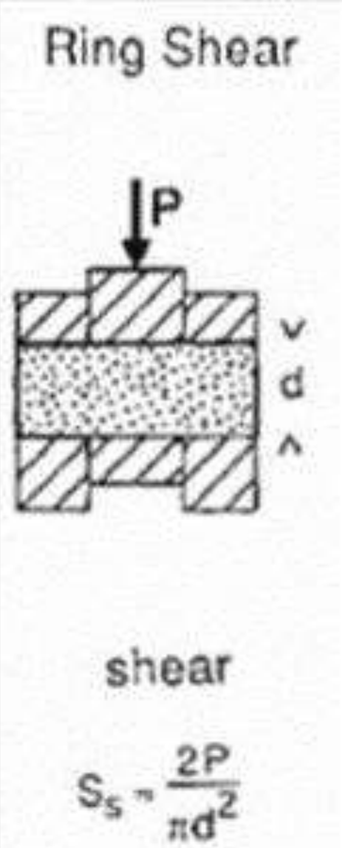
Rock Strength

The strength is the stress required to break down the rock sample. So we first need define the concept of stress.

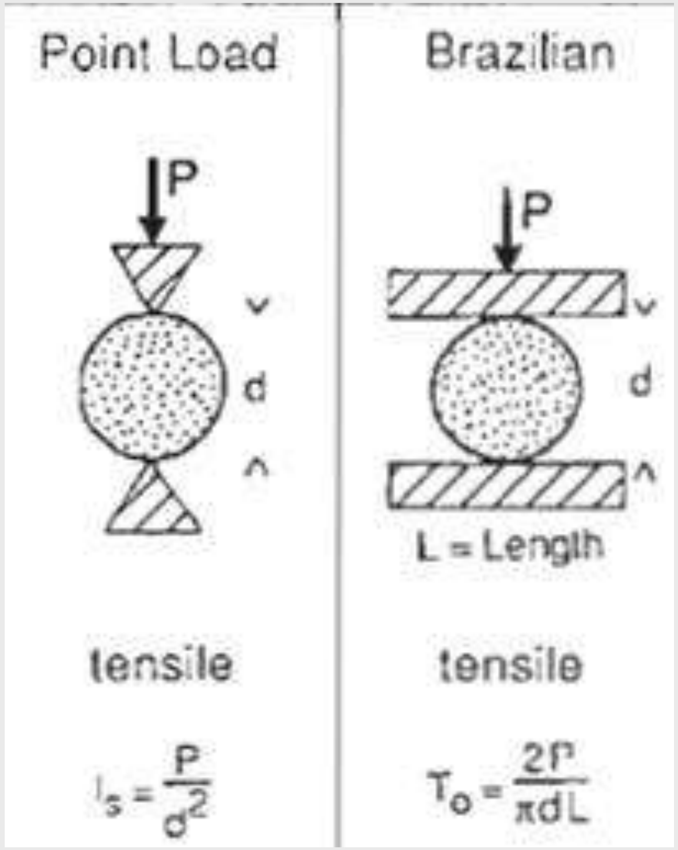
What is stress? Stress is the force per area applied on the object, it is in the same unit as pressure. In SI nit system the unit of stress is Pa for Pascal. The pressure is a concept in fluid: it corresponds to the normal stress when we expand the concept of pressure into the case for solid. Like the fluid, solid can sustain a force normal to its surface . Nevertheless, unlike the fluid, solid can also sustain the forces parallel to its surface



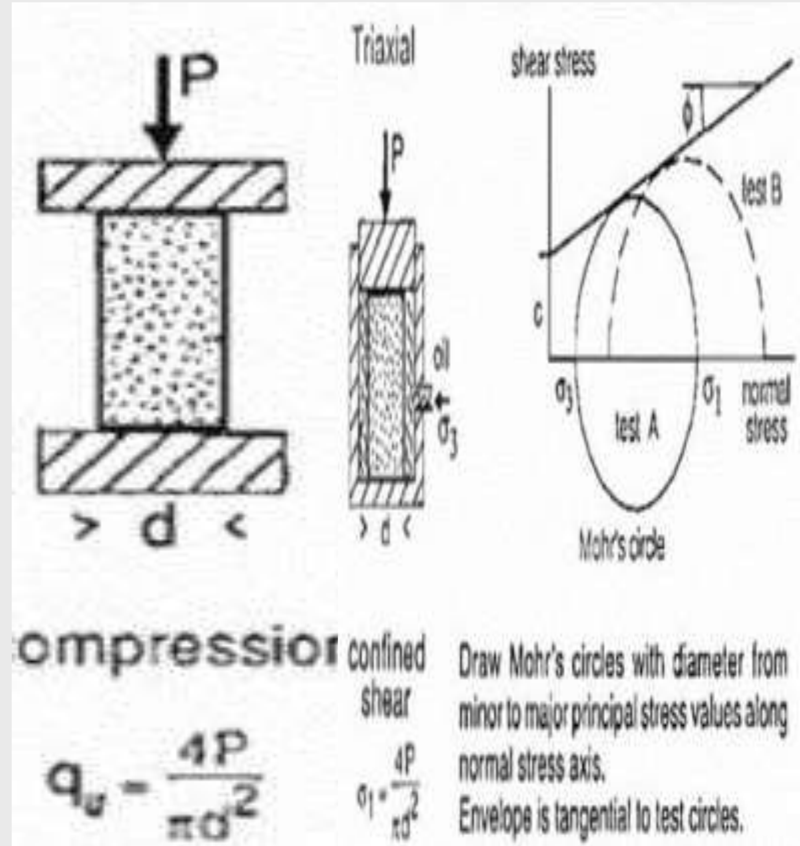
Shear



Tensile



Compression



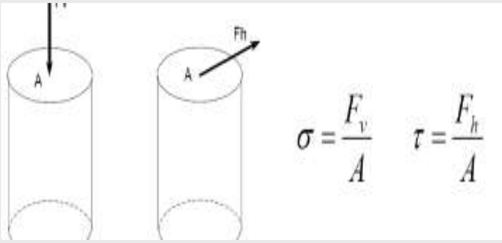
Normal Stress and Shear Stress

We can use the Greek letter **σn** to denote the normal stress, and **σs** for the shear stress:

The normal stress can be either a positive or a negative value, means either a tensile normal stress, or a compressive normal stress. The left sketch in the above figure shows a case of compressive normal stress. In earth science we define the compressive normal stress is the positive one since the rocks in depth are constantly experiencing

$$\sigma n = \frac{Pv}{A}$$

$$\sigma s = \frac{Ph}{A}$$



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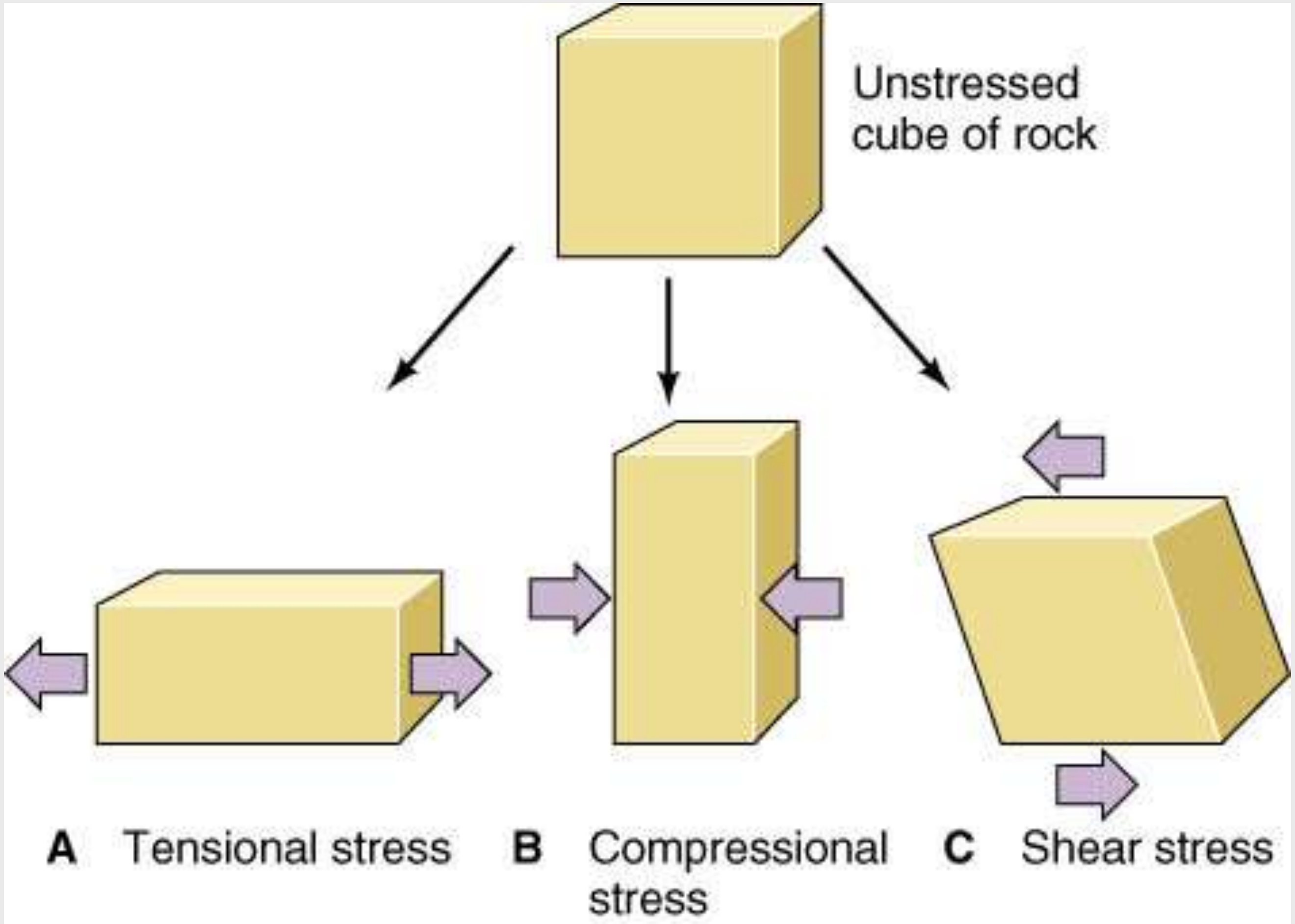


Typical rock strength values

Rock	Tmin	Tmax	Smin	Smax	Cmin	Cmax
Granite	970	3470	1950	6940	13900	34720
Basalt	1390	4170	2780	8330	20800	41700
Quartzite	1390	4170	2780	8330	20830	41660
Marble	970	2800	2080	4170	7150	34720
sandstone	560	3470	1100	5560	2780	23600
limestone	700	3470	1100	6940	410	34700
All strength are in psi unit						

1 psi = 6.895 kPa

Uniaxial Compressive Strength (UCS) Test

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the uniaxial compressive strength (a.k.a. unconfined compressive strength).

The unconfined compressive strength is measured in accordance with the procedures given in ASTM D7012 - *Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature, utilizing a specimen with the length to diameter ratio between 2:1 to 2.5:1. There are high requirements on the flatness of the end-surfaces in order to obtain an even load distribution. The specimens are loaded axially up to failure or any other prescribed level whereby the specimen is deformed and the axial and the radial deformation can be measured using special equipment.*

The unconfined compressive strength is calculated by:

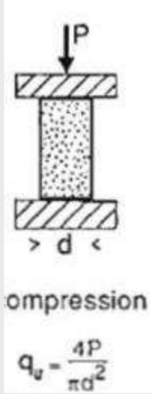
$$\sigma c = \frac{P}{Ac}$$

Where:

σc = Unconfined Compressive Strength

F = Maximum Failure Load (lbs.)

A = Cross sectional area of the core sample



Rock Deformation

Fundamental Definitions

First we need define deformation. The deformation is the change of shape and size of a material under loading. The elastic deformation is the part or the kind of deformation that can be recoverable, i.e., after the load is removed, the material changes back to its original shape and size, The part or kind of deformation that cannot be recovered is the plastic or ductile deformation.

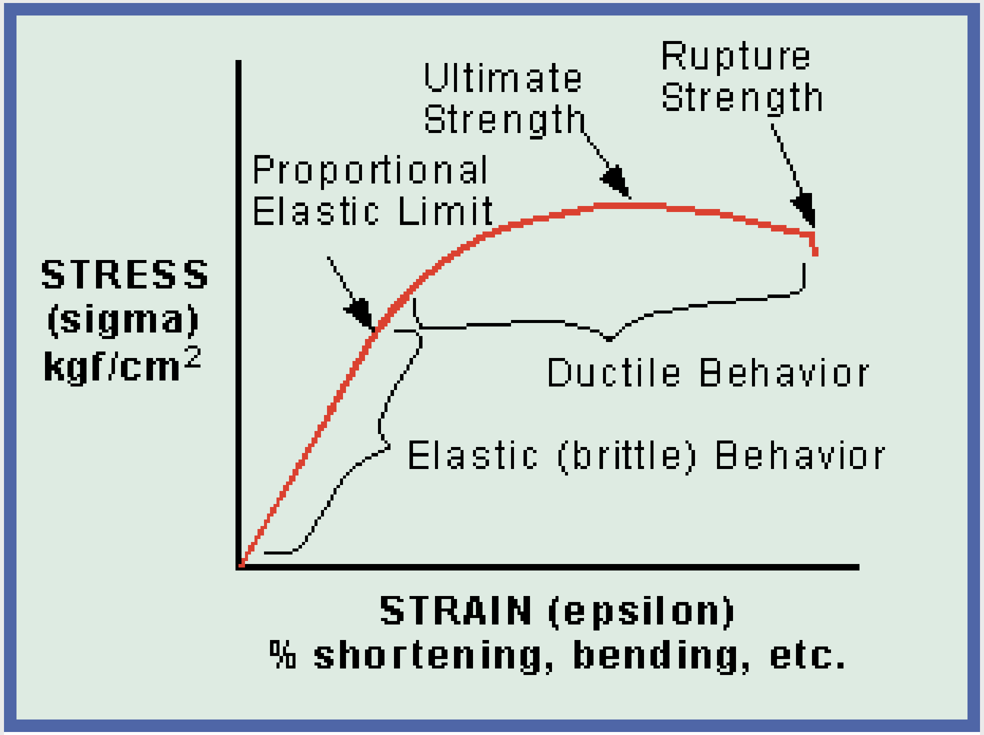
Correspondingly, the property of the material of elastic deformation is called elasticity; the property of plastic deformation is the plasticity.

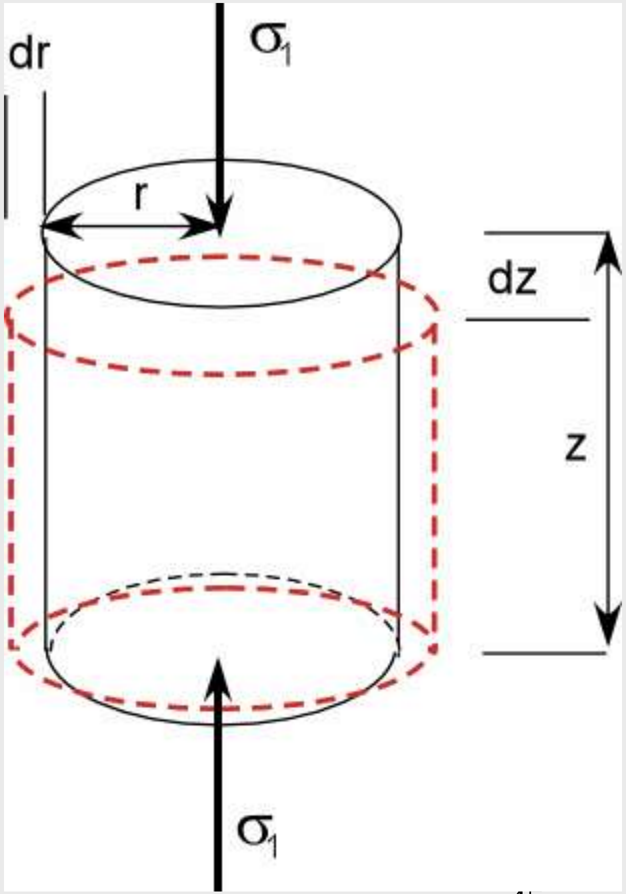
In a relatively loose definition, load is the external force acting of the material to cause deformation, so load and deformation is a pair of terms, one is the reason, the other is the result. In a more specific or more quantitative way there is another pair of terms to describe it. This is the stress and strain.

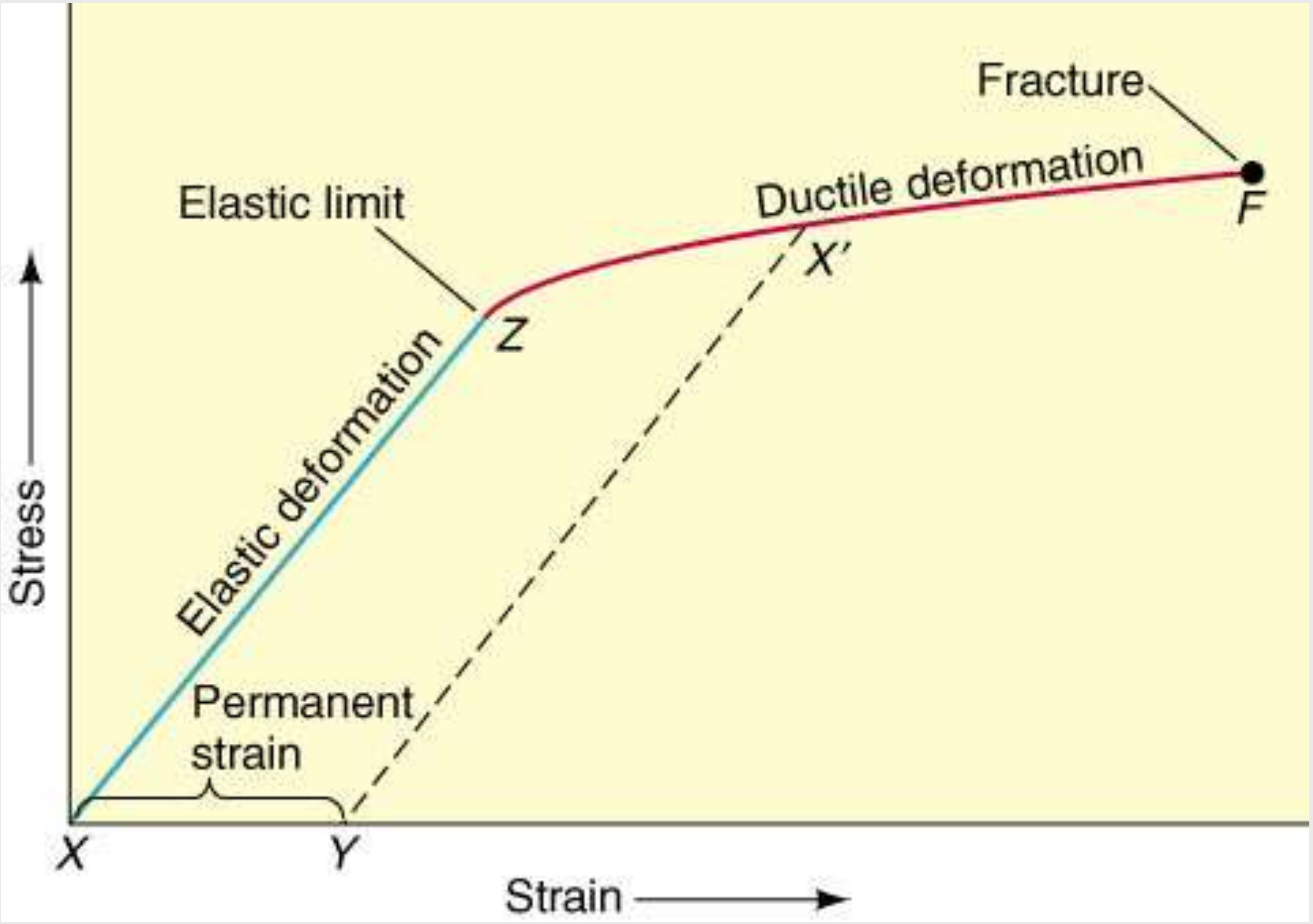
Table 7.4 Unconfined compressive strengths of the main rock types.

Descriptive term	Compressive strength ($MN\ m^{-2}$)	Indicative rock types
very weak	<1.25	some weakly compacted sedimentary rocks, some very highly weathered igneous or metamorphic rocks boulder clays
weak	1.25–5	
moderately weak	5–12.5	
moderately strong	12.5–50	some sedimentary rocks, some foliated metamorphic rocks, highly weathered igneous and metamorphic rocks
strong	50–100	some low-grade metamorphic rocks, marbles, some strongly cemented sedimentary rocks, some weathered and metamorphic igneous rocks
very strong	100–200	mainly plutonic, hypabyssal and extrusive igneous rocks (medium to coarse grained), sedimentary quartzites, strong slates, gneisses
extremely strong	>200	fine-grained igneous rocks; metamorphic quartzites, some hornfelses

The stress-strain relation of rock deformation
For a uni-axial loading test






Fracture
Elastic limit
Ductile deformation
F
X'
Z
Elastic deformation
Stress
Permanent
strain
X
Y
Strain

STRAIN

Change in shape or size of an object in
response to an applied stress.
= *Deformation*
Three Types of Strain

- ***Elastic***
- ***Ductile (Plastic)***
- ***Brittle (Rupture)***

Elastic Deformation

A temporary change in shape or size that is recovered when the applied stress is removed If the response of the material to the load/unload is instantaneous, it is a pure elastic material; If the response of the material to the load/unload needs finite time, it is a visco-elastic material; If the response of the material to the load/unload needs finite time, it is a visco-elastic material

–**Elastic deformation: Strain is a linear function of stress thus obeying Hooke's law, and the constant relationship between them is referred to as Young's modulus (E).**

–**Rocks are non ideal solids and exhibit hysteresis during unloading**

–**The elastic limit, where elastic deformation changes to plastic deformation is termed the** Yield Point. **Further stress induces plastic flow and the rock is permanently strained.**

–**The first part of the plastic flow domain preserves significant elastic stress and is known as the "**elastico-viscous**" region. This is the field of "**creep**" deformation.**

– **Solids are termed "**brittle**" or "**ductile**" depending on the amount of plastic deformation they exhibit. Brittle materials display no plastic deformation.**

–**The point where the applied stress exceeds the strength of the material is the "**ultimate strength**" and "**rupture**" results.**

–**Young's modulus "**(E)**" is the most important elastic constant derived from the slope of the stress-strain curve. Most crystalline rocks have S-shaped stress-strain curves that display "**hysteresis**" on unloading.**

Ductile (Plastic) Deformation

• A permanent change in shape or is not recovered when the stress size is removed i.e it flows or bends

•*Brittle (Rupture*)

Rupture is a kind of Brittle Deformation

• the loss of cohesion of a body under the influence of deforming stress.

• i.e. “it breaks”

Young's modulus E

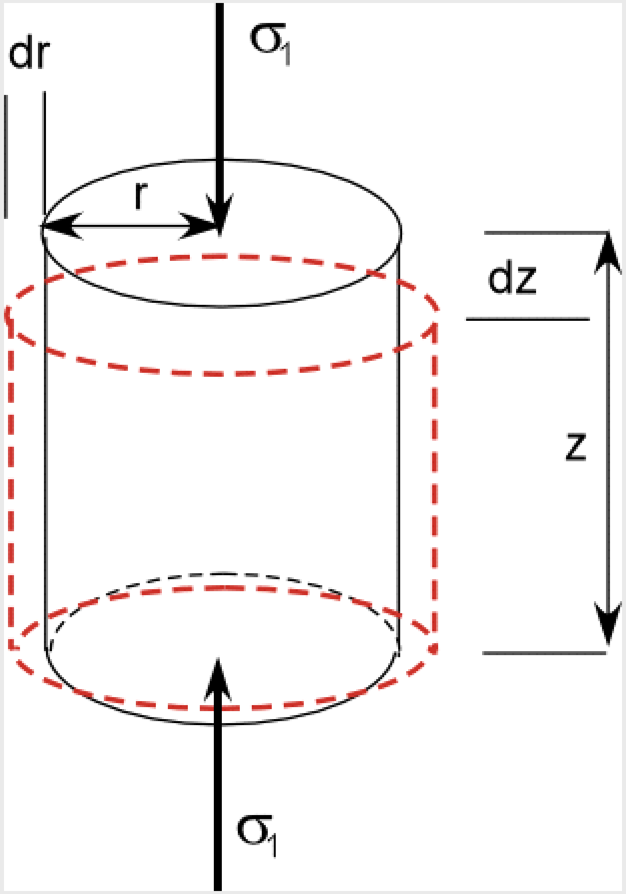
Young's modulus is the stress needed to compress the solid to shorten in a unit strain.

$$E = \frac{\sigma 1}{\frac{\Delta z}{z}}$$

Poisson's ratio ν

Poisson's measures the relativity of the expansion in the lateral directions and compression in the direction in which the uni-axial compression applies.

$$\mu = -\frac{\frac{\Delta r}{r}}{\frac{\Delta z}{z}}$$



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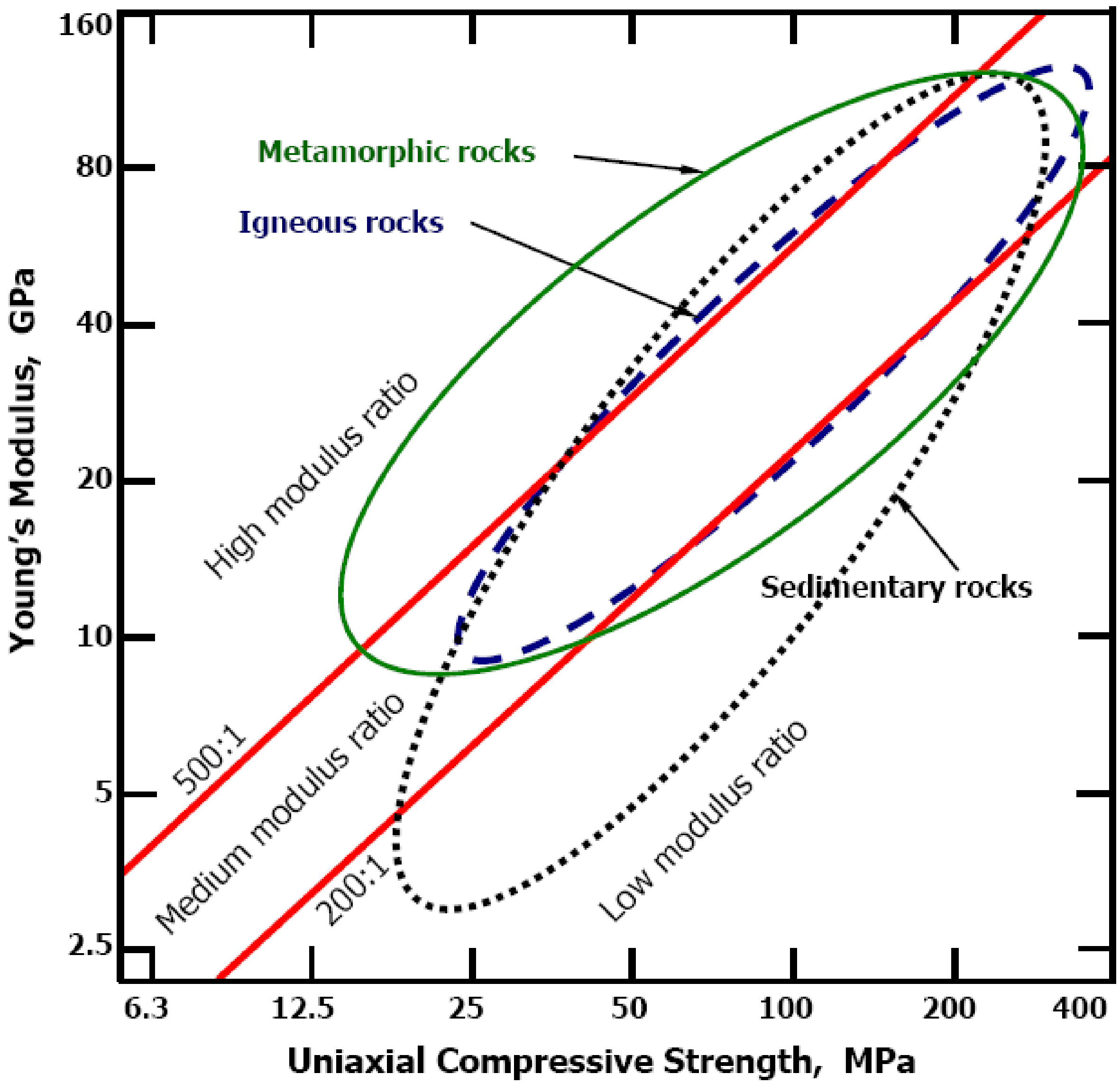


Indirect (Brazilian) Tensile Strength Test

Although rocks are much weaker in tension than in compression or shear, tensile failure also plays an important role in some engineering activities (e.g. drilling, cutting and blasting of rocks). Tensile behavior of different rock formations can vary considerably, and neglecting such a parameter may overestimate the efficiency of the formation.

A laboratory technique to measure the tensile strength of rocks is the indirect tensile tests. A cylindrical specimen is loaded diametrically across the circular cross section. The loading causes a tensile deformation perpendicular to the loading direction, which yields a tensile failure. By registering the ultimate load and by knowing the dimensions of the specimen, the indirect tensile strength of the material can be computed. The indirect tensile strength is measured in accordance with the procedures given in ASTM D3867 - *Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens, utilizing a specimen with a thickness to diameter ratio between 0.2 to 0.75.*

The indirect tensile strength is calculated by:

$$\sigma t = \frac{2P}{\pi D L}$$

Where:

σt = Indirect Tensile Strength

D = Diameter of the core sample

P = Maximum Failure Load

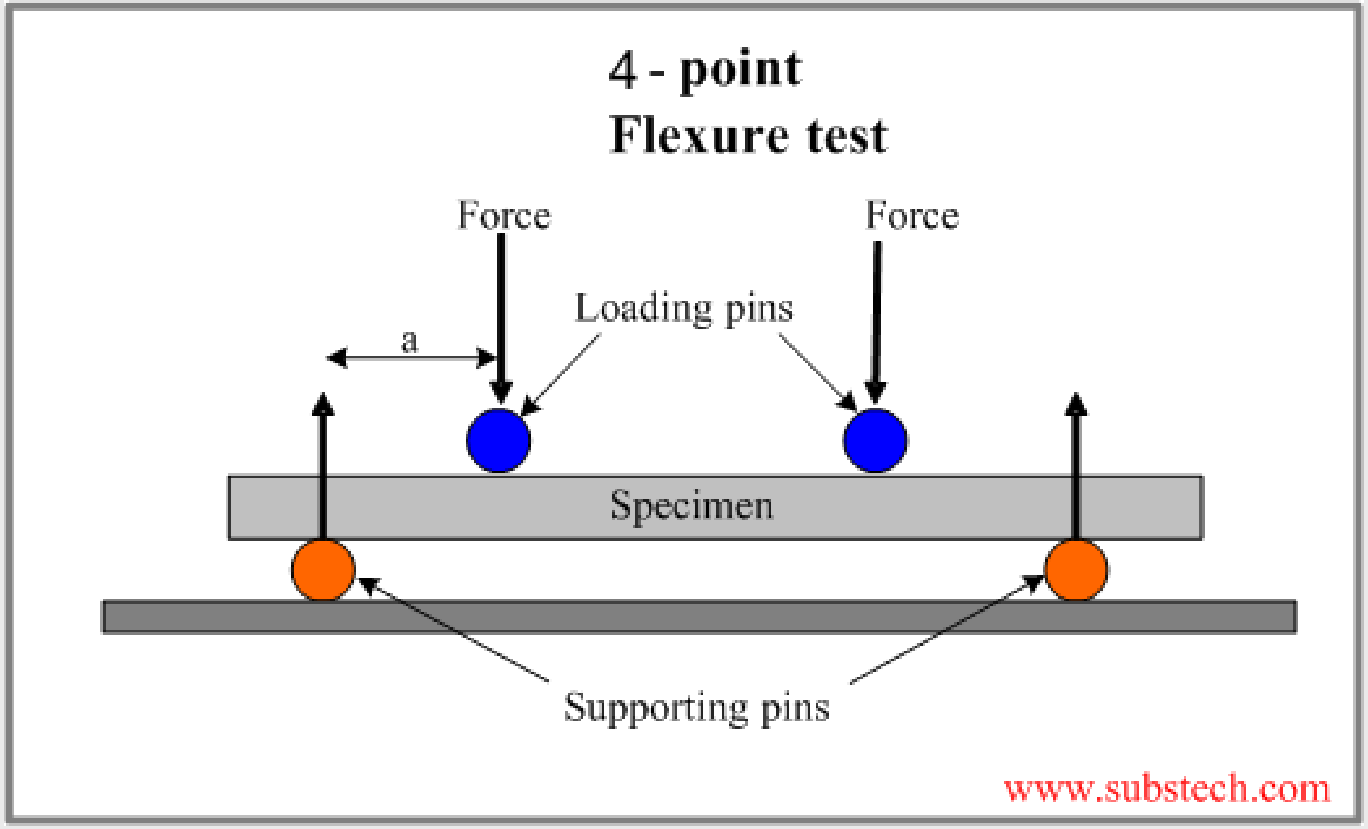
Flexural test

Another method of determining tensile strength indirectly is by means of a flexural test
in which a rock beam is failed by bending. Either three point or four point loading may
be used in the test. For a cylindrical rock specimen (diameter d) and the four point loading
arrangement as shown, it may be shown that the tensile strength (st) is

$$\sigma t = \frac{32PL}{3\pi d^3}$$

where P is the failure load applied at each of the third points along the beam. For a beam of
rectangular cross section (height h and width w) the tensile strength is

$$\sigma t = \frac{2PL}{Wd^2}$$


4 - point
Flexure test
Force
Force
Loading pins
a
Specimen
Supporting pins
www.substech.com

Point Load Test

The point load test was developed as a small, hand-portable test apparatus to provide an index for the strength classification of hard rocks in the field. Basically, the test method relies on the principle of inducing tensile stress into the rock by the application of a compressive force.

Point load test is carried out on core rock specimens to obtain the point load strength index and unconfined compressive strength. A correction is applied to account for the specimen size and shape, and the unconfined compressive strength is obtained from a correlation equation.

The point load strength is measured in accordance with the procedures given in ASTM D5731 - *Standard Test Method for Determination of Point Load Strength Index of Rock and Application of Rock Strength Classifications, utilizing a specimen with a core diameter between 1 in. to 3 in.*

The point load index strength is calculated by:

$$Is = \frac{P}{D^2}$$

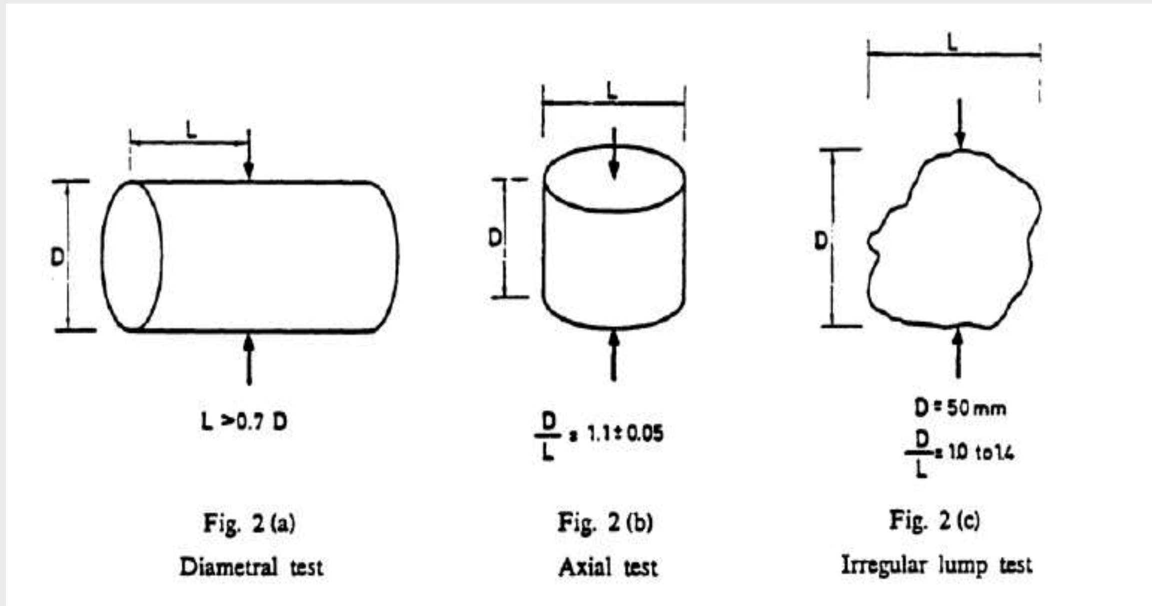
Where:

Is = Point Load Index (psi)

F = Failure Load (lbs.)

D= distance between the point loads.

Correction for the load point index



Is = Point Load Index (psi)
F = Failure Load (lbs.)
De = Distance between platen tips (in.)
De2 = D2 = for diametral core tests without penetration or, = 4A/π = for axial, block and lump test
A = LD = minimum cross sectional area of a plane through the platen contact points

$$Is = \frac{P}{D^2}$$

Relationship between point load index (I s) and unconfined compression strength is given by: t u =24 I s (50) where tu is the unconfined compressive strength, and I s(50) is the point load strength for 50 mm diameter core.

HARDNESS AND ABRASIVENESS Knowledge of the hardness and abrasiveness of rock is very important when predicting rock drillability, cuttability, borability and tunnel boring machine advance rates. These two physical properties depend to a great extent on the mineralogical composition of the rock and the type and the degree of cementation of the mineral grains. Rock hardness can be expressed using the Mohs scale used for minerals or can be measured (in a non-destructive way) using the Schmidt Rebound Hammer

Simple means' field tests that make use of hand pressure, geological hammer, etc. (Burnett, 1975), are used to determine intact rock strength classes in the British Standard (BS 5930, 1981)

Table 1. Estimation of intact rock strength.

intact rock strength	'simple means' test (standard geological hammer of about 1 kg)
< 1.25 MPa	Crumbles in hand
1.25 – 5 MPa	Thin slabs break easily in hand
5 - 12.5 MPa	Thin slabs break by heavy hand pressure
12.5 - 50 MPa	Lumps broken by light hammer blows
50 – 100 MPa	Lumps broken by heavy hammer blows
100 - 200 MPa	Lumps only chip by heavy hammer blows
> 200 MPa	Rocks ring on hammer blows. Sparks fly.

Schmidt Hammer Rebound Hardness

The Schmidt hammer is point perpendicularly and touch the surface of rock. The hammer is released and reading on the hammer is taken. The reading gives directly the Schmidt hammer hardness value. The standard Schmidt hardness number is taken when the hammer is point vertically down. If the hammer is point to horizontal and upward, correction is needed to add to the number from the hammer. The correction number is Table below.

At least 20 tests should be conducted on any one rock specimen. It is suggest to omit 2 lowest and 2 highest reading, and to use the remaining reading for calculating the average hardness value. Report of results should include descriptions of rock type, location, size and shape, and orientation of hammer axis.

Rebound Number	Vertically downward	45° downward	Horizontal	45° upward	Vertically upward
10	0	–0.8			–3.2
20	0	–0.9	–8.8	–6.9	–3.4
30	0	–0.8	–7.8	–6.2	–3.1
40	0	–0.7	–6.6	–5.3	–2.7
50	0	–0.6	–5.3	–4.3	–2.2
60	0	–0.4	–4.0	–3.3	–1.7

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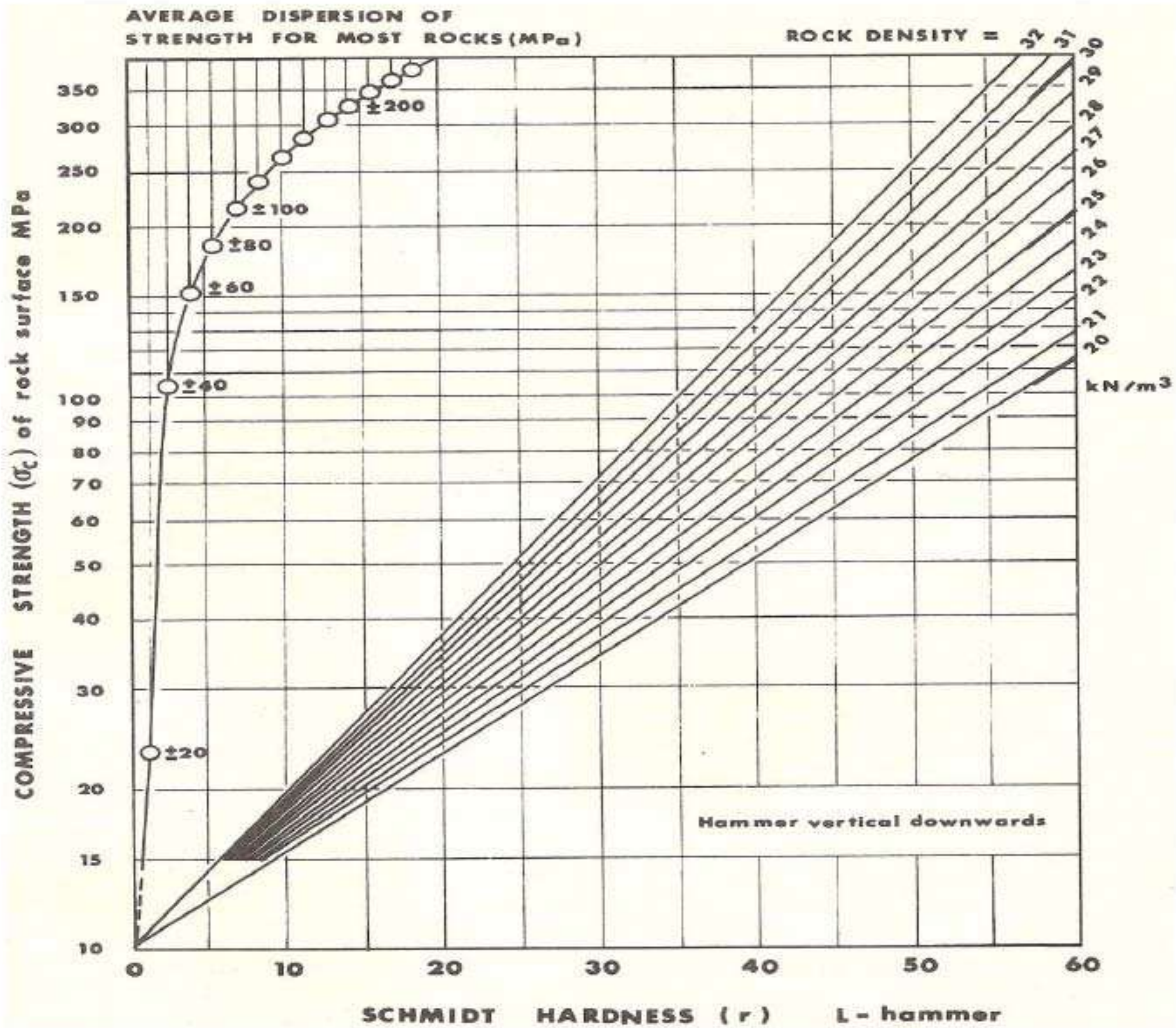


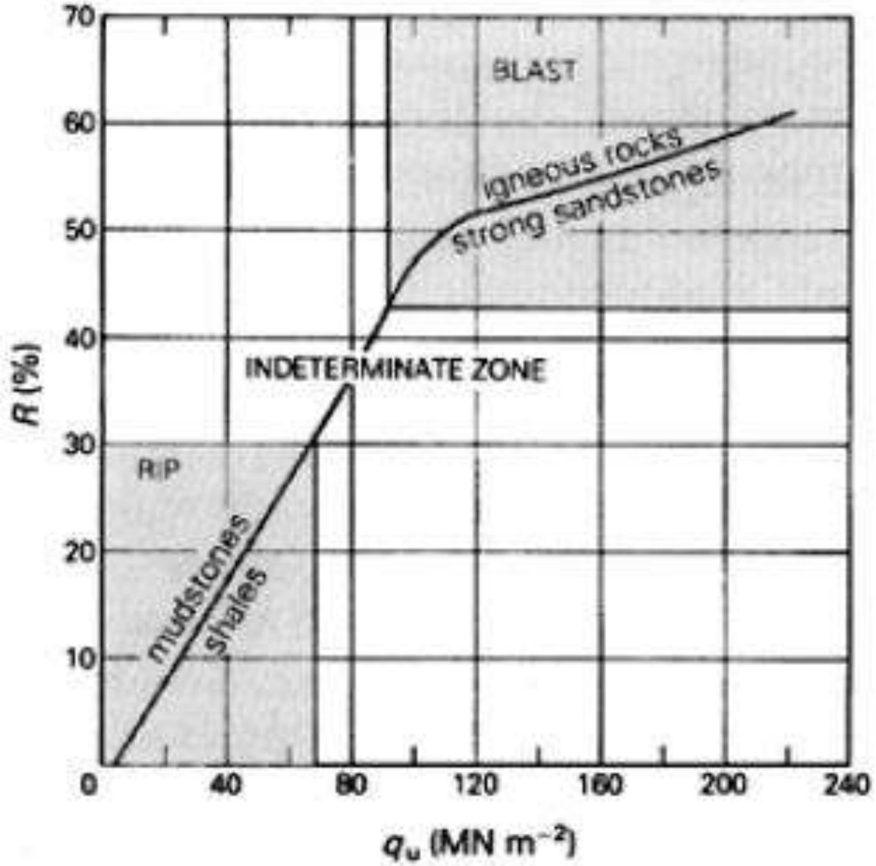


Figure 7.3 Rebound number *(R)* plotted against unconfined compressive strength (q_u) for various rock types.

Engineering classification of intact rock

There are two ways to classify the intact rock in terms of 2 parameters:

1) using compressive strength alone (C0)

2) use the ratio of E/ C0

Using compressive strength alone (C0) we can classify the rocks in to 5 classes:

A, B, C, D, E

For rocks with very high compressive strength to very low compressive strength.

Engineering Geology

Using the ratio of Young's modulus to the compressive strength E/ C0 we can classify the rocks into 3 classes:

H (for high);
M (for mediate);
L (for low).

So by combining the 2 methods we may have rocks classified as BH, BM, CM, etc.

Engineering Classification of Intact Rock Based on Compressive Strength

Class	Level of Strength	Strength in psi	Strength in MPa	Representative Rocks
A	Very high	32,000	220	Quartzite, diabase, and dense basalt
B	High	16,000-32,000	110-220	Most igneous rocks, most limestones, and dolomite, well-cemented sandstones and shales
C	Medium	8,000-16,000	55-110	Most shales, porous sandstones, and limestones
D	Low	4,000-8,000	27.5-55	Friable sandstones, porous tuff
E	Very low	4,000	25.5	Clay-shale, rock salt

Engineering Classification of Intact Rock Based on E/C_0

Class	Level of Strength	E/C0
H	High	500
M	Medium	200-500
L	Low	200

Example: (Granite) UCS = 150 MPa, E = 60 GPa

UCS = 150 Mpa , From table 1, High strength (B)
E/UCS = (60000/150) = 400 , from table 2,
Medium strength (M)
So the rock sample classified as (BM)
according to Deere and Miller classification (1966)

Engineering Geology

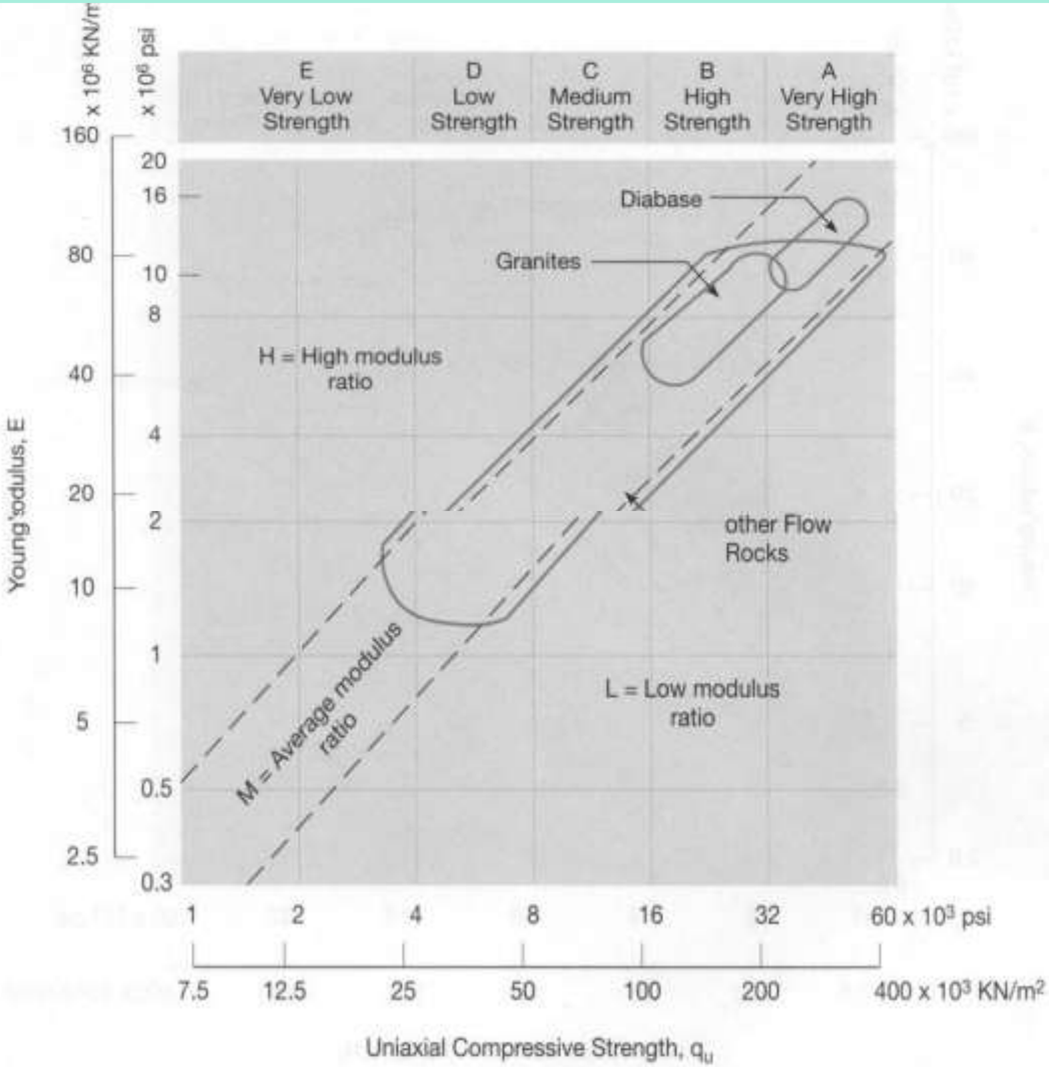


FIGURE 6.6 Engineering classification for intact rock-summary plot, igneous rocks.

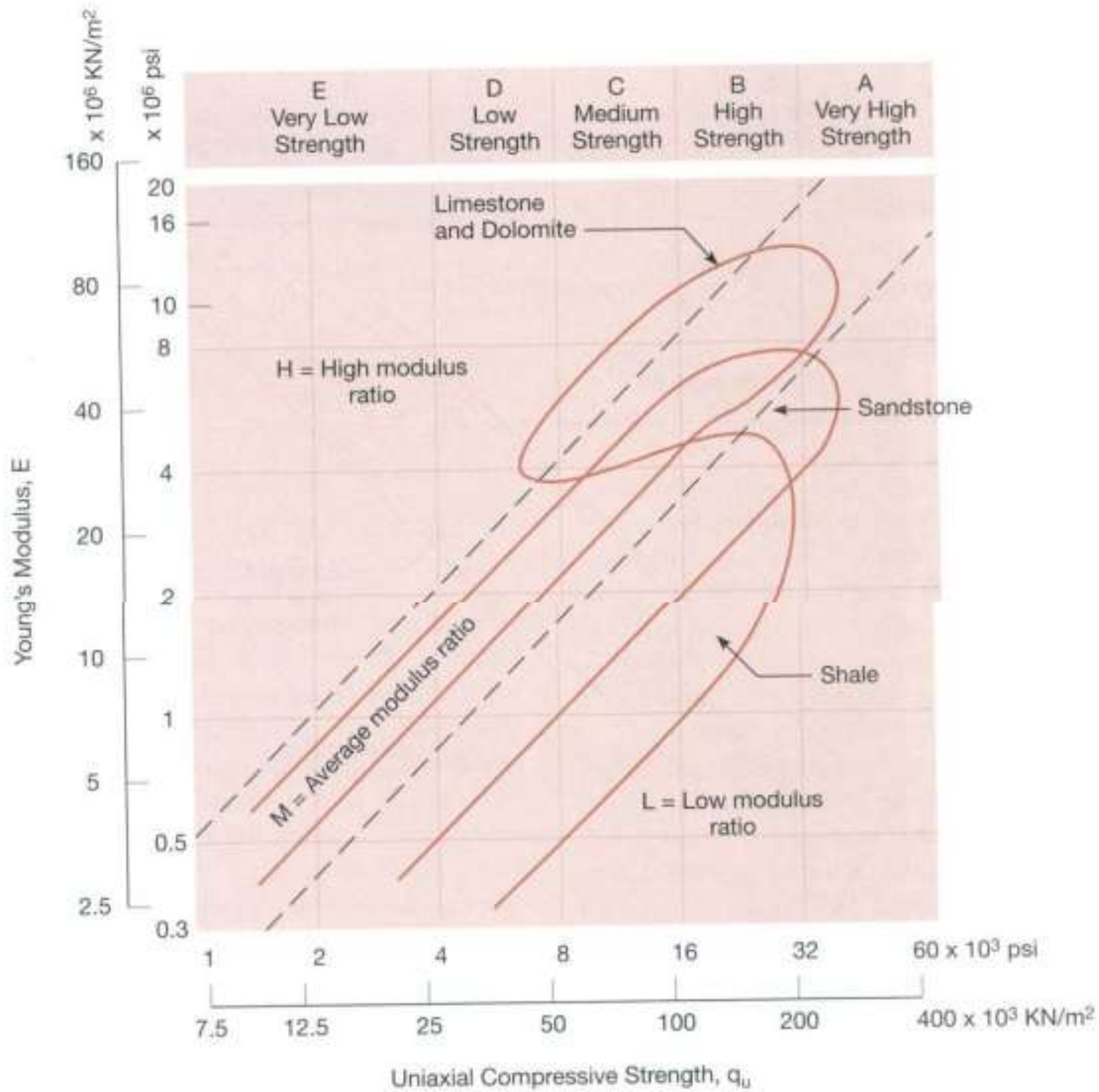


FIGURE 6.7 Engineering classification for intact rock-summary plot, sedimentary rocks.

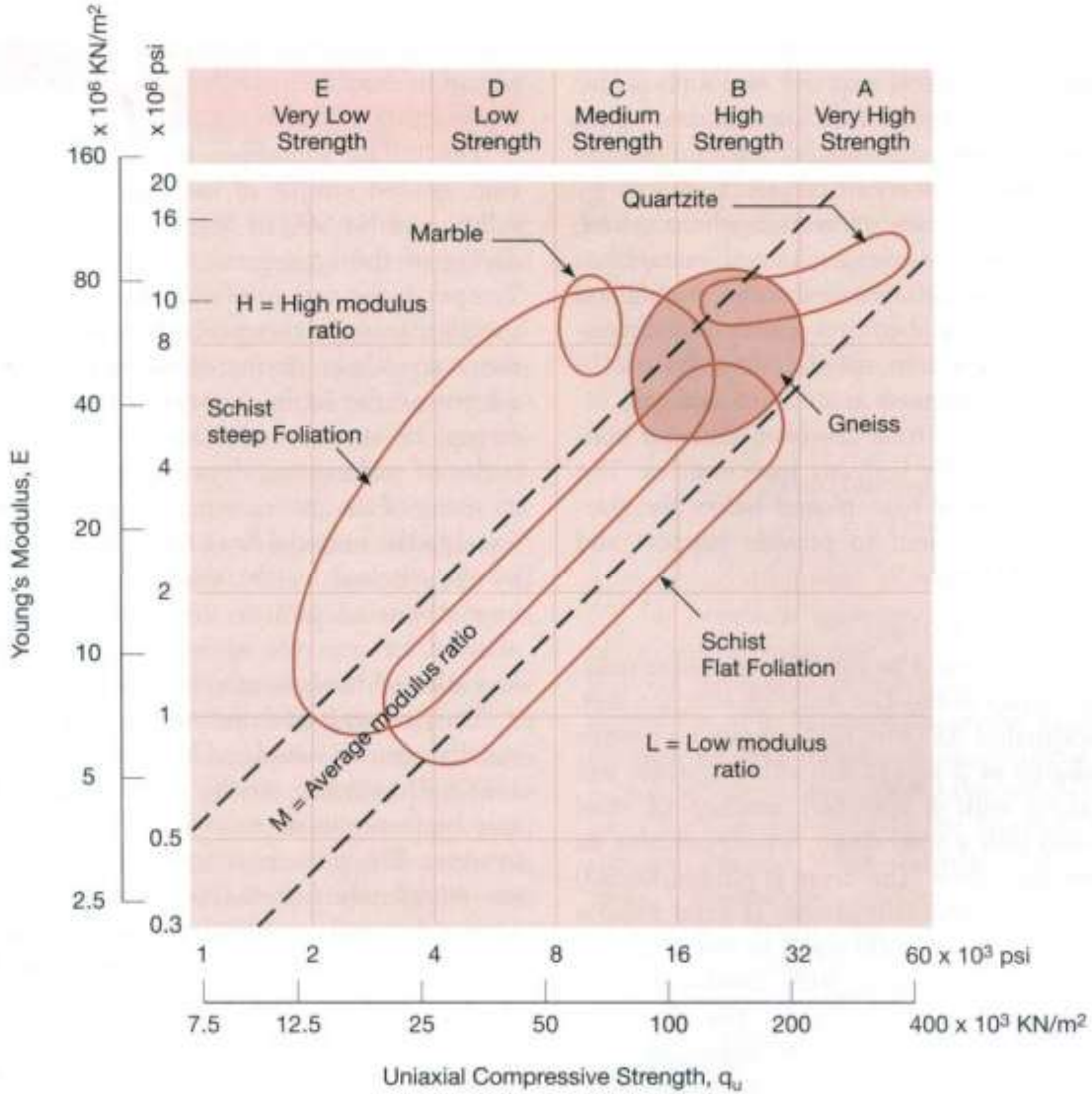


FIGURE 6.8 Engineering classification for intact rock-summary plot, metamorphic rocks.

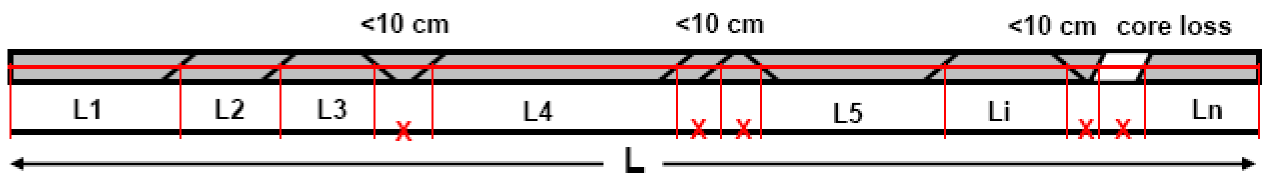
Rock Type	Mechanical Strength	Chemical Stability	Human Use
Granite	Strong	Stable	Building stone & monuments
Rhyolite	Strong	Stable	
Andesite	Strong	Stable	
Diorite	Strong	Stable	
Basalt	Strong	Pretty stable	
Gabbro	Strong	Pretty stable	
Sandstone	Strong	Generally stable	Common building stone
Shale	**Weak**	Stable	
Limestone	Strong	**Soluble in acidic water**	Common building stone roadbed
Rock salt	**Ductile**	**Very soluble**	Salt
Coal	Brittle	**Metastable**	Fuel
Slate	~Strong	Stable	Roofs; blackboards
Schist	~Strong	Pretty stable	
Gneiss	Strong	Pretty stable	Occasional building stone
Marble	Strong	**Soluble in acidic water**	Building stone & monuments
Quartzite	Strong	Stable	
Anthracite	Brittle	**Metastable**	Fuel

LBR 1/2002

Rock Quality Designation (RQD)

Rock Quality Designation (RQD) is defined as the percentage of rock cores that have length equal or greater than 10 cm over the total drill length.

$$RQD = \Sigma L_i / L \times 100\%, \quad L_i > 10 \text{ cm}$$



$$RQD = (L1 + L2 + \ldots + Ln) / L \times 100\%$$

RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

Example

Core run of 150 cm
Total core recovery = 125 cm
Core recovery ratio CR = 125/150 = 83%
On modified basis, 95 cm are counted
RQD = 95/150 =63%

Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	0
7.5	0
10	10
12.5	12.5
7.5	0
10	10
15	15
10	10
5	0
12.5	12.5
125	95

The suitability of aggregate for use in concrete can be assessed on the following

(a)The aggregate should be free from sulphide minerals, especially pyrite. Coal, clay and organic matter

(b) The specific gravity should usually be high, but this criterion depends upon the purpose for which the concrete is needed.

(c) The material should be well graded, with a wide range of particle sizes

(d) The fragments should have a rough surface, so that a good bond can be achieved between the aggregate and the cement paste.

(e) Chalcedonic silica (flint, chert, agate) and glassy siliceous rocks (rhyolite, pitchstone) are often undesirable in gravel aggregate since they react with highly alkaline cements. (This problem can be overcome by using a low-alkali cement).

(F) The shrinkage of the concrete as it dries should be measured. This test is made on cubes of concrete prepared from the aggregate and the shrinkage is expressed as a percentage. Low-shrinkage concrete has values less than 0.045%.

Site investigation

- Hussien aldeeky

Definition

The process of determining the layers of natural soil deposits that will underlie a proposed structure and their physical properties is generally referred to as site investigation.

The purpose of a soil investigation program

1. Selection of the type and the depth of foundation suitable for a given structure.

2. Evaluation of the load-bearing capacity of the foundation.

3. Estimation of the probable settlement of a structure.

4. Determination of potential foundation problems (for example, expansive soil, collapsible soil, sanitary landfill, and so on).

5. Establishment of ground water table.

6. Prediction of lateral earth pressure for structures like retaining walls, sheet pile bulkheads, and braced cuts.

7. Establishment of construction methods for changing subsoil conditions

exploration program

The purpose of the exploration program is to determine, within practical limits, the stratification and engineering properties of the soils underlying the site. The principal properties of interest will be the strength, deformation, and hydraulic characteristics. The program should be planned so that the maximum amount of information can be obtained at minimum cost.

4

1. **Assembly of all available information**

on dimensions, column spacing, type and use of the structure, basement requirements, and any special architectural considerations of the proposed building. Foundation regulations in the local building code should be consulted for any special requirements. For bridges the soil engineer should have access to type and span lengths as well as pier loadings. This information will indicate any settlement limitations, and can be used to estimate foundation loads.

Sequences of Stages for investigation

Desk Study: Literature Search : first stage of the Site Investigation The desk study is work taken up prior to commencing the work on site and the Ground Investigation. and is used to plan the Ground Investigation. A good starting point is to use the:

1. geological maps. In addition to historical maps. That allow much information to be obtained such as former uses of the site; concealed mine workings; in- filled ponds; old clay, gravel and sand pits; disused quarries; changes in topography and drainage; changes in stream and river courses; changes in potential landslide areas.

2. Ariel Photography is another useful source of information. Such records can be extremely useful in ascertaining historical use of the site, hidden foundations, changes of river course and much other hidden data.

3. Services records are also an essential part of the desk study, necessary to locate hidden services such as electricity cables, sewers and telephone wires. It is essential when conducting a desk study that as much information as possible is obtained. Work at this stage of the Investigation saves much time later and vastly improves the planning and quality of the Investigation

- Geotechnical mapping involves the plotting on suitable scales, the locations of all data which assists in understanding the geotechnical conditions existing at the site.
- They provide
  - generalized picture of geology of an area.
  - Information about the rock and soil exposed on the surface.
  - Shows extent of faults, and other geological features.

  (but in real practice the boundaries and especially the faults are interpolated, so accuracy cannot always be taken as granted)

Aims and benefits of a desk study:

- To collect, understand and interpret data
- To limit costs
- Aid in the Design Process
- Highlights problems early
- Low cost & cost effective
- Provides information which would otherwise be difficult to obtain

Sources of information

- Maps
- Geological maps & Memoirs
- Current OS Maps
- Old Maps / Aerial Photos
- Archive
  - Historical Geotechnical Info.
  - Engineering Drawings
  - Construction Records
  - Libraries
- Specialist Surveys
  - Environmental Check, Landfill etc.
  - Mining Records
  - Ecological Survey
- Observational
  - Site Visit / Walkover survey
  - People (Construction Staff, Local Residents

2.Reconnaissance of the area:

This may be in the form of a field trip to the site which can reveal information on the type and behavior of adjacent structures such as cracks, noticeable sags, and possibly sticking doors and windows. The type of local existing structure may influence, to a considerable extent, the exploration program and the best foundation type for the proposed adjacent structure.

3 .A preliminary site investigation:

In this phase a few borings are made or a test pit is opened to establish in a general manner the stratification, types of soil to be expected, and possibly the location of the groundwater table. One or more borings should be taken to rock, or competent strata, if the initial borings indicate the upper soil is loose or highly compressible. This amount of exploration is usually the extent of the site investigation for small structures.

Site Reconnaissance The Site Reconnaissance phase of a site investigation is normally in the form of a **walk over survey of the site** to recognise any difficult ground conditions. Important evidence to look for is:

- **Hydrogeology**: Wet marshy ground, springs or seepage, ponds or streams and Wells.
- **Slope Instability**: Signs of slope instability include bent trees, and displaced fences or drains.
- **Mining**: The presence of mining is often signs of subsidence and possibly disused mine shafts. Open cast mining is indicated by diverted streams replaced or removed fence/hedge lines.
- **Access**: It is essential that access to the site can be easily obtained. Possible problems include low overhead cables and watercourses

Difficult Ground Conditions

An efficient ground investigation recognizes, during the initial desk study, the possibilities or probabilities of any specific difficult ground conditions occurring within the project site It then direct the field work exploration to either eliminate the considered possibilities or determine the extent of the ground difficulties

The most common difficulties are:

- Soft and variable dirt materials
- Weathered, weak or fractured bedrock
- Natural or artificial cavities within the bedrock
- Active or potential slope failure and land slides
- Compressive landfill with or without soft spots
- Flowing groundwater or methane gas
- Unexpected old building foundations

4.A detailed site investigation:

Where the preliminary site investigation has established the feasibility of the project, a more detailed exploration program is undertaken. The preliminary borings and data are used as a basis for locating additional borings, which should be confirmatory in nature, and determining the additional samples required.

Depth of Boring

The approximate required minimum depth of the borings should be predetermined. The estimated depths can be changed during the drilling operation, depending on the subsoil encountered. To determine the approximate minimum depth of boring, engineers may use the following rule:

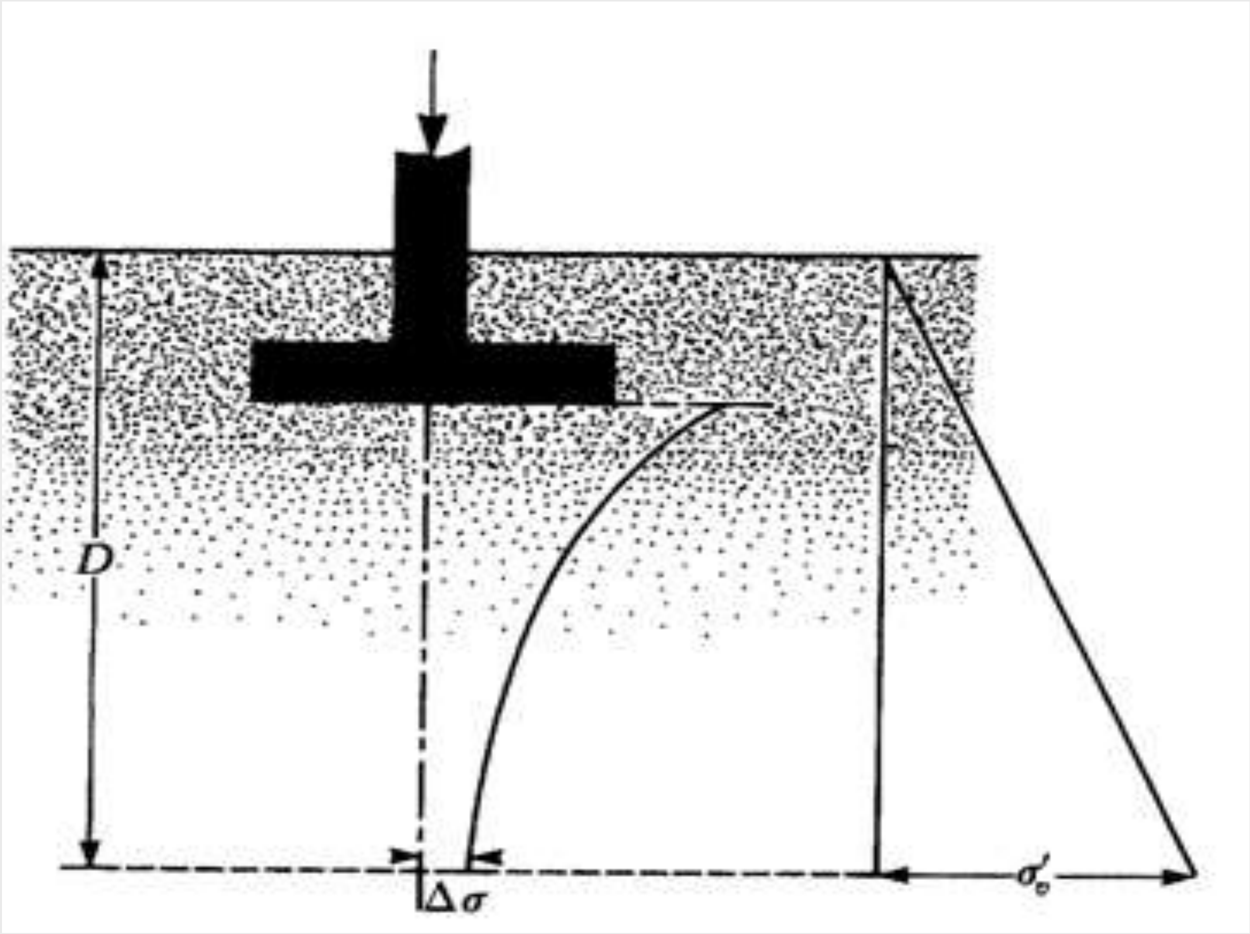
1. Determine the net increase of stress, $\Delta\sigma$ under a foundation with depth as shown in the Figure.

2. Estimate the variation of the vertical effective stress, σ'_{υ}, with depth

3. Determine the depth, D = D1, at which the stress increase $\Delta\sigma$ is equal to (1/10) q (q = estimated net stress on the foundation).

4. Determine the depth, D = D2, at which $\Delta\sigma/\sigma'_{\upsilon} = 0.05$.

5. Unless bedrock is encountered, the smaller of the two depths, D1 and D2, just determined is the approximate minimum depth of boring required. Table shows the minimum depths of borings for buildings based on the preceding rule.



Determination of the minimum depth of boring

Building width (m)	Number of Stories				
	1	2	4	8	16
	Boring Depth (m)				
30.5	3.4	6.1	10.1	16.2	24.1
61.0	3.7	6.7	12.5	20.7	32.9
122.0	3.7	7.0	13.7	24.7	41.5

For hospitals and office buildings, the following rule could be use to determine boring depth

$D_b = 3S^{0.7}$ (for light steel or narrow concrete buildings)

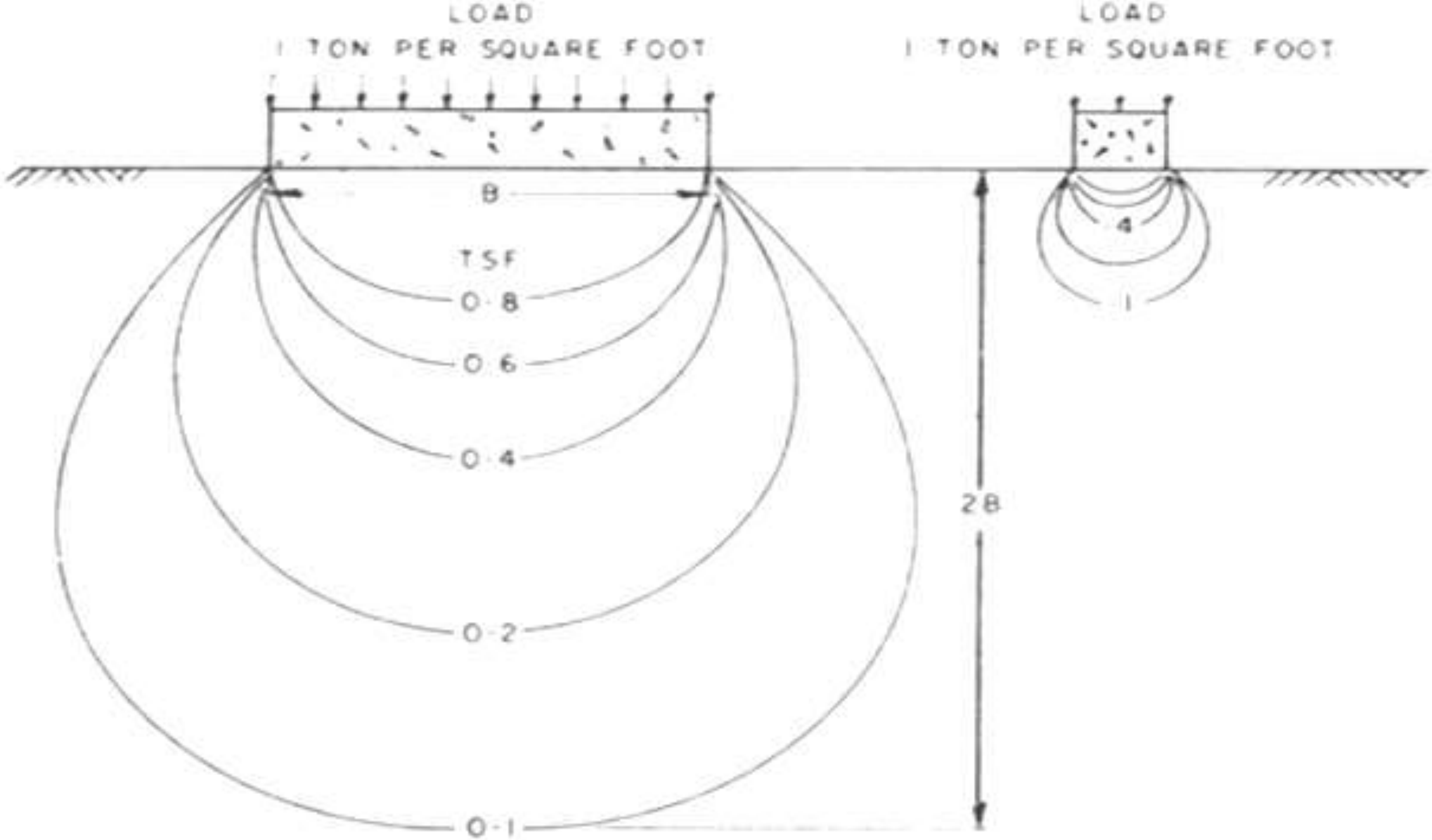
$D_b = 6S^{0.7}$ (for heavy steel or wide concrete buildings)

where:

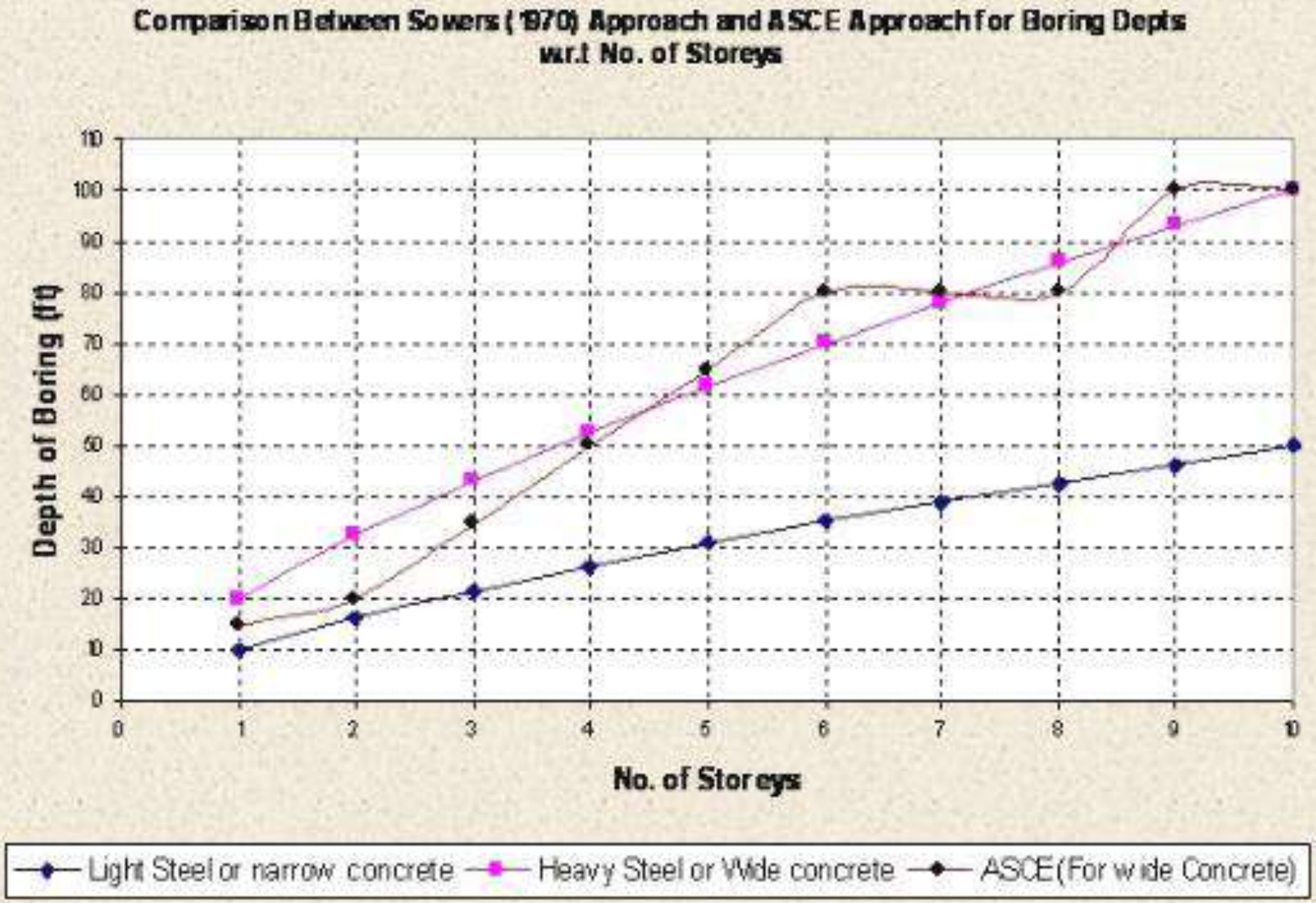
D_b = depth of boring, in meters

S = number of stories

Depth of Borehole/Depth to Investigate

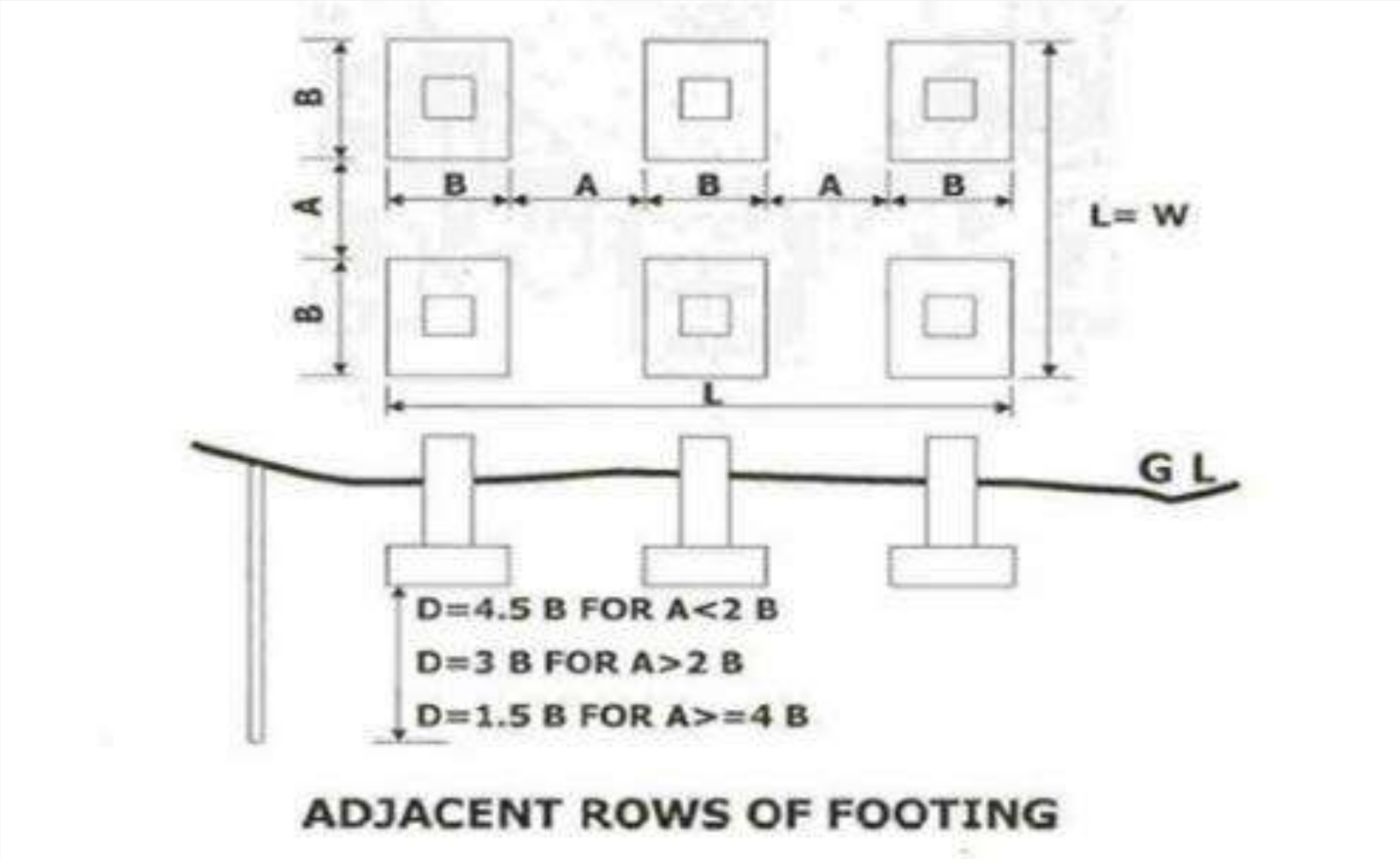


Guidelines for Depth



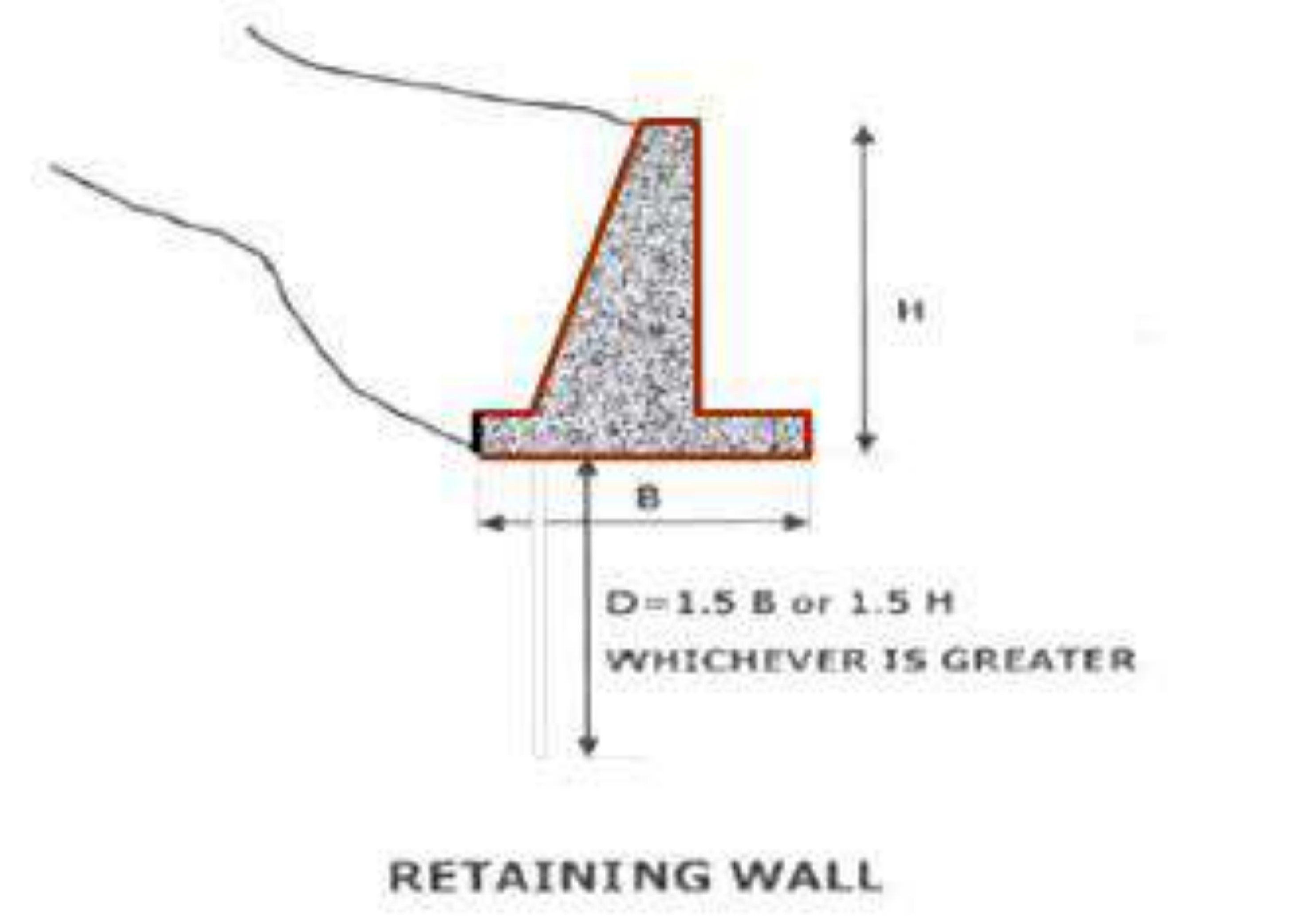
Depth of borehole for isolated footing

1. Isolated spread footing or raft: **D= 1.5 B** below the lowest part of the foundation
2. Adjacent isolated footings with **A< 2B**: **D= 1.5L** below the lowest part of the foundation

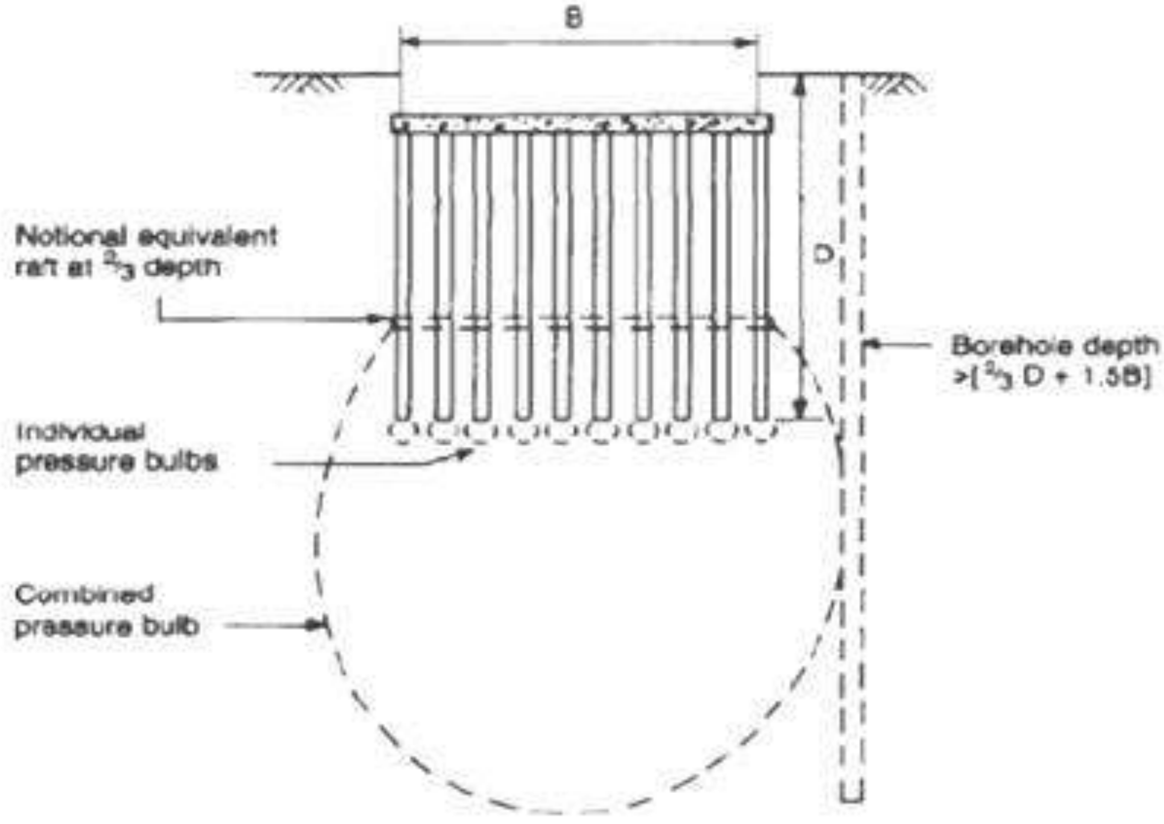


- For retaining walls:

1.5 times the width or height of retaining wall, whichever is more



Depth to investigate for Large Structure on piles



(c) Large structure on friction piles

When deep excavations are anticipated, **the depth of boring should be at, least 1.5 times the depth of excavation**. Sometimes subsoil conditions are such that the foundation load may have to be transmitted to the bedrock. The minimum depth of core boring into the bedrock is about 3m. If the bedrock is irregular or weathered, the core borings may have to be extended to greater depths.

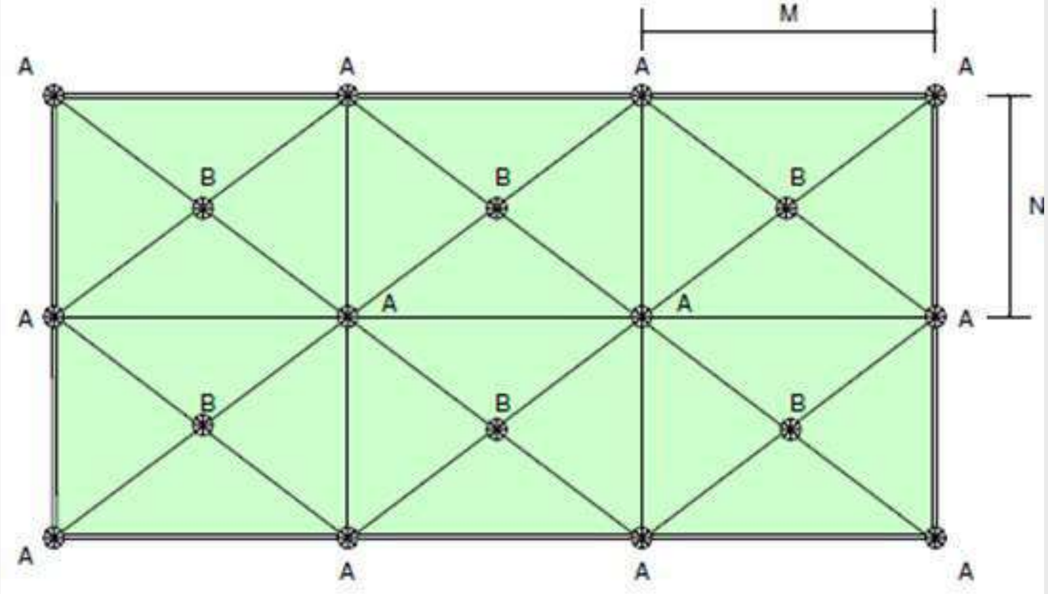
Spacing Boring

There are no hard and fast rules for the spacing of the boreholes. The following table gives some general guidelines for borehole spacing. These spacing can be increased or decreased, depending on the subsoil condition. If various soil strata are more or less uniform and predictable, the number of boreholes can be reduced.

Approximate Spacing of Boreholes

Type of project	Spacing (m)
Multistory building	10-30
One story industrial plants	20-60
Highways	250-500
Residential subdivision	250-500
Dams and dikes	40-80

Selection of Borings



Column or Wall Loads	Depth				Spacing			
	Borings A		Borings B		M		N	
	Feet	Meters	Feet	Meters	Feet	Meters	Feet	Meters
Light	10-20	3-6	20-25	6-7.5	100	30	100	30
Medium	20-25	6-7.5	30-40	9-12	80-100	25-30	80-100	25-30
Heavy	30-40	9-12	50-80	15-25	50-80	15-25	50-80	15-25

HOW MANY BOREHOLES, HOW DEEP?

Spacing:	buildings	10 – 30 m apart;
	road lines	30 – 300 m apart;
	landslides	at least 5 in line for profile.

Depth: 1·5 × foundation width, below founding depth, plus at least one deeper control hole to 10 m below foundation unless rockhead found; 3 m below rockhead to prove sound rock; probes to 3–10 m to locate rock cavities.

These are only rough guidelines.
Spacing and depth may be varied considerably in light of local conditions and appropriate to size of structure.

Table-1 Spacing exploratory borings for medium to heavy buildings.

Subsurface Conditions	Structural footprint Area for Each Boring	
	(m^2)	(ft^2)
Poor quality and / or erratic	200	2,000
Average	300	3,000
High quality and uniform	700	7,000

Table-2 Depths of exploratory borings for buildings on shallow foundations.

Subsurface Conditions	Minimum Depth of Borings (*S* = number of stories and *D* = the anticipated depth of the foundation)	
	(m)	(ft)
Poor and / or erratic	$6S^{0.7} + D$	$20S^{0.7} + D$
Average	$5S^{0.7} + D$	$15S^{0.7} + D$
High quality and uniform	$3S^{0.7} + D$	$10S^{0.7} + D$

A four-story reinforced concrete frame office building will be built on a site where the soils are expected to be of average quality and uniformity. The building will have a 100 ft x 120 ft footprint and is expected to be supported on spread footing foundations located about 3 ft below the ground surface. The site appears to be in its natural condition, with no evidence of previous grading. Bedrock is 100-ft below the ground surface. Determine the required number and depth of the borings.

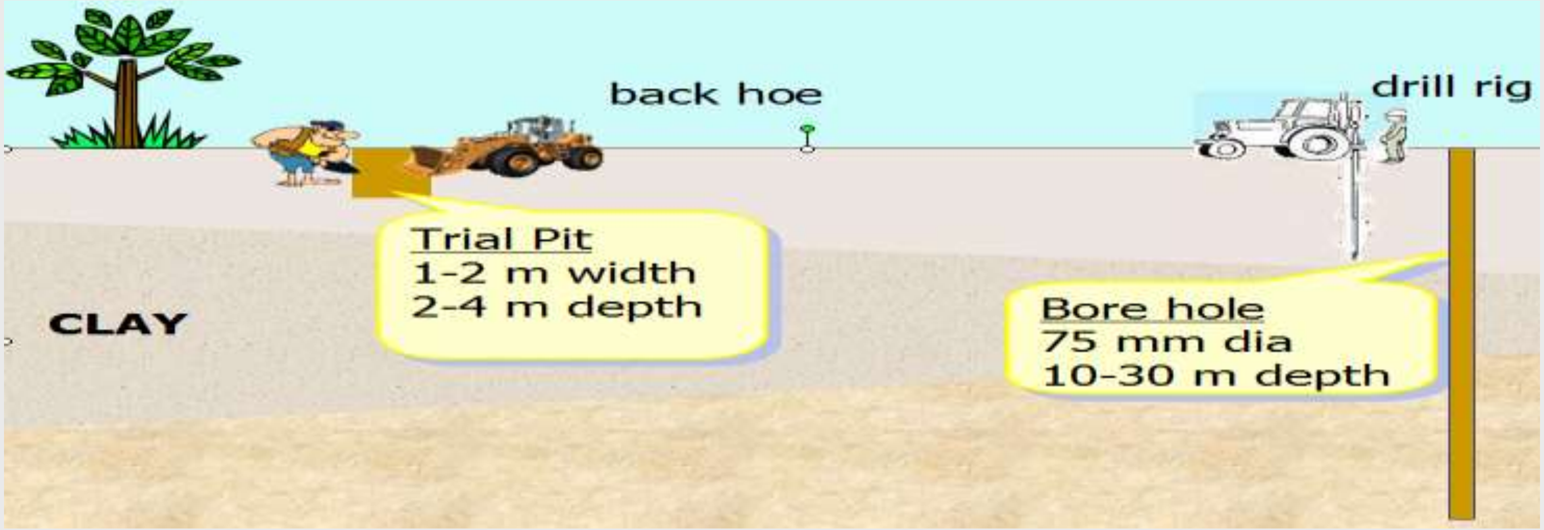
Solution:

A reinforced concrete building is heavier than a steel framed building of the same size. Hence, the design engineer will want soil conditions that are at least average or better. Table-1 below suggests one boring for every 3,000 ft^2 of building footprint area. Since the total footprint area i 100 ft x 120 ft =12,000 ft^2, use ***four borings.***

From Table-2 the minimum depth required for the borings, $15S^{0.7} + D = 15(4)^{0.7} + 3 =$ *43 ft*. Most engineers want one of the borings to go to a slightly greater depth to check the next lower stratum's strength.

SOIL BORING

The earliest method of obtaining a test hole was to excavate **a test pit using a pick and shovel. Because of economics, the current procedure is to use power-excavation** equipment such as a backhoe to excavate the pit and then to use hand tools to remove a block sample or shape the site for in situ testing. This is the best method at present for obtaining quality undisturbed samples or samples for testing at other than vertical orientation.



Trial Pits : Trial pits are shallow excavations going down to a depth no greater than 6m. It is used extensively at the surface for block sampling and detection of services prior to borehole excavation. care should be taken as gases such as methane and carbon dioxide can build up in a trial pit. Breathing apparatus must therefore be used if no gas detection equipment is available.

Depth	Excavation Method
0-2m	By Hand
2-4m	Wheeled Back Hoe
4-6m	Hydraulic Excavator

Support for a trial pit generally takes one of three forms:

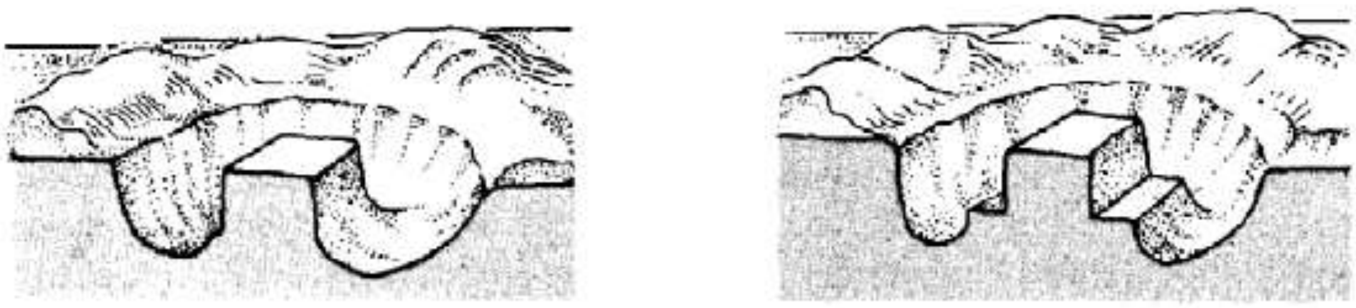
- Timbering
- Steel frames with hydraulic jacks
- Battered or tapered sides

a test pit

Block sampling

Block sampling has traditionally involved the careful hand excavation of soil around the sample position, and the trimming of a regular-shaped block. This block is then sealed, before being encased in a rigid container, and cut from the ground.

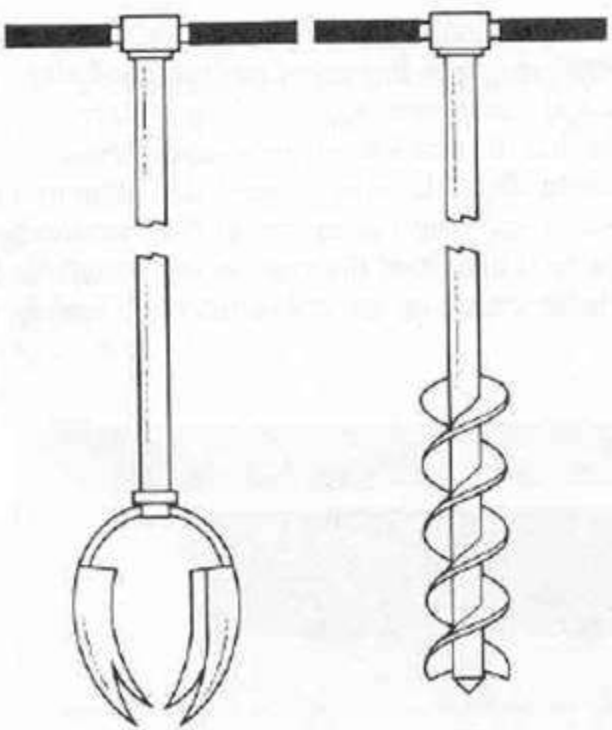
Undisturbed block sampling is limited to cohesive soils and rocks. The procedures used for obtaining undisturbed samples vary from cutting large blocks of soil using a combination of shovels, hand tools and wire saws, to using small knives and spatulas to obtain small blocks



(a) Level ground surface, mark outline of sample and carefully excavate trench

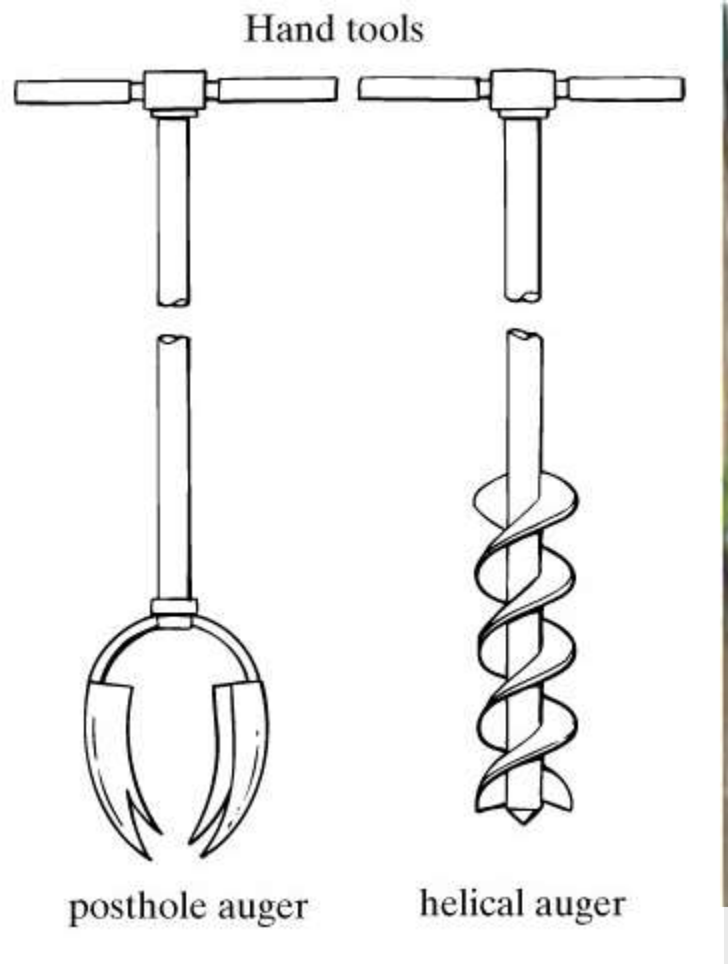
(b) Deepen excavation below base of sample, and trim to size with a knife

Boreholes: used to determine the nature of the ground (usually below 6m depth) in a qualitative manner and then recover undisturbed samples for quantitative examination



An Iwan auger (left) and a Slip auger.

Boring tools

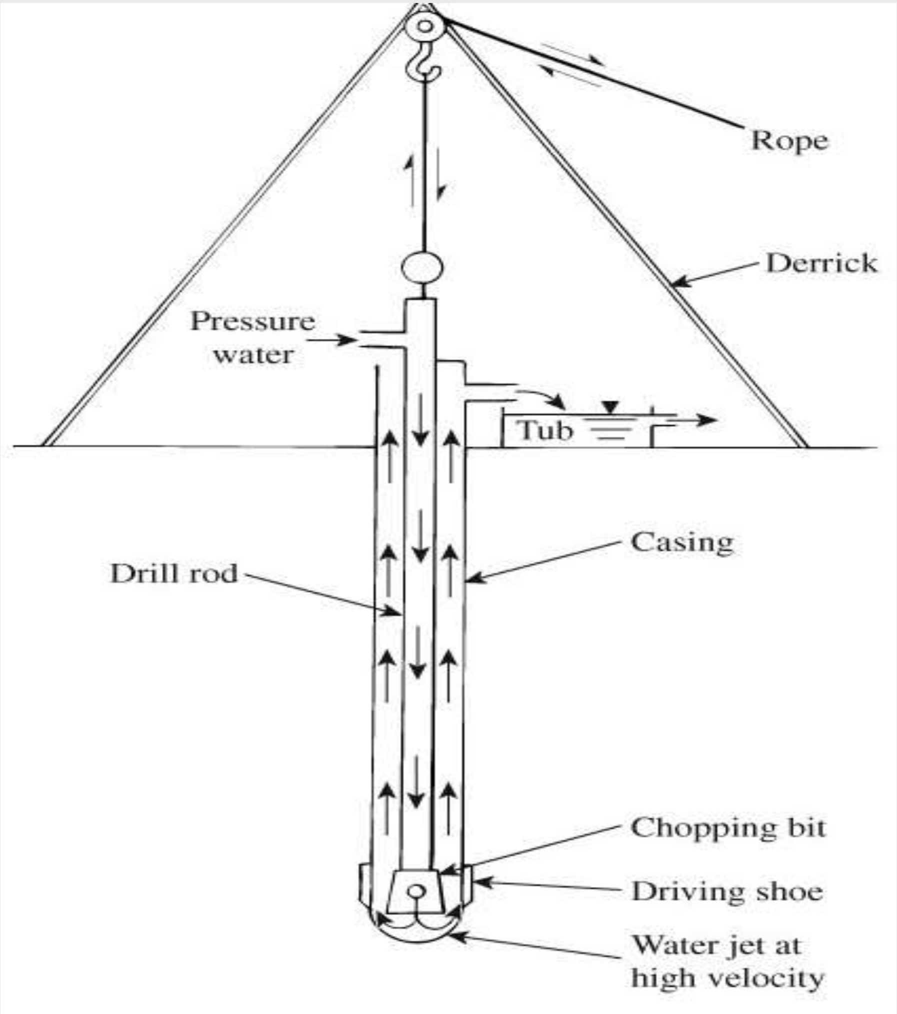


Auger boring

Power drills

Engineering Geology

Wash Borings. is one of the methods of advancing a borehole. A steel casing (a hollow tube), typically 6 feet long, is driven into the ground. The soil inside the casing is removed by means of a chopping bit that is attached to a drilling rod. The loose soil particles are washed out with a water jet, which is collected at the surface in a container, where the engineer can observe the material coming up at each depth.



Wash boring

Drilling Mud

Drilling throughout rock is assisted with the aid of Bentonite(type of clay) that lubricate the drilling bit

Preparation of Boring Logs

1. Name and address of the drilling company
2. Driller's name
3. Job description and number
4. Number, type, and location of boring
5. Date of boring
6. Subsurface stratification, which can he obtained by visual observation of the soil brought out by auger, split-spoon sampler, and thin-walled Shelby tube sampler
7. Elevation of water table and date observed, use of casing and mud losses, and so on
8. Standard penetration resistance and the depth of SPT
9. Number, type, and depth of soil sample collected
10. In case of rock coring, type of core barrel used and, for each run, the actual length of coring, length of core recovery, and ROD

Engineering Geology

Boring Log

Name of the Project: Two-story apartment building

Location: Johnson & Olive St. Date of Boring: March 2, 1982

Boring No. 3 Type of Boring: Hollow stem auger Ground Elevation: 60.8 m

Soil description	Depth (m)	Soil sample type and number	N	w_n (%)	Comments
Light brown clay (fill)					
Silty sand (SM)	1				
	2	SS-1	9	8.2	
*G.W.T. 3.5 m	3	SS-2	12	17.6	$LL = 38$ $PI = 11$
Light gray silty clay (ML)	4				
	5	ST-1		20.4	$LL = 36$ $q_u = 112\ kN/m^2$
	6	SS-3	11	20.6	
Sand with some gravel (SP)	7				
End of boring @ 8 m	8	SS-4	27	9	

N = standard penetration number (below/304.8 mm)
w_n = natural moisture content
LL = liquid limit; PI = plasticity index
q_u = unconfined compression strength
SS = split-spoon sample; ST = Shelby tube sample

*Ground water table observed after one week of drilling

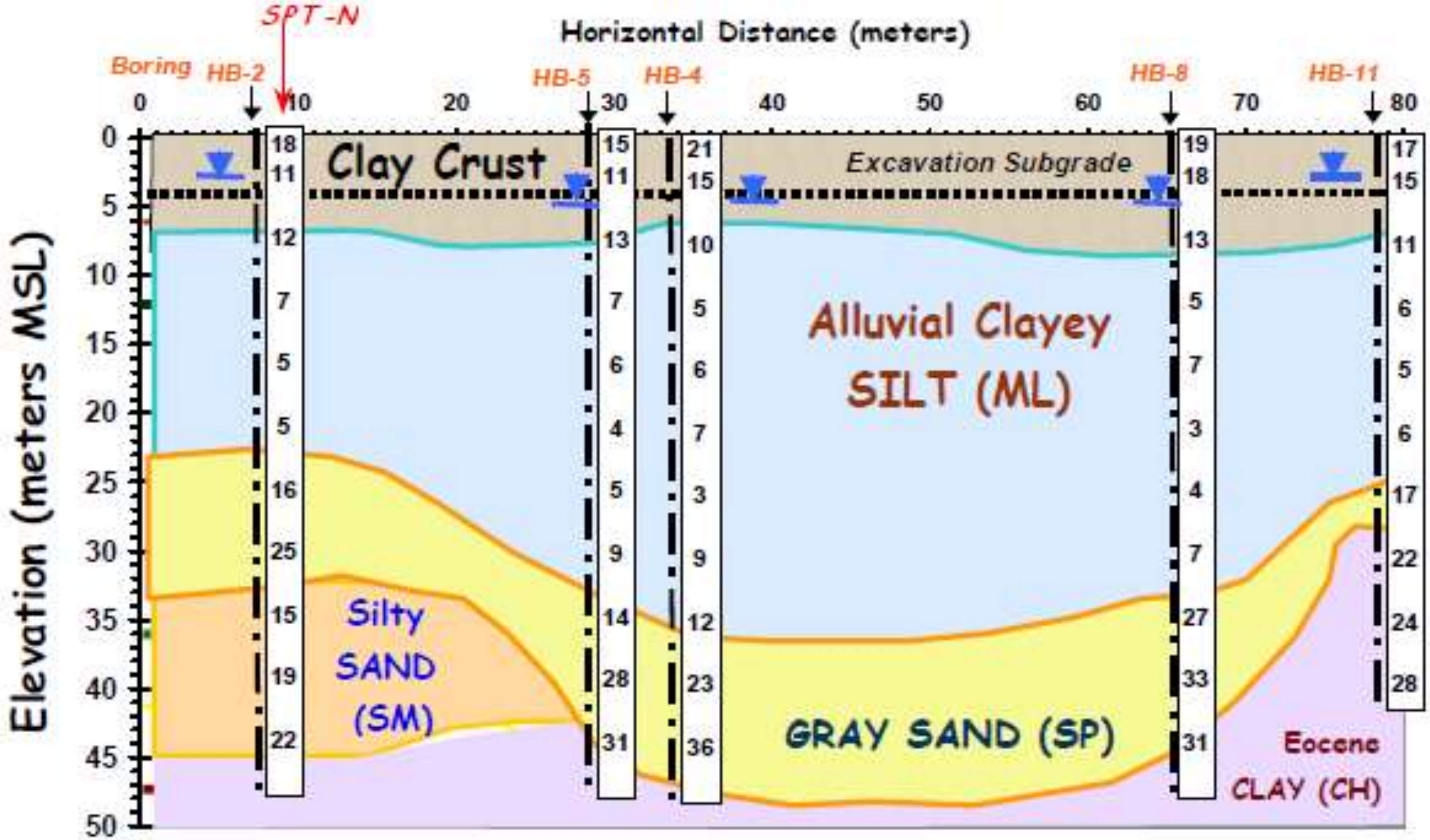
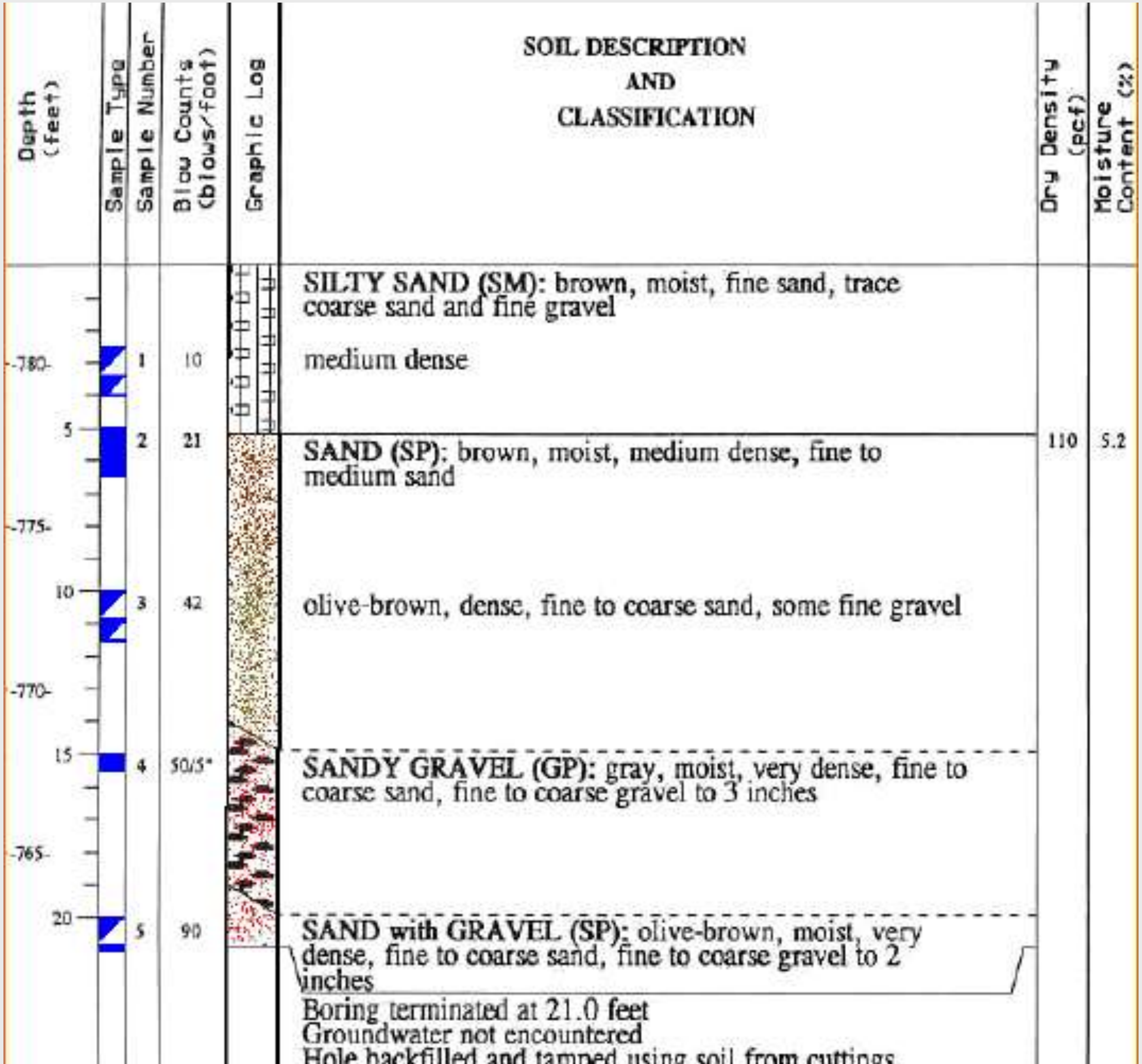


Figure 11-5. Subsurface Profile Based on Boring Data Showing Cross-Sectional View.

Read the boring log shown below and determine, (1) the location of the phreatic surface, (2) the depth of the boring and (3) the number of samples taken.



Solution:

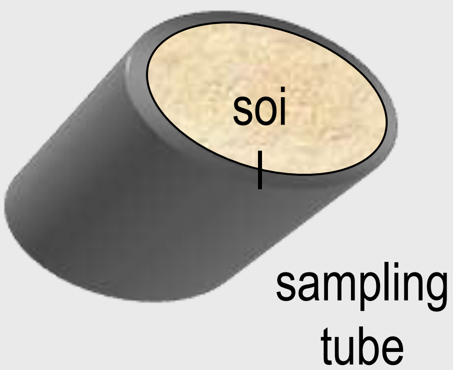
(1) The phreatic surface (the water table) was *not* encountered in this boring and is noted at the bottom of the report;

(2) The boring was terminated at 21 feet in depth; and

(3) Five samples were taken. Only one sample (#2) was used for laboratory tests (dry density and moisture content). Samples #1 and #3 were complete split-spoon samples. Samples #4 and #5 were incomplete split-spoon samples because of the high blow counts.

SOIL SAMPLING

Two types of soil samples can be obtained during sampling **disturbed and undisturbed. The most important engineering properties required for foundation design are strength, compressibility, and permeability. Reasonably good estimates of these properties for cohesive soils can be made by laboratory tests on undisturbed samples** which can be obtained with moderate difficulty. It is nearly impossible to obtain a truly undisturbed sample of soil; so in general usage the term "undisturbed" means a sample where some precautions have been taken to minimize disturbance or remolding effects. In this context, the quality of an "undisturbed" sample varies widely between soil laboratories.



Good quality samples necessary.

$A_R < 10\%$

$$A_R = \frac{O.D.^2 - I.D.^2}{I.D.^2} \times 100\,(\%)$$

area ratio

Engineering Geology

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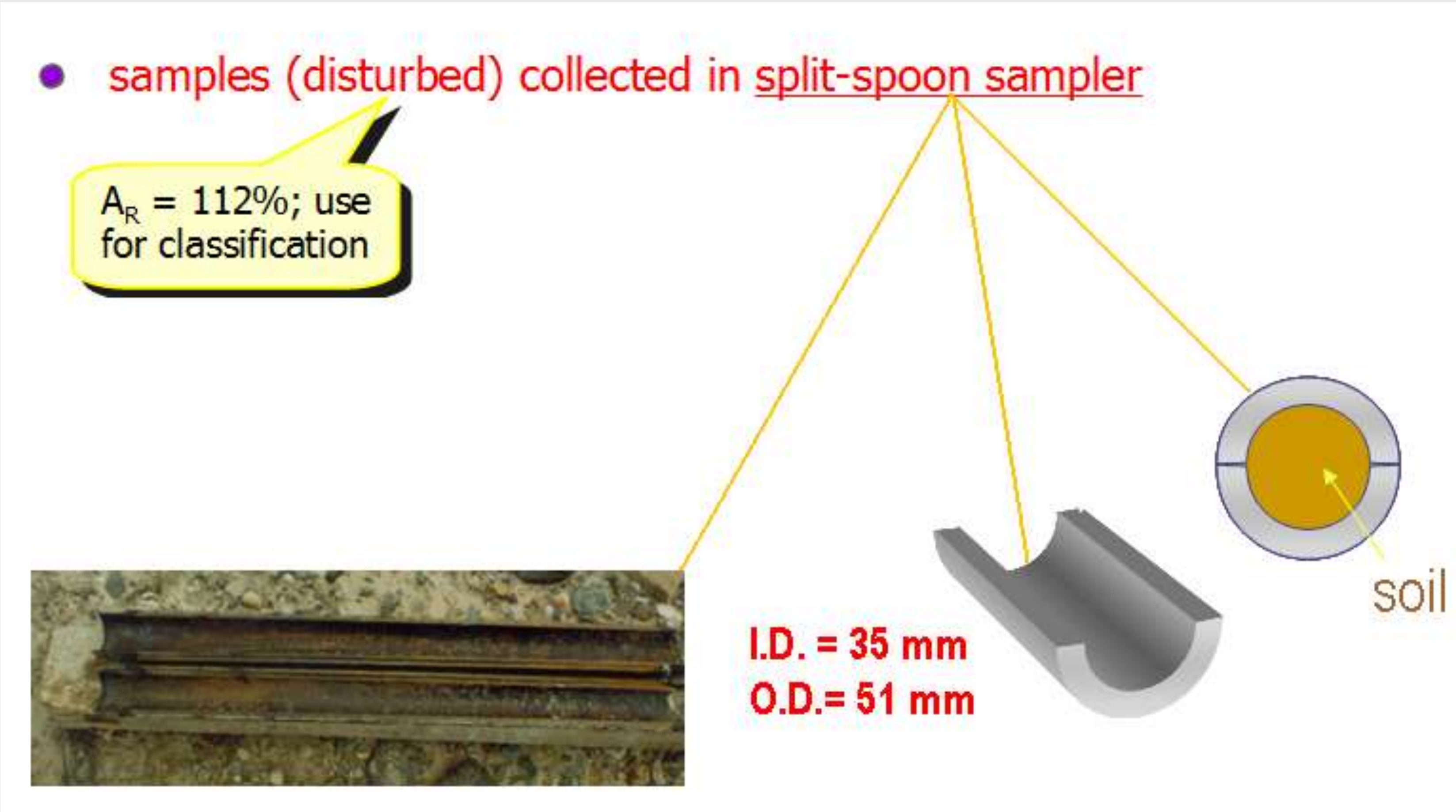


Common Sampling Methods

Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially Undisturbed	Sands, silts, & clays	Hydraulic push with plastic lining	4
Piston	Undisturbed	Silts and clays	Hydraulic Push	1
Pitcher	Undisturbed	Stiff to hard clay, silt, sand, partially weather rock, and frozen or resin impregnated granular soil	Rotation and hydraulic pressure	<1
Denison	Undisturbed	Stiff to hard clay, silt, sand and partially weather rock	Rotation and hydraulic pressure	<1
Modified California	Disturbed	Sands, silts, clays, and gravels	Hammer driven (large split spoon)	<1
Continuous Auger	Disturbed	Cohesive soils	Drilling w/ Hollow Stem Augers	<1
Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

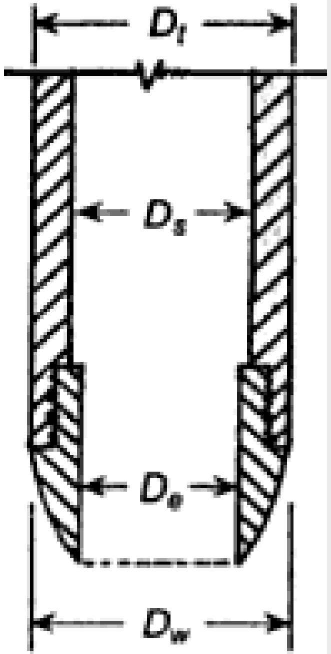
Soil Sampling.

* Disturbed soil samples can provide:

1) a grain size analysis,
2) the determination of plastic and liquid limits,
3) find the specific gravity of the solids,
4) determine the organic content, and
5) classify the soil.

* Undisturbed soil samples will, in addition to the above, provide:

6) determine the consolidation parameters,
7) find the soil hydraulic conductivity (permeability), and
8) determine the shear strength.



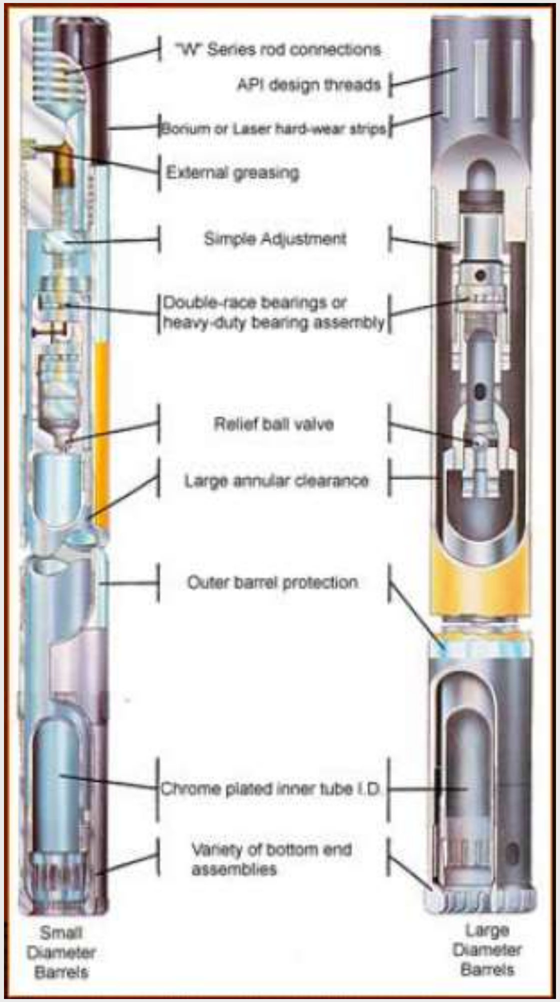
Sample Disturbance

The degree of disturbance is

$$A_r(\%) = \frac{D_o^2 - D_i^2}{D_i^2} \times 100$$

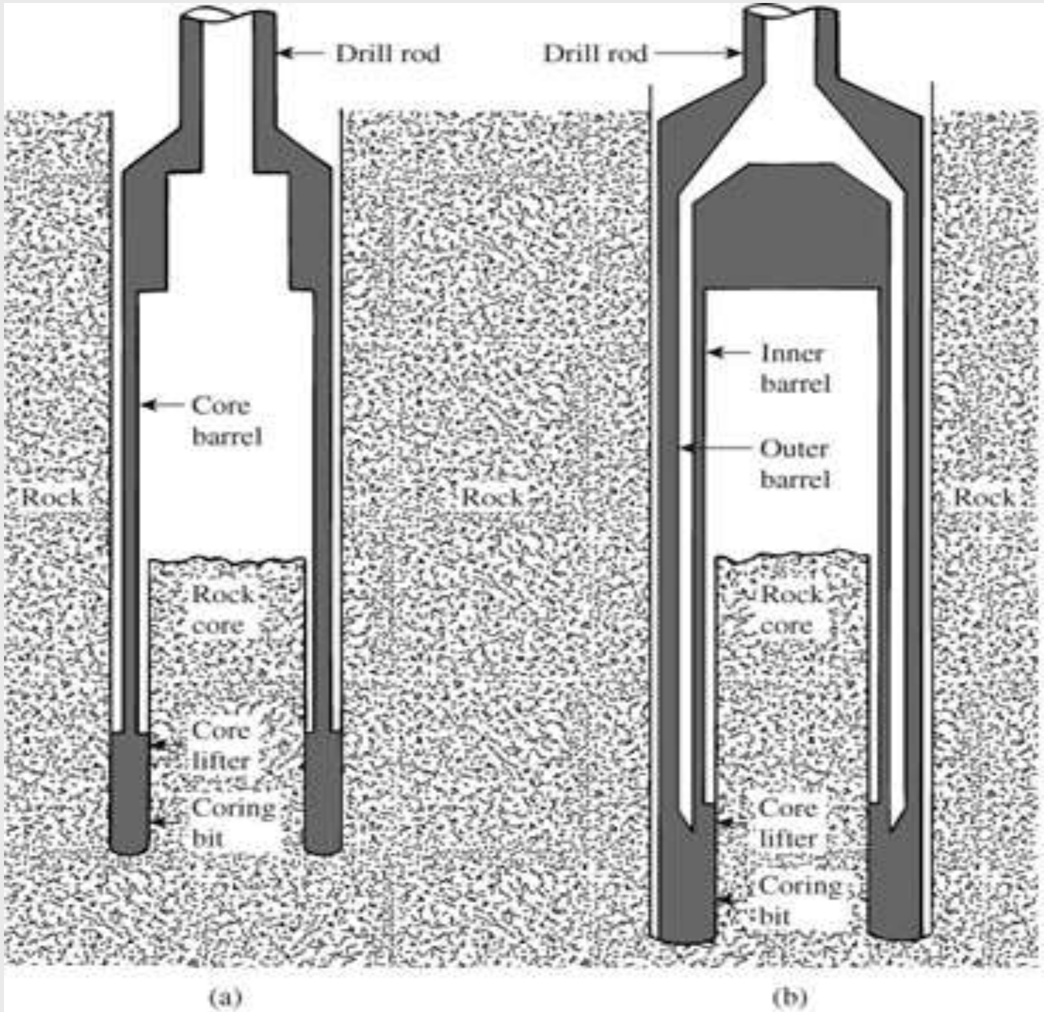
where D_o = outside diameter of the sampler, and D_i = inside diameter of the sampler.

ROCK SAMPLING



Rock cores are necessary if the soundness of the rock is to be established.
small cores tend to break up inside the drill barrel.
Larger cores also have a tendency to break up (rotate inside the barrel and degrade), especially if the rock is soft or fissured.

Rock coring



Rock coring: (a) single-tube core barrel; (b) double-tube core barrel

Drill bits for rock penetration

ROCK SAMPLING - Definition

$$\text{Recovery Ratio} = \frac{\sum \text{Lengths of intact pieces of core}}{\text{Length of core advance}}$$

$$\text{RQD} = \frac{\sum \text{Lengths of intact pieces of core} \geq 10.16 \text{ cm}}{\text{Length of core advance}}$$

Rock Core Drilling

Done with either tungsten carbide or diamond core bits

Use a double or triple tube core barrel when sampling weathered or fractured rock

Used to determine Rock Quality Designation

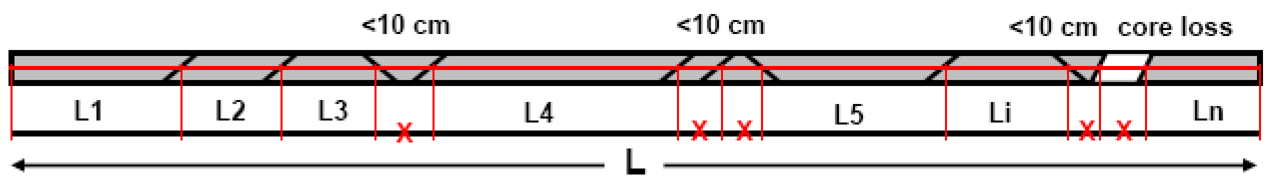
core barrel

Rock Quality Designation RQD

RQD

Rock Quality Designation (RQD) is defined as the percentage of rock cores that have length equal or greater than 10 cm over the total drill length.

$$RQD = \Sigma L_i / L \times 100\%, \quad L_i > 10\ cm$$



$$RQD = (L1 + L2 + \ldots + Ln) / L \times 100\%$$

RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

Example on Core Recovery & RQD

Core run of 150 cm
Total core recovery = 125 cm
Core recovery ratio = 125/150 = 83%
On modified basis, 95 cm are counted
RQD = 95/150=63 %

Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	0
7.5	0
10	10
12.5	12.5
7.5	0
10	10
15	15
10	10
5	0
12.5	12.5
125	95

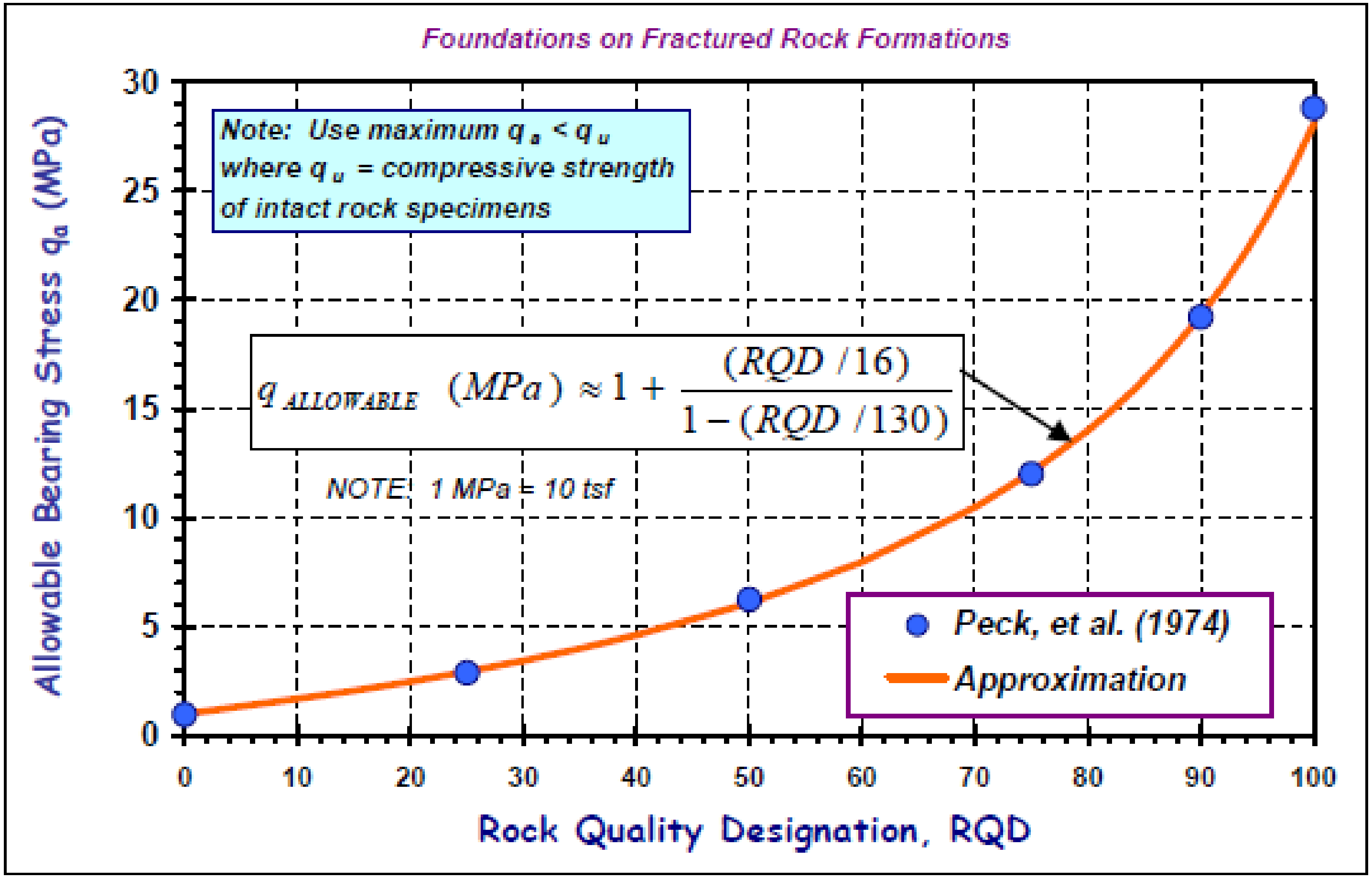


Figure 10-19. Allowable Bearing Stress on Fractured Rock from RQD (after Peck, et al. 1974).

Properties Governing Rock Mass Behavior **Rock mass is a matrix consisting of rock material and rock discontinuities. rock discontinuity are: joints. Faults, bedding planes and dyke intrusions . Properties of rock mass therefore are governed by the parameters of rock joints and rock material, as well as boundary conditions,. T he behavior of rock changes from continuous elastic of intact rock materials to discontinues running of highly fractured rock masses**

Prime parameters governing rock mass property

Joint Parameters	Material Parameters	Boundary Conditions
Number of joint sets Orientation Spacing Aperture Surface roughness Weathering and alteration	Compressive strength Modulus of elasticity	Groundwater pressure and flow In situ stress

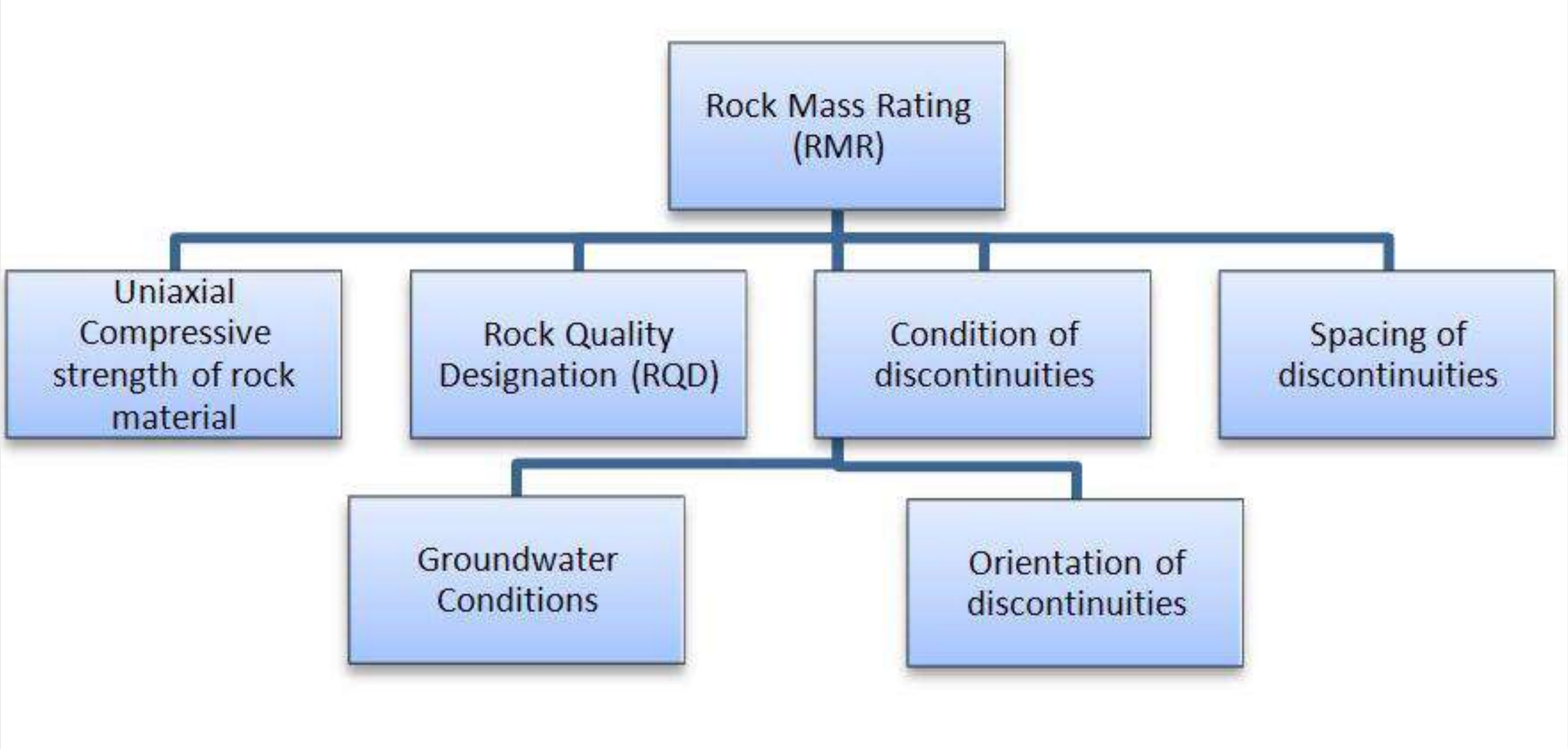
Rock Mass Rating System (RMR) Is a rock classification system uses five basic parameters for classification and properties evaluation. A sixth parameter helps further assess issues of stability to specific problems. Originally intended **for tunneling & mining applications, it has been extended for the design of cut slopes and foundations**. [stand--up time of an unsupported excavation] The six parameters used to determine the RMR value are: Uniaxial compressive strength (σu)*.

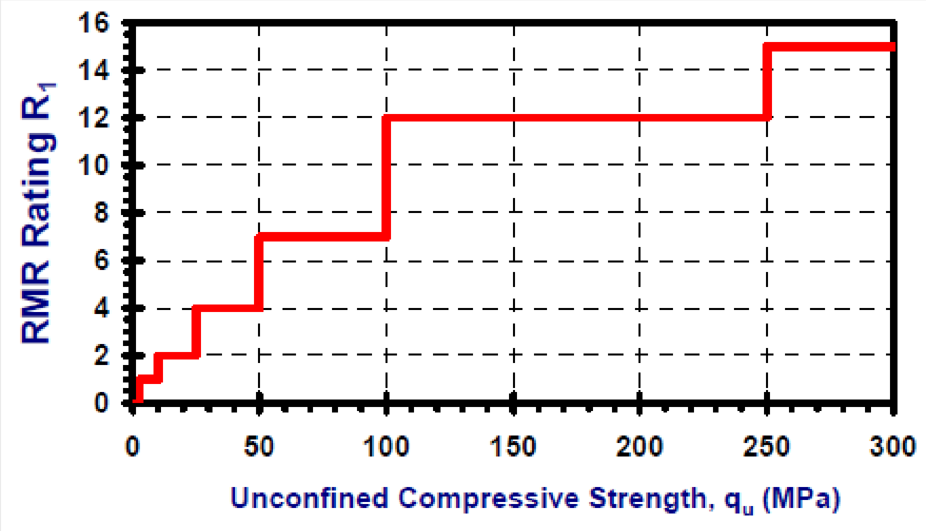
- Rock Quality Designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation of discontinuities (dip and strike of discontinuities, plane of weakness)

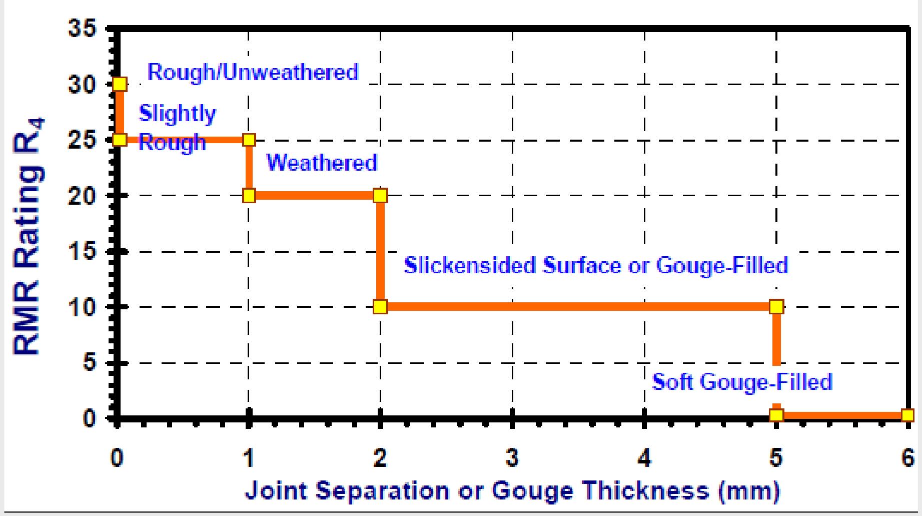
*Note: Value may be estimated from point load index (Is).

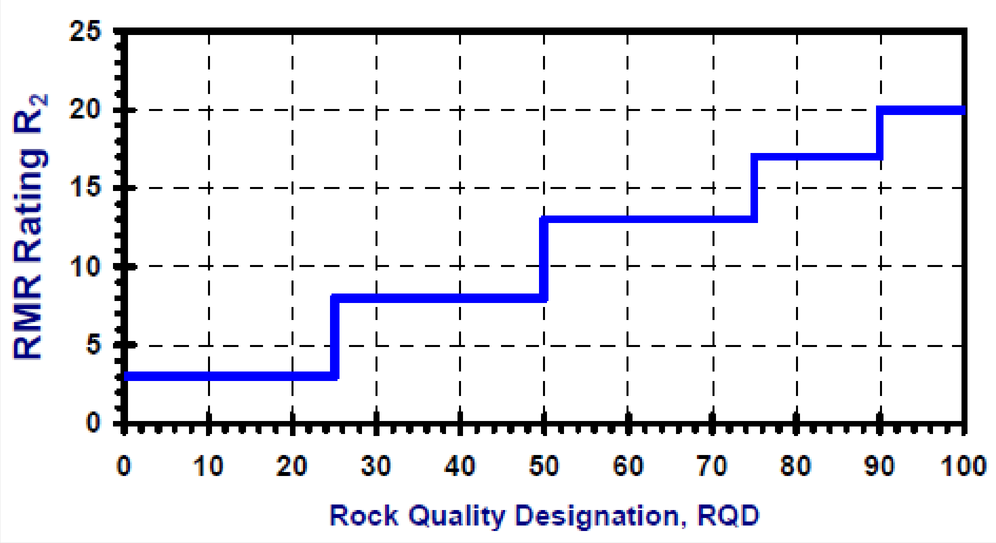
The rating is obtained by summing the values assigned for the first five components

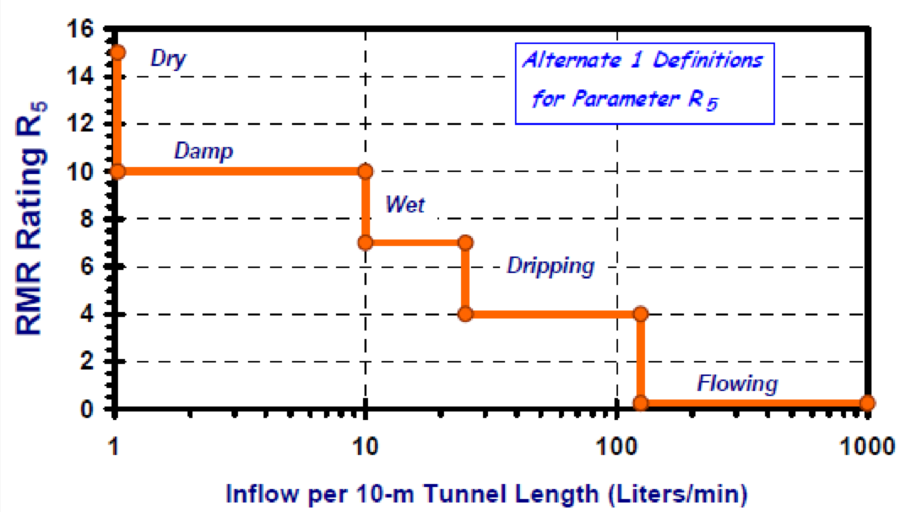
$$RMR = \sum_{i=1}^{5} (R_i)$$

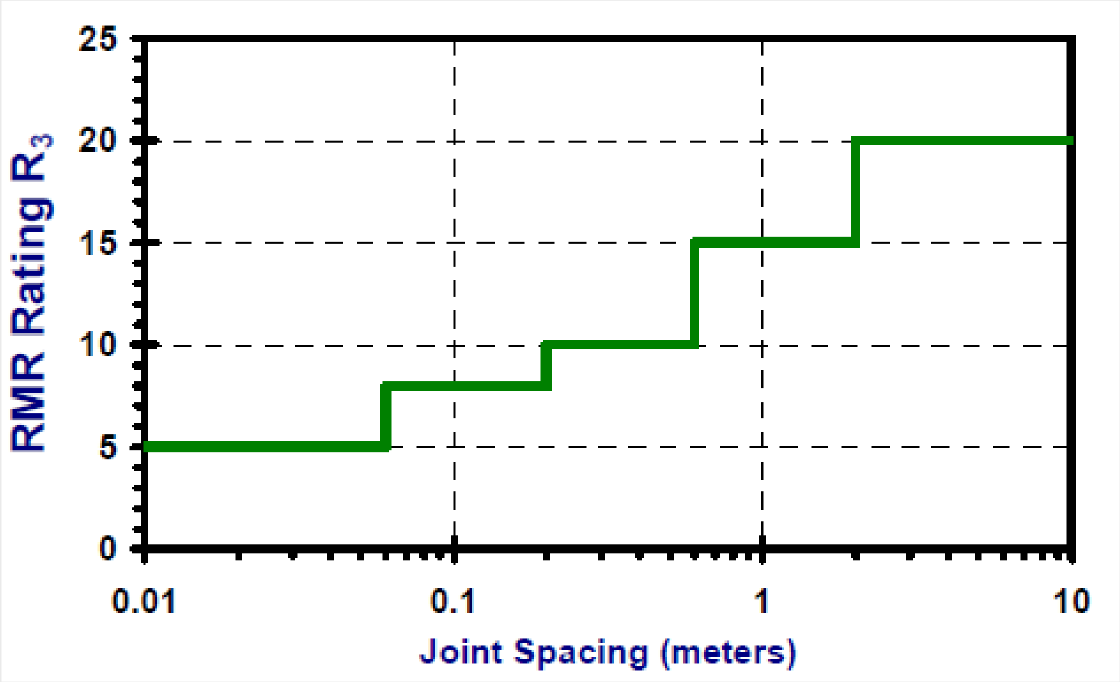

Rock Mass Rating (RMR)
Uniaxial Compressive strength of rock material
Rock Quality Designation (RQD)
Condition of discontinuities
Spacing of discontinuities
Groundwater Conditions
Orientation of discontinuities


RMR Rating R1
Unconfined Compressive Strength, qu (MPa)

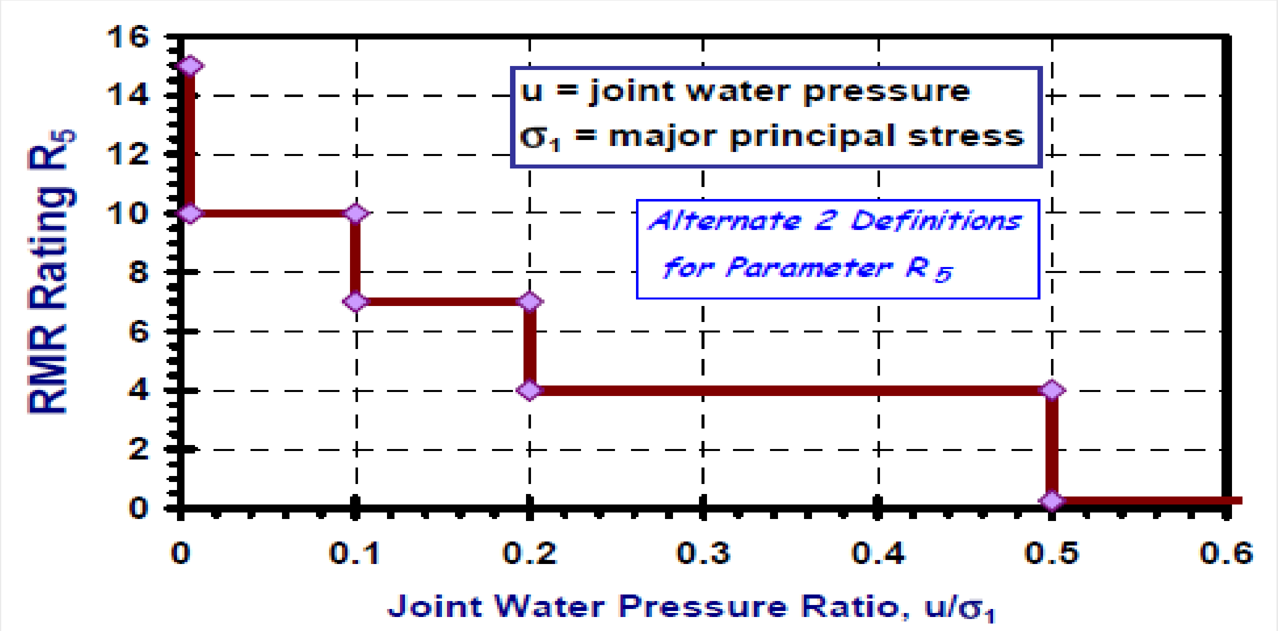

RMR Rating R4
Rough/Unweathered
Slightly Rough
Weathered
Slickensided Surface or Gouge-Filled
Soft Gouge-Filled
Joint Separation or Gouge Thickness (mm)


RMR Rating R2
Rock Quality Designation, RQD


RMR Rating R5
Dry
Damp
Wet
Dripping
Flowing
Alternate 1 Definitions for Parameter R5
Inflow per 10-m Tunnel Length (Liters/min)



RMR Rating R_3
25
20
15
10
5
0
0.01
0.1
1
10
Joint Spacing (meters)



RMR Rating R_5
16
14
12
10
8
6
4
2
0
u = joint water pressure
σ_1 = major principal stress
Alternate 2 Definitions
for Parameter R_5
0
0.1
0.2
0.3
0.4
0.5
0.6
Joint Water Pressure Ratio, u/σ_1

Rock mass classification RMR system

(a) Five basic rock mass classification parameters and their ratings

	Parameter								
1.	Strength of intact rock material	Point load strength index (MPa)	> 10	4 – 10	2 – 4	1 – 2			
		Uniaxial compressive strength (MPa)	> 250	100 – 250	50 – 100	25 – 50	5 – 25	1 – 5	< 1
	Rating		*15*	*12*	*7*	*4*	*2*	*1*	*0*

	Parameter					
2.	RQD (%)	90 – 100	75 – 90	50 – 75	25 – 50	< 25
	Rating	*20*	*17*	*13*	*8*	*3*
3.	Joint spacing (m)	> 2	0.6 – 2	0.2 – 0.6	0.06 – 0.2	< 0.06
	Rating	*20*	*15*	*10*	*8*	*5*
4.	Condition of joints	not continuous, very rough surfaces, unweathered, no separation	slightly rough surfaces, slightly weathered, separation <1 mm	slightly rough surfaces, highly weathered, separation <1 mm	continuous, slickensided surfaces, or gouge <5 mm thick, or separation 1–5 mm	continuous joints, soft gouge >5 mm thick, or separation >5 mm
	Rating	*30*	*25*	*20*	*10*	*0*

	Parameter						
5.	Groundwater	inflow per 10 m tunnel length (l /min), or	none	< 10	10 – 25	25 – 125	> 125
		joint water pressure/major in situ stress, or	0	0 – 0.1	0.1 – 0.2	0.2 – 0.5	> 0.5
		general conditions at excavation surface	completely dry	damp	wet	dripping	flowing
	Rating		*15*	*10*	*7*	*4*	*0*

(b) Rating adjustment for joint orientations

Strike and dip orientation of joints		very favourable	favourable	fair	unfavourable	very unfavourable
Rating	tunnels	0	– 2	– 5	– 10	– 12
	foundations	0	– 2	– 7	– 15	– 25
	slopes	0	– 5	– 25	– 50	– 60

(c) Effects of joint orientation in tunnelling

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° – 20°
Drive with dip		Drive against dip				
Dip 45° – 90°	Dip 20° – 45°	Dip 45° – 90°	Dip 20° – 45°	Dip 45° – 90°	Dip 20° – 45°	irrespective of strike
very favourable	favourable	fair	unfavourable	very unfavourable	fair	fair

The Geo mechanics Classification System for Rock Mass Rating (RMR)

Rock mass classes determined from total ratings and meaning

RMR Ratings	81 – 100	61 – 80	41 – 60	21 – 40	< 20
Rock mass class	A	B	C	D	E
Description	very good rock	good rock	fair rock	poor rock	very poor rock
Average stand-up time	10 year for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 0.5 m span
Rock mass cohesion (KPa)	> 400	300 – 400	200 – 300	100 – 200	< 100
Rock mass friction angle	> 45°	35° – 45°	25° – 35°	15° – 25°	< 15°

GROUND WATER TABLE LEVEL

Groundwater conditions and the potential for groundwater seepage are fundamental factors in virtually all geotechnical analyses and design studies. Accordingly, the evaluation of groundwater conditions is a basic element of almost all geotechnical investigation programs
. Groundwater investigations are of two types as follows:

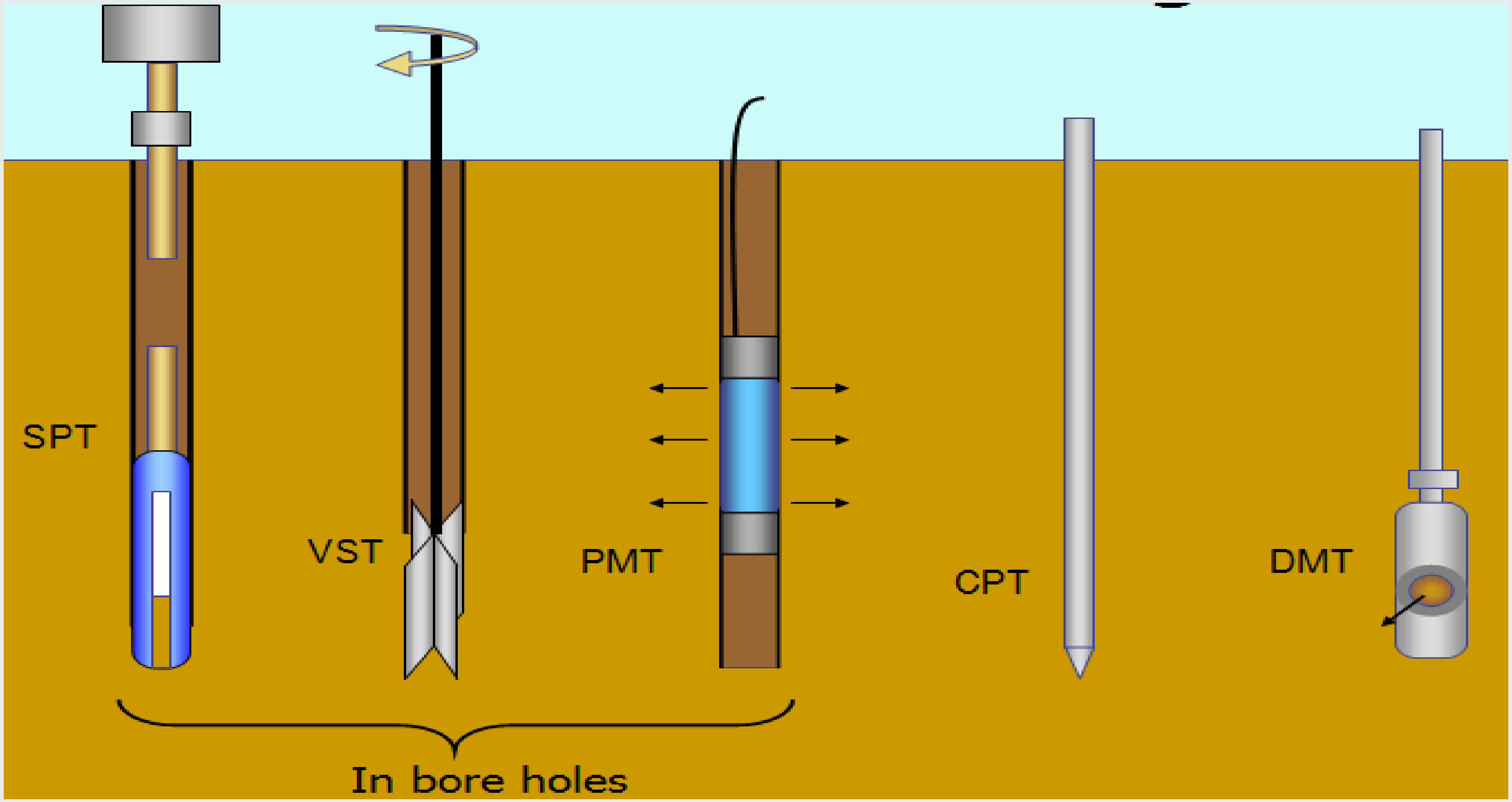
Determination of groundwater levels and pressures.

Measurement of the permeability of the subsurface materials.

FIELD STRENGTH TESTS

The following are the major field tests for determining the soil strength:

1. **Vane shear test (VST).**
2. **Standard Penetration Test (SPT).**
3. **Cone Penetration Test (CPT).**
4. **The Borehole Shear Test (BST).**
5. **The Flat Dilatometer Test (DMT).**
6. **The Pressure-meter Test (PMT).**
7. **The Plate Load Test (PLT).**


SPT
VST
PMT
CPT
DMT
In bore holes

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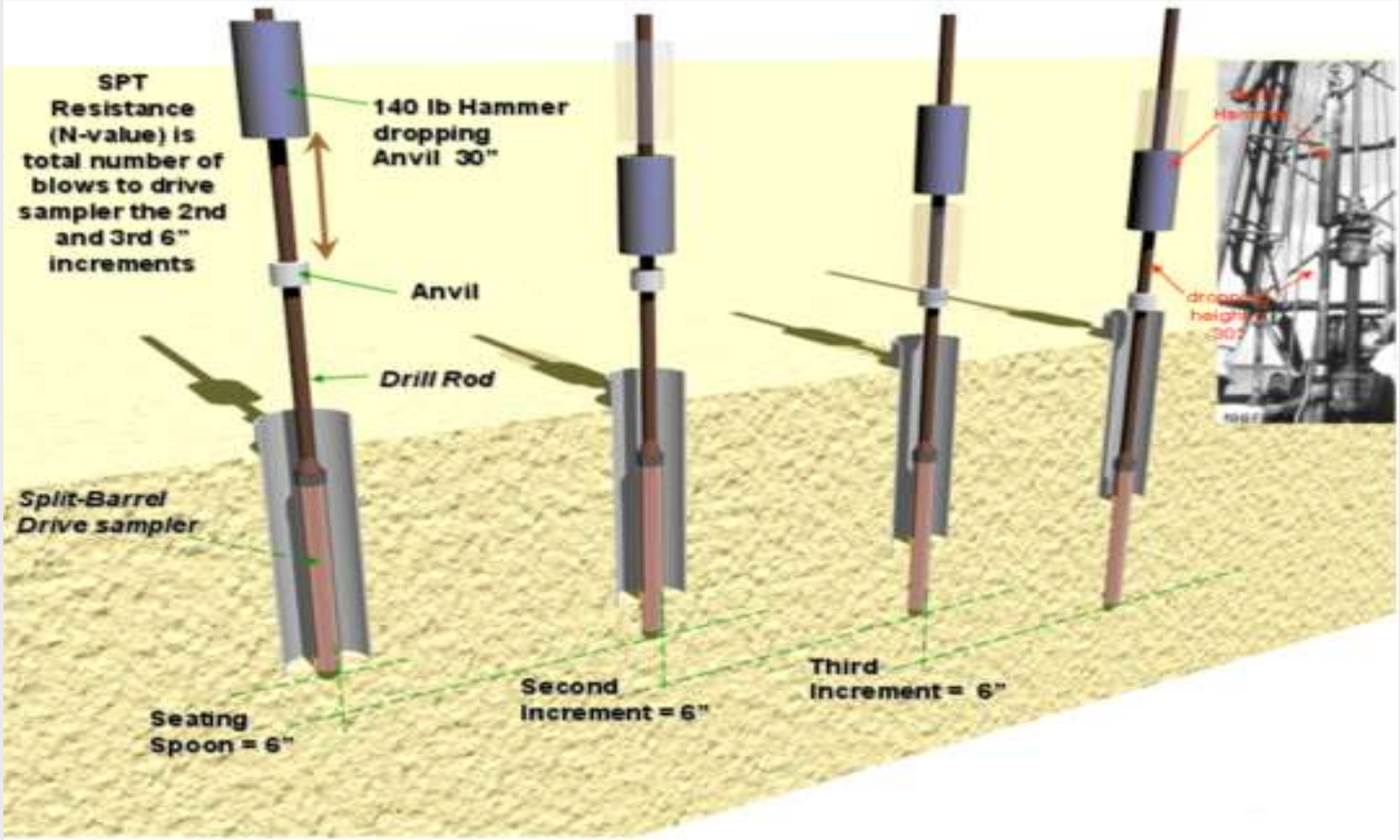

Standard Penetration Test (SPT)

is an in-situ dynamic penetration test to provide information on the geotechnical engineering properties of soil

N Value

The test uses a thick-walled sample tube, with an outside diameter of 50 mm and an inside diameter of 35 mm, and a length of around 650 mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a weight of 63.5 kg. falling through a distance of 760 mm. The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm up to a depth of 450 mm is recorded. The sum of the number of blows required for the second and third 150mm of penetration is termed the "standard penetration resistance" or the "N-value". In cases where 50 blows are insufficient to advance it through a 150 mm interval the penetration after 50 blows is recorded. The blow count provides an indication of the density of the ground,.

The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels from which it is virtually impossible to obtain undisturbed samples.

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60}$$

TABLE 4.4 BOREHOLE, SAMPLER, AND ROD CORRECTION FACTORS

Factor	Equipment Variables	Value
Borehole diameter factor, C_B	2.5 - 4.5 in (65 - 115 mm)	1.00
	6 in (150 mm)	1.05
	8 in (200 mm)	1.15
Sampling method factor, C_S	Standard sampler	1.00
	Sampler without liner (~~not recommended~~) (generally used)	1.20
Rod length factor, C_R	10 - 13 ft (3 - 4 m)	0.75
	13 - 20 ft (4 - 6 m)	0.85
	20 - 30 ft (6 - 10 m)	0.95
	> 30 ft (> 10 m)	1.00

Adapted from Skempton (1986).

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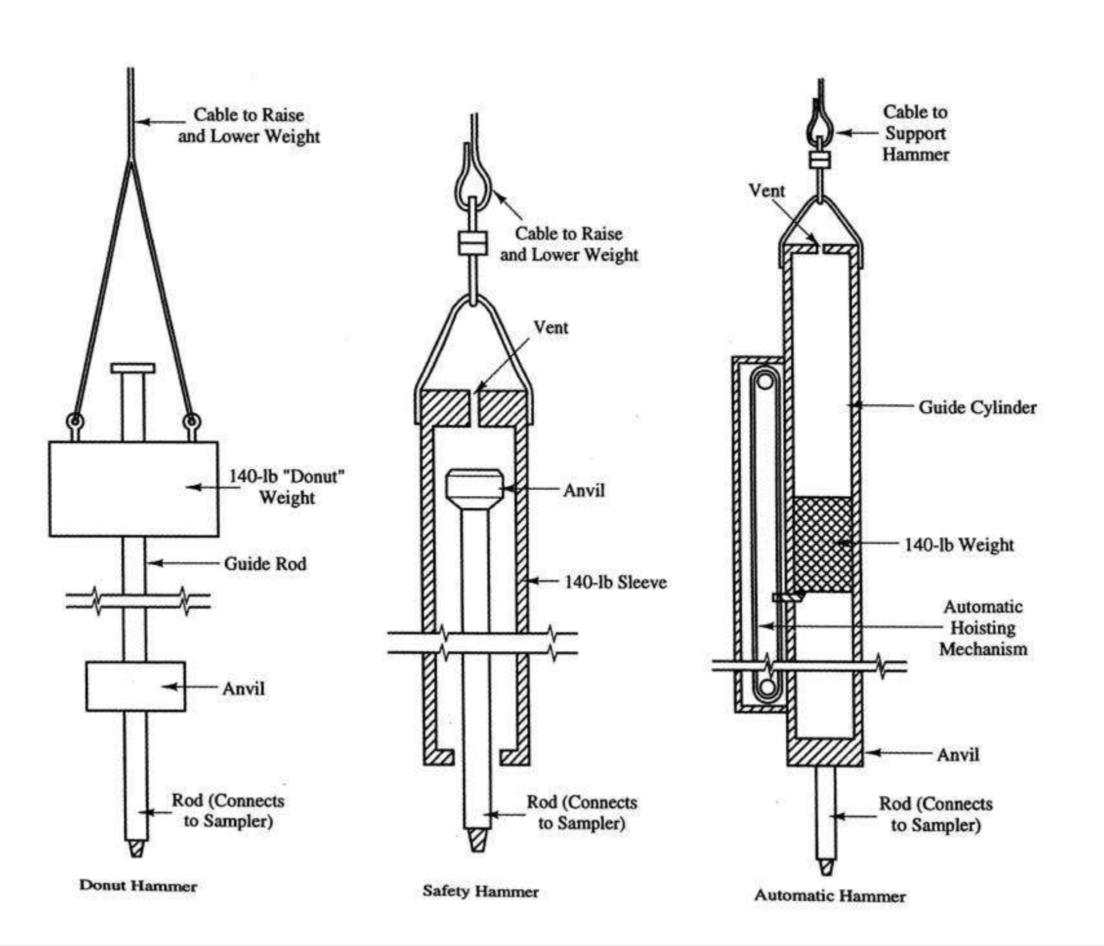
Em: Hammer efficiency =0.6 for safety hammer and = 0.45 for doughnut hammer



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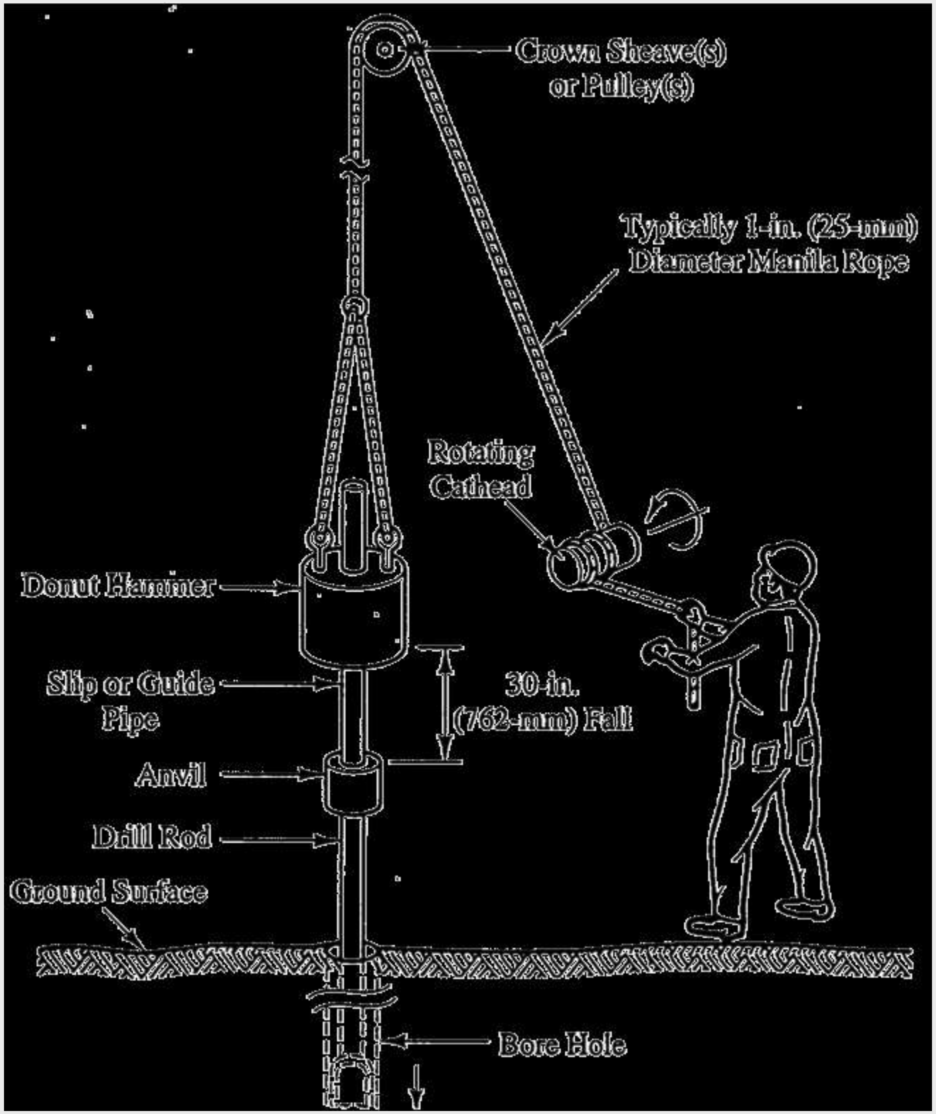

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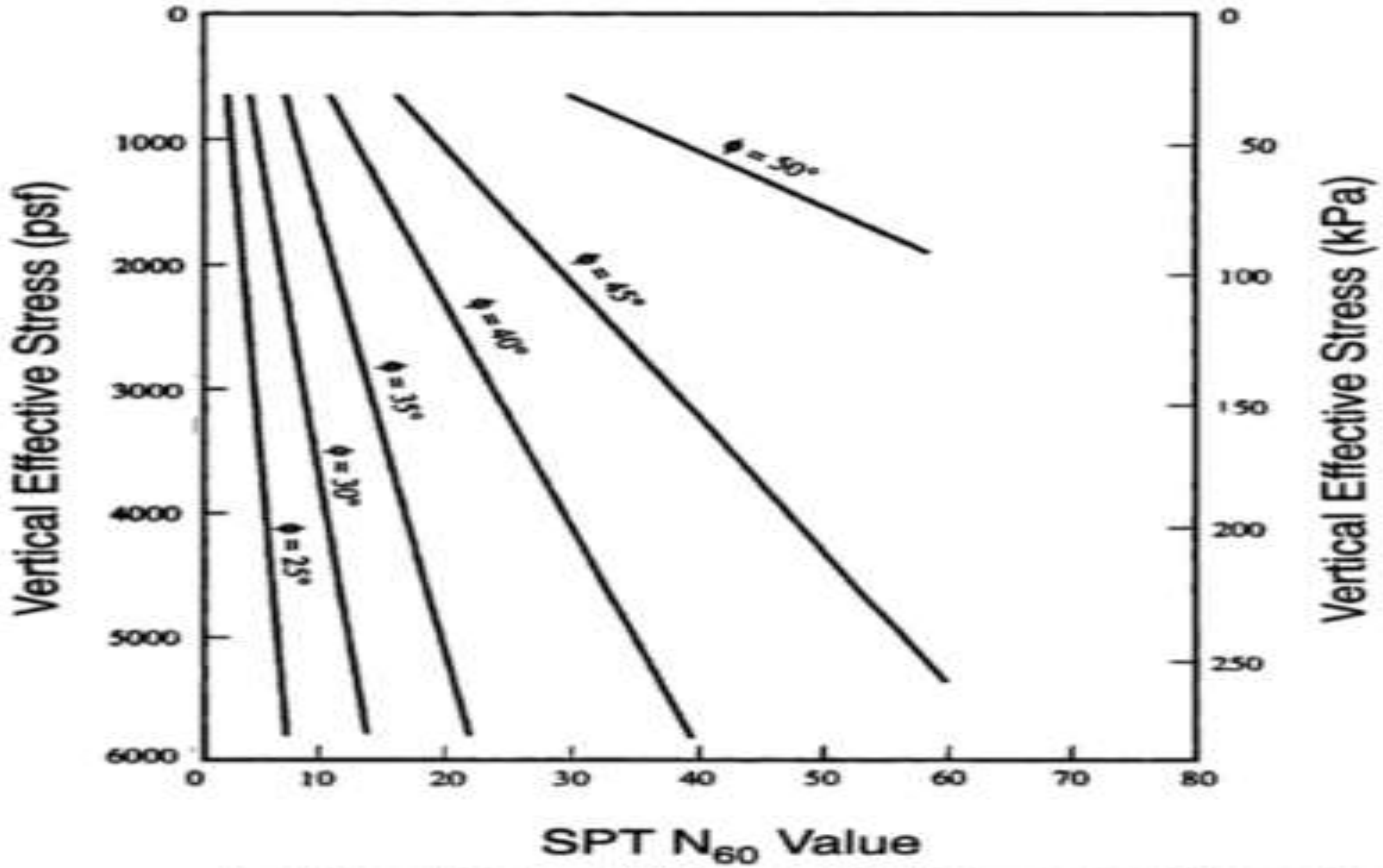
Corrections are normally applied to the SPT blow count to account for differences in:

- energy imparted during the test (60% hammer efficiency)
- the stress level at the test depth

The following equation is used to compensate for the testing factors (Skempton, 1986):

$$N_{60} = 1.67\, E_m C_b C_r N$$

where N_{60} = SPT N-value corrected for field testing procedures
E_m = hammer efficiency (for U.S. equipment, E_m equals 0.6 for a safety hammer and equals 0.45 for a doughnut hammer)
C_b = borehole diameter correction (C_b = 1.0 for boreholes of 65- to 115-mm diameter, 1.05 for 150-mm diameter, and 1.15 for 200-mm diameter hole)
C_r = rod length correction (C_r = 0.75 for up to 4 m of drill rods, 0.85 for 4 to 6 m of drill rods, 0.95 for 6 to 10 m of drill rods, and 1.00 for drill rods in excess of 10 m)
N = measured SPT N-value



Empirical correlation between SPT N_{60} value, vertical effective stress, and friction angle for clean quartz sand deposits. *(Adapted from DeMello, 1971; reproduced from Coduto, 1994.)*

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Relative density and consistency of soil

(a) Relative density of sand and SPT values, and relationship to angle of friction

SPT(N)	Relative density (D_r)	Description of compactness	Angle of internal friction (φ)
4	0.2	Very loose	Under 30°
4–10	0.2–0.4	Loose	30–35°
10–30	0.4–0.6	Medium dense	35–40°
30–50	0.6–0.8	Dense	40–45°
Over 50	0.8–1.0	Very dense	Over 45°

(b) N values, consistency and unconfined compressive strength of cohesive soils

N	Consistency	Unconfined compressive strength (kPa)
Under 2	Very soft	Under 20
2–4	Soft	20–40
5–8	Firm	40–75
9–15	Stiff	75–150
16–30	Very stiff	150–300
Over 30	Hard	Over 300

Permeability

The simplest test for the topmost stratum's permeability is performed after the SPT test. The hole is expanded by a 6-inch diameter auger, and the hole is filled up with water. The drop in the head is measured in time using the straight edge shown above left, , and a rough estimate of permeability is calculated.

Coefficient of permeability in different soils **Permeability is the ease with which the water flows through a soil medium**

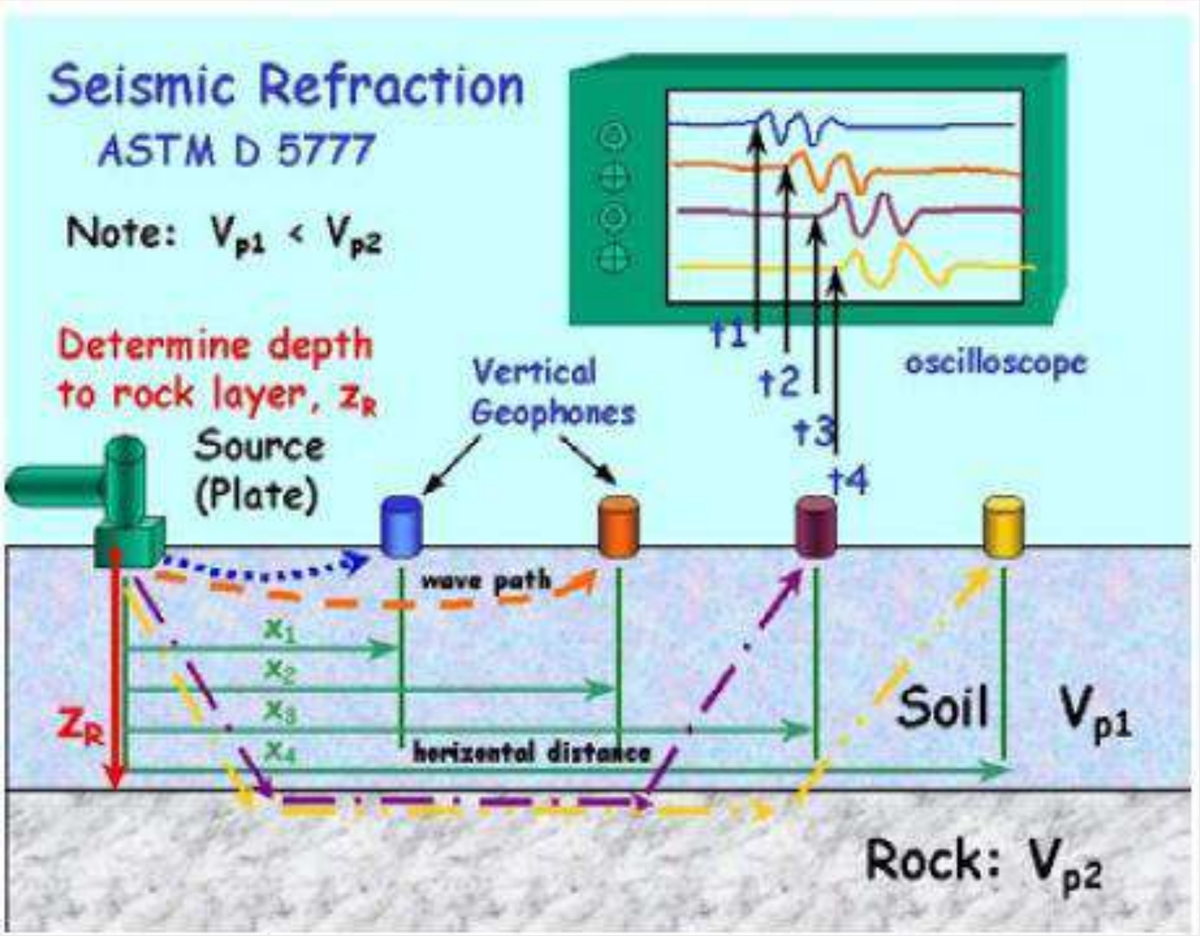
Classification of soils according to their coefficients of permeability (after Kulhawy and Mayne, 1990; and Terzaghi and Peck, 1967)

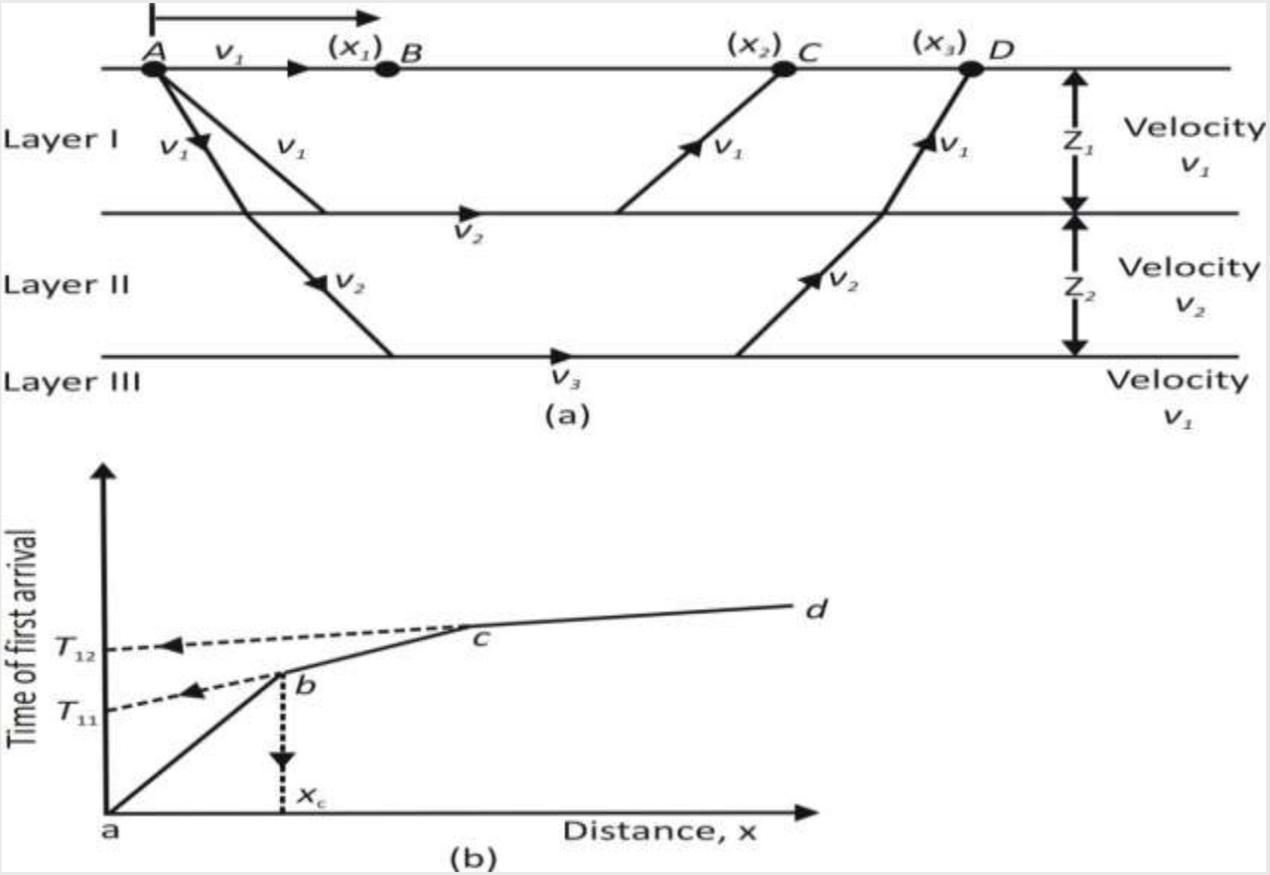
Soil	Coefficient of permeability k (cm/s)	Degree of permeability
Gravel	Over 10^{-1}	High
Sandy gravel, clean sand, fine sand	10^{-1} to 10^{-3}	Medium
Sand, dirty sand, silty sand	10^{-3} to 10^{-5}	Low
Silt, silty clay	10^{-5} to 10^{-7}	Very low
Clay	Less than 10^{-7}	Practically impermeable

Geophysical Exploration

Seismic Refraction Survey

Seismic refraction surveys are useful in obtaining preliminary information about the thickness of the layering of various soils and the depth to rock or hard soil at a site. Refraction surveys are conducted by impacting the surface, as at point A in figure 2.41a and observing the first arrival of the disturbance (stress waves) at several other points (e.g., B, C, D,…). The impact can be created by a hammer blow or by a small explosive charge. The first arrival of disturbance waves at various points can be recorded by geophones


Seismic Refraction
ASTM D 5777
Note: $V_{p1} < V_{p2}$
Determine depth to rock layer, z_R
Source (Plate)
Vertical Geophones
oscilloscope
t1
t2
t3
t4
wave path
x_1
x_2
x_3
x_4
horizontal distance
Z_R
Soil
V_{p1}
Rock: V_{p2}



Seismic refraction survey

The impact on the ground surface creates two types of *stress wave: P waves (or plane waves) and S waves (or shear waves). The P waves travel faster than S waves; hence the first arrival of disturbance waves will be related to the velocities of the P waves in various layers. The velocity of P waves in a medium is*

$$v = \sqrt{\frac{Es \times (1 - \mu s)}{(\rho) \times (1 - 2\mu s) \times (1 + \mu s)}}$$

Where

Es =modulus of elasticity of the medium

P = Density of medium

μ=Poisson'sratio

To determine the velocity, *v, of P waves in various layers and the thicknesses of those layers, use the following procedure.*

1. Obtain the times of first arrival, $t1$, $t2$, $t3$,…, at various distances, $x1$, $x2$, $x3$,…, from the point of impact.

2. Plot a graph of time, *t, against distance, x. the graph will look like the one shown in **figure 2.41b.***

3. Determine the slopes of the lines ab,bc,cd,…

Slope of ab= 1/v1

Slope of bc= = 1/v2

Slope of cd = 1/v3

Where $v1$, $v2$, $v3$,… are the *P-wave velocities in layers I, II, III,…., respectively (**figure 2.41b**)*

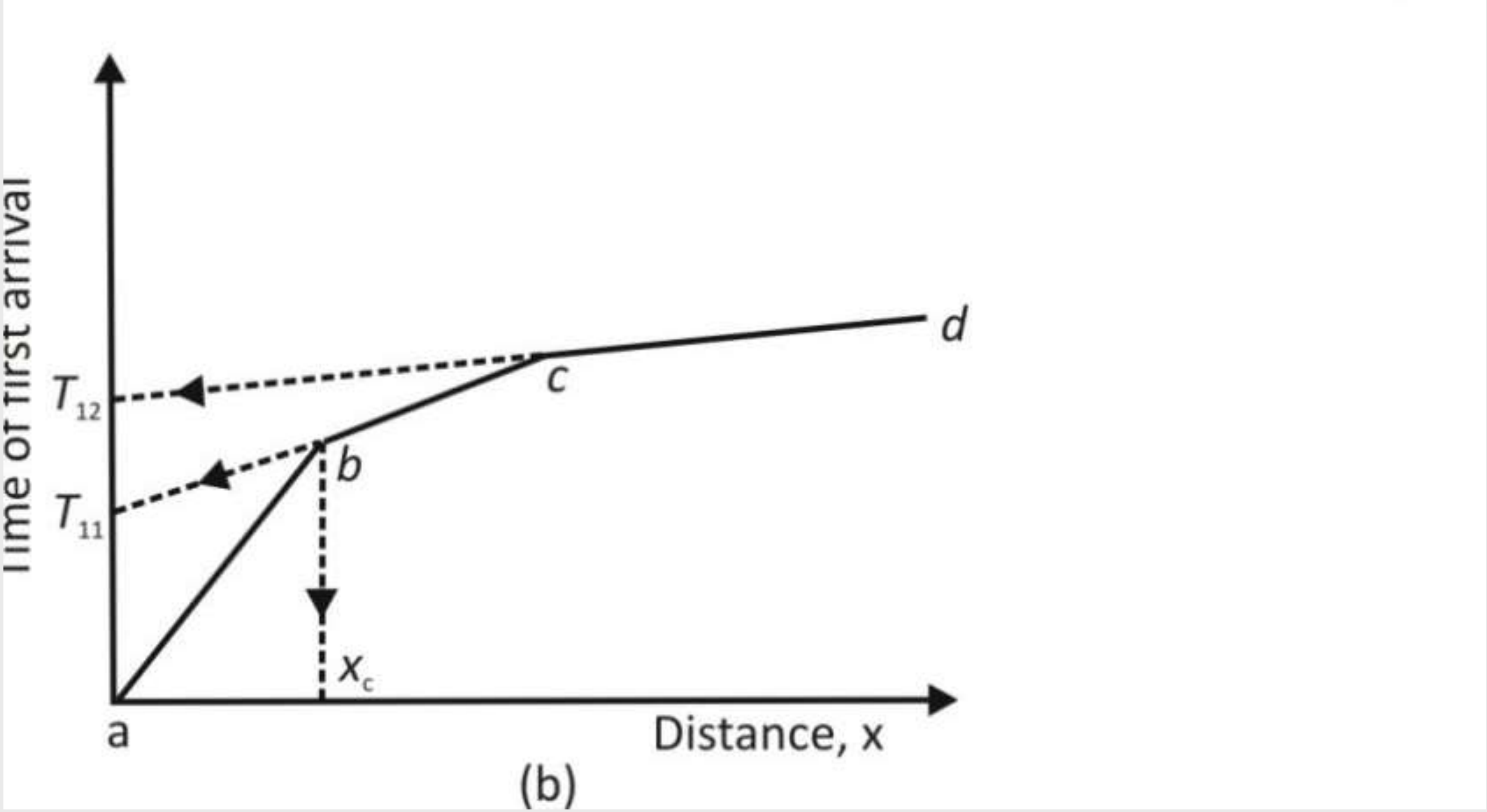
4. Determine the thickness of the top layer as

$$Z1 = \frac{1}{2}\ xc\sqrt{\frac{V2 - V1}{V2 + v1)}}$$

The value of xc can be obtained from the plot, as shown in figure

5. Determine the thickness of the second layer, $Z2$, shown in figure , as

$$Z2 = \frac{1}{2}\left[Ti2 - 2Z1\frac{\sqrt{V3^2 - V1^2}}{V3 \times V1}\right] \times \frac{V3 \times V2}{\sqrt{(V3^2 - V2^2)}}$$


Time of first arrival
T12
T11
a
b
c
d
xc
Distance, x
(b)

Example

The results of a refraction survey at a site are given in the following table. Determine the *P-wave velocities and the thickness of the material encountered*

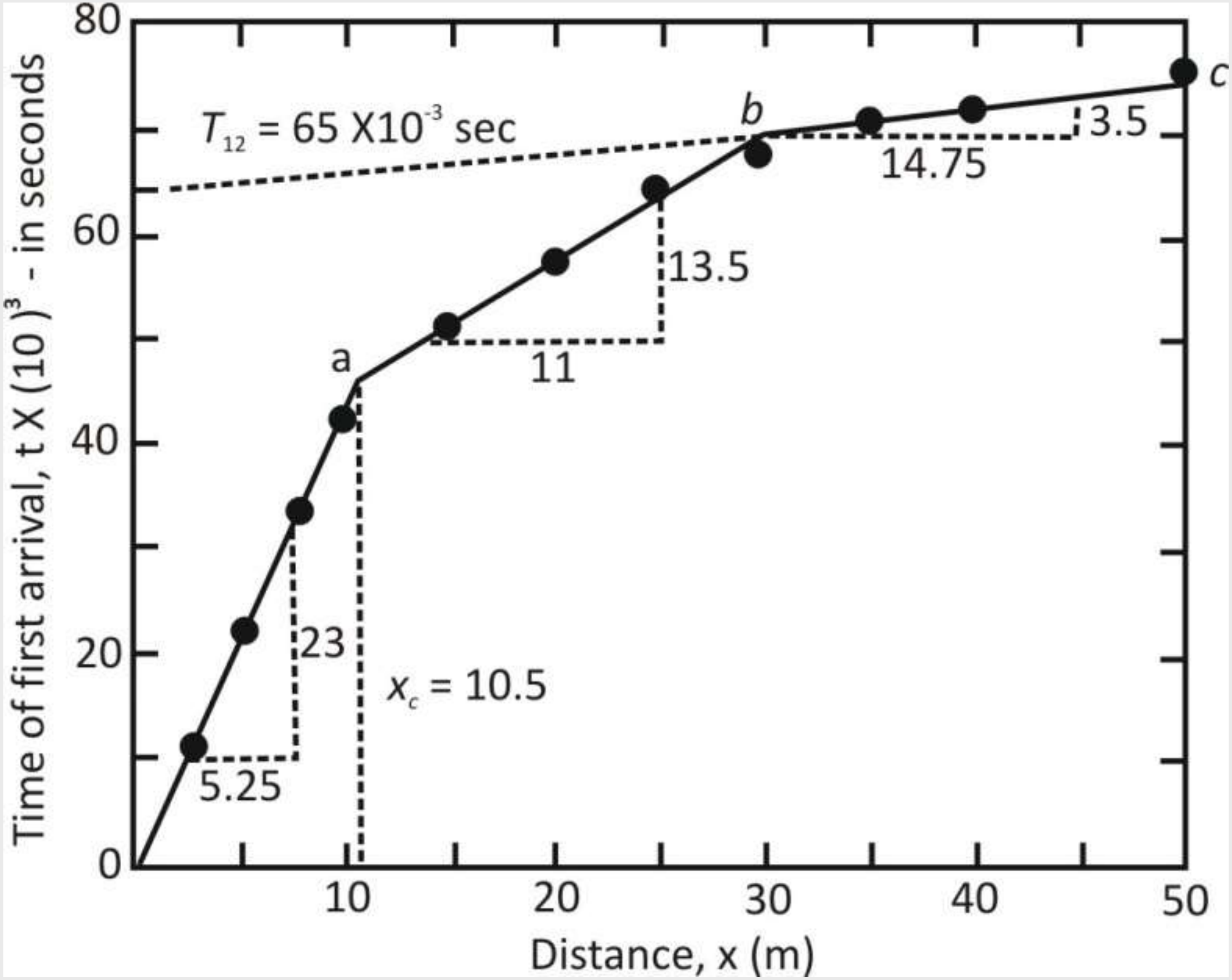
Distance from source(m)	Time first arrial (sec× 10^{3})
2.5	11.2
5	23.3
7.5	33.5
10	42.5
15	50.9
20	57.2
25	64.4
30	68.6
35	71.1
40	72.1
45	75.5

Solution

Velocity In figure below , the times of first arrival are plotted against the distance from the source of disturbance. The plot has three straight-line segments. The velocity of the top three layers can now be calculated as follows

Slope of segment 0a= 1/v1= time /distance = $23 \times 10^{-3}/5.25$
Or
$v1 = 5.25 \times 10^{3}/23 = 228$ m/sec(top layer)

Slope of segment ab =1/v2=$13.5 \times 10^{-3}/11$
Or
$v2 = 11 \times 10^{3}/13.5 = 814.8$ m/sec(middle layer)
Slope of segment bc= 1/v3= $3.5 \times 10^{-3}/14,75$
Or
V3 = 4214 m/sec(third layer)



80
60
40
20
0
10
20
30
40
50
Distance, x (m)
Time of first arrival, t X (10)^3 - in seconds
T12 = 65 X10^-3 sec
a
b
c
5.25
23
xc = 10.5
11
13.5
14.75
3.5

Comparing the velocities obtained here with those given in table 10 indicates that the third layer is a *rock layer.*

Thickness of Layers

From figure, *xc*= 10.5 m, so

$$Z1 = \frac{1}{2}\ xc\sqrt{\frac{V2 - V1}{V2 + v1)}}$$

$$z1 = \frac{1}{2} \times \sqrt{\frac{814.8 - 228}{814.8 + 228}} \times 10.5 = 3.94m$$

$$Z2 = \frac{1}{2}\left[Ti2 - 2Z1\frac{\sqrt{V3^2 - V1^2}}{V3 \times V1}\right] \times \frac{V3 \times V2}{\sqrt{(V3^2 - V2^2)}}$$

$$z2 = \frac{1}{2}\left[65 \times 10^{-3} - \frac{\sqrt{4214^2 - 228^2}}{4214 \times 228}\right] \times \frac{4214 \times 814.8}{\sqrt{4214^2 - 814.8^2}} = 12.66\text{m}$$

Thus , the rock layer lies at depth of Z1+Z2 = 3.94+12.66 = 16.6m

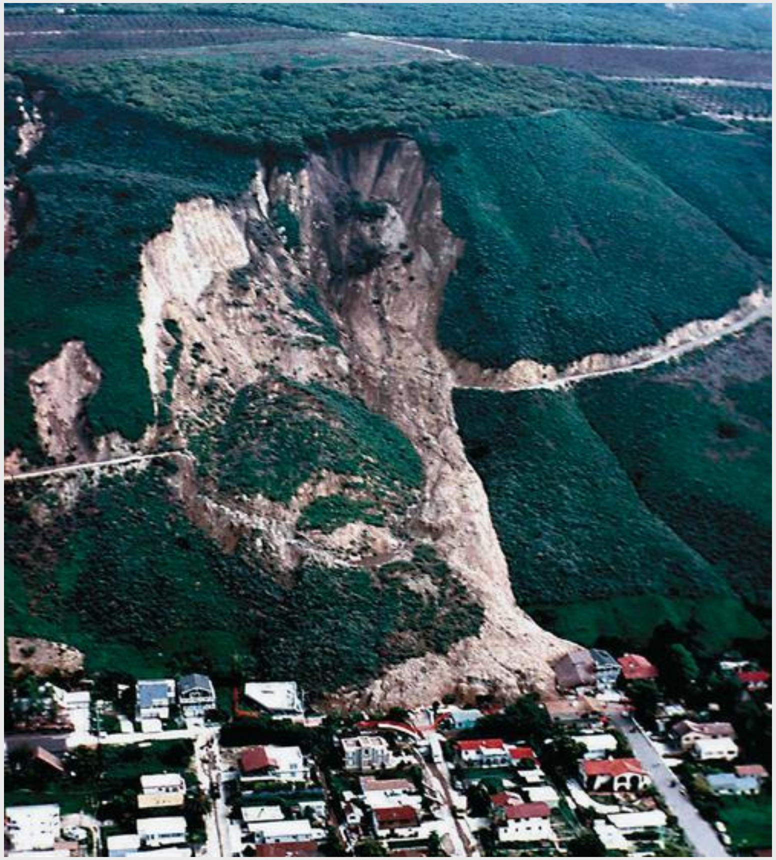
Site Investigation Cost

Saving on the ground investigation budget generally prove to be false economies
After an inadequate ground investigation, unforeseen ground conditions can and frequently **raise project costs by 10% or more**

Typical Ground Investigation Costs

Project	% Total costs	% Foundations costs
Buildings	0·05–0·2	0·5–2
Roads	0·2–1·5	1–5
Dams	1–3	1–5

Mass movements



- Hussien aldeeky

Mass-Wasting

Mass-Wasting is the down slope movement of rock and regolith near the Earth's surface mainly due to the force of gravity. It is an important part of the erosional process, as it moves material from higher elevations to lower elevations where transporting agents like streams and glaciers can then pick up the material and move it to even lower elevations. Mass-wasting processes are occurring continuously on all slopes; some act very slowly, others occur very suddenly, often with disastrous results

Mass-wasting processes are occurring continuously on all slopes; some act very slowly, others occur very suddenly, often with disastrous results

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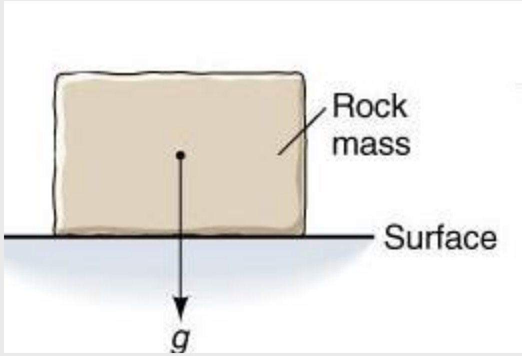
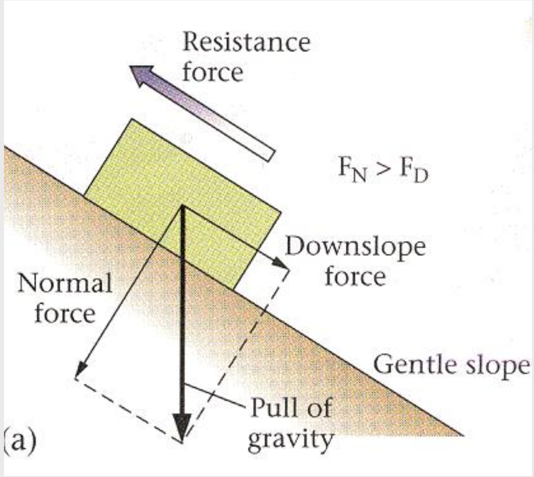
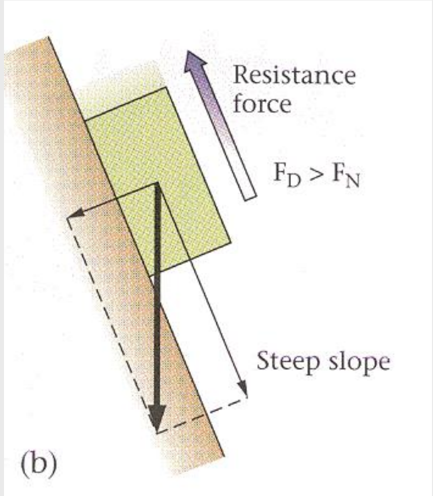
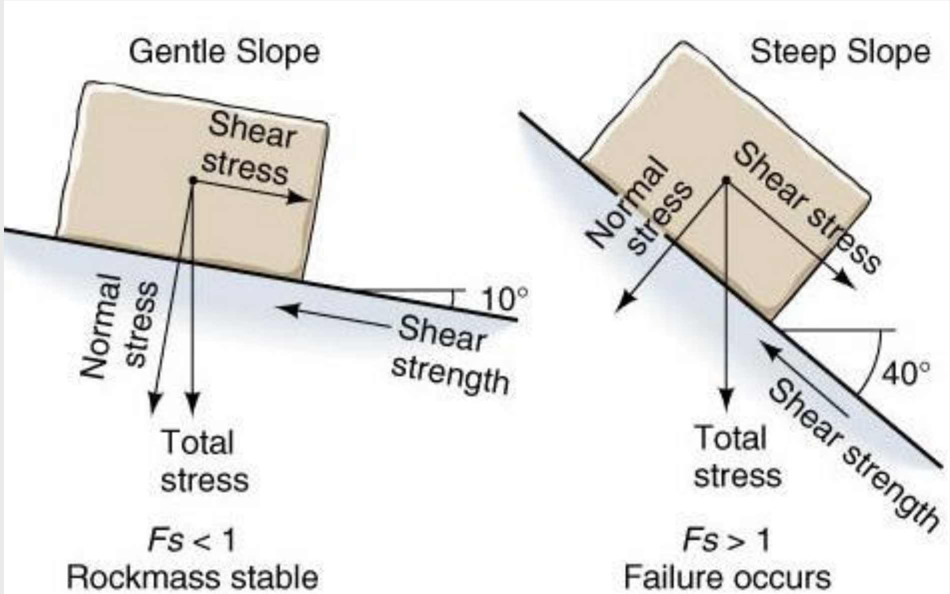






Mass movement Agents

1-Gravity
2- Running water
3- Glacial ice •
4-Wind
5- Wave action (shorelines) •
6- Strong ground shaking (earthquakes, tsunamis)



Safety Factor

$$SF = \frac{\sum Ff}{\sum Fs}$$

If S.F.<1 then failure occurs

S.F.>1 then Stable

Driving Forces

i.e., Shear Force

Fs = W sin θ

Fs: Shear force

W: Weight

θ : Dip of slope

Resisting Forces

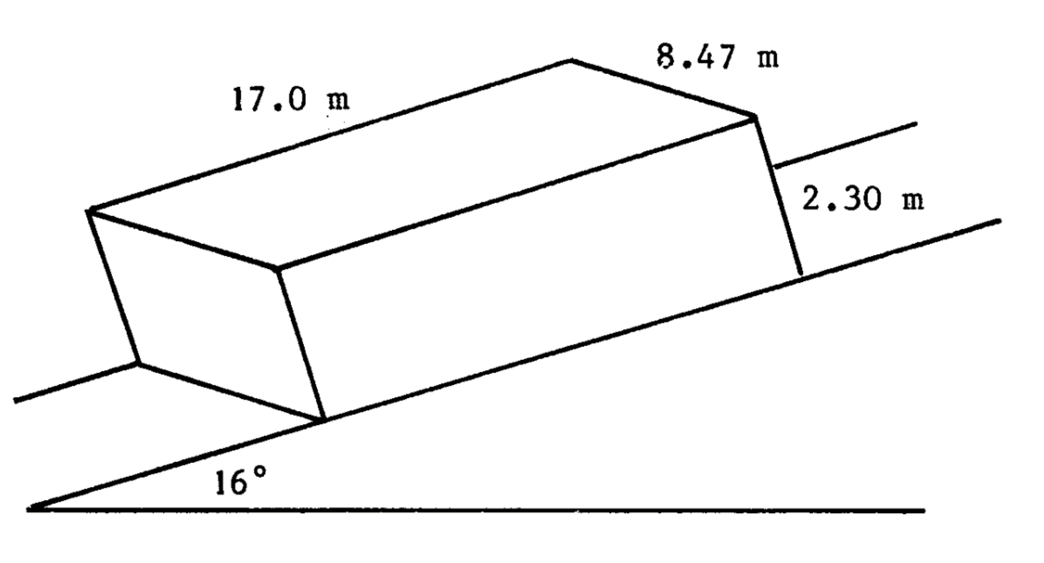
–Friction and Cohesion of Soil or Rock

Ff =μ (W cosθ)+ C × A

μ : coefficient of static friction (tan Ø)

EXAMPLE 2 A rectangular block of rock, density 2.90 g/cm^3 and edge lengths 17.0 m, 2.30 m, 8.47 m, rests on a 16.0° incline, as shown in Fig.(4.5). An extra driving force of 734 kN, acting parallel to and down the incline, will just start the block sliding. The angle of friction between block and incline is 7.00°. Find the cohesion stress on the block.

$$FS = \frac{(W\cos\alpha/A)\tan\phi + c}{(W\sin\alpha/A)}.$$



The weight of the block is calculated from

$$W = \rho V g$$

Hence,

$$W = (2900\ \text{kg/m}^3)[(17\ \text{m})(8.47\ \text{m})(2.3\ \text{m})](9.8\ \text{m/s}^2),$$
$$W = 9.412\ \text{X}\ 10^6\ \text{N}.$$

From Fig.(4.5), the area of contact A between block and slope is seen to be

$$A = (17\ \text{m})(8.47\ \text{m}),$$
$$A = 144.0\ \text{m}^2.$$

With the extra driving force, the block just starts sliding; this implies that $FS = 1$. Use Eq.(4.12), with all quantities in SI base units, to get

$$FS = \frac{W \cos\alpha \tan\phi + cA}{W \sin\alpha + F_{\text{ext}}},$$

$$1 = \frac{(9.412\ \text{X}\ 10^6\ \text{N}) \cos 16^\circ \tan 7^\circ + c(144\ \text{m}^2)}{(9.412\ \text{X}\ 10^6\ \text{N}) \sin 16^\circ + 734\ \text{X}\ 10^3\ \text{N}},$$
$$c = 15.4\ \text{kPa}.$$

EXAMPLE 3

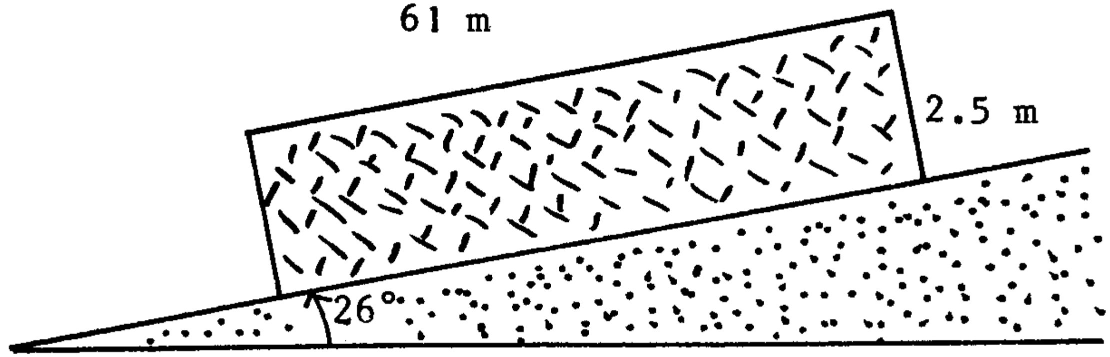


Fig.(4.8) Example 3

The slab shown in Fig.(4.8) has a width of 13 m; its density is 3.2 g/cm^3. The angle of friction between the slab and the slope is 20° and cohesion equals 75 kN/m^2. Rock bolts are installed but not tightened. Each bolt has an area of 6.2 cm^2 and shear strength 740 MPa. A factor of safety of 3.0 is desired. How many rock bolts are needed?

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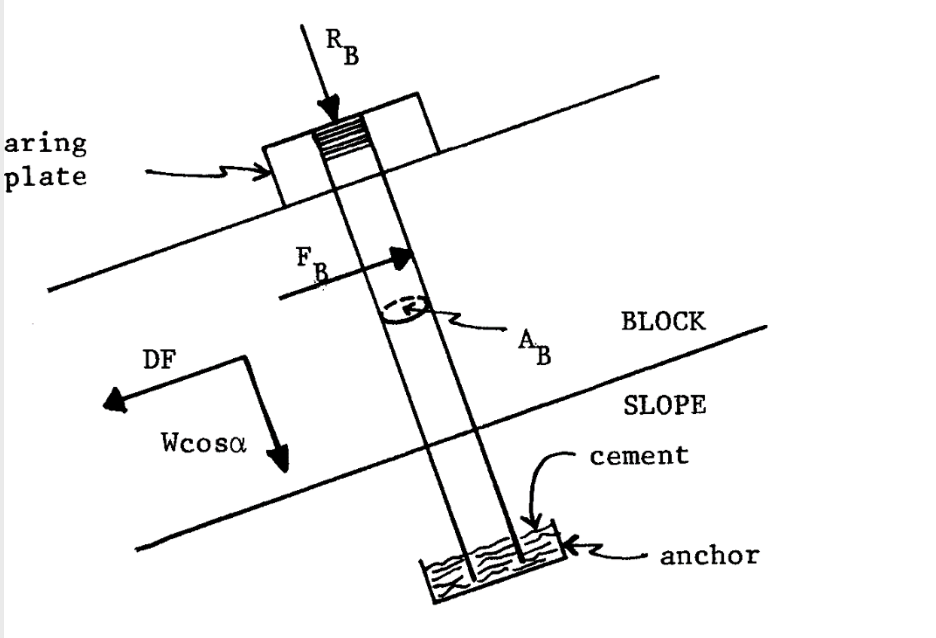

$$FS = \frac{(W\cos\alpha + n\sigma_{\mathrm{B}}A_{\mathrm{B}})\tan\phi + cA + n\tau_{\mathrm{B}}A_{\mathrm{B}}}{W\sin\alpha + F_{\mathrm{ext}}}.$$

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Calculate the weight of the slab from $W = \rho V g$; the result is $W = 62.2$ MN. The angle of friction is $\phi = 20°$ and the angle of the slope, from Fig.(4.8) is $\alpha = 26°$. With cohesion present, $c = 75 \text{ X } 10^3 \text{ N/m}^2$, the contact area between slab and slope must be calculated. This area is $A = (61 \text{ m})(13 \text{ m})$, $A = 793 \text{ m}^2$. Since the bolts are not tightened, $\sigma_B = 0$. The bolt cross-sectional area is $A_B = 6.2 \text{ X } 10^{-4} \text{ m}^2$ and their shear strength is $\tau_B = 740 \text{ X } 10^6$ Pa. (The SI prefixes cannot be overlooked.) Write Eq.(4.20) with $\sigma_B = 0$, and also with $F_{ext} = 0$, since no extra driving force is mentioned. Using SI base units, then, and with $FS = 3$, the result is

$$n = \frac{W[(FS)\sin\alpha - \cos\alpha\tan\phi] - cA}{A_B \tau_B},$$

$$n = \frac{(62.2 \text{ X } 10^6 \text{ N})(3\sin 26° - \cos 26° \tan 20°) - (75 \text{ X } 10^3 \text{ Pa})(793 \text{ m}^2)}{(6.2 \text{ X } 10^{-4} \text{ m}^2)(740 \text{ X } 10^6 \text{ N})},$$

$$n = 4.3.$$

Of course, there cannot be 4.3 identical bolts. Suppose that "safety first" is the work philosophy; then install $n = 5$ bolts.

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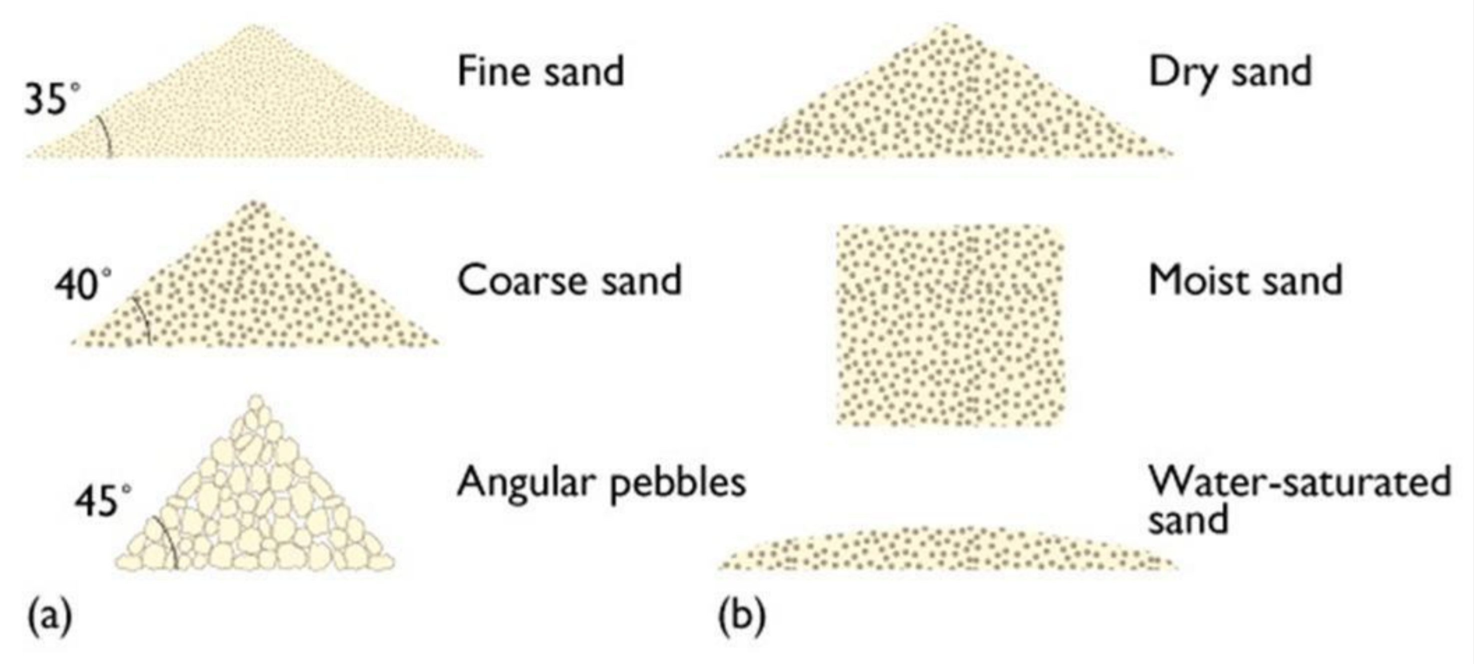
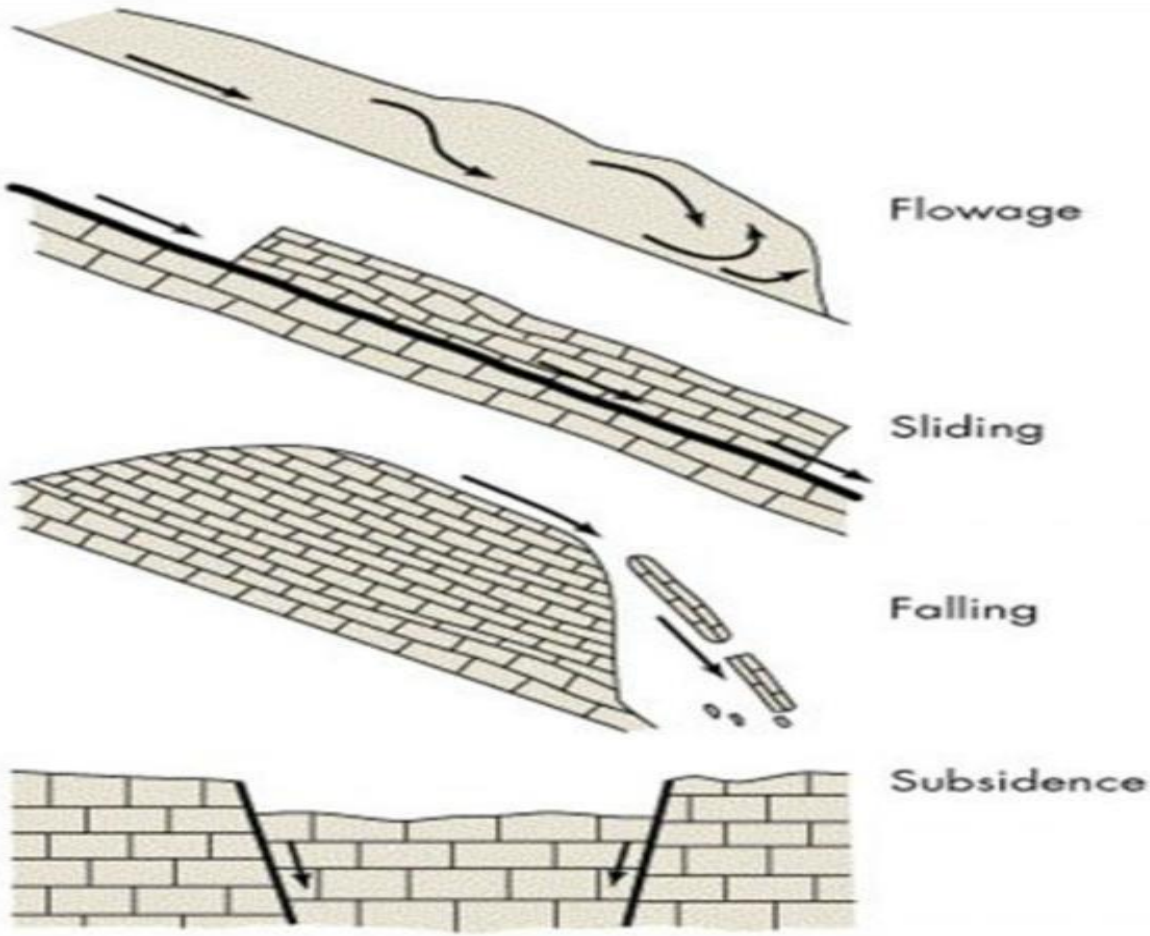
Angle of Repos

Angle of Repose Function of
- **Particle size**
- **Particle shape**
- **Moisture Content**



Types of Mass Movement



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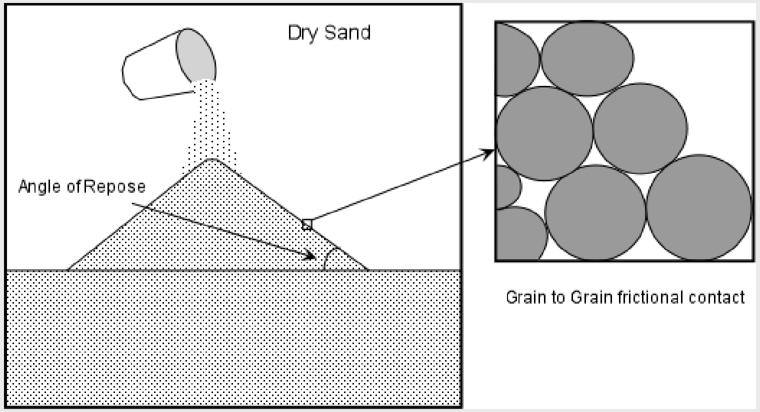

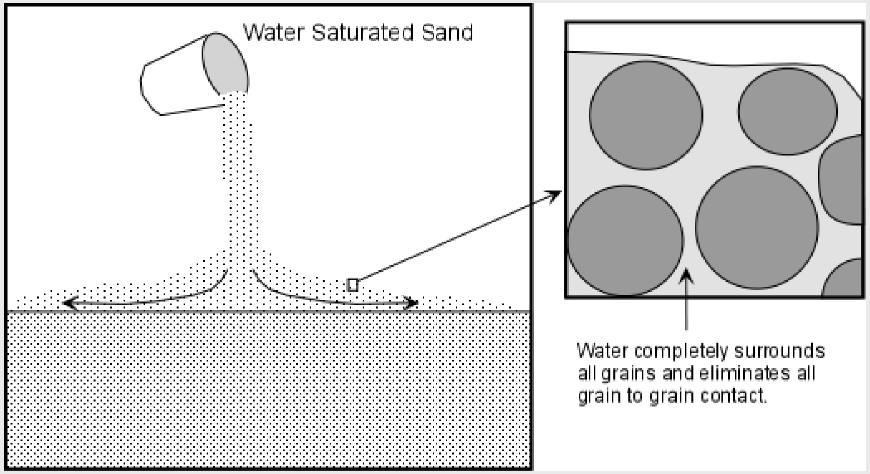

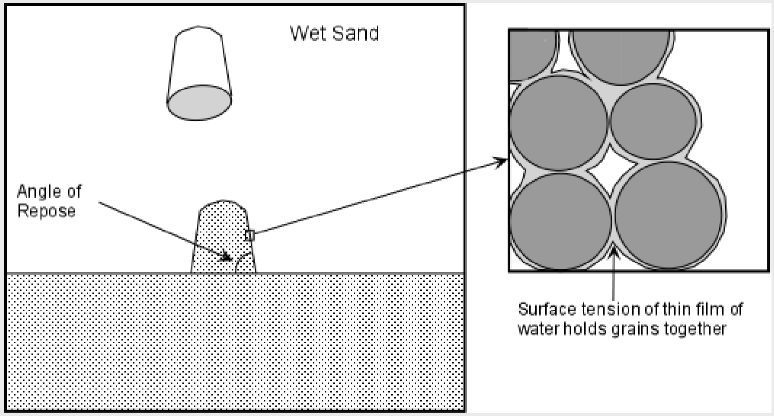

- Important factors include:
  - The role of water
    - Diminishes particle cohesion (friction)
    - Water adds weight
  - Oversteepening of slopes—slope angle
    - Stable slope angle (**angle of repose**) is different for various materials
    - Oversteepened slopes are unstable

Evidences of an unstable slope

- **buildings - cracked, stuck doors**
- **crooked fences and retaining walls**
- **broken underground pipes**
- **uneven pavement**
- **uneven ground**
- **cracks in ground**
- **trees - tilted - buttressed**
- **rock falls**
- **slump features**

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Slope failure

Slope failure is the collapse of rock or sediment mass.

•Three major types of slope failure:

–Slumps.

–Falls.

–Slides.

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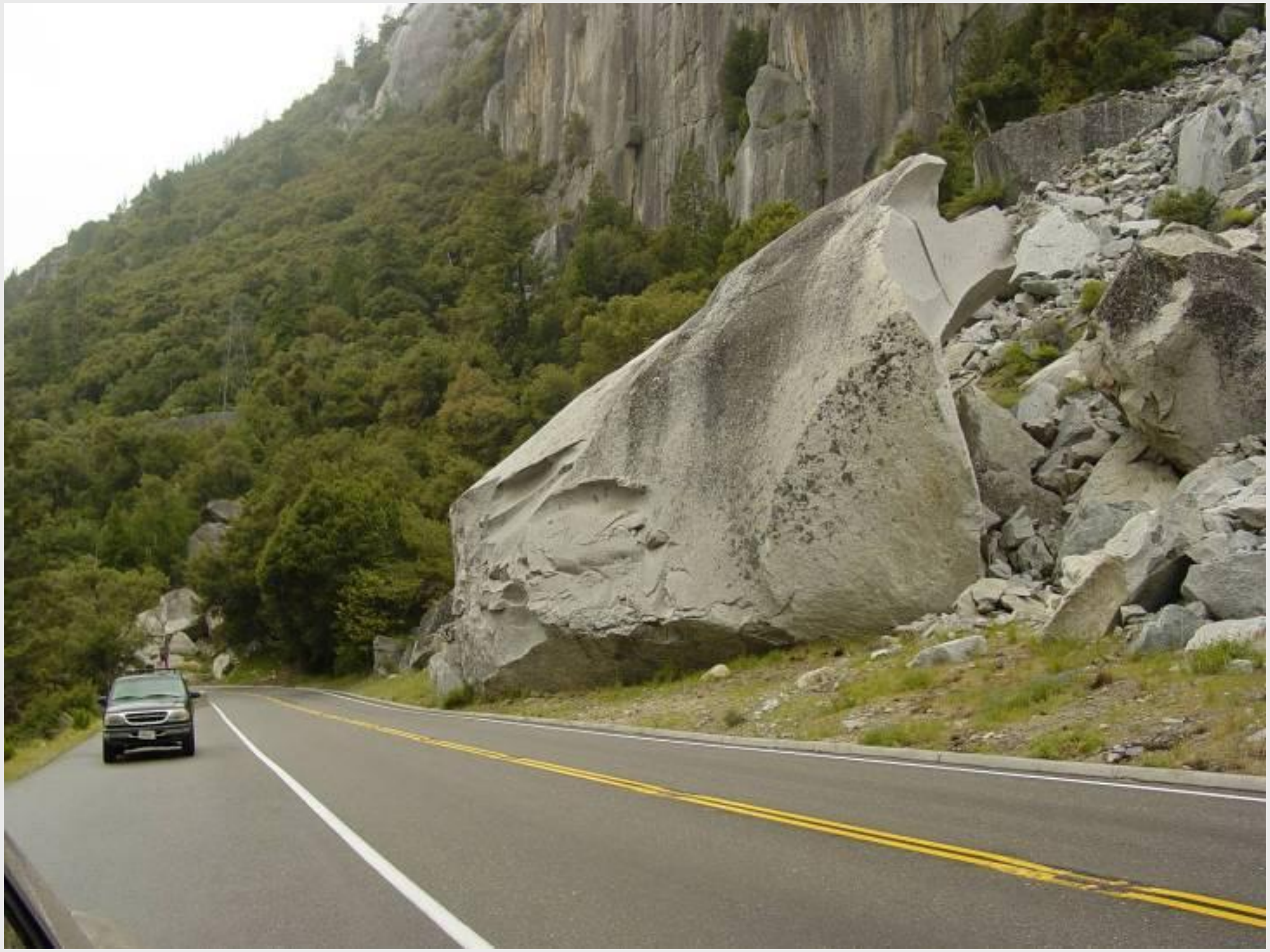
Flow- Soil Creep

Rock falls,



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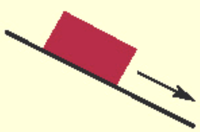
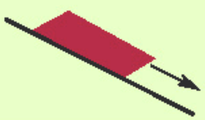
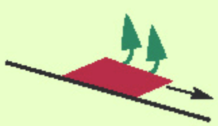
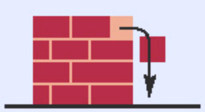
Major categories of mass wasting are **Slides, Flows, and Falls**

		MATERIAL			
MECHANISM		Rock	Fine-grained Soil	Coarse-grained Soil	VELOCITY
SLIDE		Slump	Earth slump	Debris slump	Slow
		Block glide	Earth slide	Debris slide	Rapid
FLOW		Rock avalanche	Mudflow, avalanche	Debris flow, avalanche	Very Rapid
		Creep	Creep	Creep	Extremely slow
FALL		Rockfall	Earthfall	Debrisfall	Extremely rapid

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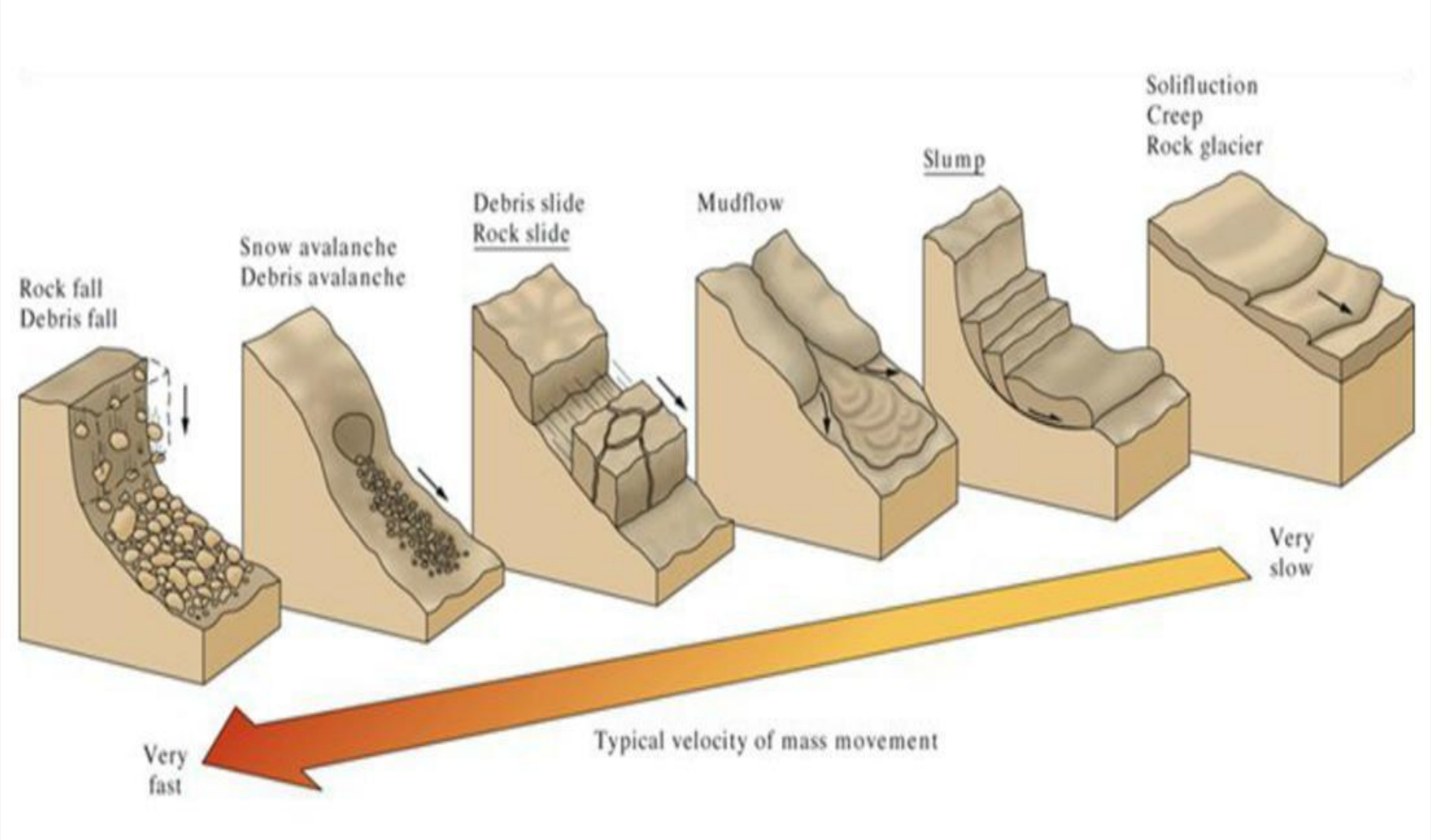

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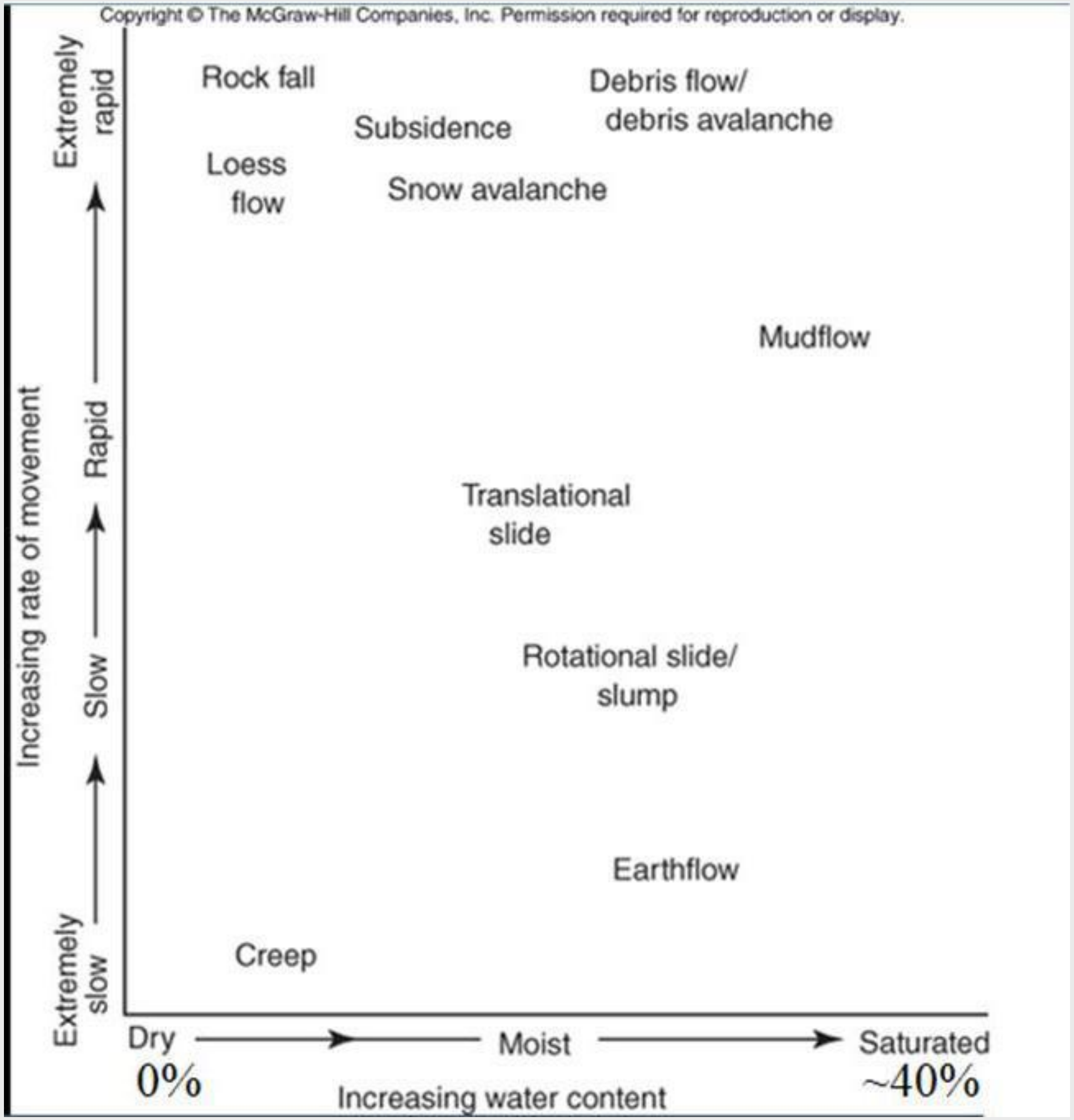
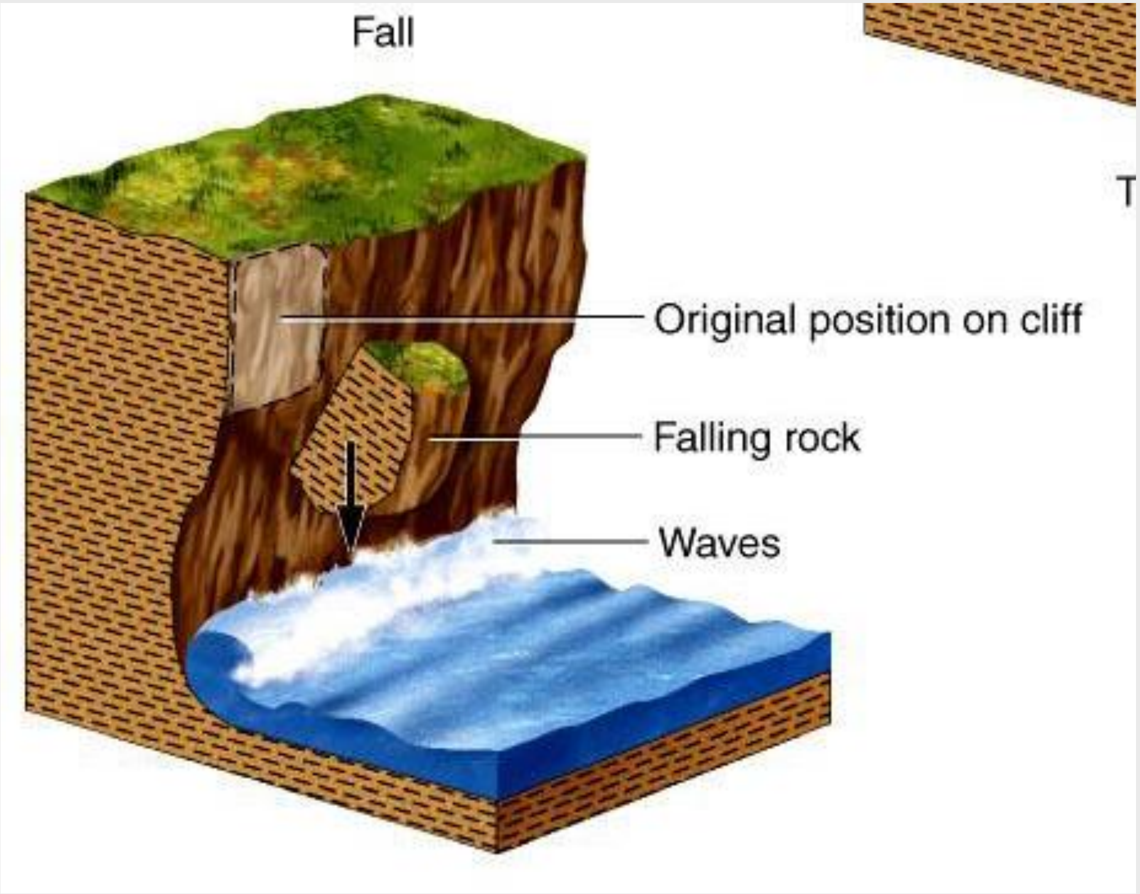
> 100 km/year



< 1 cm/year

Fall



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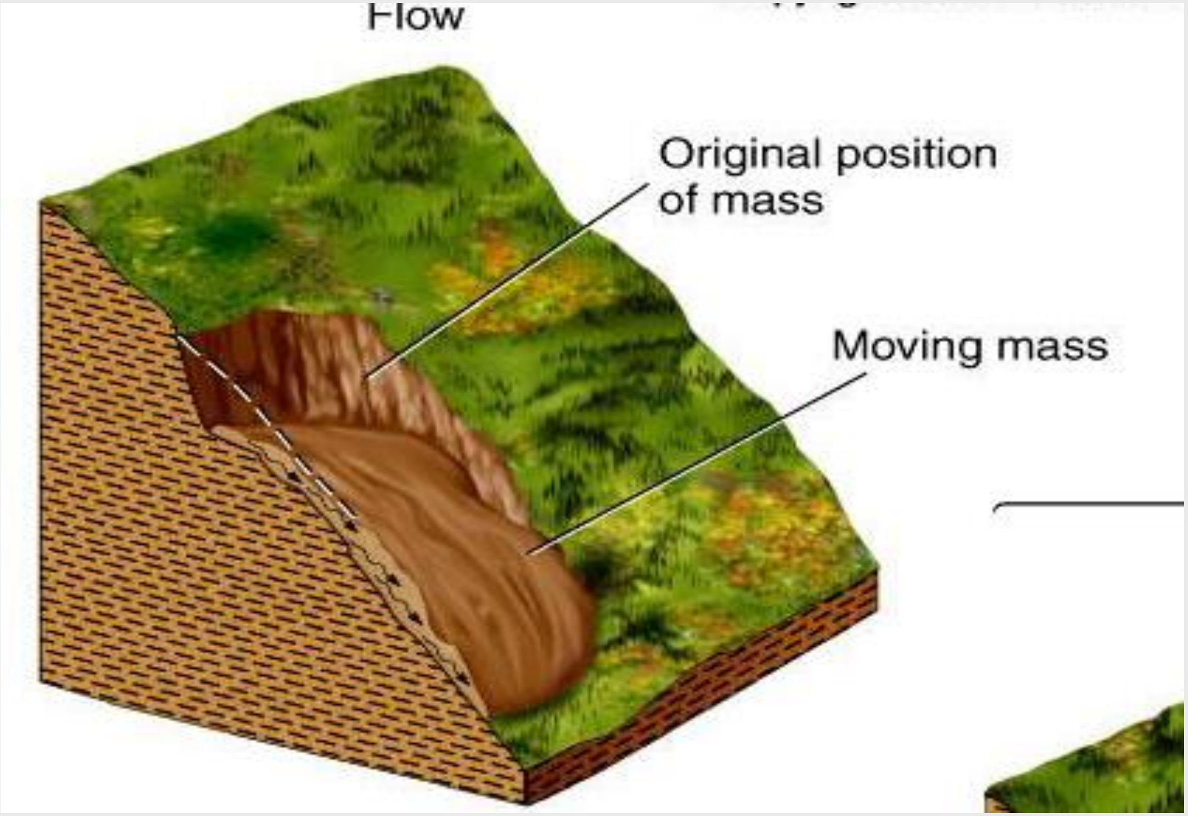
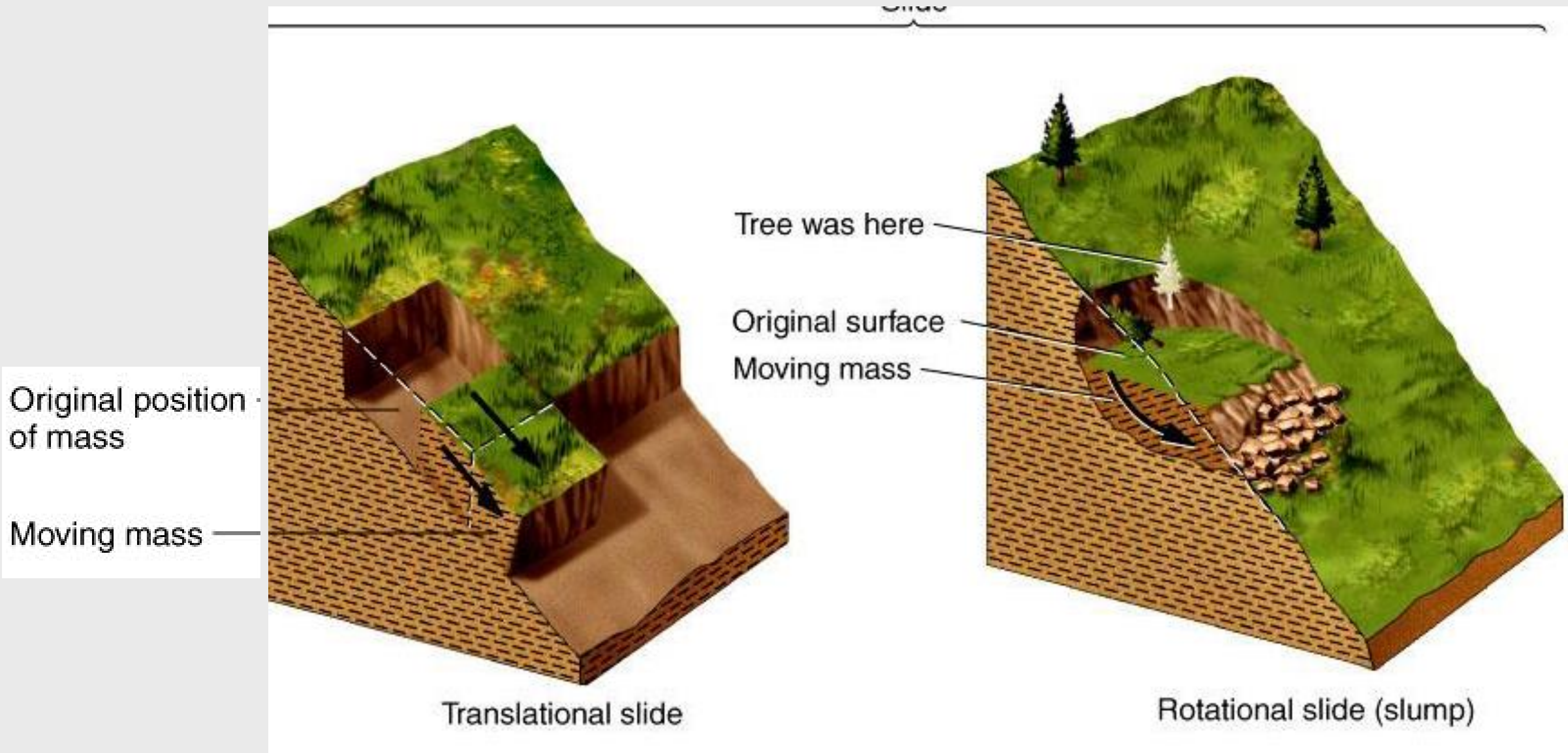
Flow



Slides


Original position of mass
Moving mass
Translational slide
Tree was here
Original surface
Moving mass
Rotational slide (slump)

Mass wasting phenomena can be directly linked to weathering processes

Climate	Weathering	Mass wasting
Arid	Physical weathering only	Rockfalls, rockslides
Temperate	Physical weathering and slow-moderate chemical weathering	Rockfalls, rockslides, slumps
Humid	Rapid chemical weathering and physical weathering in high elevations	Mudflows, debris flows, slumps, rockfalls

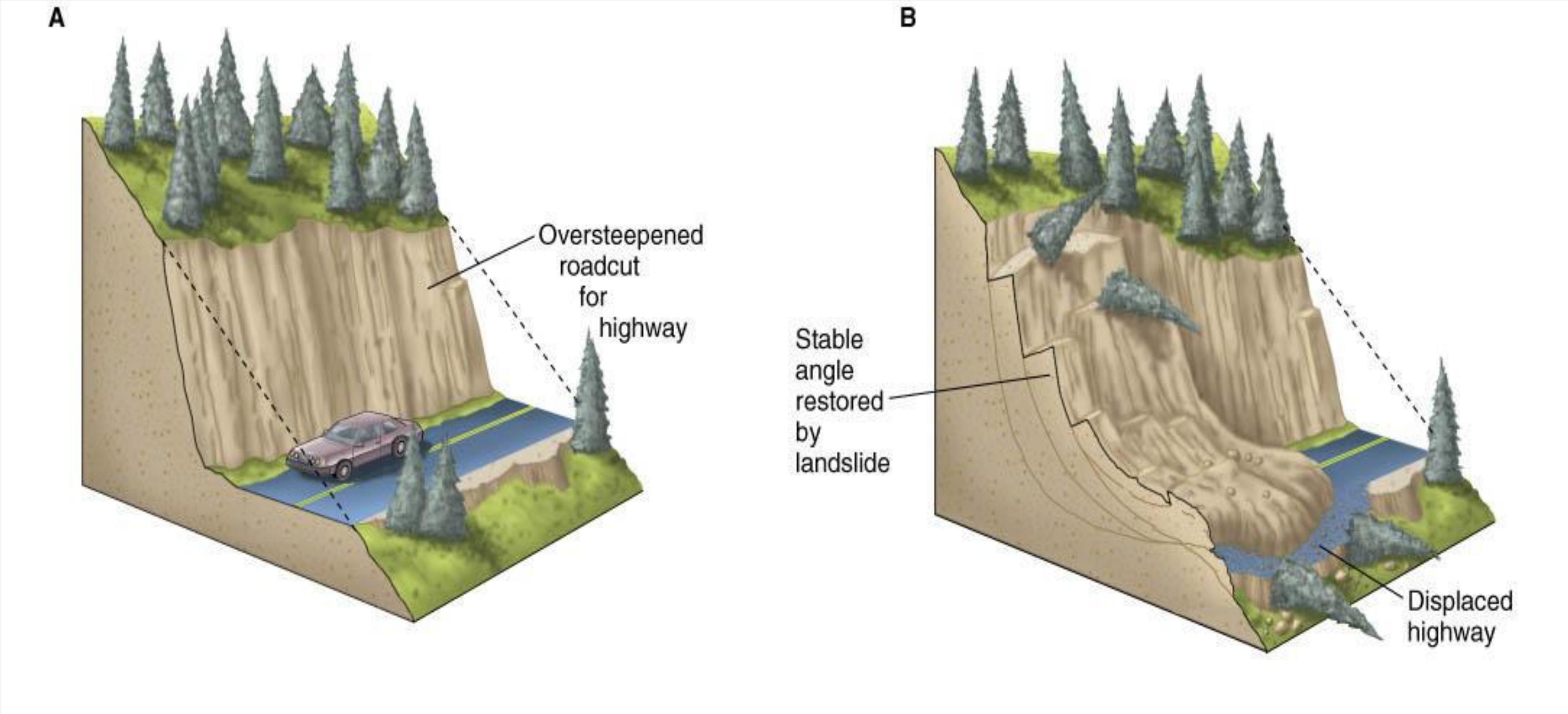
Slides : Down slope movement of a large unit of rock or soil down a distinct surface of failure or slide plane .

Slides are generally caused by :

- water saturation or weathering which weakens a slope
- increased steepness of a slope caused by undercutting at the base
- increased weight added at the top of a slope
- shaking (by earthquakes, explosions) that triggers movement on a vulnerable slope

There are 2 main types:

- Rotational slide (slump) occurs on a curving, concave-up surface.
- Translational slide (block glide) occurs on a flat inclined surface.


A
Oversteepened
roadcut
for
highway
B
Stable
angle
restored
by
landslide
Displaced
highway

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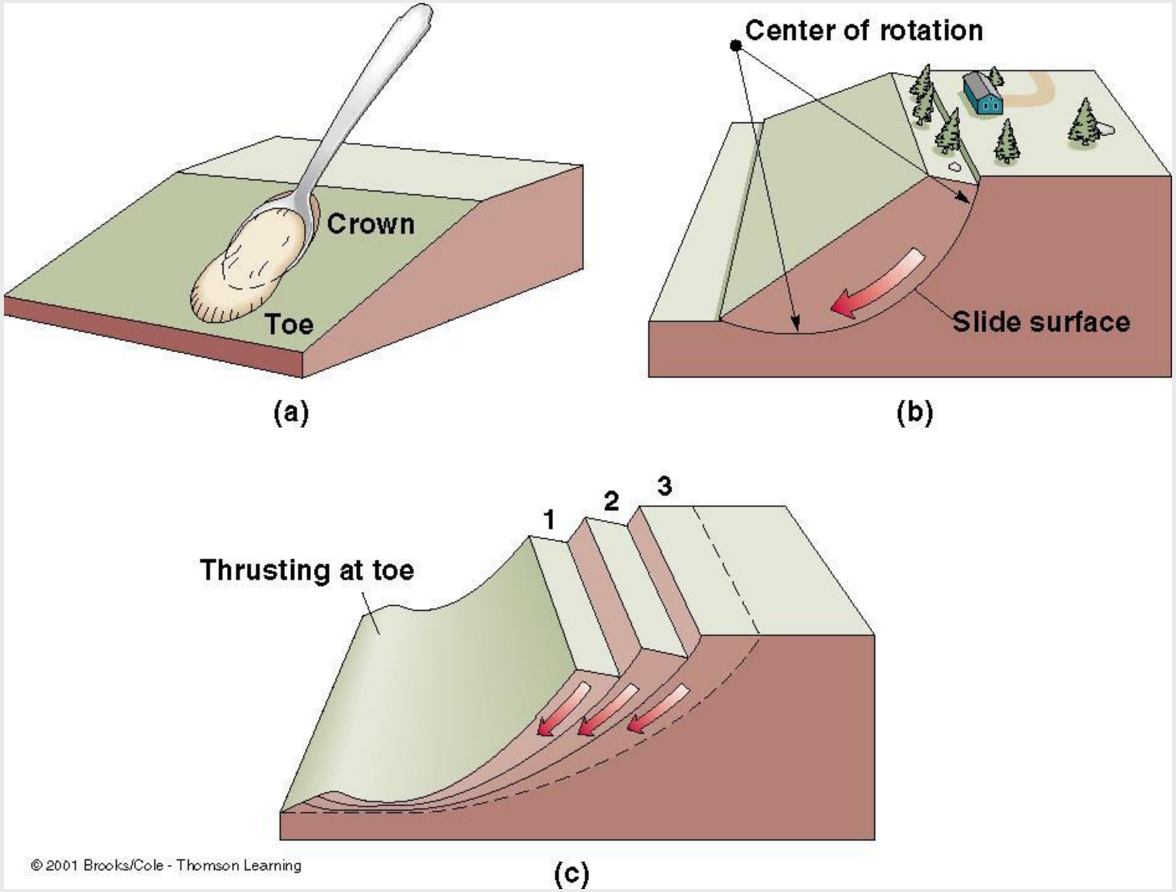
Rotational Slide

A Rotational Slide occurs along a curving, concave-up surface of failure, often spoon-like in shape The mass pushes out at the bottom of the slide to form a bulge of material called the toe



Translational Slide

A Translational Slide (block glide) occurs on a relatively flat sloping surface of failure. One very common cause of translational slides is dipping planes of weakness in the rock. These planes might be:

- **sedimentary bedding planes,**
- **metamorphic foliation planes,**
- **faults, or fractures in the rock**.

A translational slide is likely to occur if the slope dips at an angle that is greater than the dip of the planes of weakness in the rock

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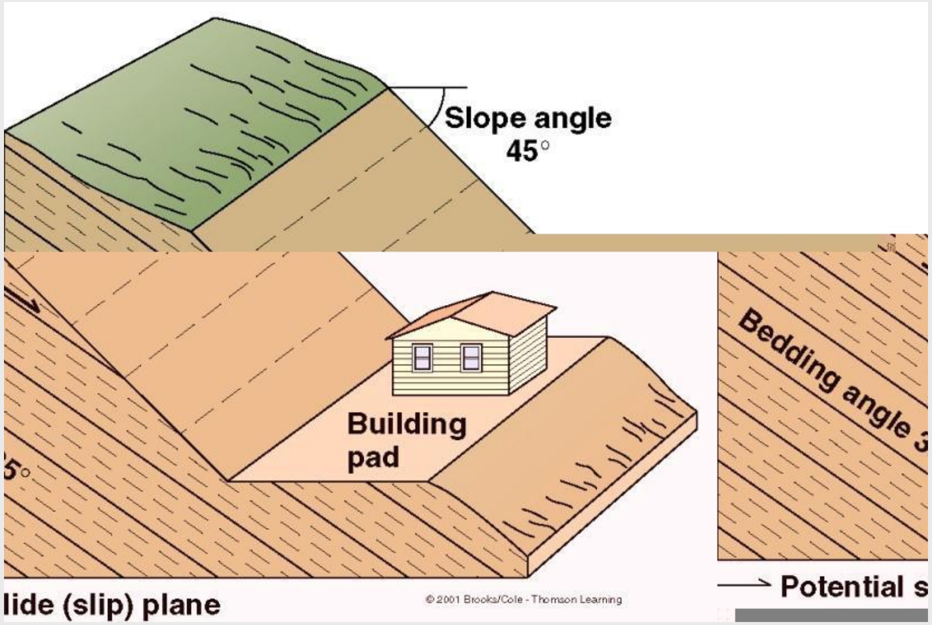
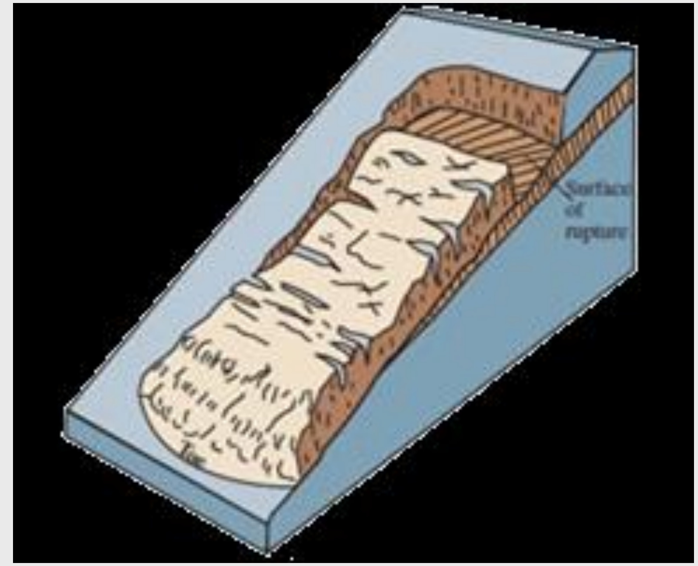
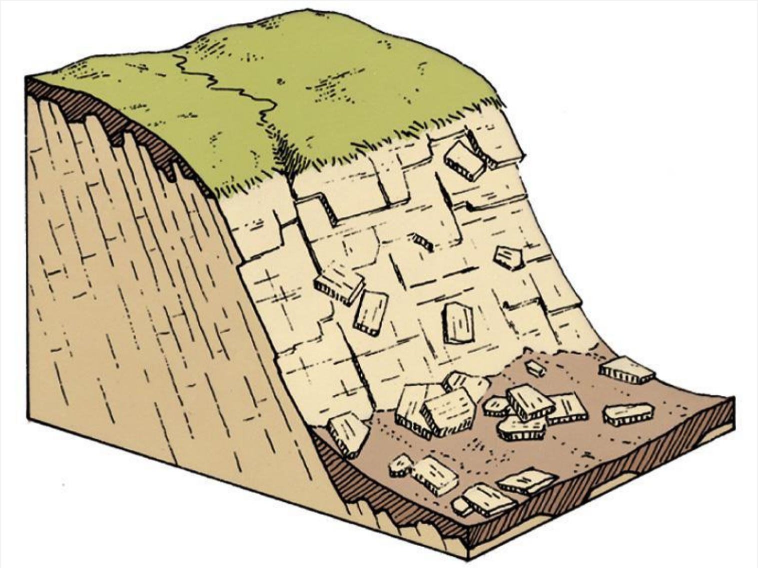




For example, the slope shown has been cut at an angle 45□ > the dip angle of the planes of weakness in the sedimentary layers. With nothing to hold the layers back, they may slide onto the house.

Land-Rock Slide

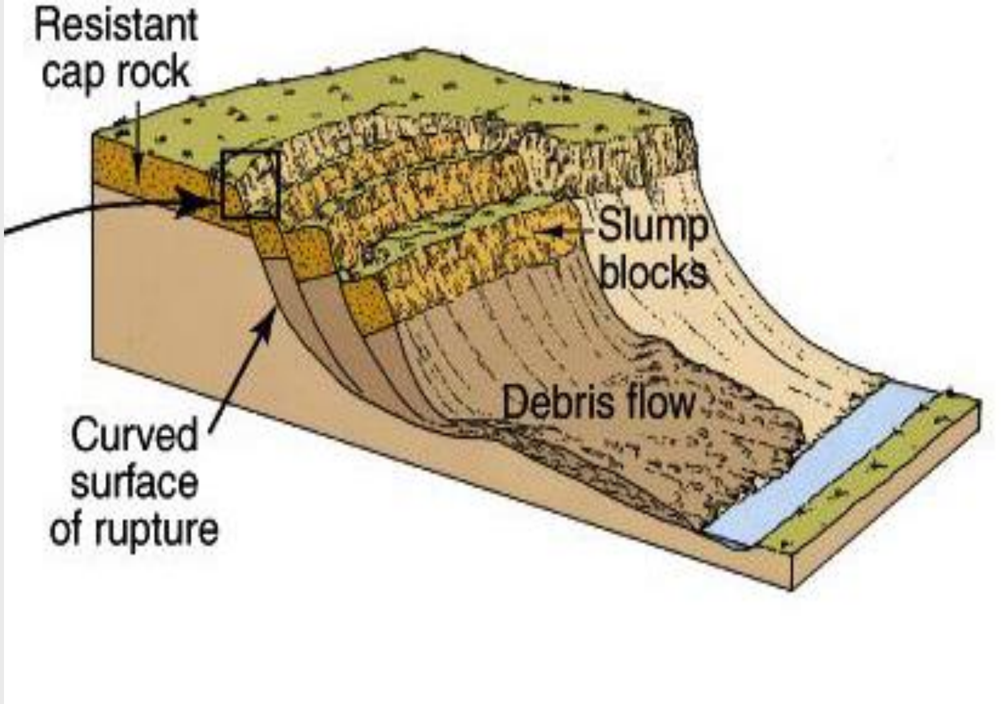


Movement of material along a defined slippage plane, Sudden and rapid movement

- **Large blocks of rock detach along bedding planes, joints, fractures, etc.**
- **Occur on steep slopes**
- **Can be triggered by rain falls or ground vibration, Fastest and most destructive type of mass wasting**

Slump

Slow to rapid movement
•Material moves as a coherent unit along a curved surface (spoon-shaped)
•Blocks of material rotate
•Debris flows commonly associated with sump

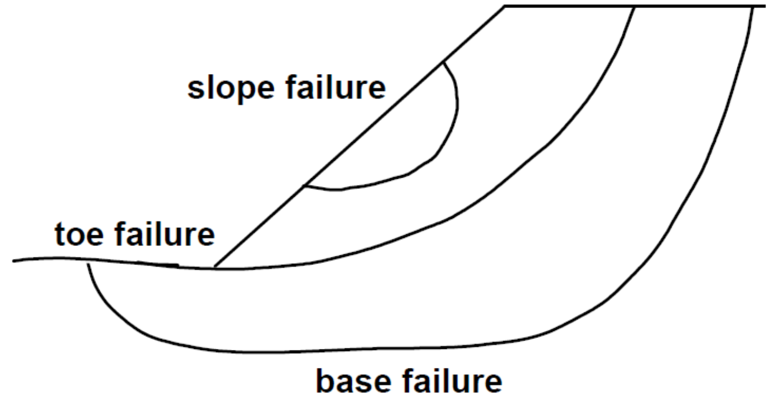


The slope failure (slump)

Circular surface of failure is common for considering essentially homogeneous materials (soils, loose or weak materials); Slumps usually occur in humid areas, groundwater plays an important role in slump failure. In springtime, after the thawing, after heavy rainfall, slump failures are very common in all natural slopes, road cuts, out slopes, and embankments.

Three types of slump failure

- Slope failure: weak near surface materials;
- toe failure: extended slope or additional excavation;
- Base failure: flat weak zone at depth.



Slump

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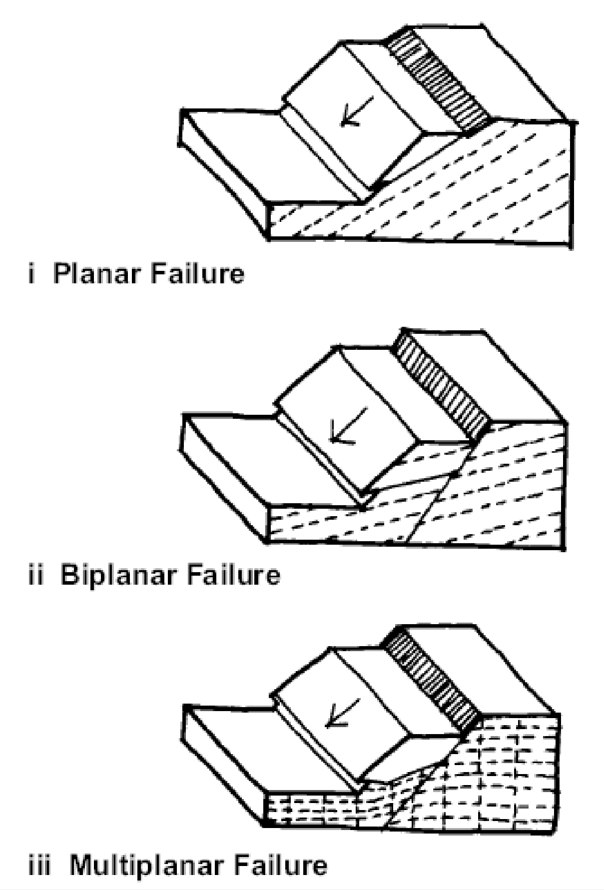
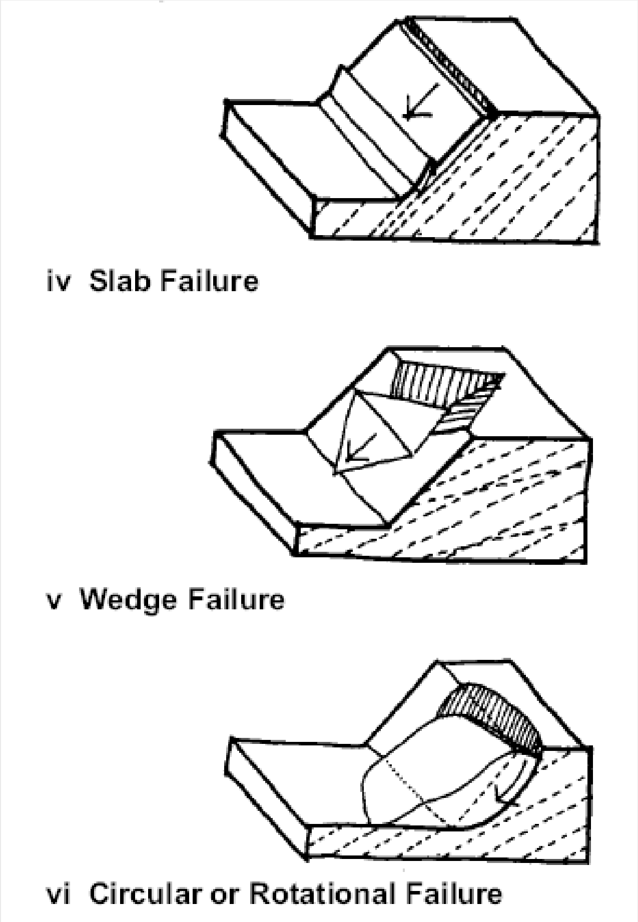
General modes of slope failure





Whenever the resultant weight of a block, W, projects beyond the down slope outside corner of a rectangular shaped blocks, toppling can result, as sketched here.

- Toppling usually occurs when low friction discontinuities dip between 50 and 70 degrees from horizontal. These can be joints, bedding, or foliation planes

Flows - Down slope movement of loose material in a plastic or semi fluid state. A sediment flow is a mixture of rock, and/or regolith with some water or air. further subdivisions are on the basis of the velocity at which flowage occurs

Sediment Flows Sediment flows occur when sufficient force is applied to rocks and regolith that they begin to flow down slope. They can be broken into two types depending on the amount of water present.

1.Slurry Flows- are sediment flows that contain between about 20 and 40% water. As the water content increases above about 40% slurry flows grade into streams. Slurry flows are considered water-saturated flows.

2. Granular Flows - are sediment flows that contain between 0 and 20% water. Granular flows are possible with little or no water. Fluid-like behavior is given these flows by mixing with air. Granular flows are not saturated with water.

Slurry Flows

Solifluction –flow age at rates measured on the order of centimeters per year of regolith containing water. Solifluction produces distinctive lobes on hill slopes. These occur in areas where the soil remains saturated with water for long periods of time.

Debris Flows - often result from heavy rains causing saturation of the soil and regolith with water. A debris flow is a moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. To be considered a debris flow the moving material must be loose and capable of "flow", and, at least 50% of the material must be sand-size particles or larger.

Mudflows - these are a highly fluid, high velocity mixture of sediment and water that has a consistency ranging between soup-like and wet concrete. They move at velocities greater than 1 km/hr and tend to travel along valley floors. Mudflows can travel for long distances over gently sloping stream beds. Because of their high velocity and long distance of travel they are potentially very dangerous

Solifluction

Debris flow

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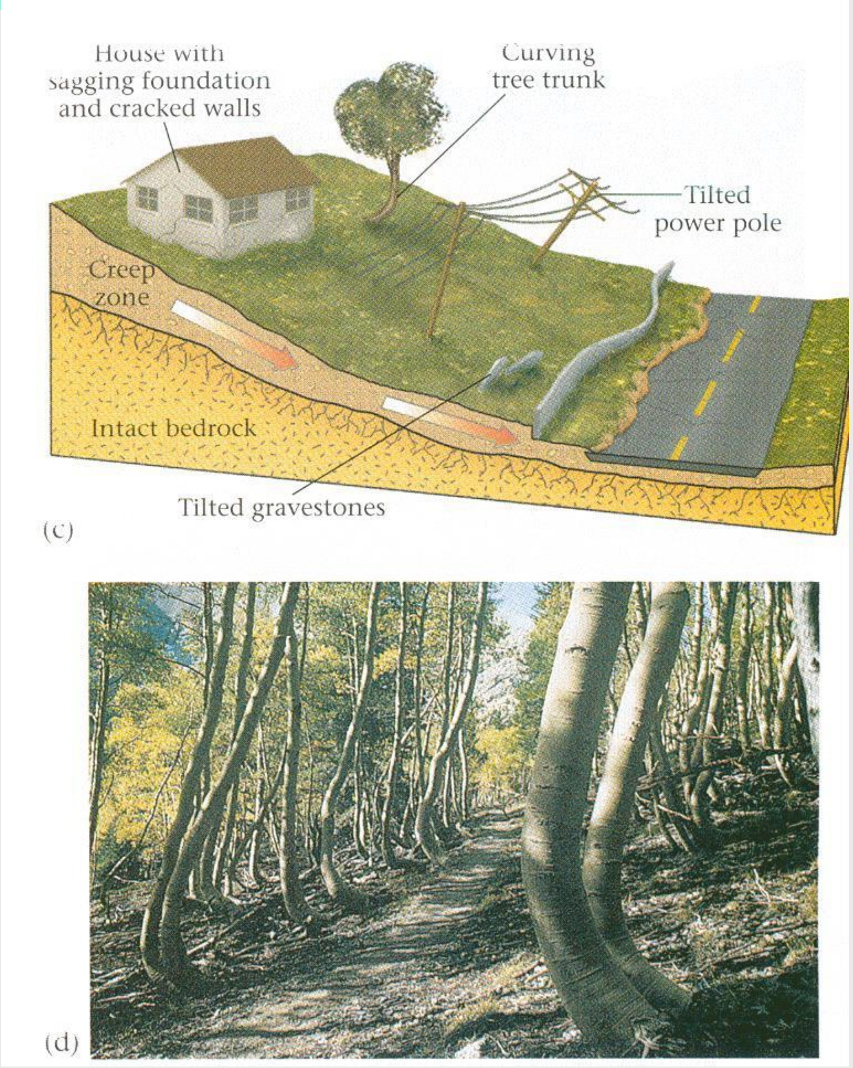
Granular Flows Creep - the very slow, usually continuous movement of regolith down slope. Creep occurs on almost all slopes, but the rates vary. Evidence for creep is often seen in bent trees, offsets in roads and fences, and inclined utility poles

Earth flows - are usually associated with heavy rains and move at velocities between several cm/yr and 100s of m/day. They usually remain active for long periods of time




Earthflow


Earthflow

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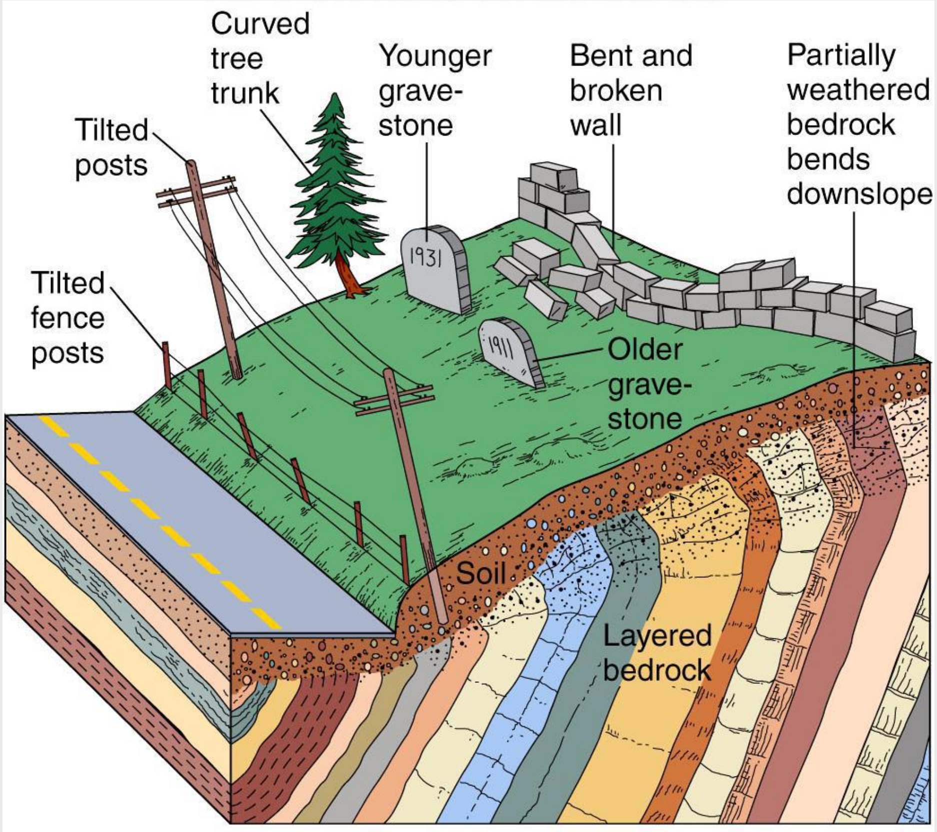
Creep

- Down slope movement of soil and uppermost bedrock
- Creep happens at too slow of a rate to observe directly
- creep can be identified by it's effect on objects

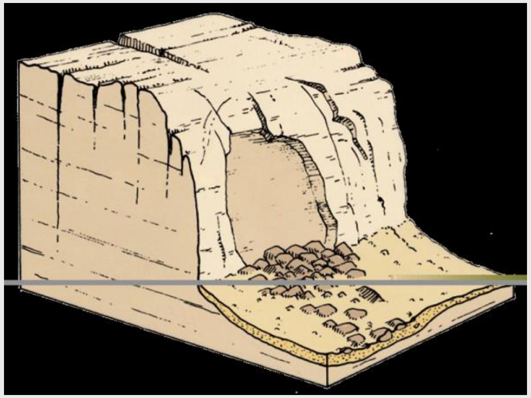


One cause of creep is **frost wedging**. Freezing lifts particles at right angles to the slope, and thawing allows the particles to fall back to a slightly lower level. Thus each cycle moves the material a short distance downhill.


Soil Creep

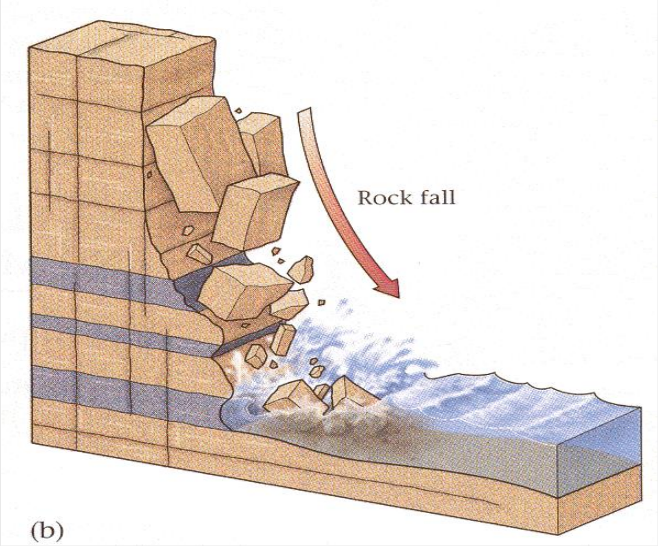
Falls - Abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering. At the base of most cliffs is an accumulation of fallen material termed **talus**

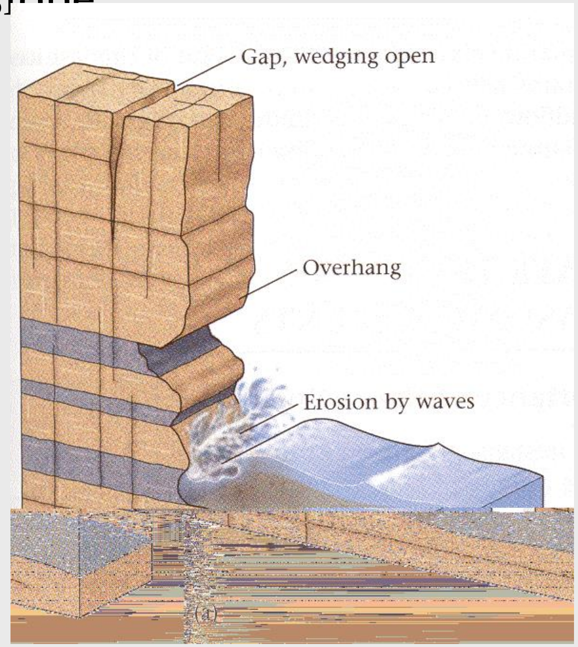
Talus slope



Rock Fall (Rock Avalanche)

- Sudden and rapid free fall movement of rock
- Occur on steep slopes
- Forms talus piles
- Can grade into a rockslide if material greater a slope greater than the angle of repose





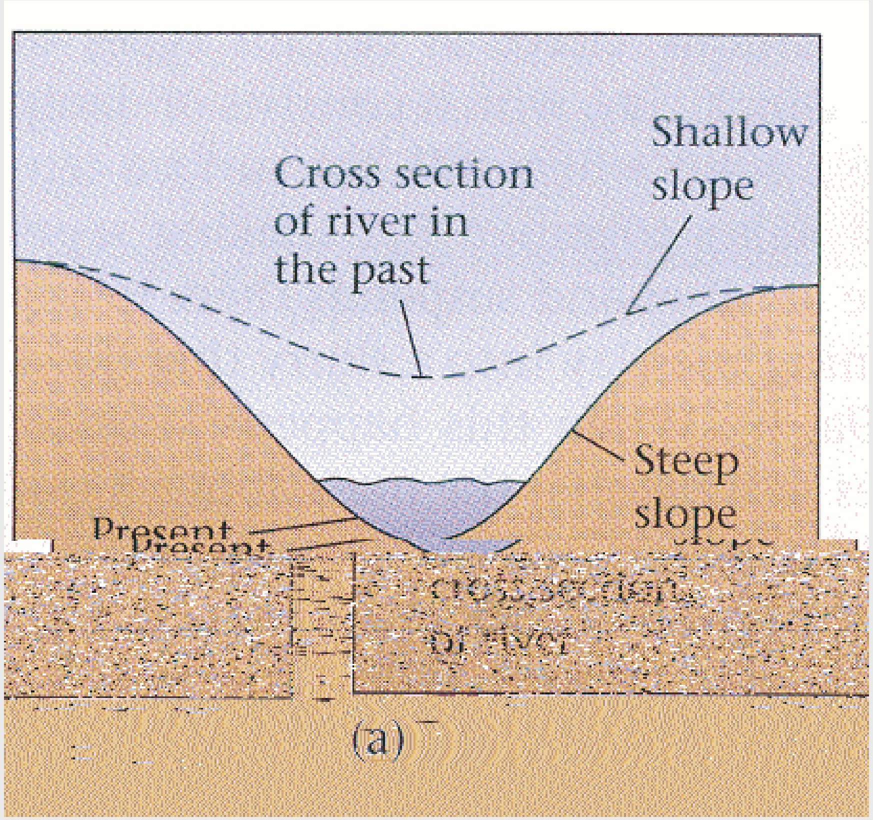
Speeds of mass movement:
slow->fast

soil creep -> earth slump ->
debris flow, mud flow ->
rockslide -> rock fall

Over-steepening of the Slope

Water

- **human-induced or by natural processes – increases the down slope force.**
- **Stream undercutting a valley wall**
- **Waves cutting cliffs on a shoreline.**
- **Construction of roads, buildings, homes etc.**



A river cuts into the base of a slope, steepening the sides of the valley, making the slopes unstable

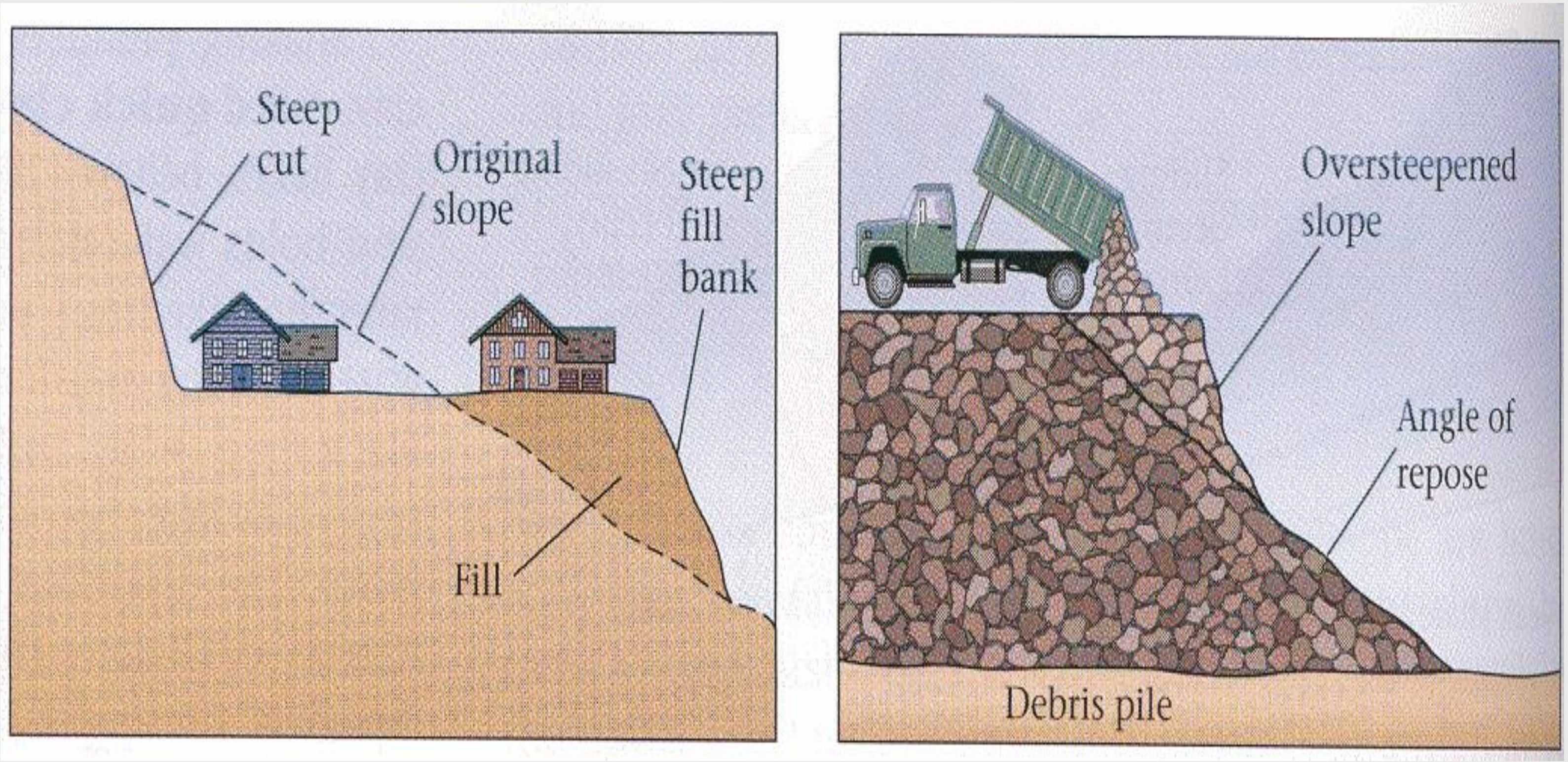
Influence of water

Water is an important factor in the occurrence of mass movement. Most rapid mass movements occur during or after periods of heavy rainfall.

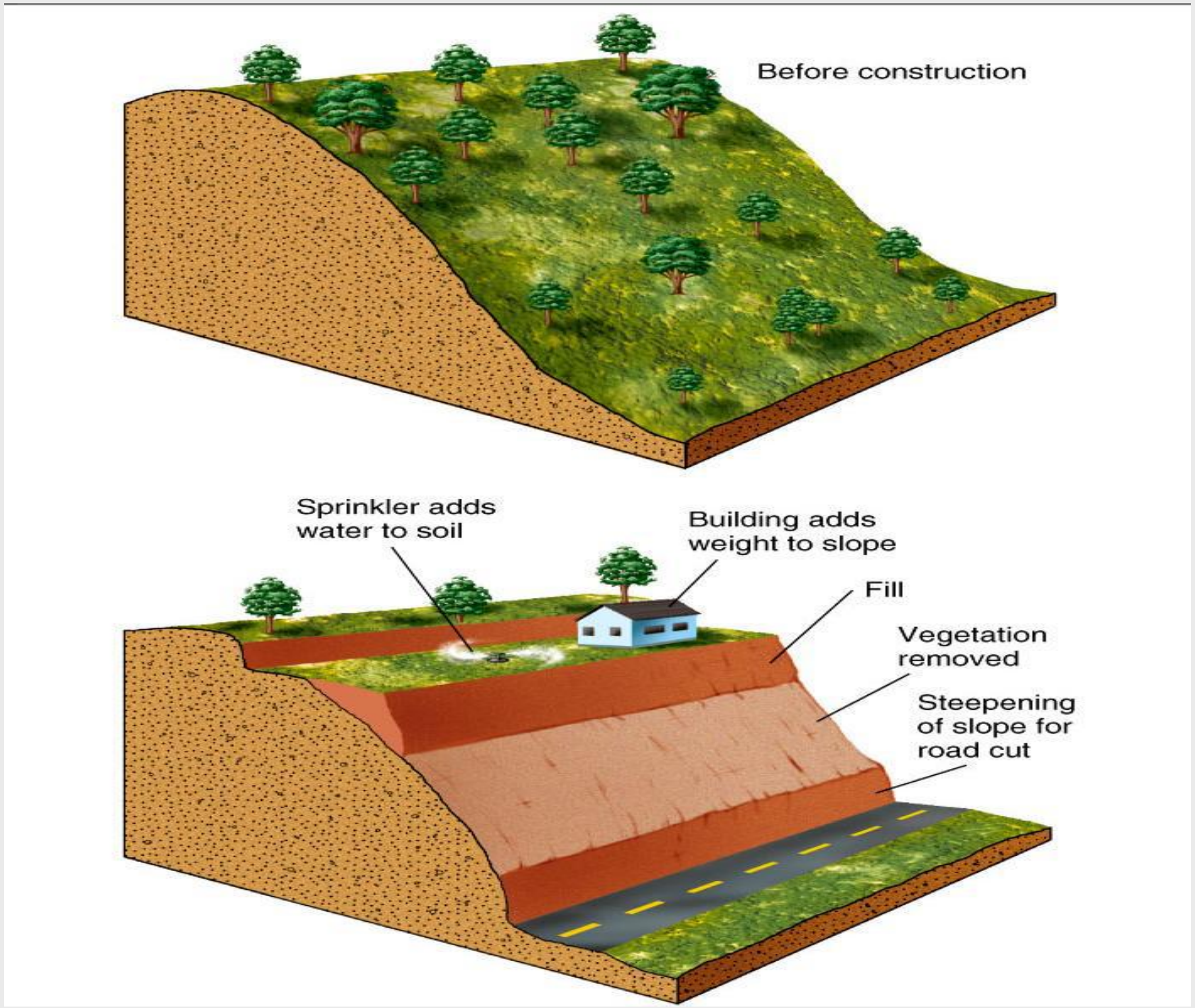
The addition of water increases pore pressure, decreases the effective normal stress acting in the slope, and thus decrease the shear resistance of the soil according to the Mohr-Coulomb equation:

$$S = C + \sigma_e \tan(\phi)$$

On the other hand, the driving force increases with the weight of water added to the soil.



Cutting terraces in a hill slope creates a steeper slope


Before construction
Sprinkler adds
water to soil
Building adds
weight to slope
Fill
Vegetation
removed
Steepening
of slope for
road cut

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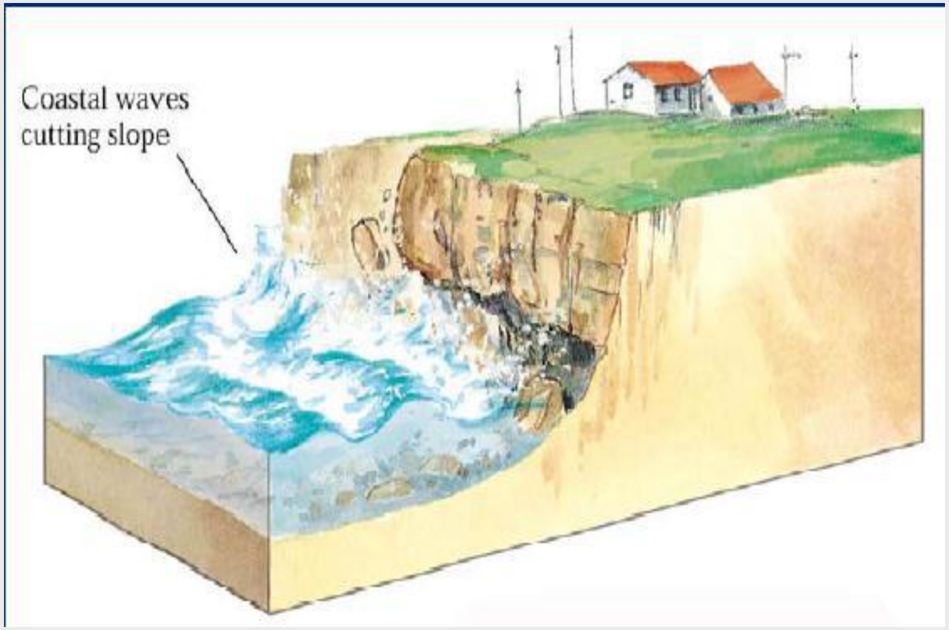

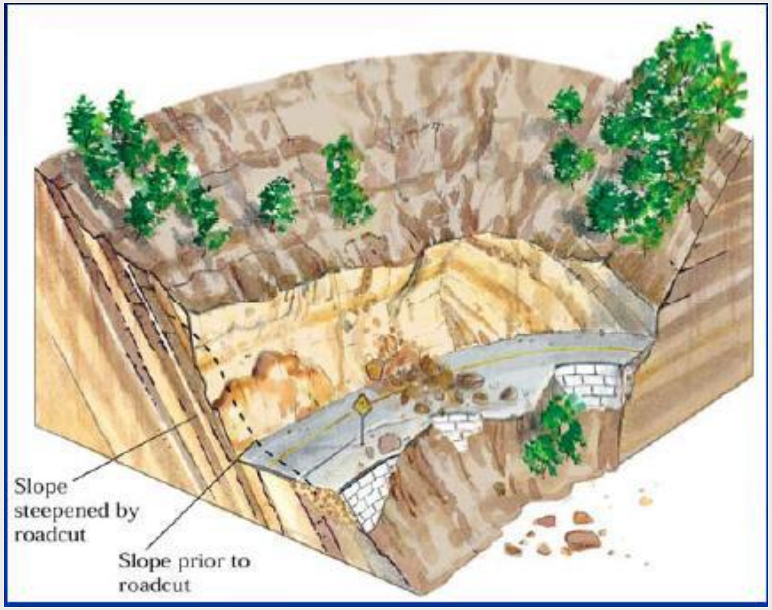

Preventing slope failure Engineering solutions

Careful planning of human activities : AVOID
–sensitive slopes
–loading
–cutting
–wetting

•drainage and dewatering –
•grading and benching
•retaining walls
•bolting, netting, spray crete
Preventing slope failure Engineering solutions

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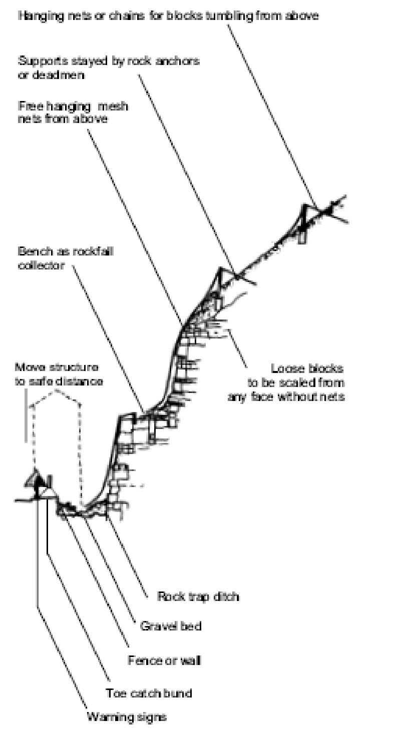
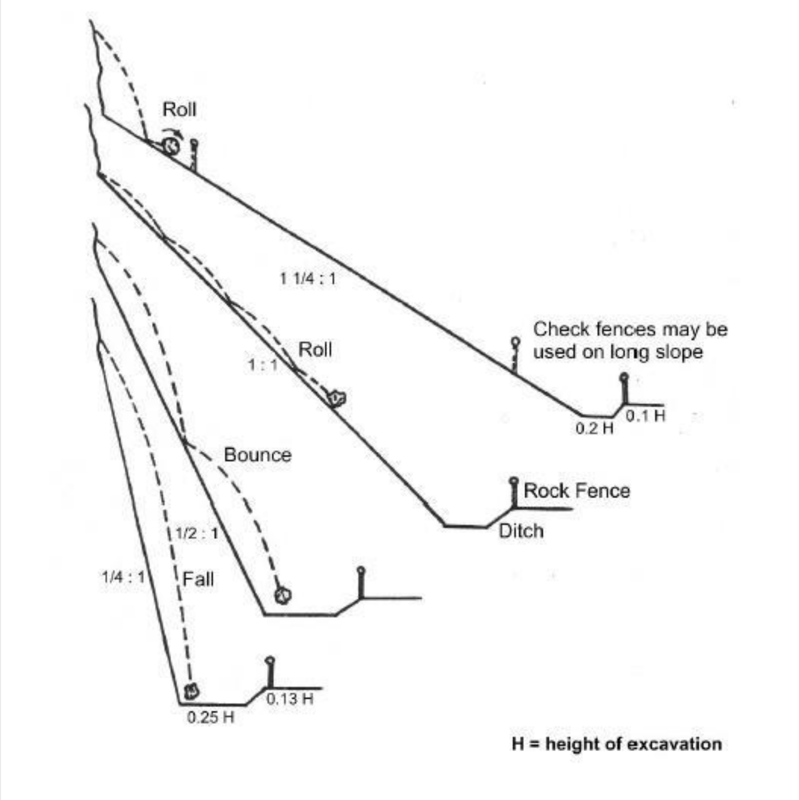
Netting can be anchored along the top of the slope (and to the face) using galvanised rock dowels and cables; the method is commonly employed for permanent slopes above roads and buildings. The purpose of the mesh is only partly to restrict or stop rockfall but mainly to control it by trapping blocks between the mesh and the rock face thereby reducing the velocity which may cause the rock to move away from the slope onto people and structures.



screen mesh is a relatively cheap and effective method to protect the roadway. The screen mesh is also referred to as "slope revetment" (covers the face of the slope) or as "rock-fall barrier



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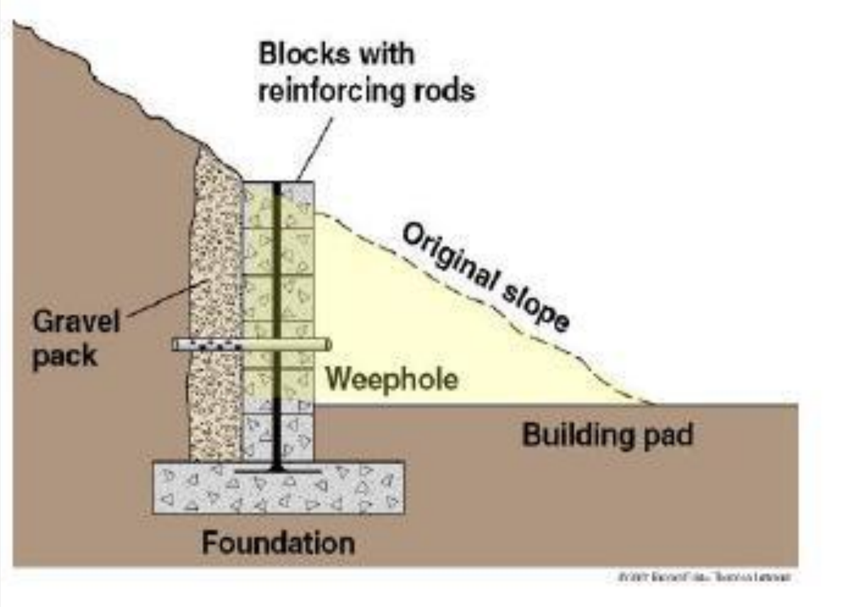
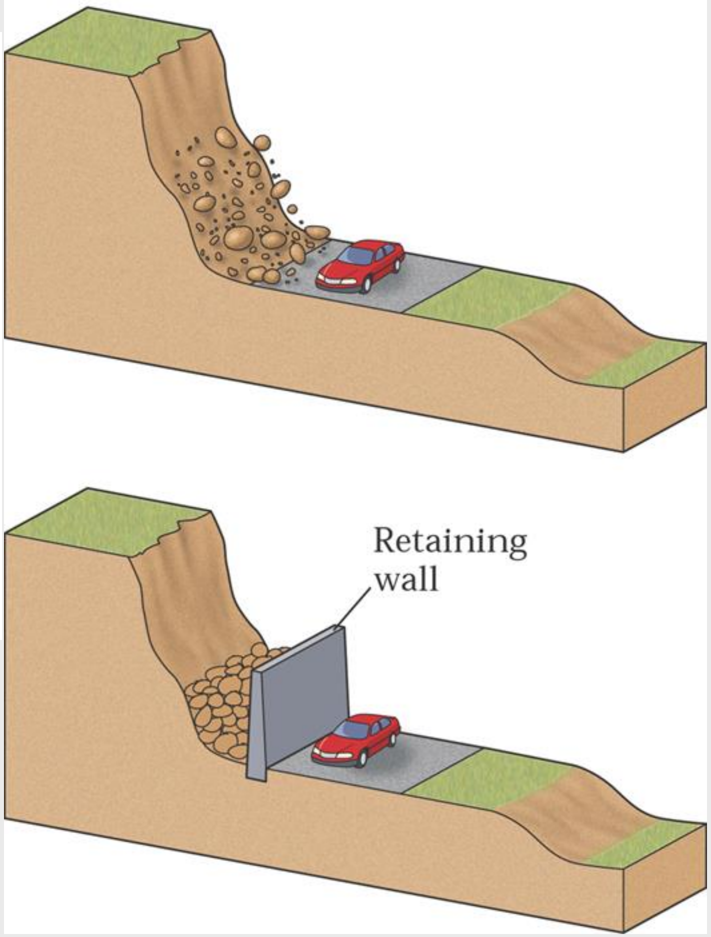
Retaining wall are also commonly used to stabilize slopes, typically in places where the base of the slope has been cut away to create more flat building area.

Retaining walls must be strong enough to replace the resisting force supplied by the original slope. It must also be equipped with a water drainage system, The layer of gravel in back of the wall allows water behind the wall to drain into perforated pipes, called weep holes.

These walls can be constructed of concrete or brick, stone-filled wire baskets called **gabions**, or a series of piles of long concrete, steel, or wooden beams driven into the ground

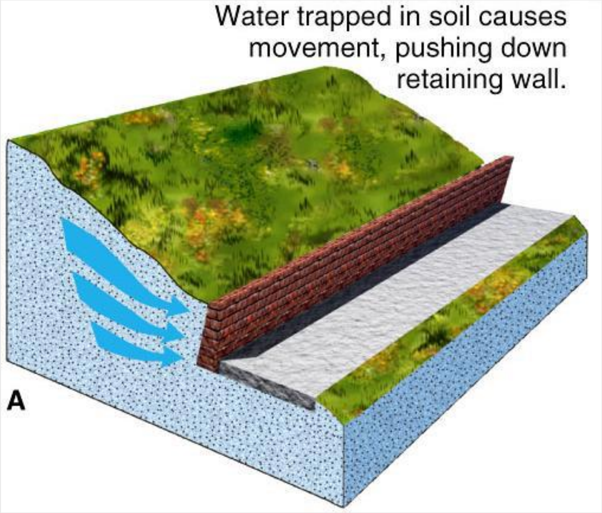

Blocks with
reinforcing rods
Original slope
Gravel
pack
Weephole
Building pad
Foundation

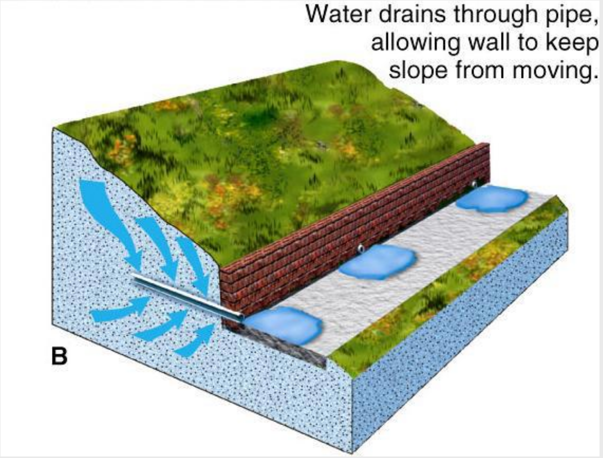

Retaining
wall

Reduce Risks Some solutions include:

- Increase shear strength
  - Re-compact soils
  - Re-vegetate soil slopes
  - Construct retaining wall with anchors

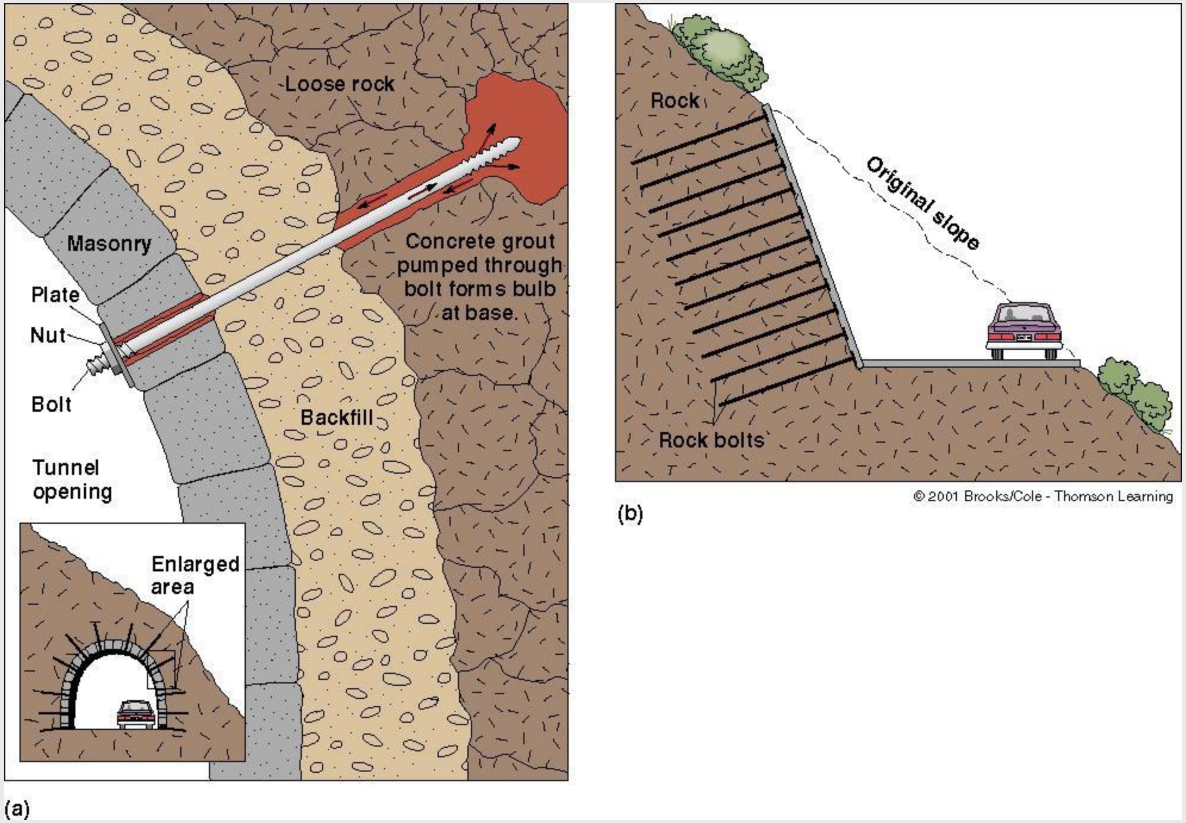
- Prevent Saturation
  - Prohibit over-irrigation
  - Install surface drains
  - Install subsurface drains

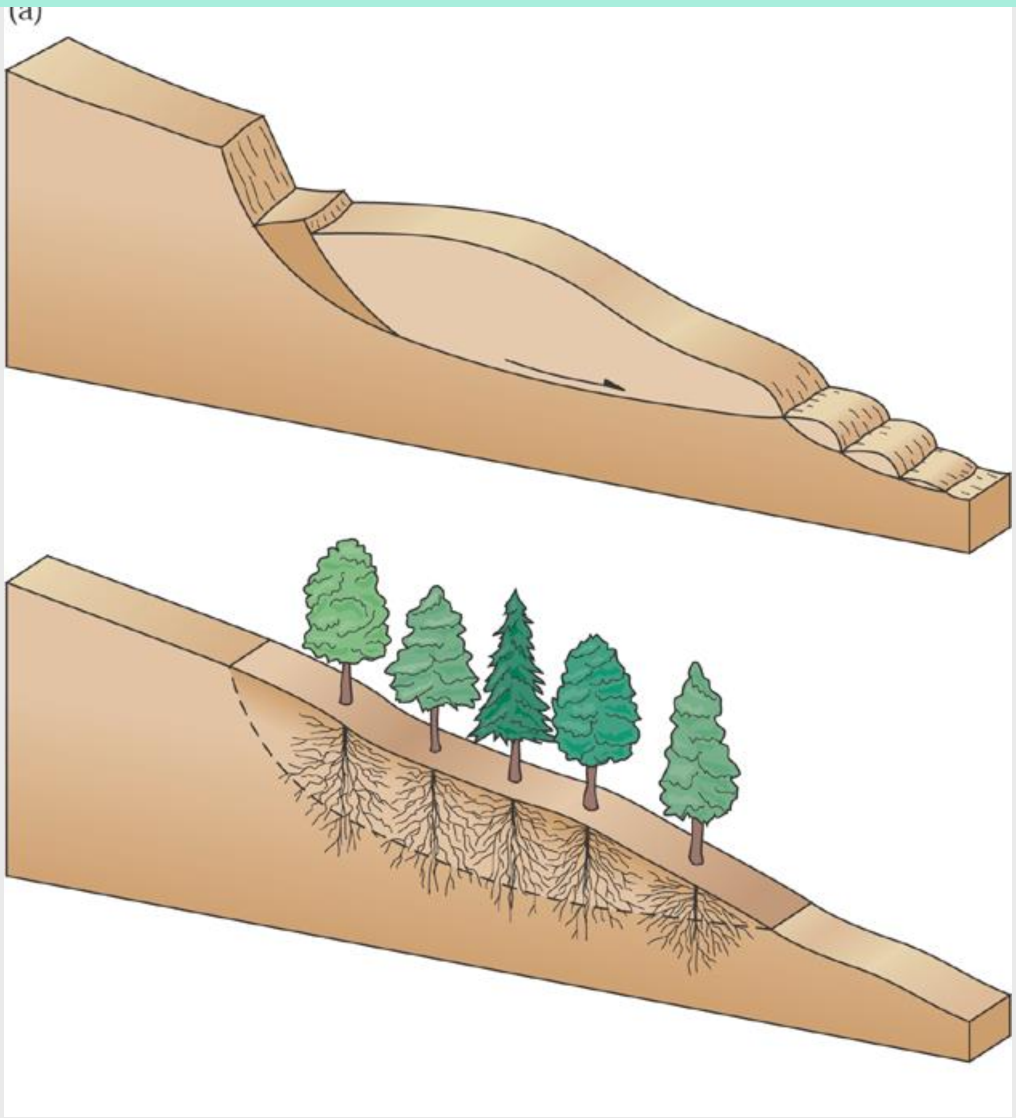




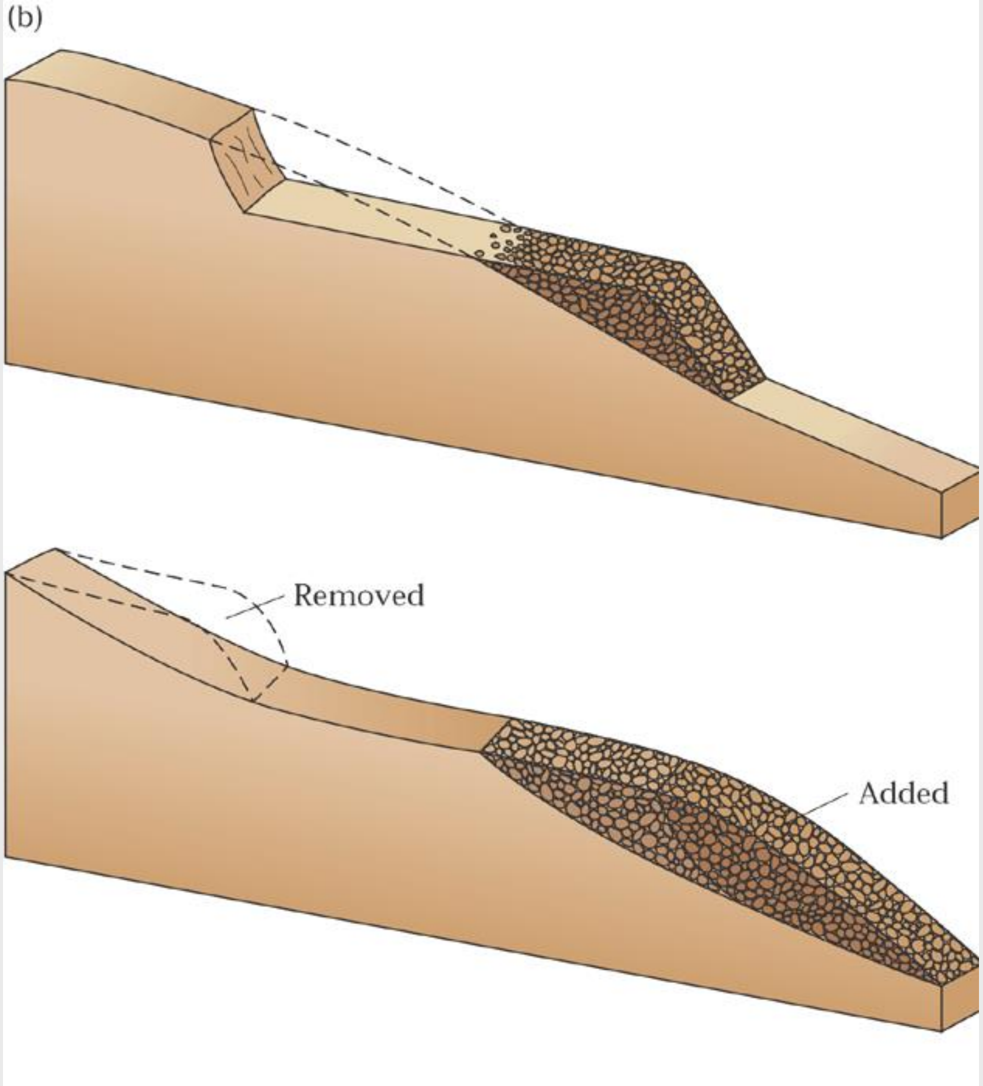
Shotcrete is another type of retaining device. A layer of concrete is sprayed out of a pressurized gun to cover a slope. It is important to install drain systems to remove water from within the slope, so water does not build up behind the shotcrete layer

Rock bolts are a type of retaining device used to reinforce slopes consisting of cracked and fractured rock. They can be used to reinforce cliffs, overhangs, and tunnels. Bolts that are anchored in concrete are particularly strong.

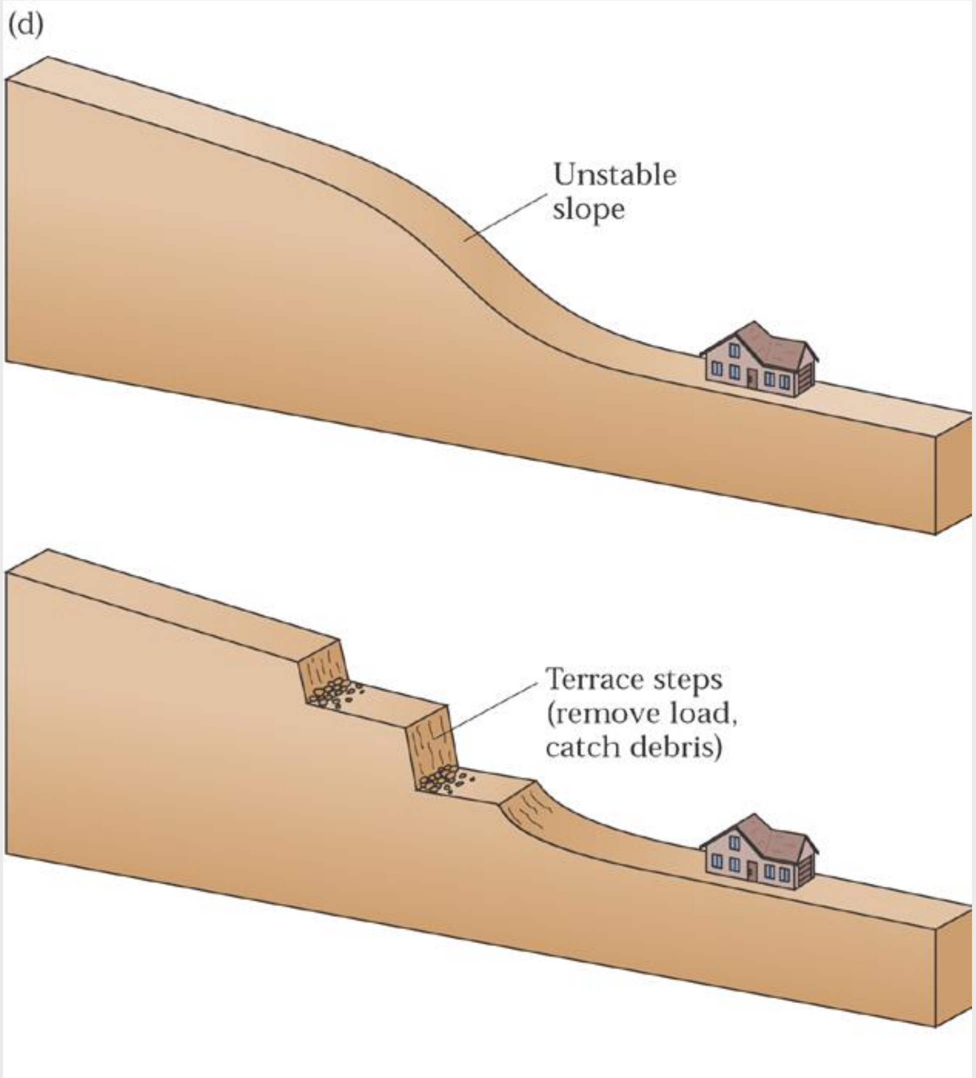




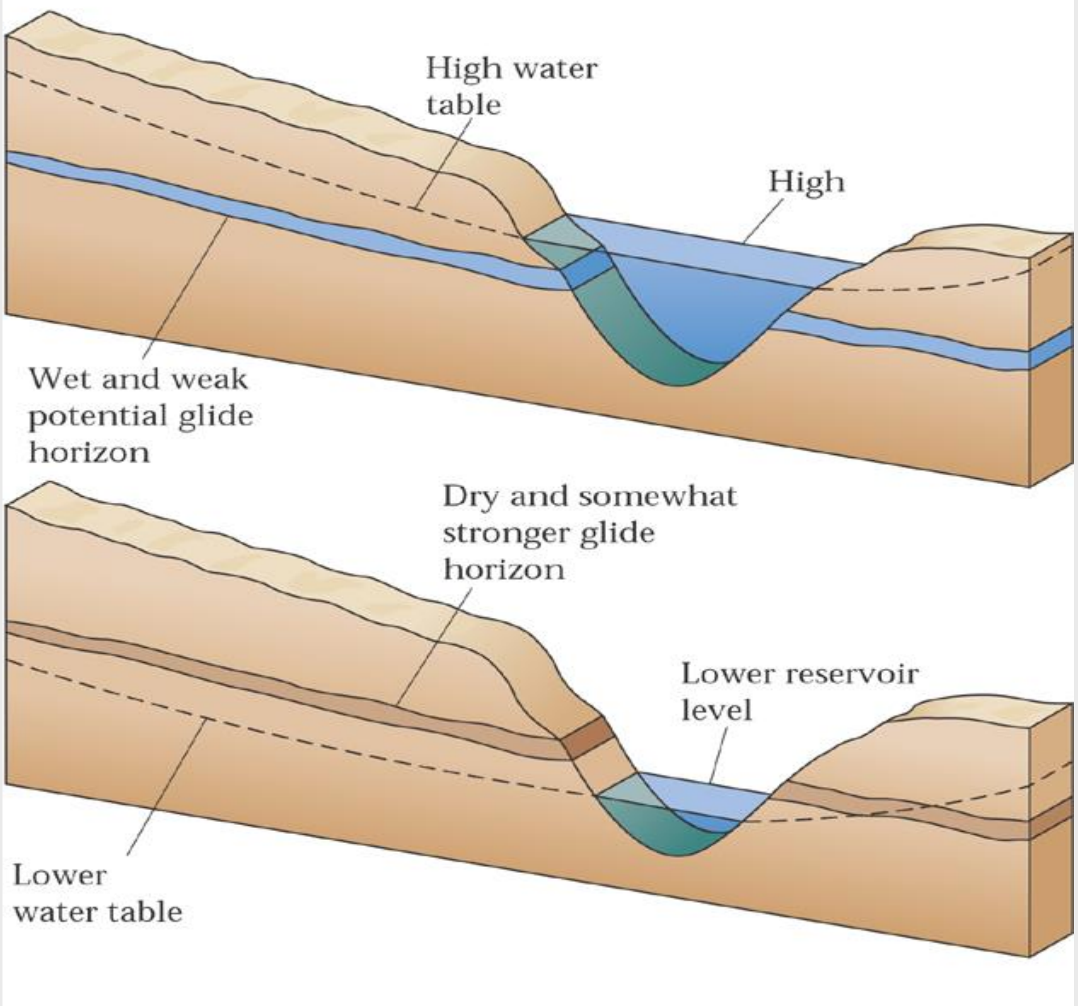
Revegetation:
Revegetation removes water, and tree roots bind regolith. (W.W. Norton)



Regrading:
Redistributing the mass on a slope eases the load where necessary, adds support where necessary, and decreases slope angles.



Terracing a steep slope may decrease the load and provide benches to catch debris.



Reducing subsurface water: Lowering the level of water table may allow a glide horizon to dry out.

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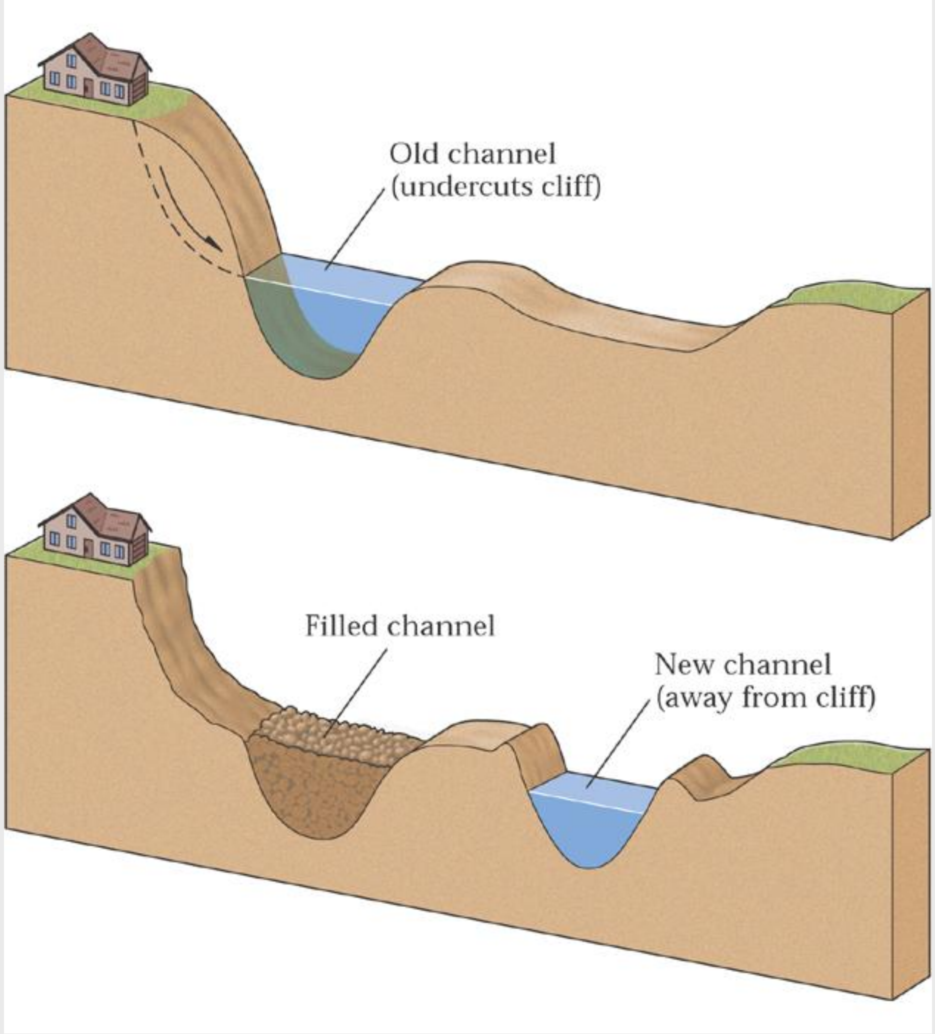
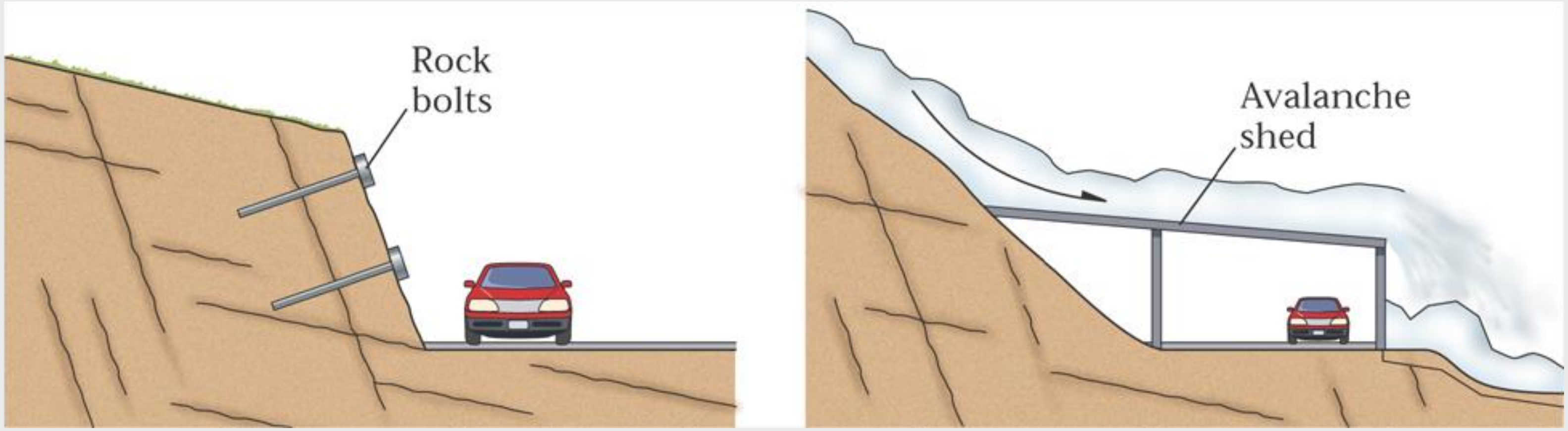


Preventing undercutting: Relocating a river channel away from cliff stops undercutting, and filling the channel adds support.



Bolting holds loose blocks in place. An avalanche shed diverts avalanche debris over a roadway.

Subsidence

Subsidence is the sinking downward of the earth's surface. It can be caused by natural processes, but most problems involving subsidence are caused by human activities like: pumping of water, crude oil, or natural gas from deep underground collapse of underground mines or natural caves Subsidence causes problems in the form of :

- **cracked ground, and**
- **damage or destruction of structures,**
- **pipelines, drainage systems,**
- **sewer systems**.

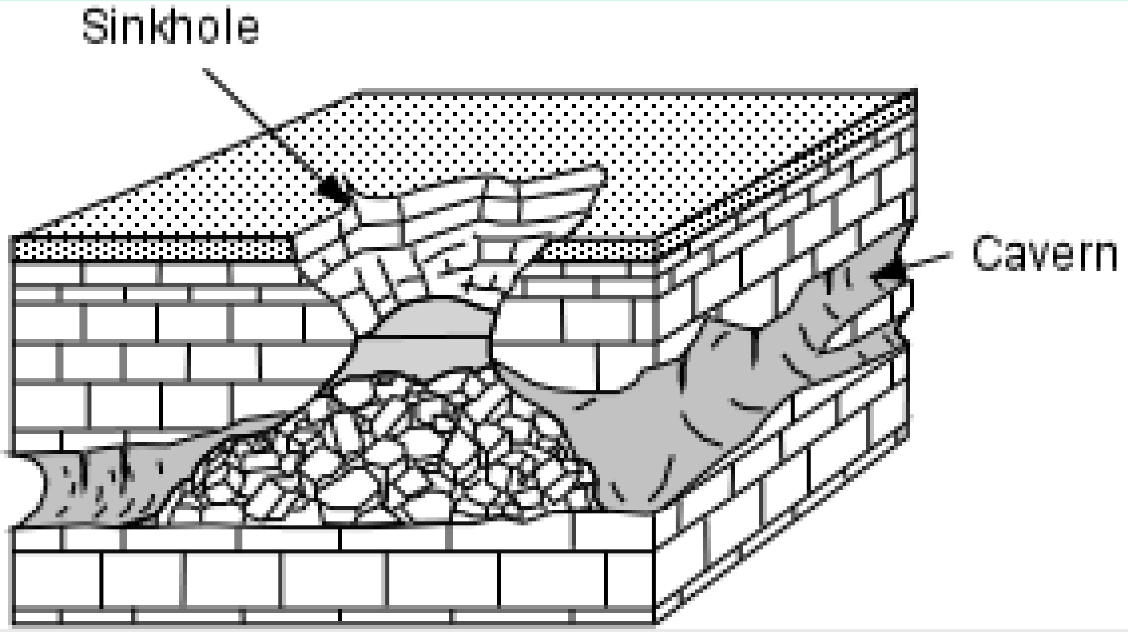
Mitigation of subsidence is accomplished by:

• replacing underground fluids as they are pumped out
• support pillars and infilling of underground mines to prevent collapse
• building structures on deep foundation pillars to hold them in place if the ground subsides

Lowering the land surface by a vertical downward movement is called Subsidence.

The mechanisms of subsidence include:

- compaction;
- consolidation;
- plastic outflow of weak layers (organic, silty layer near surface, etc.);
- collapse of subsurface openings.



sinkholes can form in any area where highly water soluble rocks occur close to the surface. Such rocks include rock salt made of the mineral halite, and gypsum deposits, both of which easily dissolve in groundwater.

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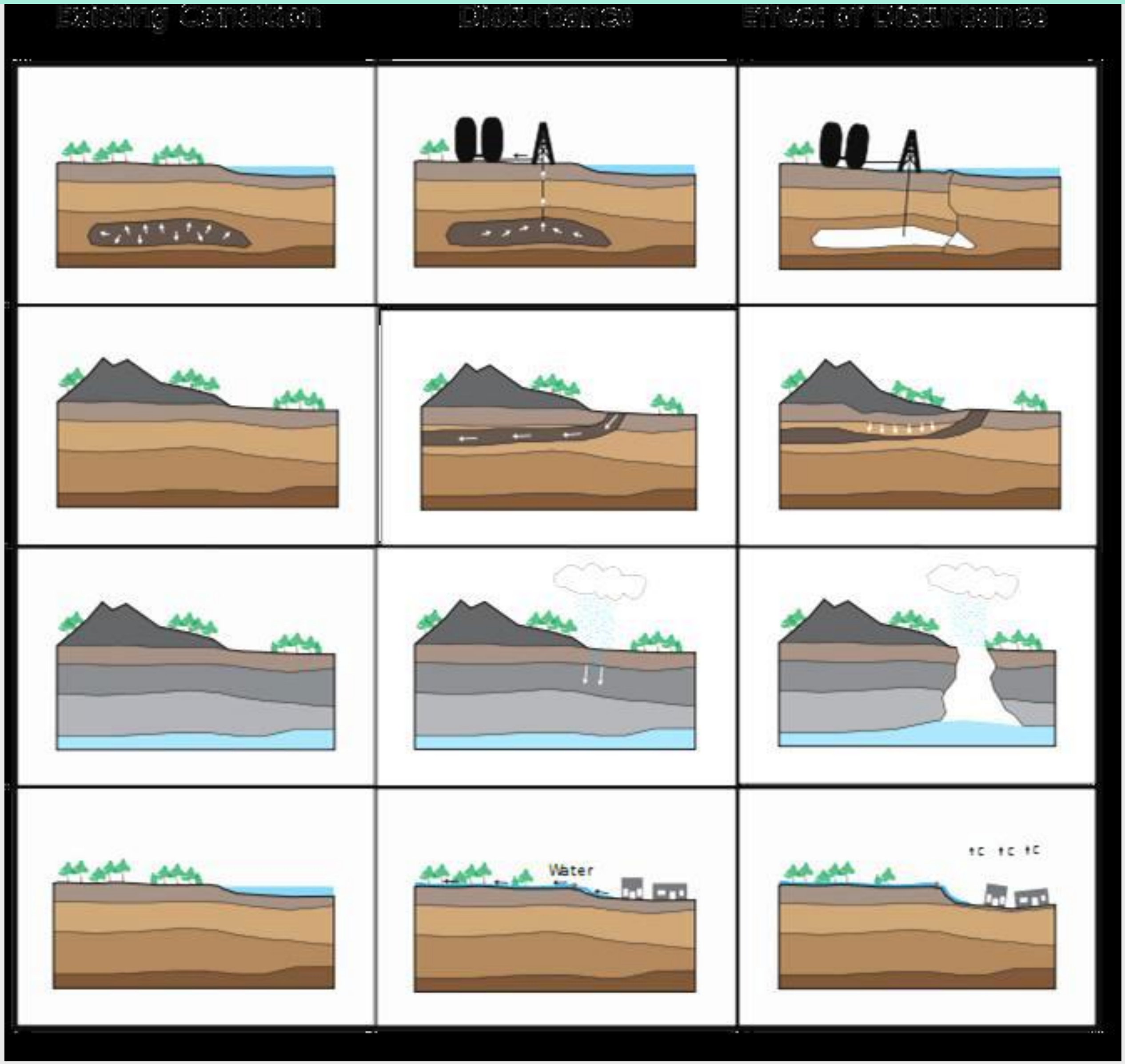
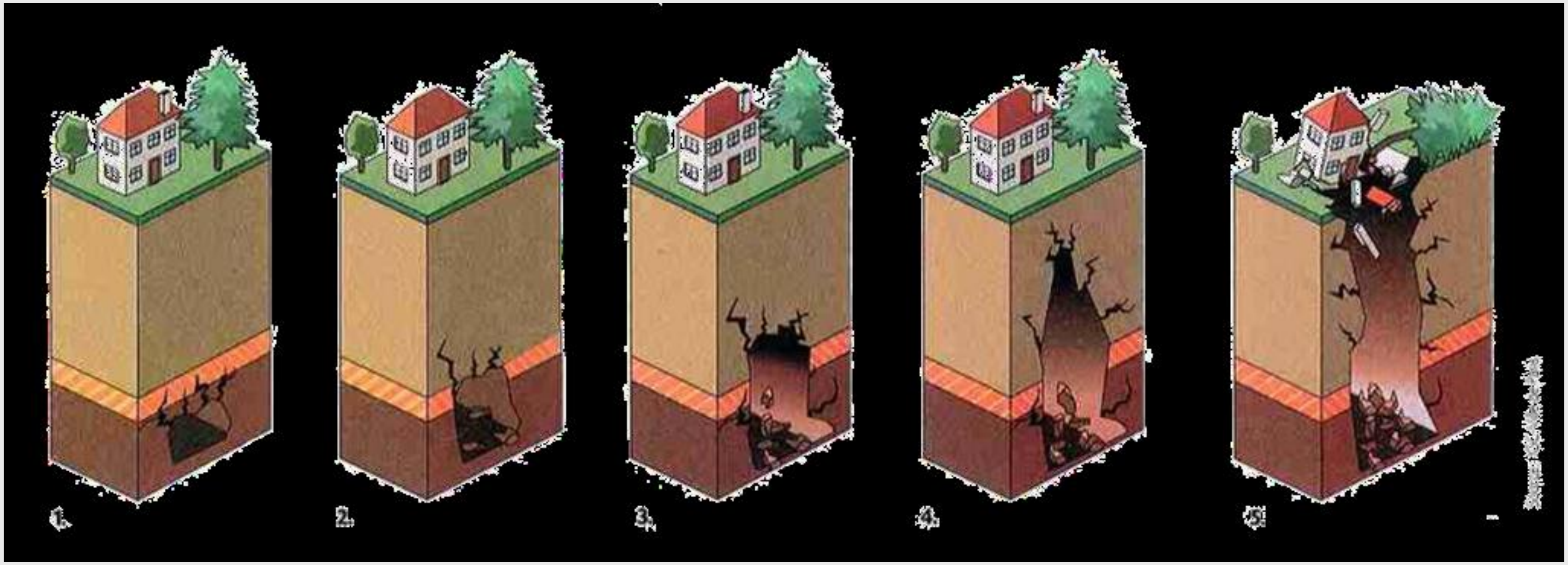
Oil and natural gas extraction

Mining

Dissolution of Limestone

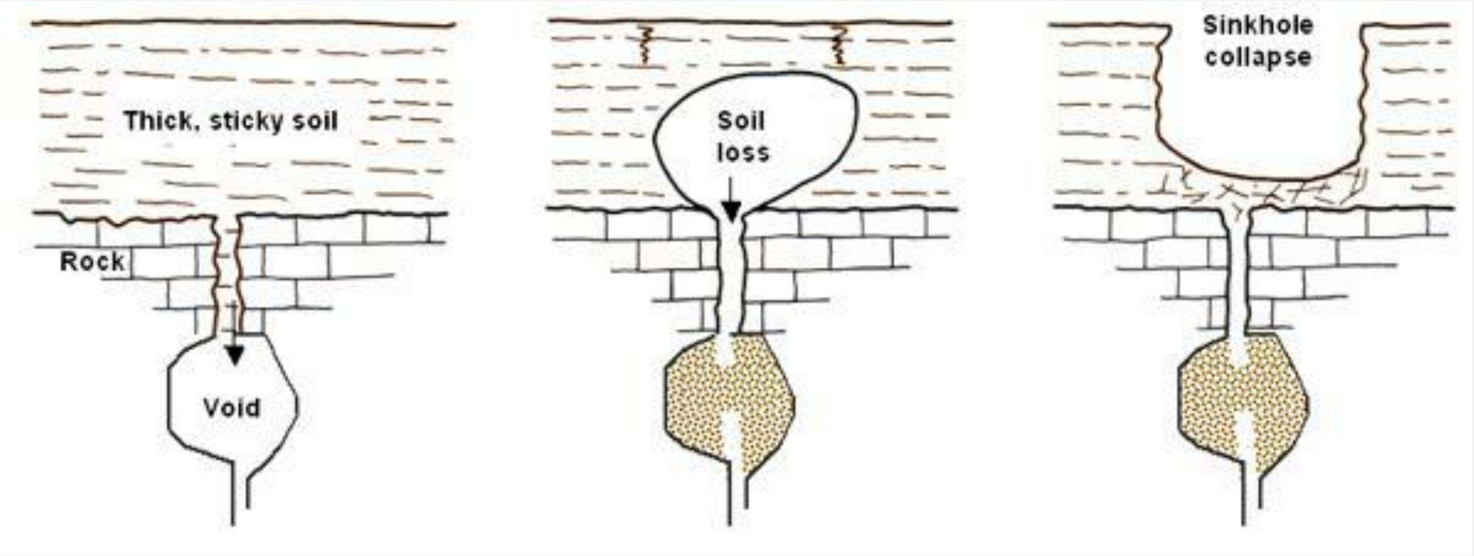
Ground water-related





Settlement occurs due to downward pressure.
Subsidence occurs due to the removal of earth beneath the foundations. Settlement is usually easily dealt, whereas subsidence can prove difficult and costly to repair.

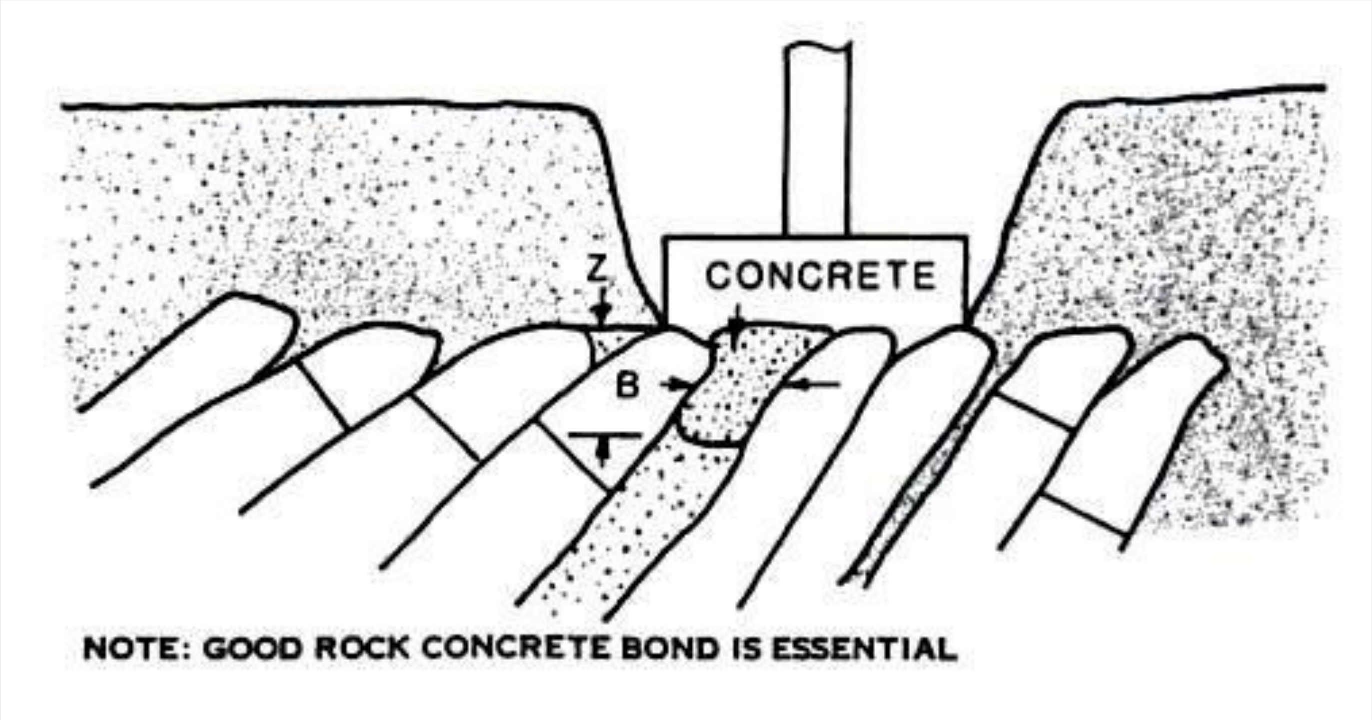
Cavities are very famous in limestone deposits Cavities have been used for centuries as disposal sites for various forms of waste. A consequence of this is the pollution of groundwater resources, with serious health implications in such areas



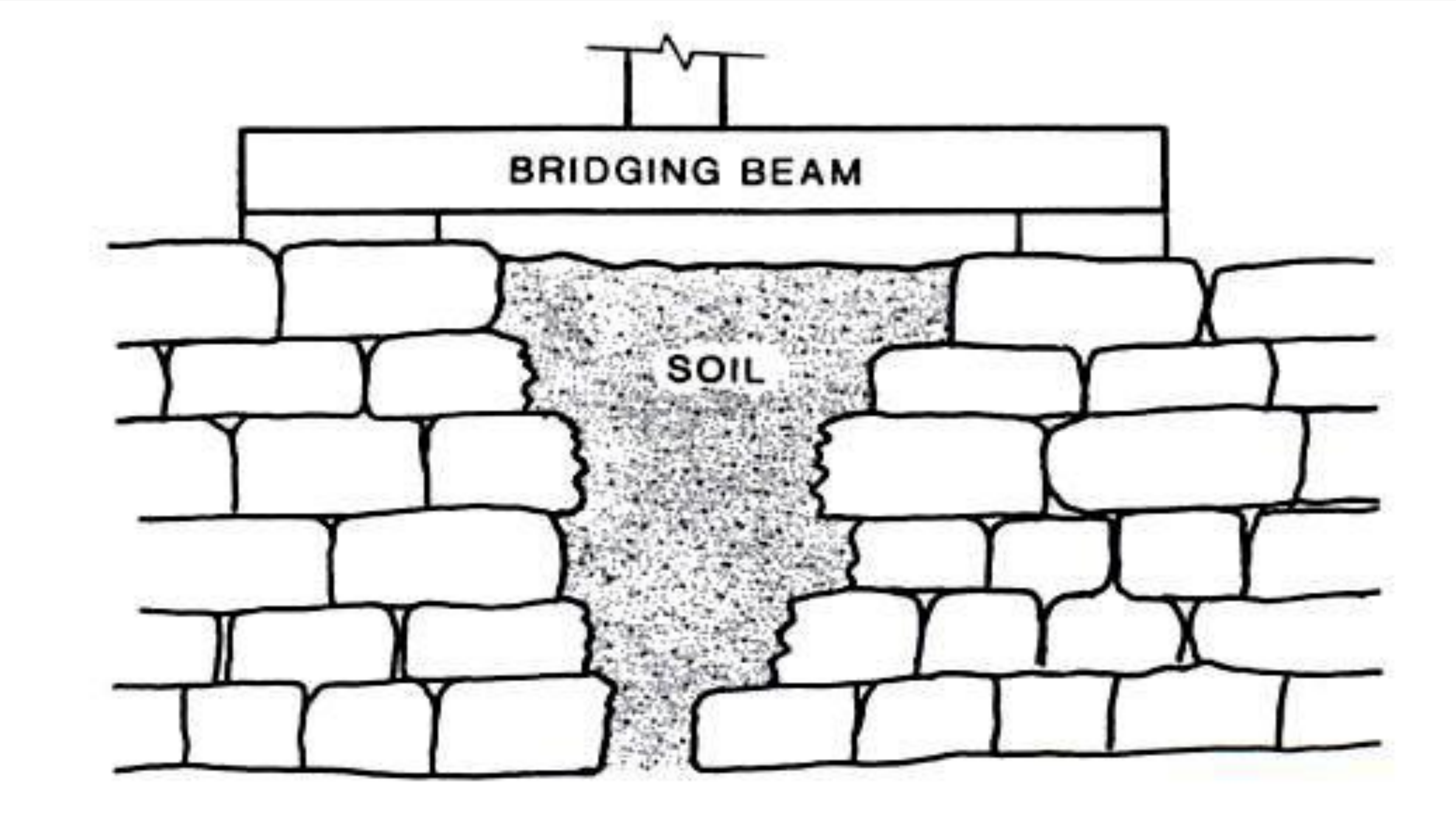
Mitigation of subsidence is accomplished by: replacing underground fluids as they are pumped out support pillars and infilling of underground mines to prevent collapse building structures on deep foundation pillars to hold them in place if the ground subsides

Treatments

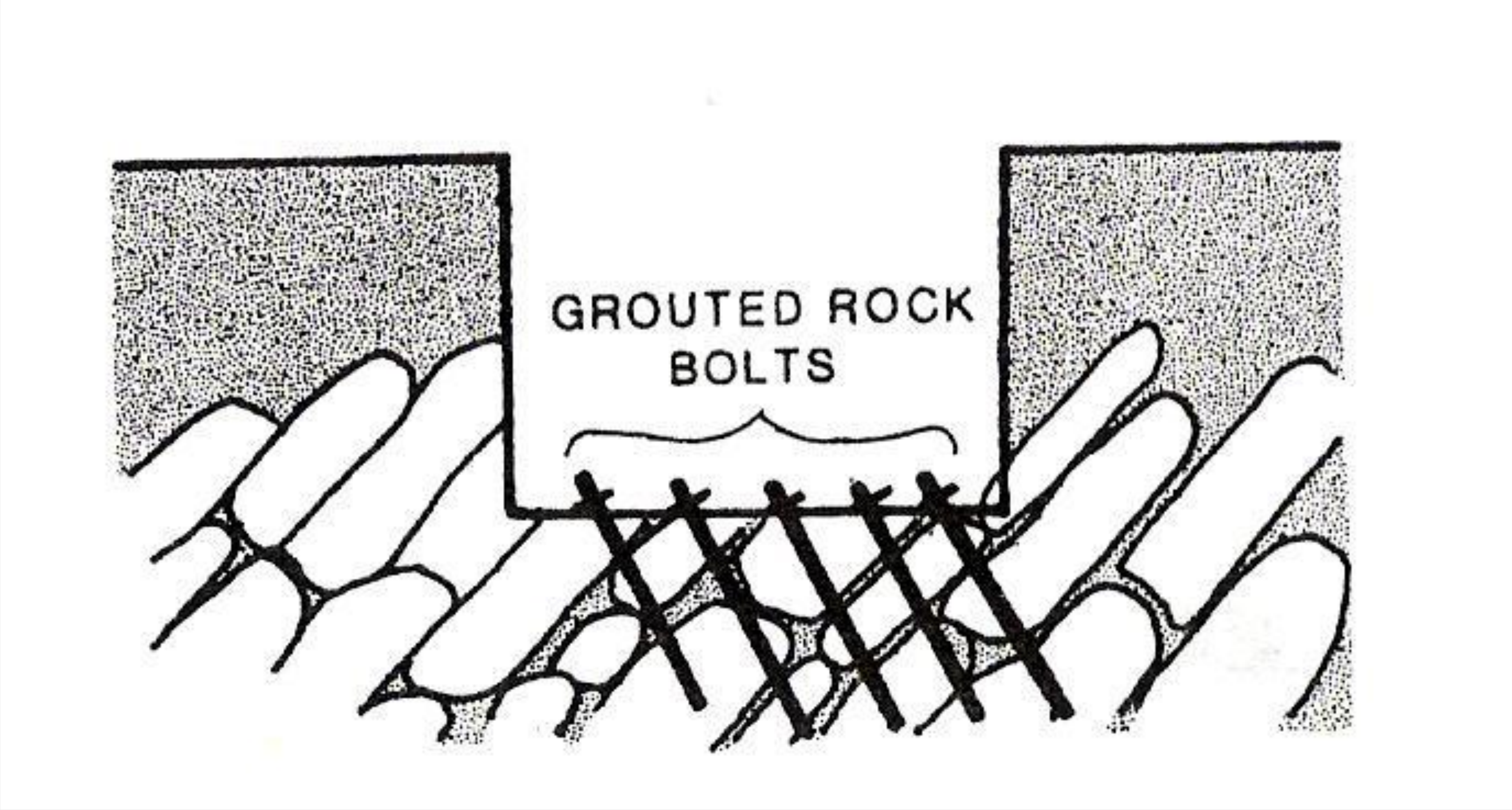
1-For wide fissures or voids beneath the foundation, the voids should be filled with concrete in order to prevent local spalling of the edge of the fissures under and immediately beneath the foundation. Called dental filling



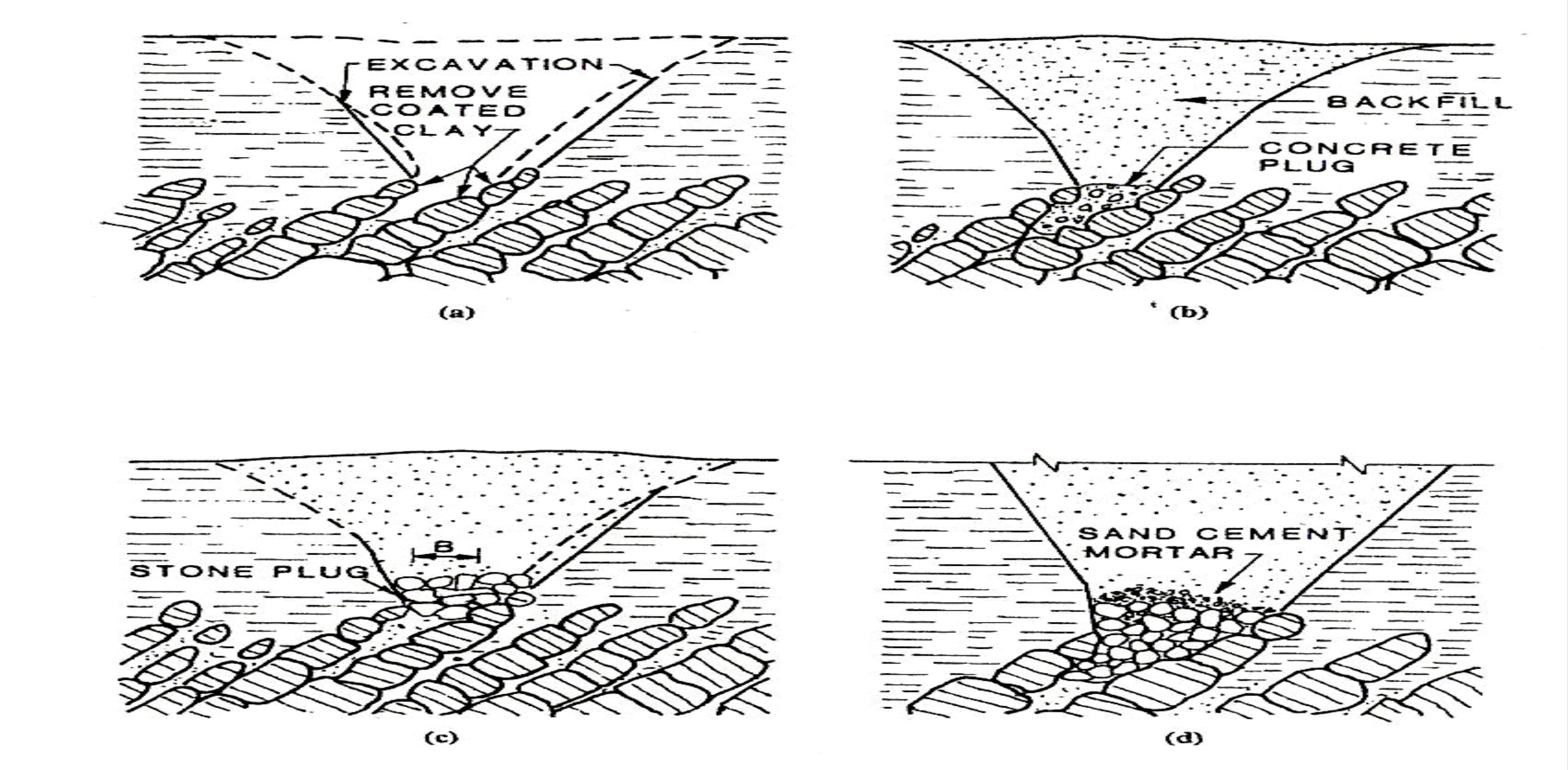
2-When a very wide slot or pit is found beneath a foundation, a bridge over that opening with a properly reinforced beam or slab may be used



3-Dipping fractured rock may require reinforcing, using grouted dowels or tensioned rock bolts. The objective is to bind the rock blocks together.



Open sinkhole Treatment: Open sinkholes and cavities require treatment if they cannot be avoided. The most effective approach is to excavate and cleaning soil to the narrowest point of the bottom, non-reinforced concrete plug is placed with height equal 1.5 times width, then rock fill plug, with diameter of the deeper rock pieces and then partially grouted rock fill using rock smaller than 1.5 the width is then constructed to bridge across the opening and transfer load of future backfill to the rock



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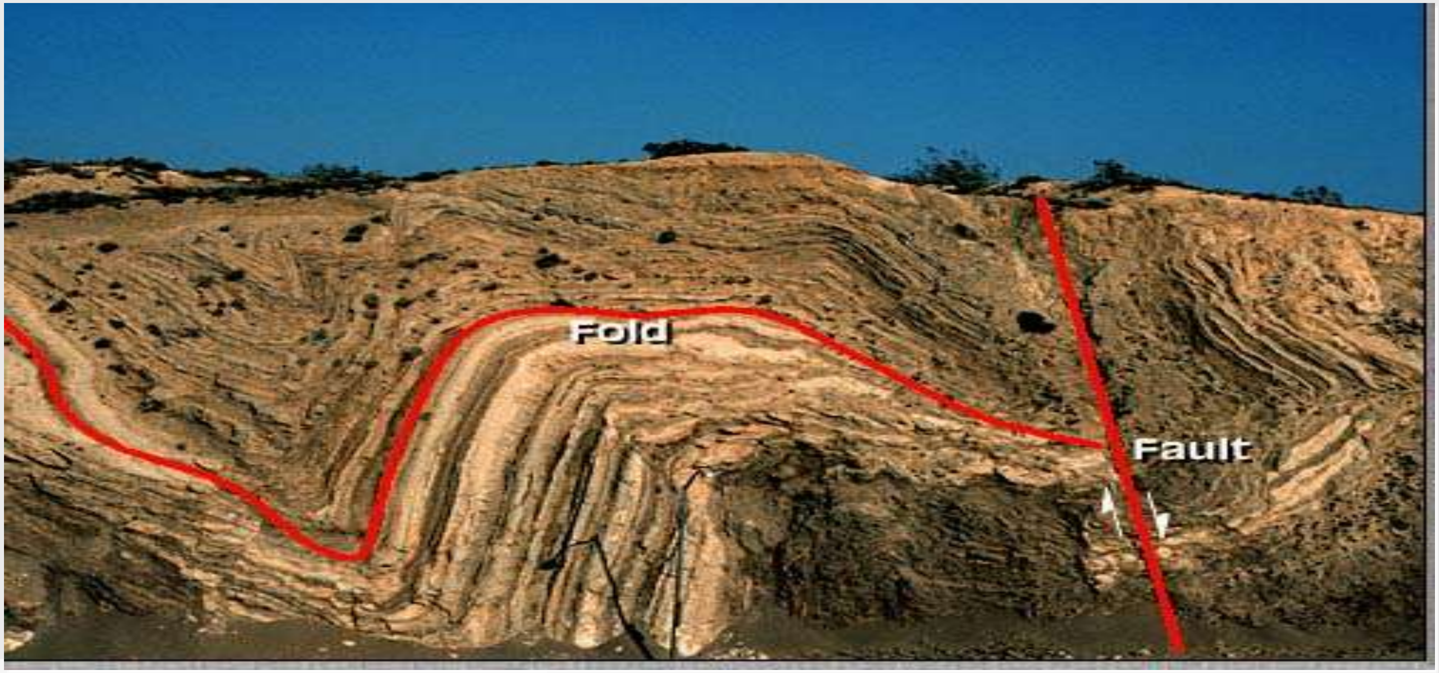
Geological Structures



- Hussien aldeeky

Deformation

- The theory of plate tectonics tells us that the Earth's plates are in constant motion
- They move apart, collide and slide past one another
- As well as generating earthquakes and volcanoes these processes also deform the rocks of the crust

Many rocks have been deformed by dynamic forces that cause fracturing, folding, and faulting of rocks. Processes that cause deformation are associated with plate boundaries and mountain building processes.

- **Deformation is simply a change in shape and/or volume of rocks**.
- We can measure these changes both in the
- field and the lab in order to try and understand how rocks deform

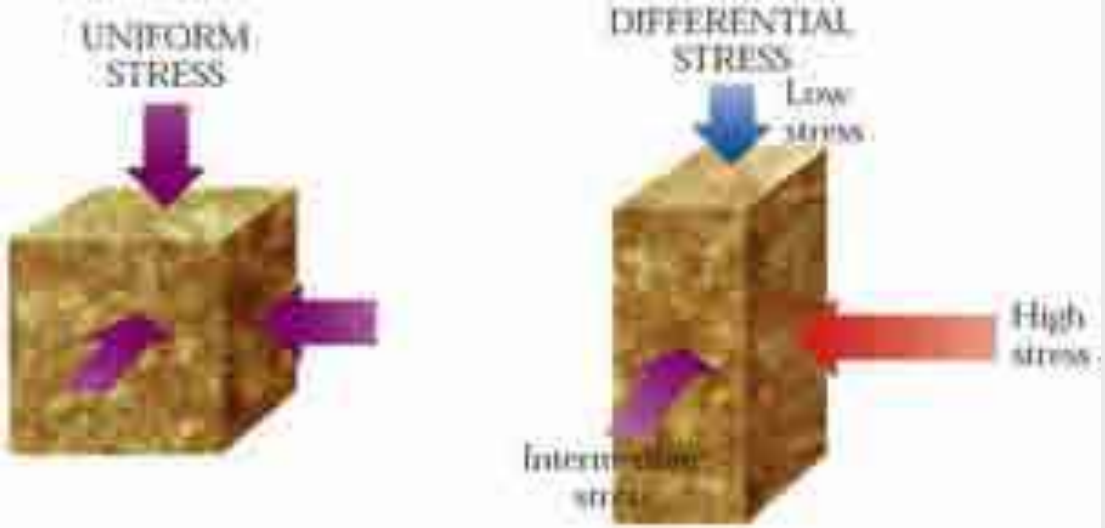
Engineering Geology

- **Stress and strain**

Stress is the force applied to a given area of rock. • It has the same definition as pressure (*force acting on a surface per unit area)*

However, pressure is generally considered to be acting equally

- in all directions • So geologists use the term stress
- **• Differential stress**
- **• Uniform stress**
- Uniform stress can
- also be thought of
- **as confining**
- **pressure or**
- **confining stress**



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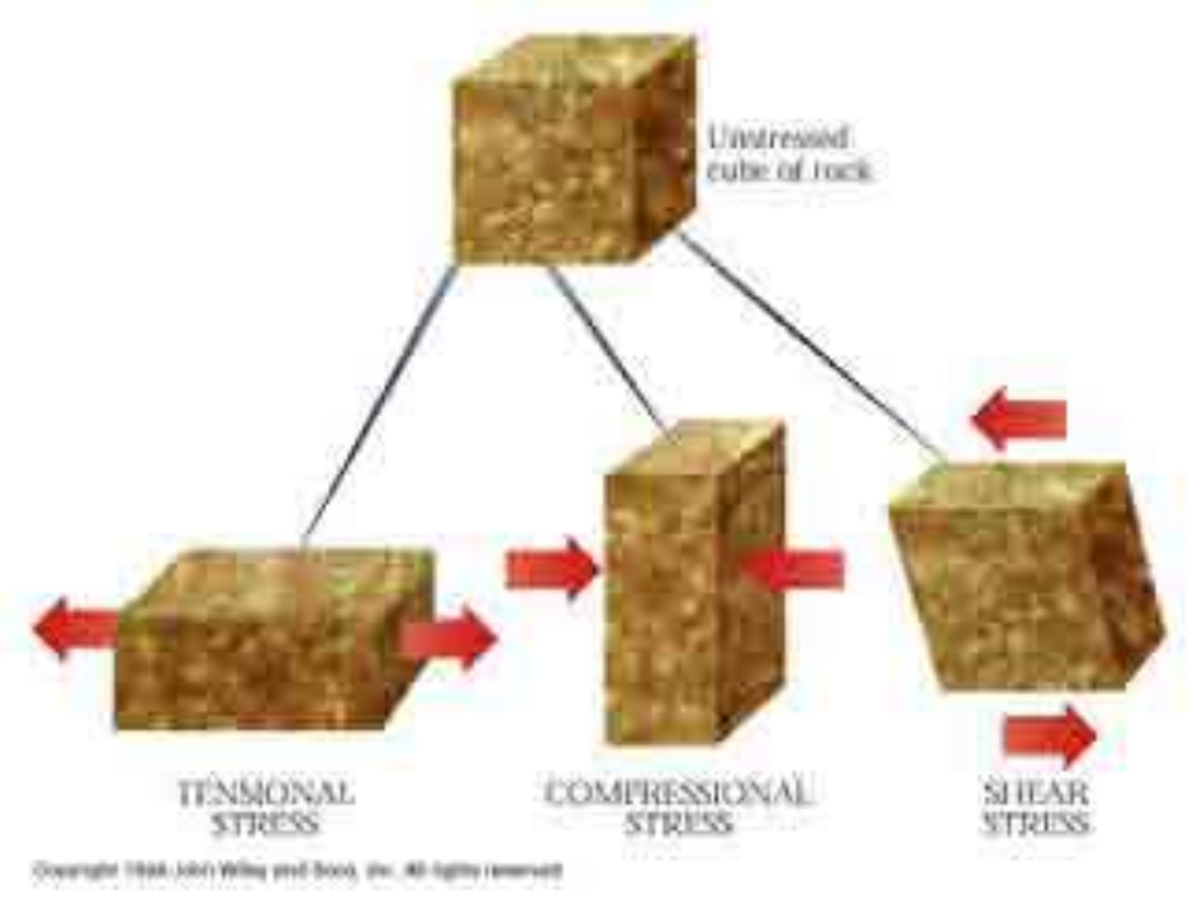
Stress comes in three flavors:

Compression

Tension

Shear



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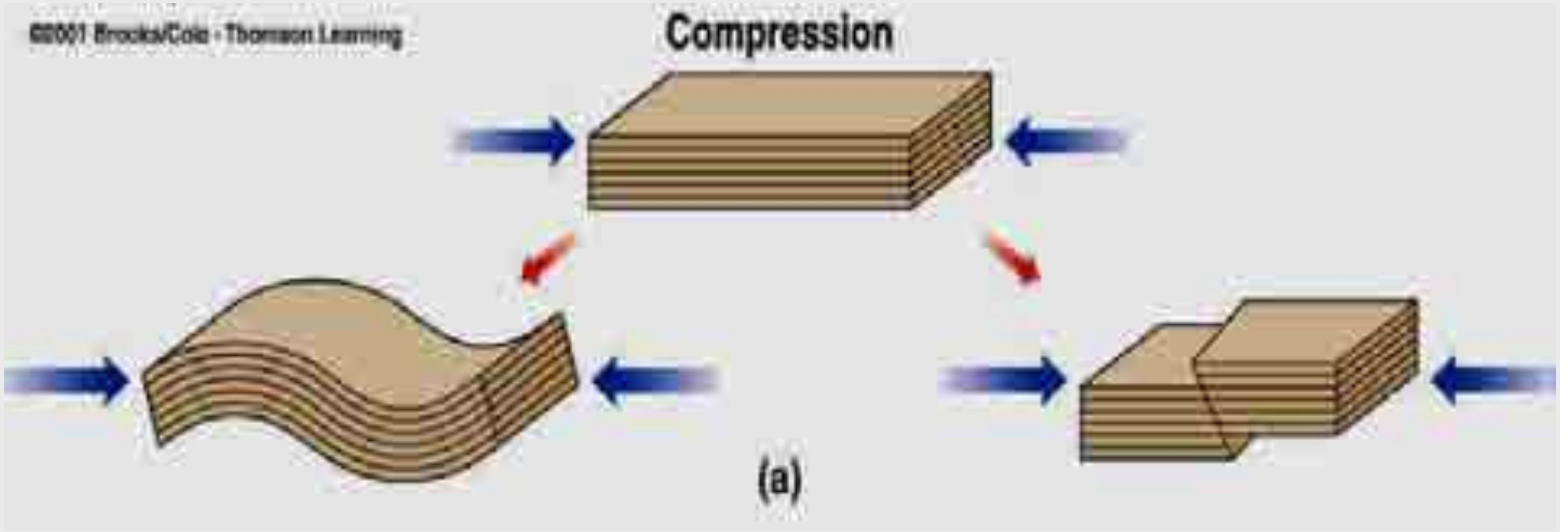
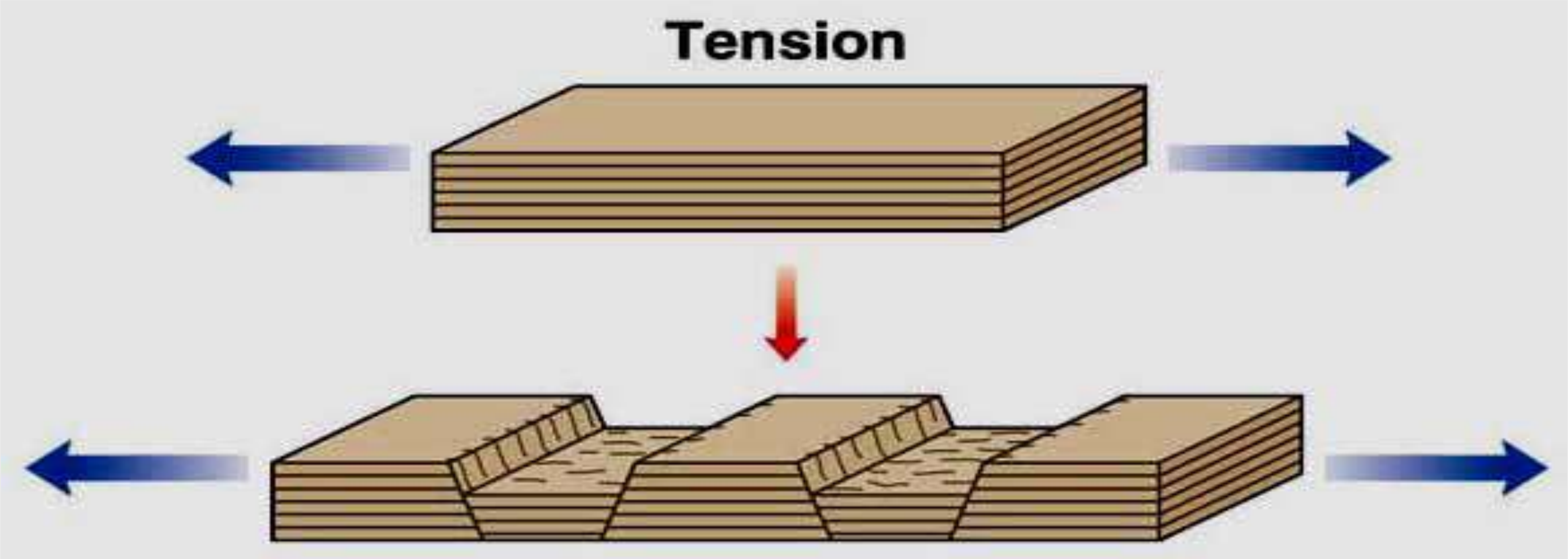
Compression

In compression, rocks are squeezed by external forces acting toward one another. Compression causes rock to shorten along the direction of compression. **Compression causes folding as well as reverse and thrust faulting**



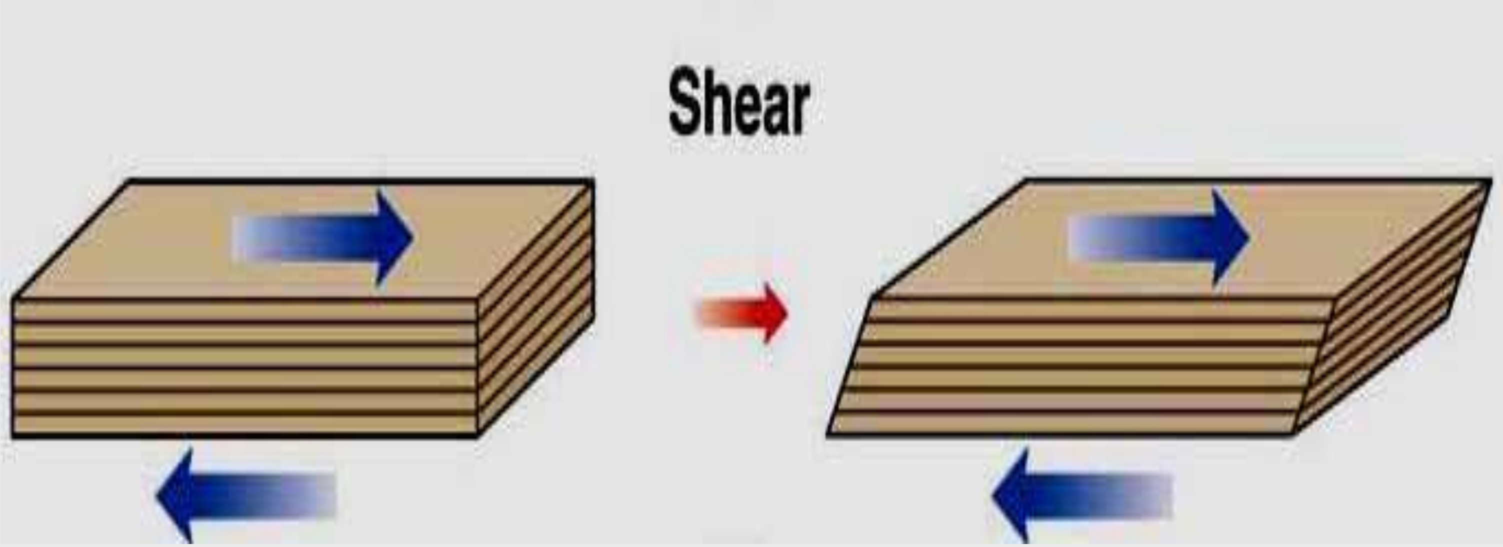
Tension

Tension results from force acting in opposite directions, which tends to lengthen rocks and pull them apart. **Tension causes normal faults.**



Shear

In shear stress, forces act opposite one another in a horizontal plane. Shear stress causes rocks to slip past one another in a horizontal plane as with **strike-slip faults.**

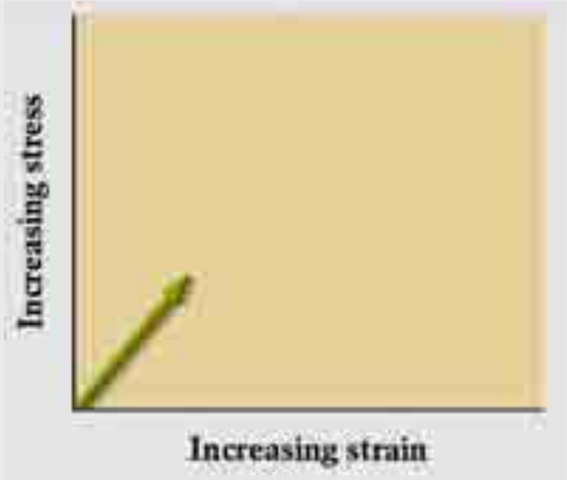


Strain

- Strain also comes in three flavors
- **Elastic strain**
- **Plastic strain**
- **Brittle strain**

Elastic deformation

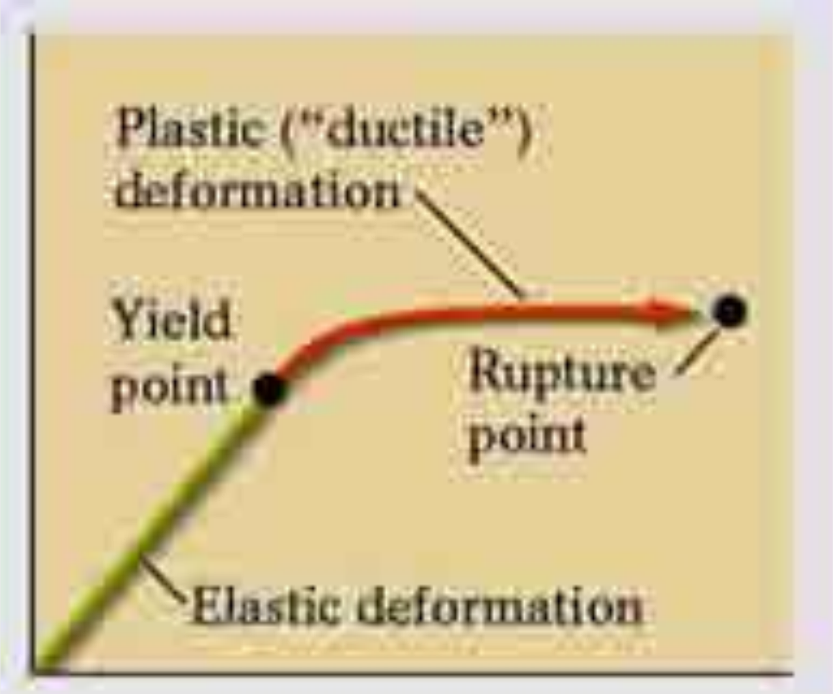
- This is a non permanent change in volume or shape
- A good example of this is a metal spring



• Plastic strain
(Ductile deformation)

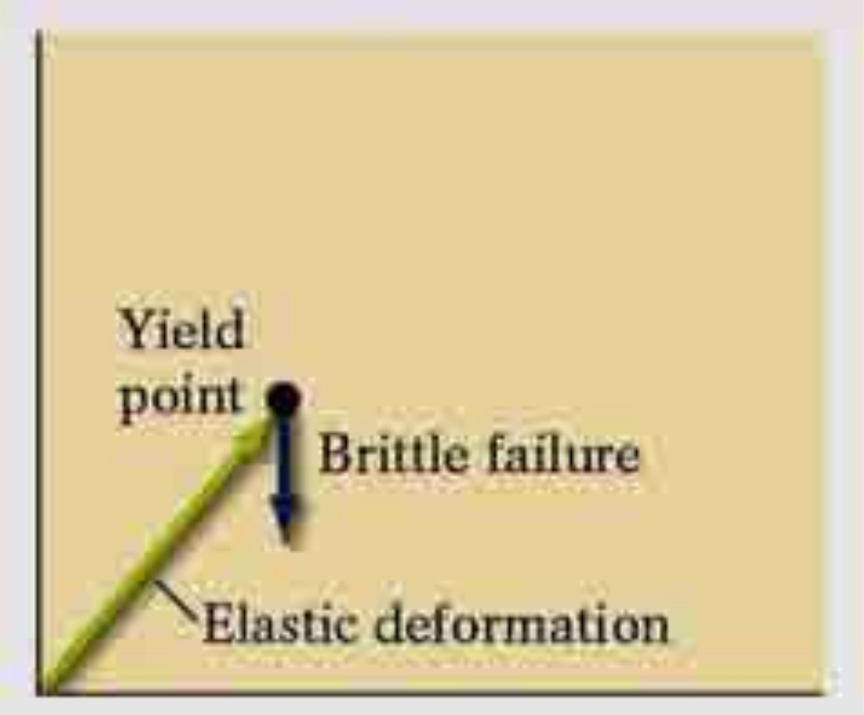
Once the elastic limit is exceeded rocks will deform

• Ductile deformation is permanent

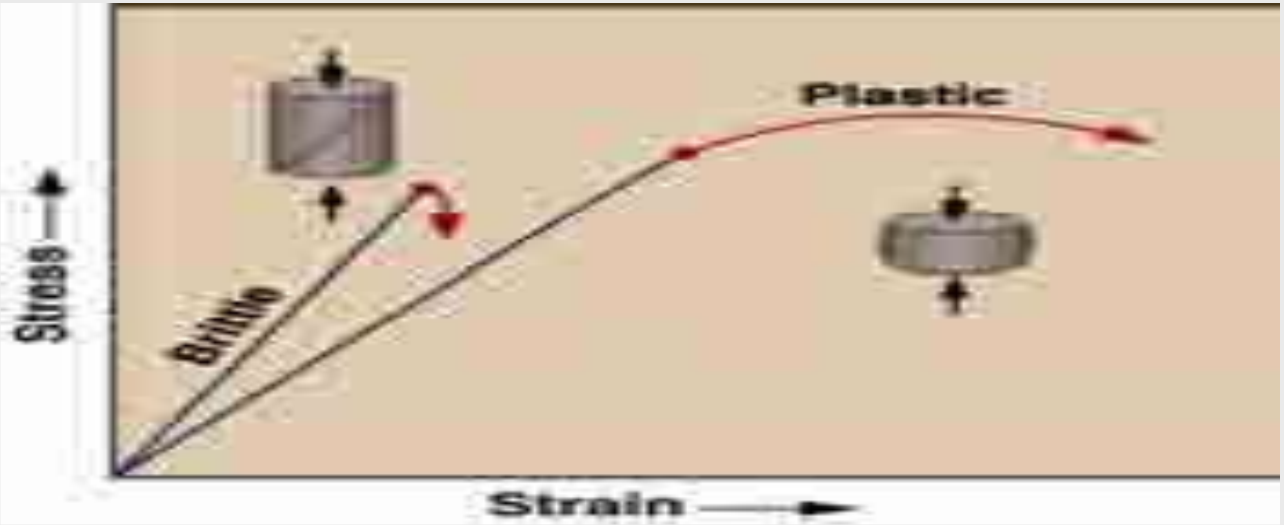


Brittle deformation

This occurs when rocks fracture rather than bend



Deformation in rocks



Brittle or ductile

• The response to deformation is controlled by the

1- nature of the stress,

2-, temperature,

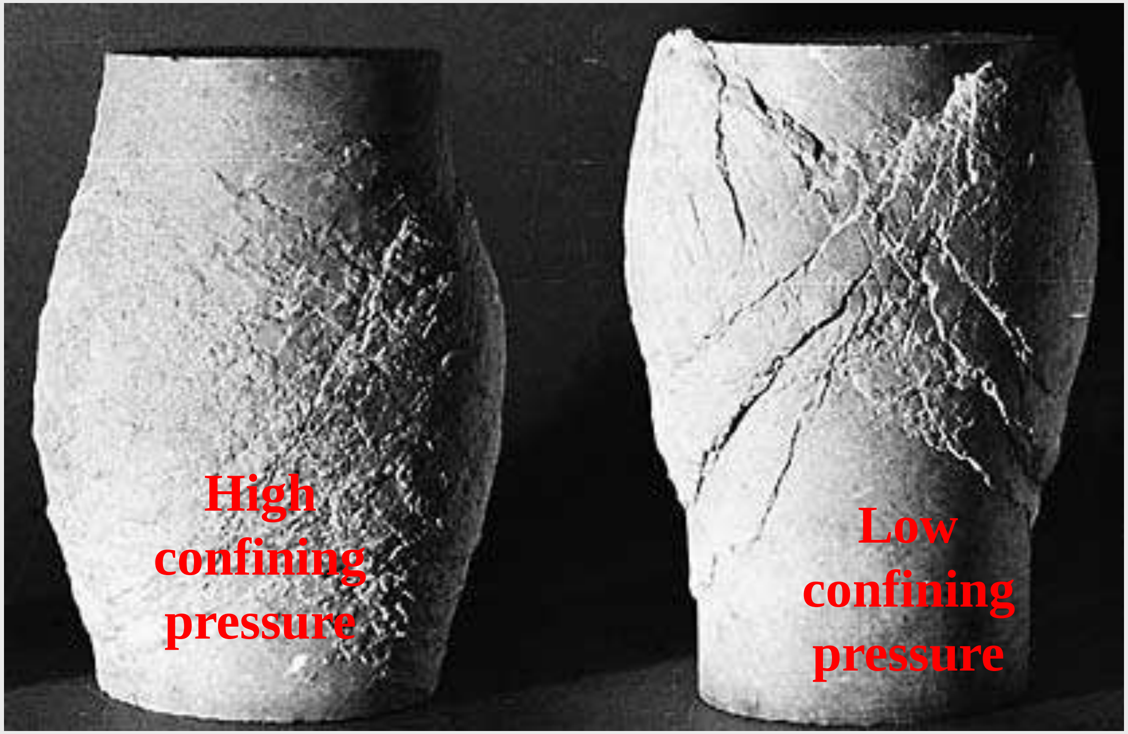
3- time

4- rock type

• **Any rock under the great pressures and high temperatures of Earth's interior is more ductile that it would be at Earth's surface.**

Confining pressure

High confining pressure reduces brittleness by hindering fracture formation



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Temperature

• **Solids become more ductile and less brittle at high temperatures**
• Glass can be blown when hot but will shatter when cold
• This is why the asthenosphere ‘flows

Rate of deformation

• The rate at which stress is applied determines if the failure will be brittle or ductile
• Think of ‘silly putty’ - it bounces if dropped but shatters if hit with a hammer
• Strain rate - this is the rate at which a rock is deformed
• **Low strain rate results in ductile behavior**

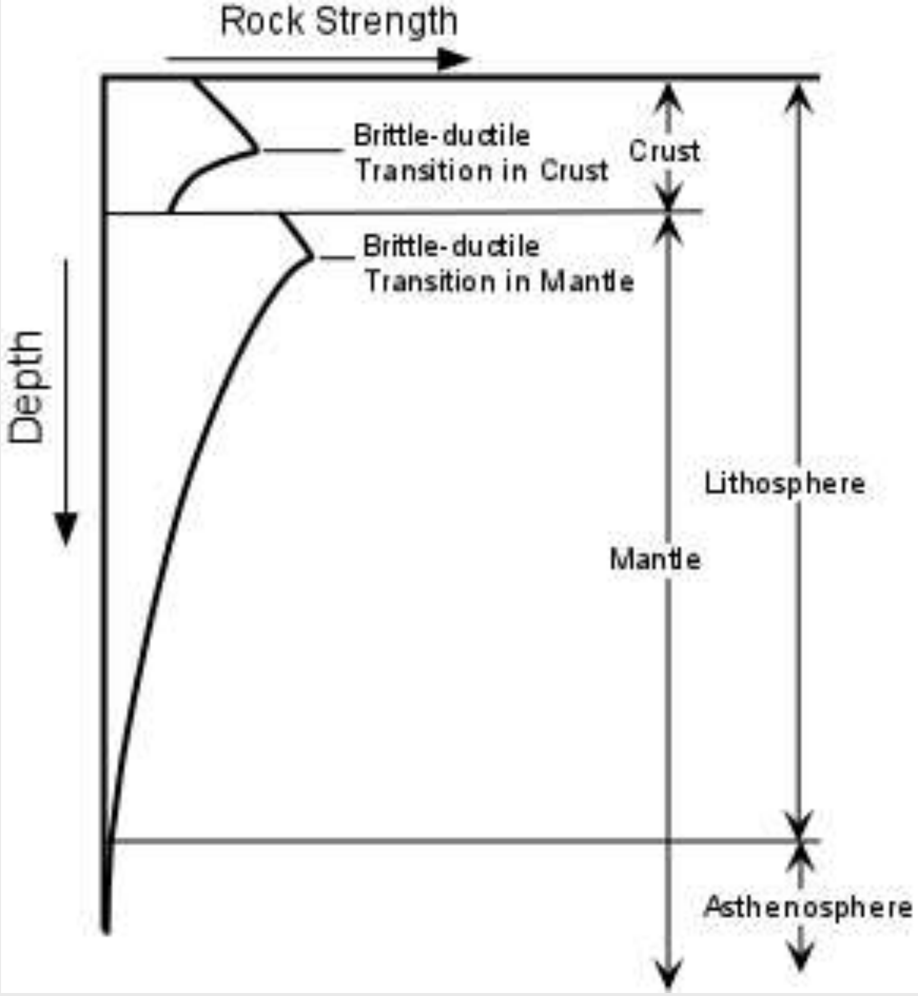
Composition

Composition : 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. Thus, the mineralogical composition of the rock will be a factor in determining the deformational behavior of the rock. presence or absence of water. Water appears to weaken the chemical bonds and forms films around mineral grains along which slippage can take place. **wet rock tends to behave in ductile manner, dry rocks tend to behave in brittle manner**

Summary

- **Low temperatures, low confining pressures and high strain rates result in brittle behavior**
- **High temperatures, high confining pressures and low strain rates result in ductile behavior**

Brittle-Ductile Properties of the Lithosphere



Brittle-Ductile Properties of the Lithosphere rocks near the surface of the Earth behave in a brittle manner.

Crustal rocks are composed of minerals like quartz and feldspar which have high strength, particularly at low pressure and temperature. deeper in the Earth the strength of these rocks initially increases.

At a depth of about 15 km we reach a point called **the brittle-ductile transition zone.**

Below this point rock strength decreases because fractures become closed and the temperature is higher**, making the rocks behave in a ductile manner**.

At the base of the crust the rock type changes to peridotite which is rich in olivine. Olivine is stronger than the minerals that make up most crustal rocks, **so the upper part of the mantle is again strong**.

But, just as in the crust, increasing temperature eventually predominates and at a depth of about 40 **km the brittle-ductile transition zone in the mantle occurs**.

Below this point rocks behave in **an increasingly ductile manner Brittle and ductile**

Engineering Geology

Deformation & Geologic Structures

- **Any feature resulting from rock deformation is a geologic structure,**

Especially Joints (الشروخ) , and faults (الفوالق), Folds , الطيات

- **Folding occurs in response to ductile Deformation**

- **Faulting occurs in response to brittle deformation**

.

Brittle structures

Brittle failure results in fractures in a rock.
These basically take two forms

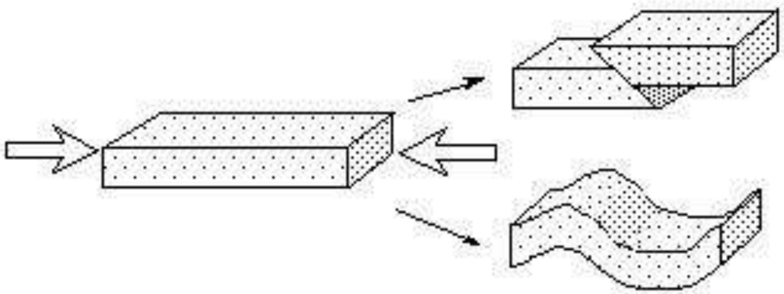
Joints are fractures in a rock along which no displacement has occurred.

Faults are fractures along which blocks have moved parallel with the fracture surface

Joints are generally small but pervasive
Faults can vary from micro fractures to continent scale (San Andreas fault or East African Rift)

Types of Rock Deformation

Type of deformation	*Typical action*	*Geologic result*	*Favorable geologic environment*	*Favorable rock types*	*Favorable strain rate*
Brittle	Breakage	Faults	Near surface (Low P & T)	Sandstone, Limestone, Igneous Rocks	Fast
Ductile	Bending & flowing	Folds	Deep (High P & T)	Salt, Shale, Slate, Schist	Slow



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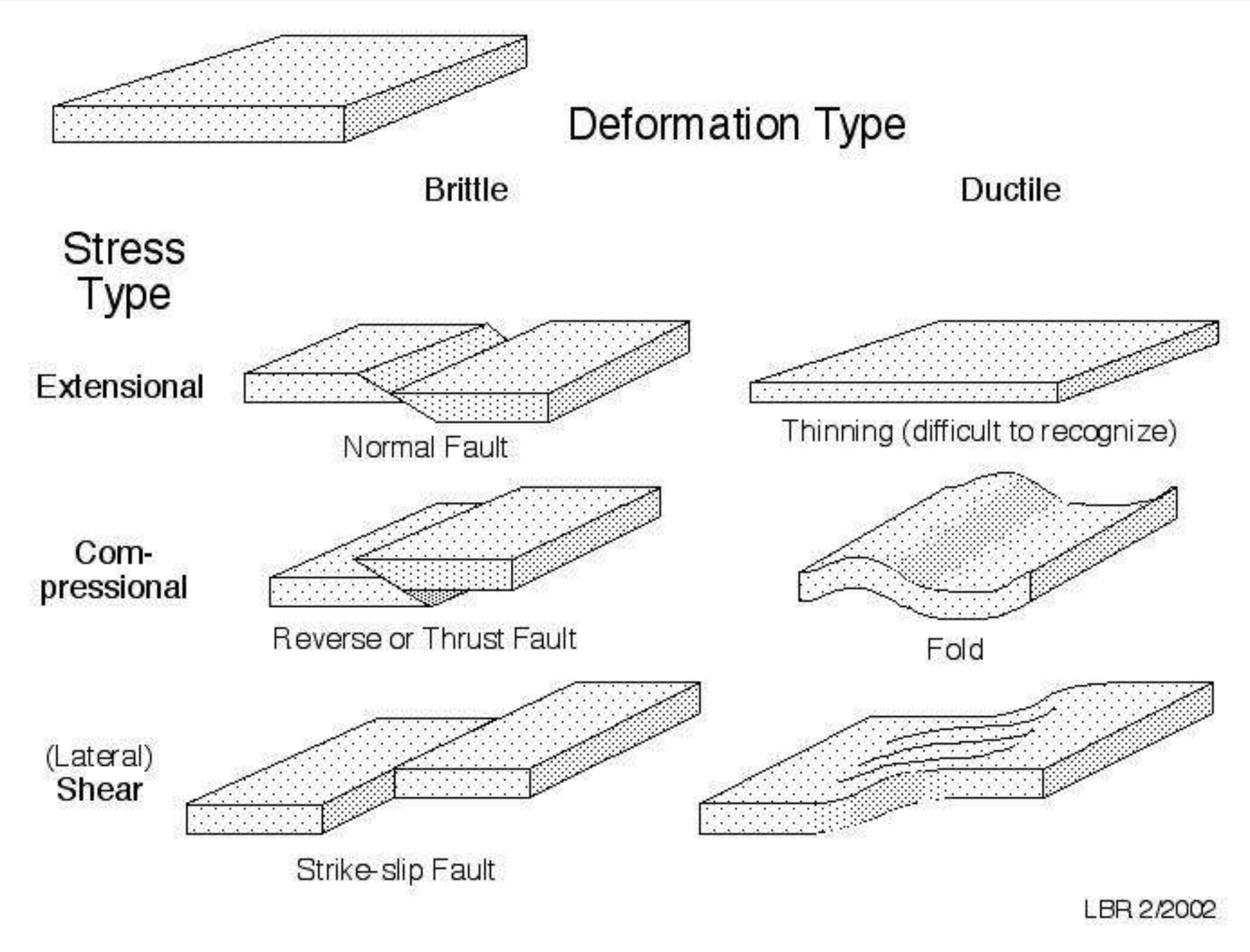
Deformation Type
Brittle
Ductile
Stress Type
Extensional
Normal Fault
Thinning (difficult to recognize)
Com-
pressional
Reverse or Thrust Fault
Fold
(Lateral)
Shear
Strike-slip Fault
LBR 2/2002

Joints

Joints are cracks or fractures present in the rocks along which there has been no displacement. Joints occur in all types of rocks. They may be vertical, inclined or even horizontal. There dip and strike are measured in the same way as that of sedimentary strata.

Formation of Joints: Joints are formed as a result of contraction due to cooling or consolidation of rocks. They are also formed when rocks are subjected to compression or tension during earth movements.

Tension Joints:

Tension joints are those which are formed as a result of tensional forces. These joints are relatively open and have rough and irregular surfaces.

Shear Joints: Shear joints are those which are formed due to shearing stresses involved in the folding and faulting of rocks. These joints are rather clean cut and tightly closed.

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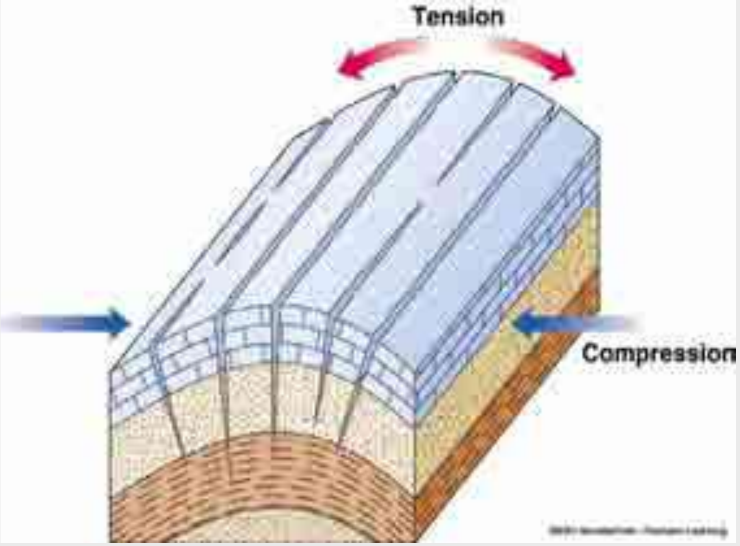
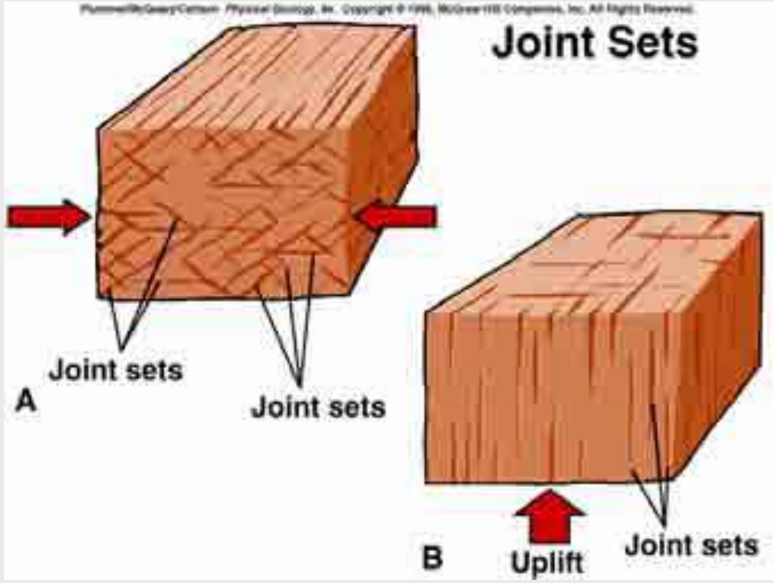




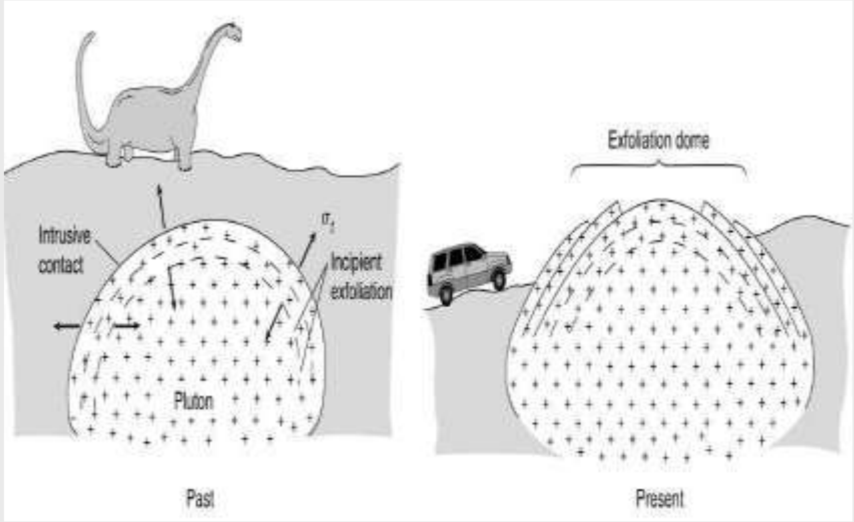
Types of Joints

Tectonic joints : caused by regional stresses in the crust and tend to occur in systematic orientations over fairly broad areas

Columnar jointing: is the tendency of sheets of igneous rock, usually lava flows but sometimes dikes or sills, to break into polygonal columns due to stresses as the rock cools and shrinks.

Exfoliation joints: often occur in intrusive rocks. They are most likely due to the rocks forming deep in the crust under pressure. As the rocks are brought to the surface by uplift and erosion, they expand and fracture.

Exfoliation



The main joint characteristics

- joint plane planarity or waviness,

- joint surface smoothness, and

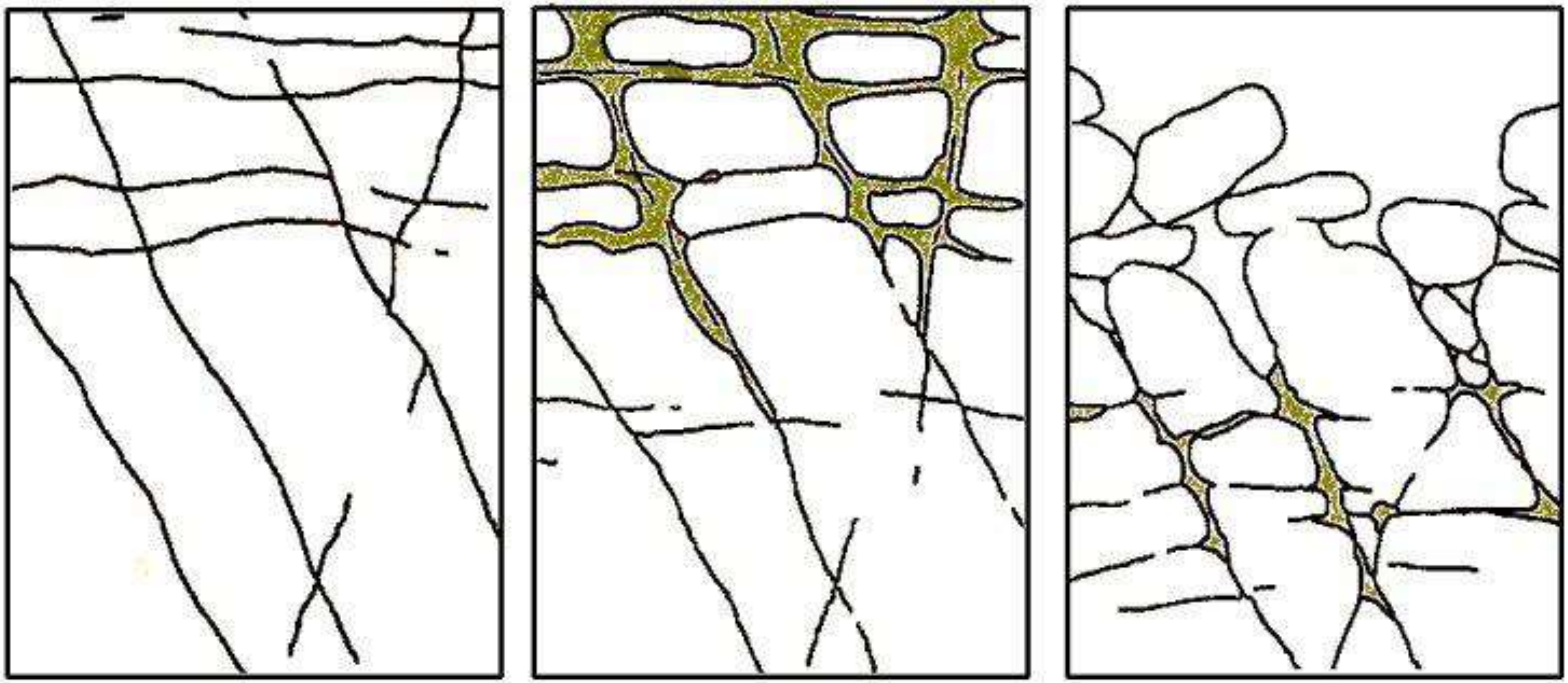
- condition (alteration) of the joint wall (whether it is weathered/altered or has coating or the joint has some sort of filling

- Joint size (length) and continuity

Joints can be measured and characterized in different ways, manly from:
field observations at terrain surface or in tunnel
drill core logging
seismic or sound velocities

1. Degree of jointing. This property can be measured as rock quality designation (RQD),
2. Orientation of joints and joint sets. This has special interest when the joint set is unfavourably orientated parallel or at a small angle to a tunnel or cavern. This feature is used as input to the RMR system

3. Pattern of joints



Criss crossing joints are formed by the cooling of the magma, compression, and the the relief of pressure.

The bedrock is weathered into soil along the joints during subhumid climate periods.

Erosion by wind and rain over the centuries has removed the loose soil and helps continue shaping the rocks.

<u>* الآثار الهندسية للفواصل و الشروخ :-</u>

١- تسبب حدوث تغير في الخواص الهندسية و الطبيعية للصخور .

٢- تعمل الفواصل كقنوات تجميع المياه السطحية أو الجوفية.

٣- تملأ الفواصل بمواد رسوبية ذات مقاومة ضعيفة .

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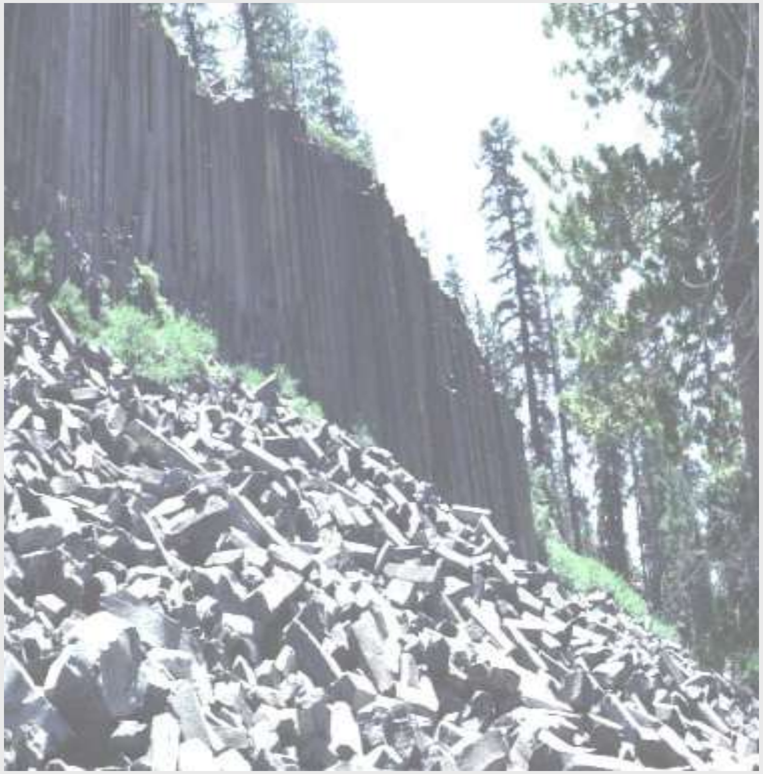


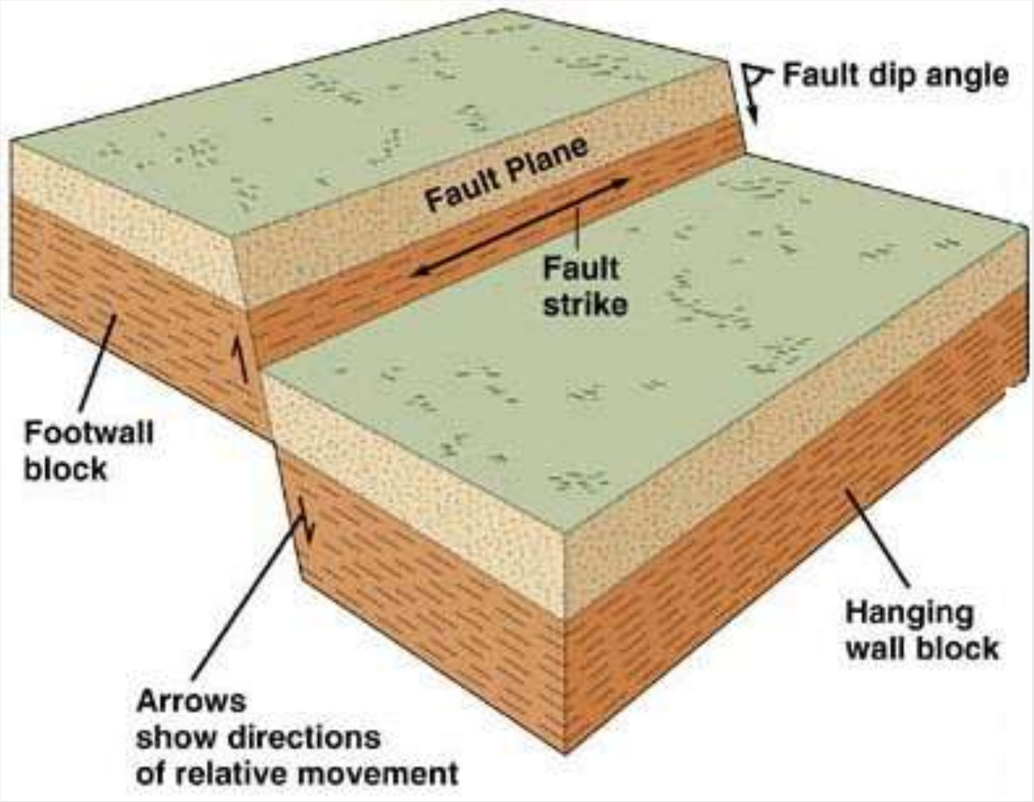
A fault

A fault is a fracture within some particular rocky mass within the earth's crust.

Not all faults penetrate to the surface, but those that do often show a fault scarp, a cliff or bluff formed by vertical movement along the fault plane

faults terminology

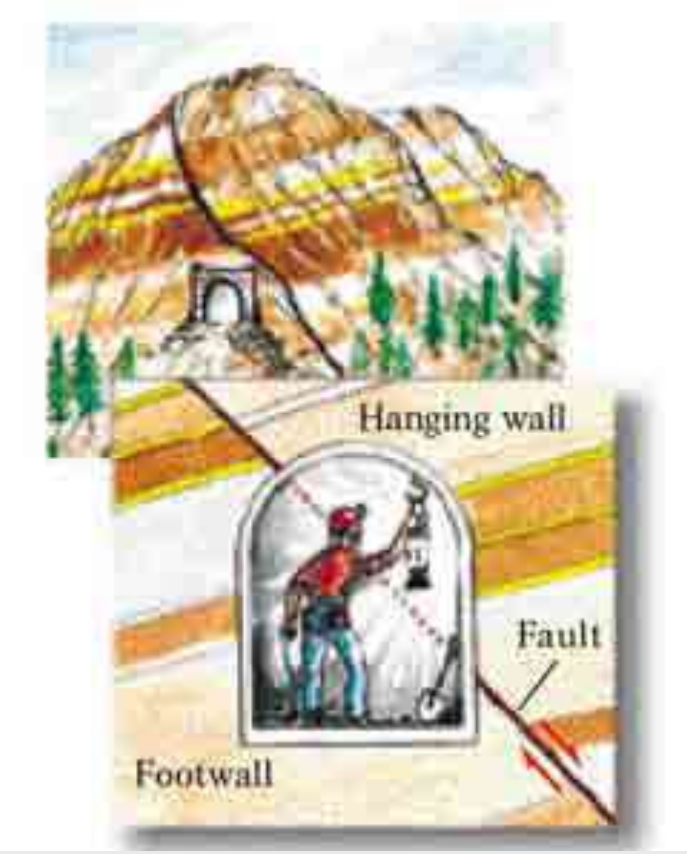
- **Fault plane (fault scarp)**
- **Hanging wall**
- **Footwall**

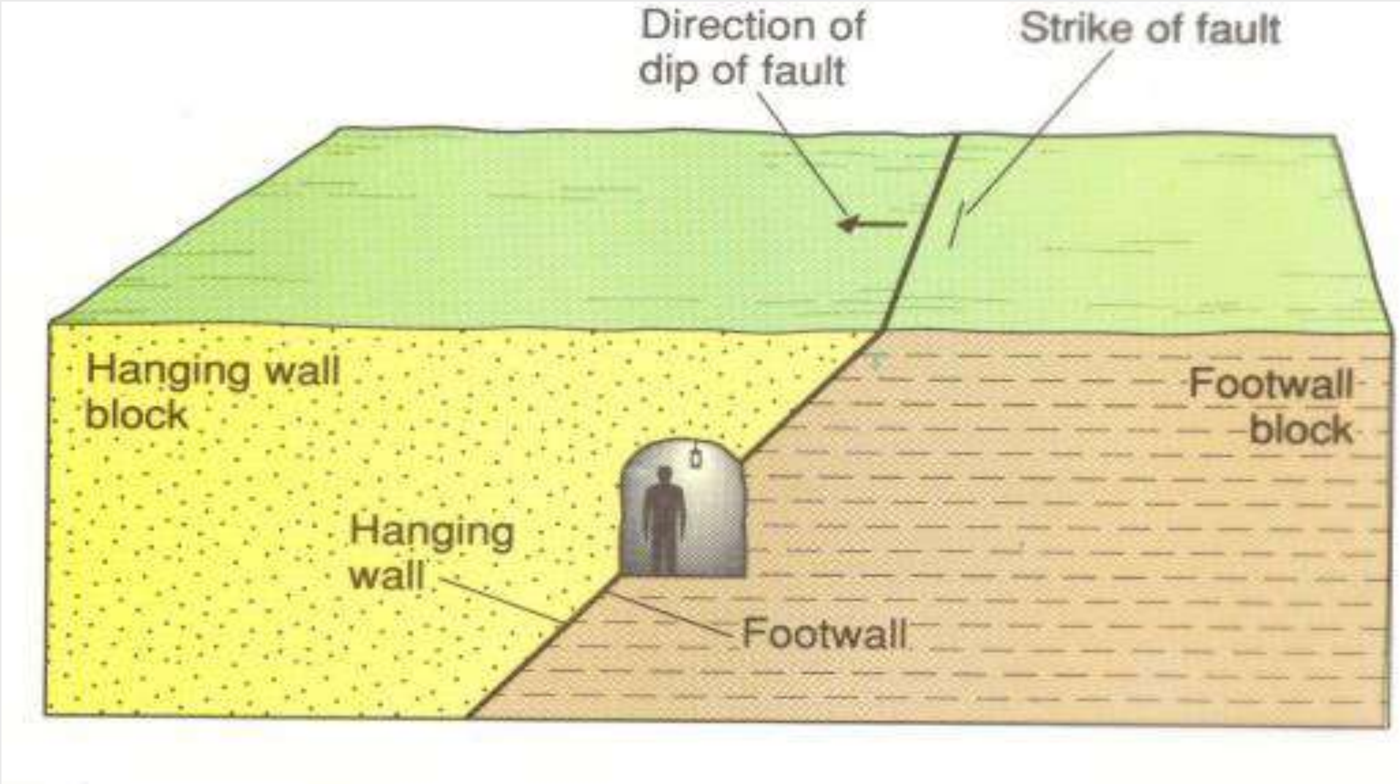


Fault plane: along which the rock or crustal material has fractured

Hanging wall block: rock material above the fault plane

Foot wall: rock material below the fault plane





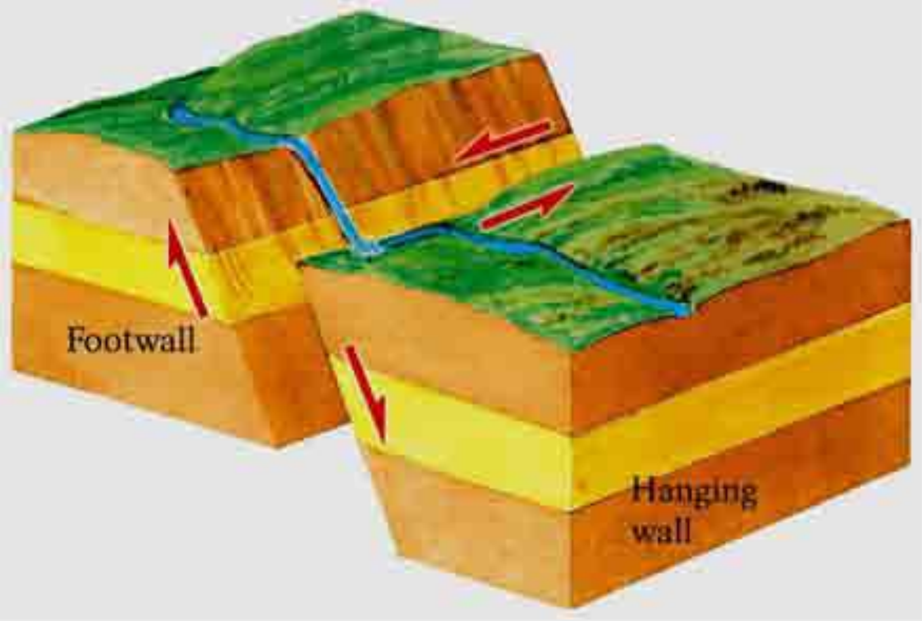
64 Hanging Wall, Footwall Relationship
Figure 15.24

Fault types

We can only think of the movement on faults in terms of relative movement

- **Normal or dip-slip faults**
- **Reverse faults**
- **Strike slip faults**
- **Oblique slip faults**

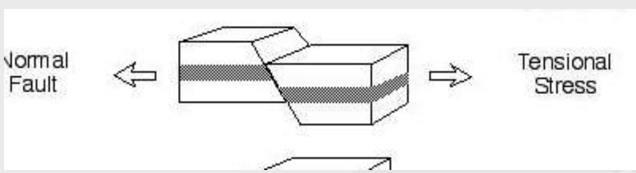
– some combination



Normal dip-slip faults

All movement on a dip-slip fault is parallel to the dip of the fault plane, that is, movement is up or down the fault plane.

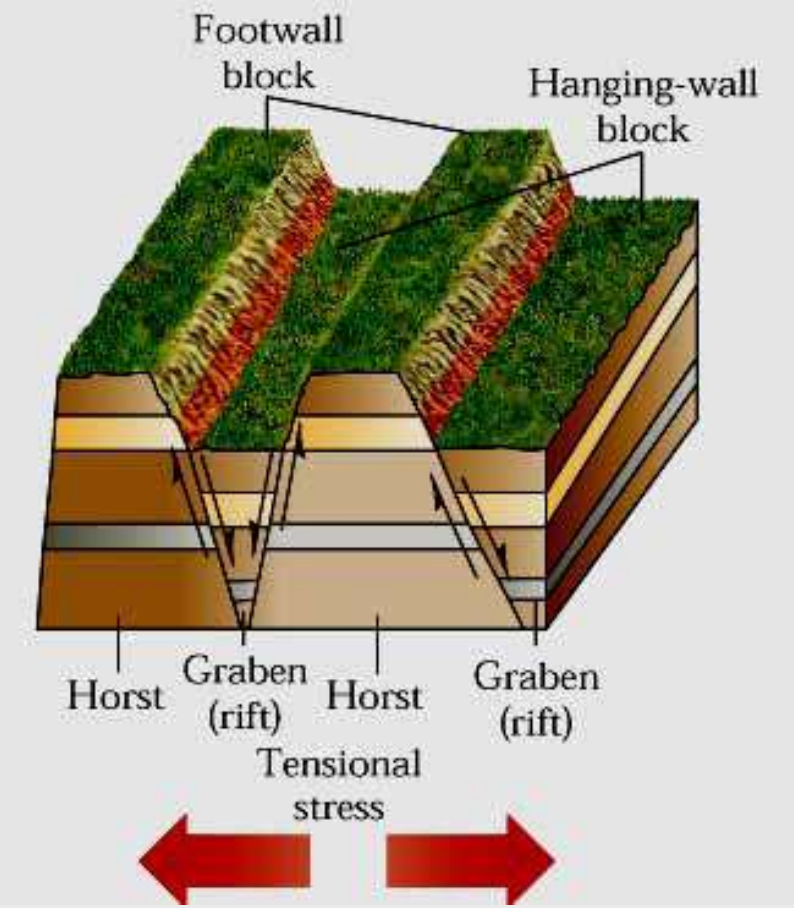
• In a normal fault, the hanging wall moves down the fault plane. Normal faults result from tensional stress



Horst & Graben structures

graben fault is produced when tensional stresses result in the subsidence of a block of rock.
On a large scale these features are known as Rift Valleys

A horst fault is the development of two reverse faults causing a block of rock to be pushed up



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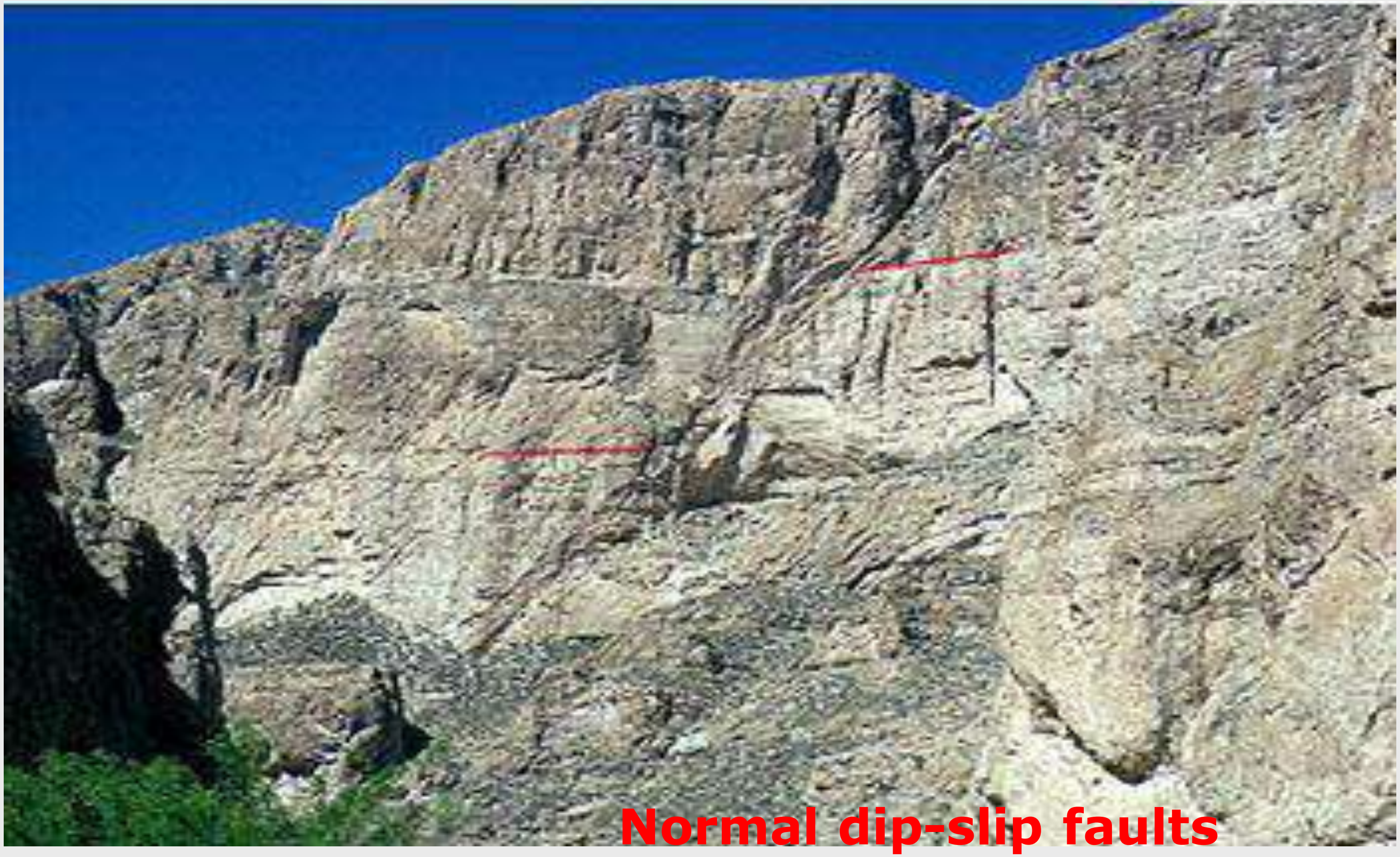
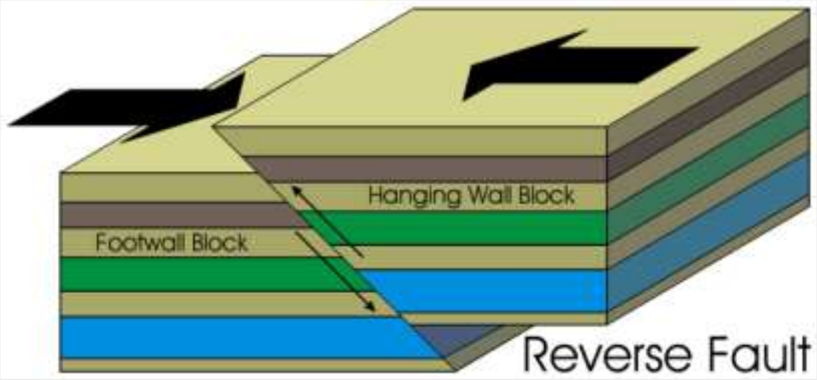


Reverse dip-slip faults

Reverse faults are dip-slip faults where the hanging wall has moved up the inclined fault plane. In reverse faults, the dip of the fault plane is >45° . Formed by compression stress



Reverse dip-slip faults

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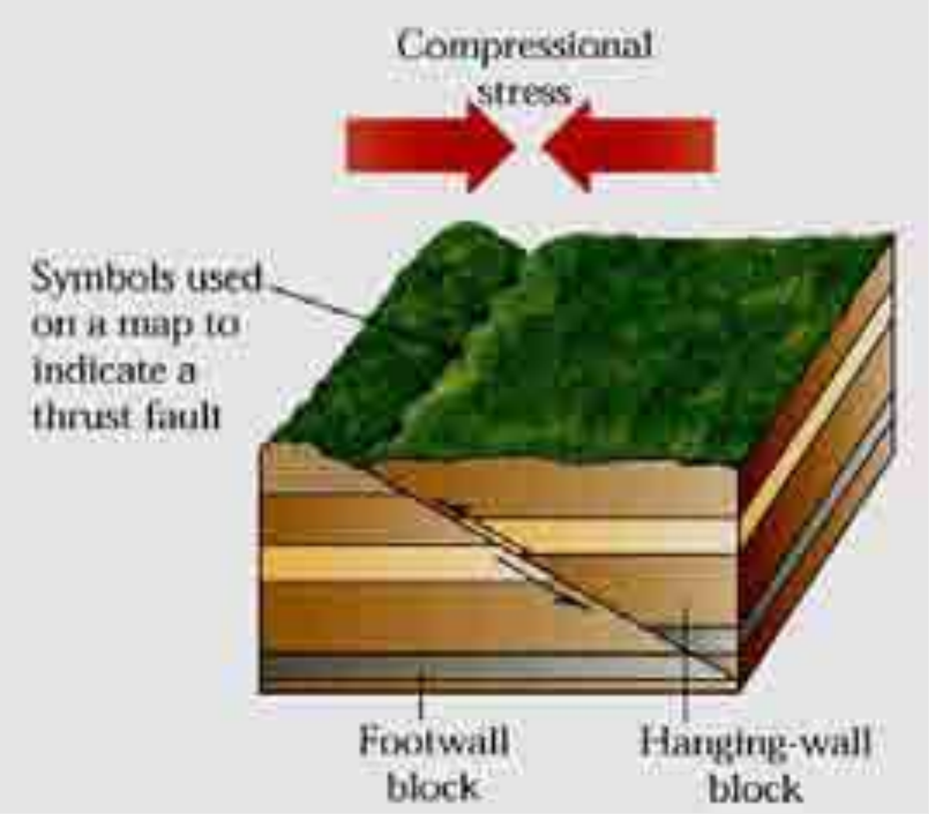
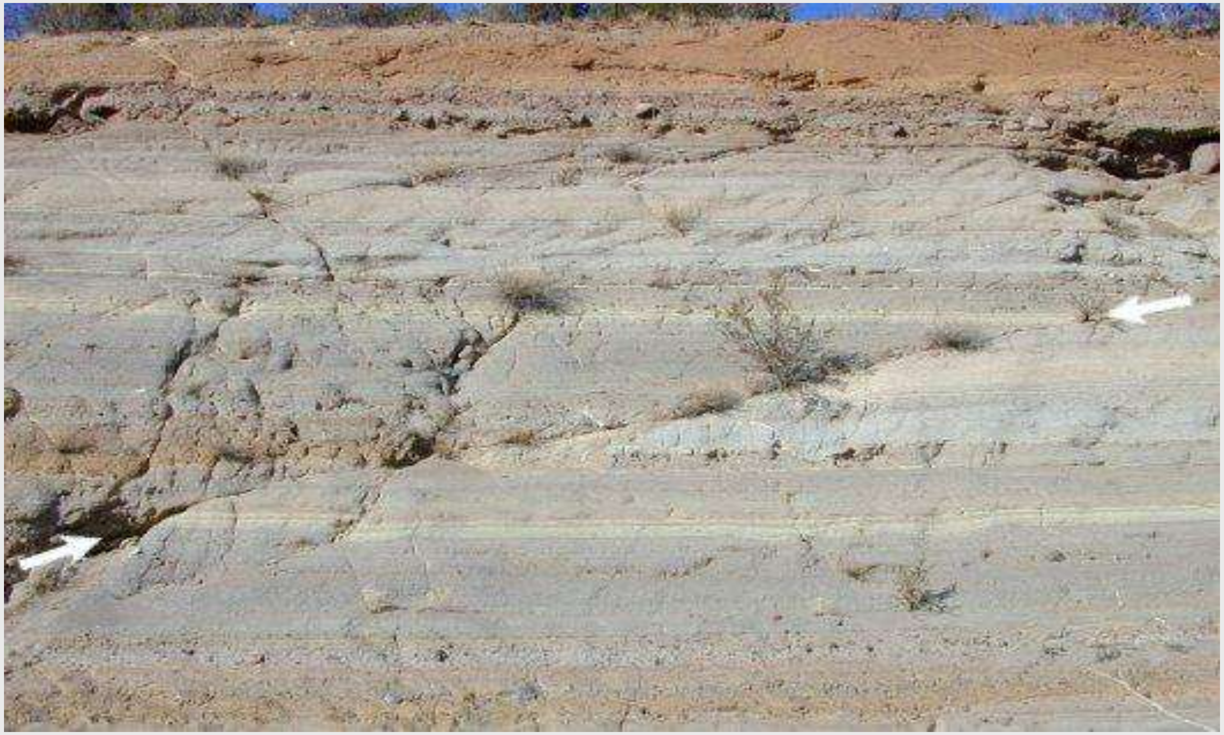
Reverse faults in shale layers, Trail to the Base of

Thrust faults

Reverse faults with fault plane dips of <45° are called thrust faults

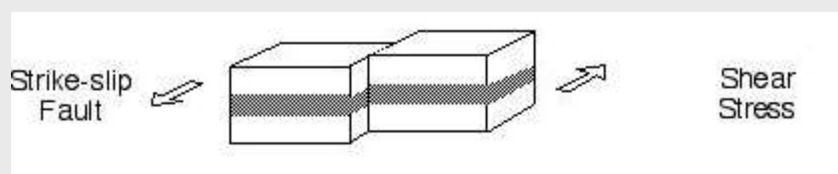


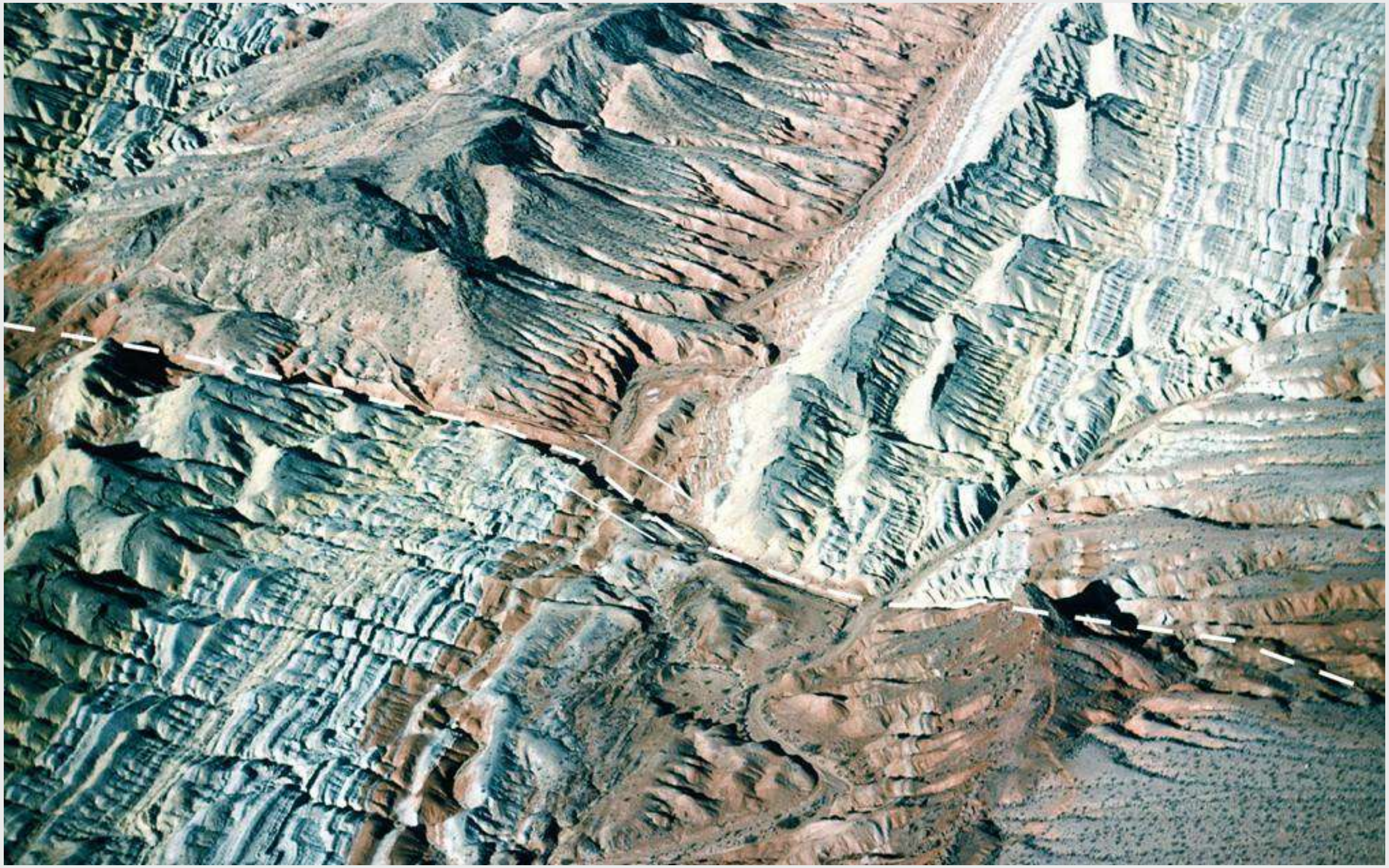


Thrust Fault : Fault plane is at less than 30 degrees Movement is more horizontal than vertical due to the low angle of the fault plane. Develop due to **compressional stress**

Strike-Slip Faults

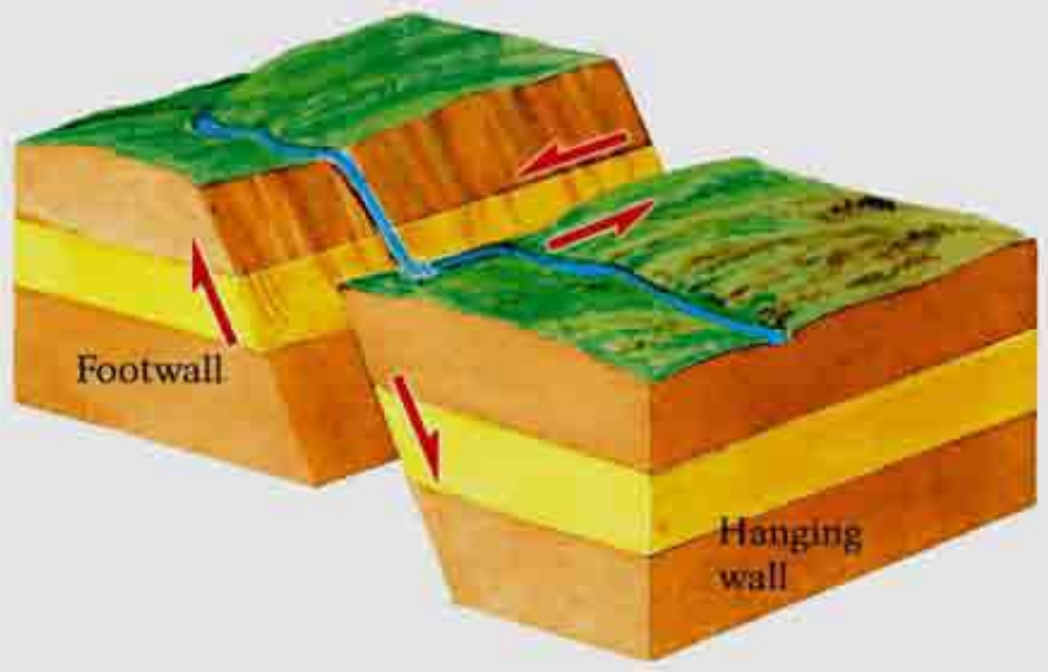
Strike-slip faults are caused by shearing forces, which cause blocks on either side of the fault plane to slide laterally past one another





Strike-Slip Faults

Oblique slip.



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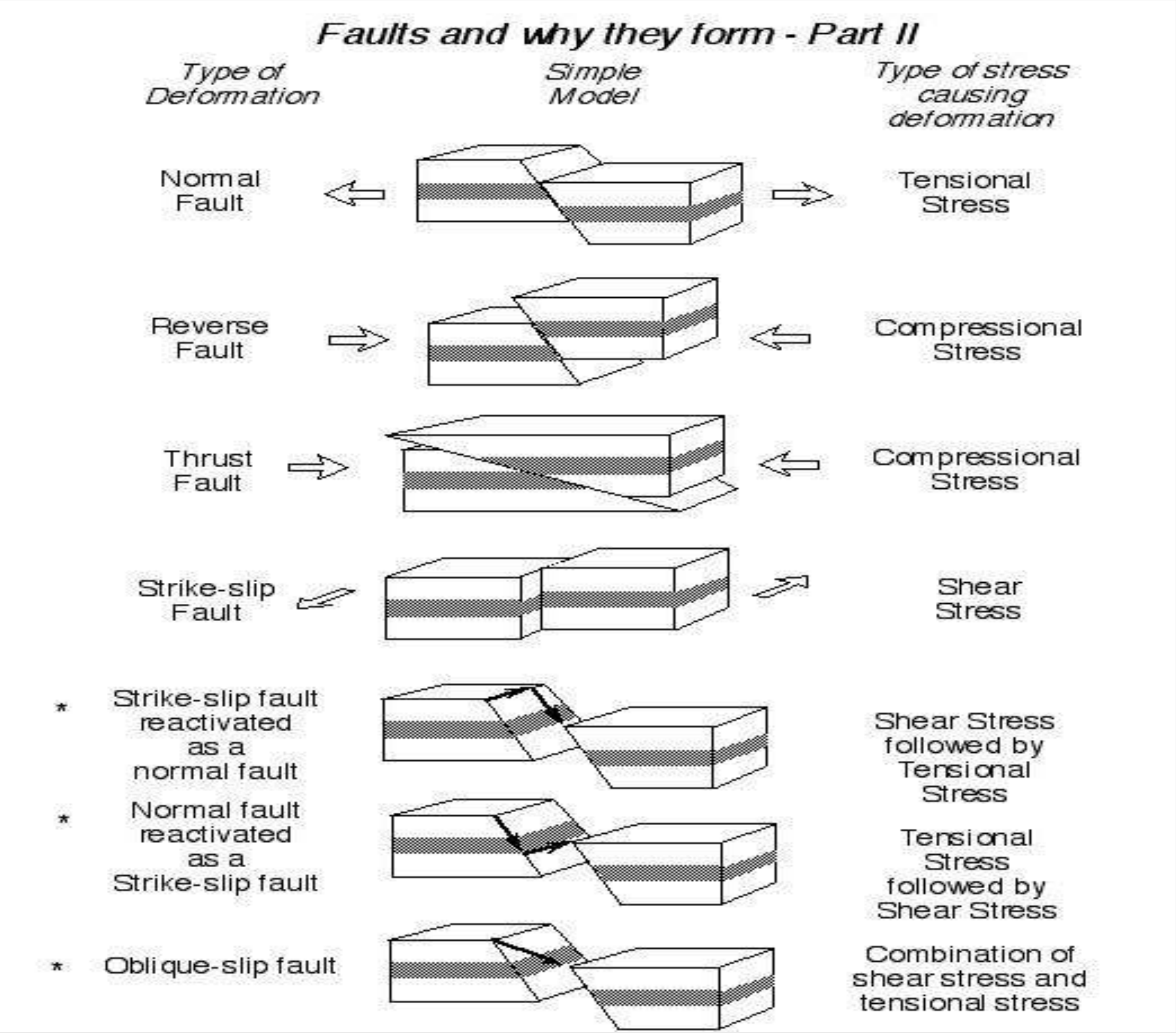
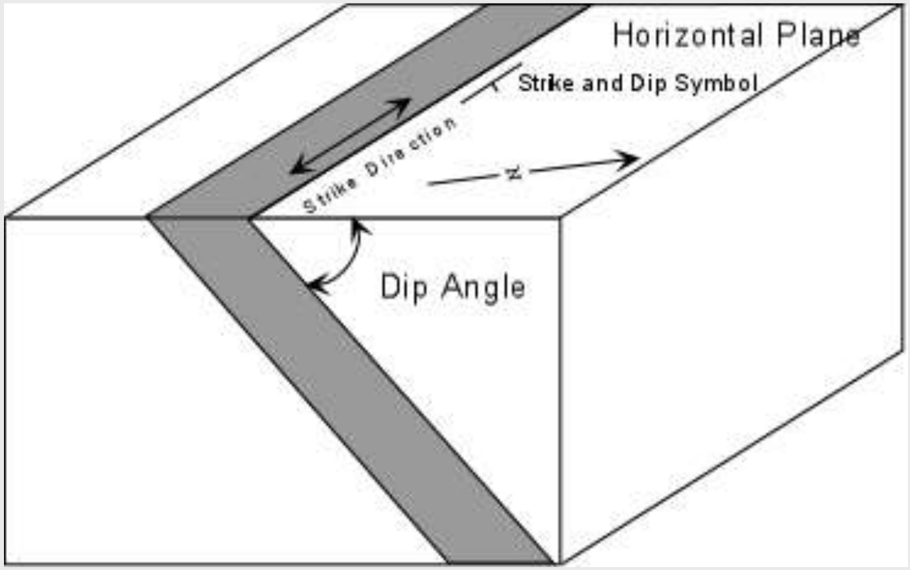

Faults and why they form - Part II
Type of Deformation
Simple Model
Type of stress causing deformation
Normal Fault
Tensional Stress
Reverse Fault
Compressional Stress
Thrust Fault
Compressional Stress
Strike-slip Fault
Shear Stress
* Strike-slip fault reactivated as a normal fault
Shear Stress followed by Tensional Stress
* Normal fault reactivated as a Strike-slip fault
Tensional Stress followed by Shear Stress
* Oblique-slip fault
Combination of shear stress and tensional stress

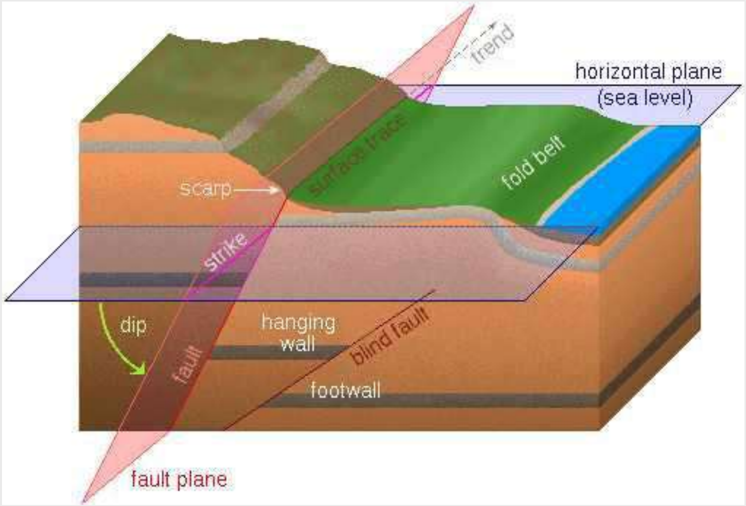
Define the orientation of a planar feature

define two terms - strike and dip.

strike is the compass direction of any horizontal line on the plane.

dip is the angle between a horizontal plane and the inclined plane, measured perpendicular to the direction of strike.





90˚ dip = vertical fault plane

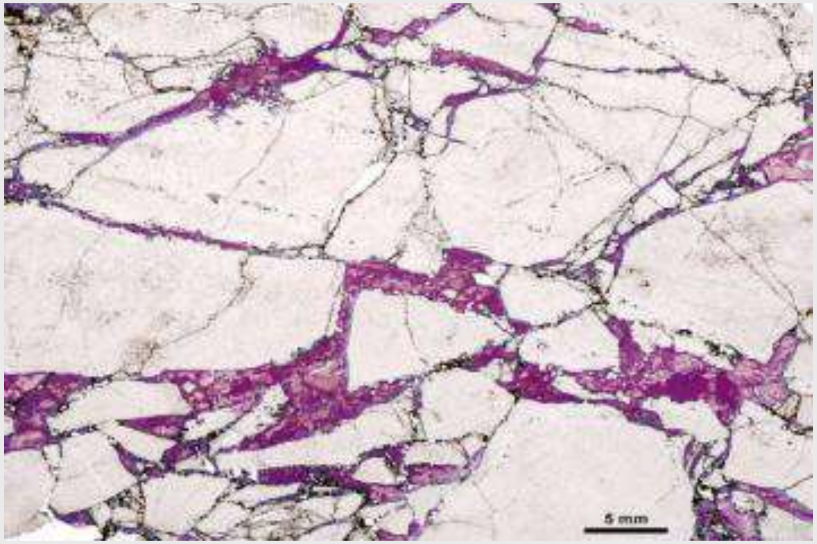
0˚ strike = North parallel fault plane

Importance of Geologic Structures in Civil Engineering Operations Geologic structures are an evidence of deformation in the rocks formations. Whether they , they are weak zones to be investigated and the appropriate treatment to be resorted to during the construction in a project.

- The formations are to be reinforced in terms of their strength.
- It is essential to prevent seepage in rock masses with discontinuities or planes of weakness through appropriate ground modification techniques in construction of dams, reservoirs and tunnels

Effect of faults on structures

1-A fault breccia: a rock broken up by fracture close to a moving fault.
Accumulate on the plane of the fault and cemented.
Weak materials causing failures to structures



2. Fault under bridge foundation; will cause settlement of the foundation and therefore the project should be re-planed and select place away from the fault

3.Fault under a concrete dam

is important to check the dip angle of the fault and the resultant force

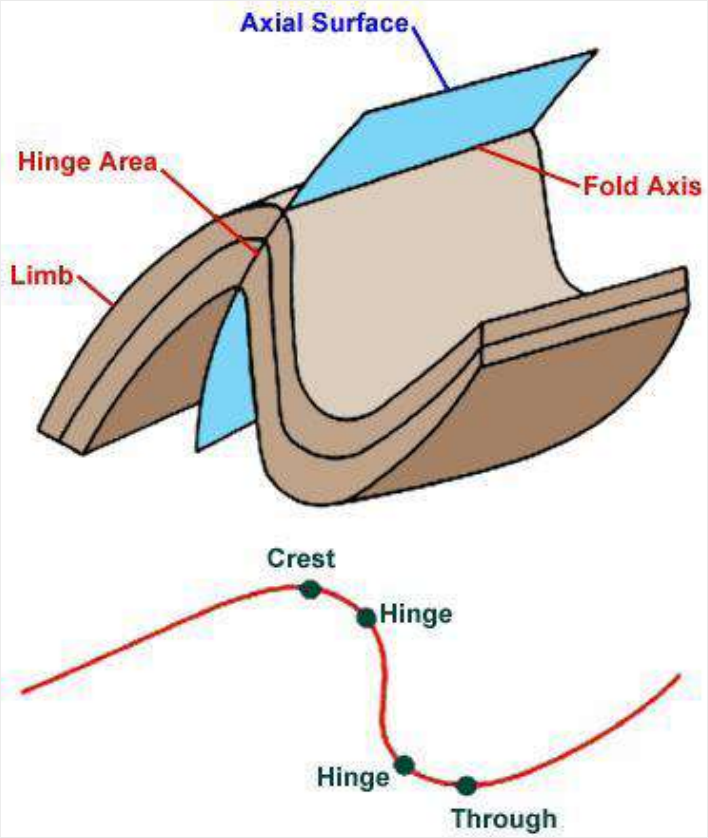
Resultant direction same as fault
Dangerous condition on the structure

Resultant direction not in the same direction as fault Not Dangerous and the structure is safe

Folds

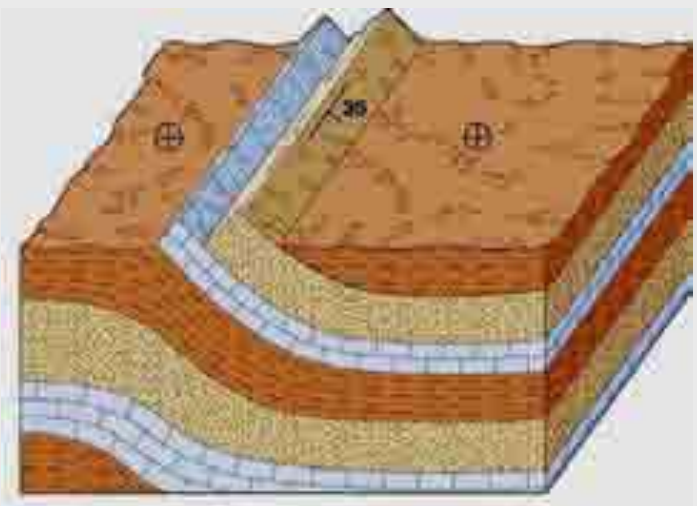
When rocks deform in a ductile manner they bend and flow to form folds

- **They range in scale from mm to km**
- **There are three basic fold types**
- **Monoclines**
- **Synclines**
- **Anticlines**


Axial Surface
Hinge Area
Fold Axis
Limb
Crest
Hinge
Hinge
Through

Monoclines

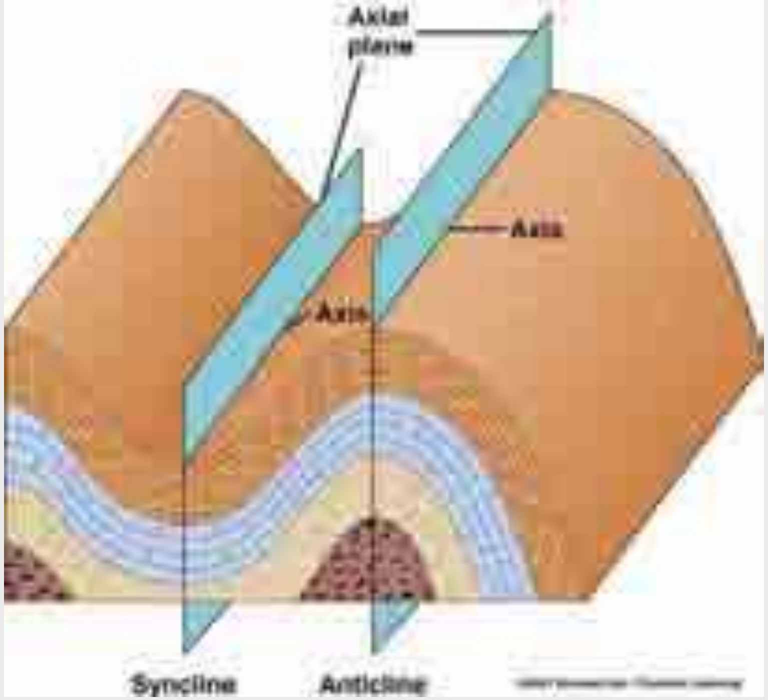
Monoclines are simple bends or flexures in otherwise horizontal or uniformly dipping layers. Monoclines often drape deep fractures in the rock along which vertical movement has occurred (special kind of fold with only one limb)



Engineering Geology

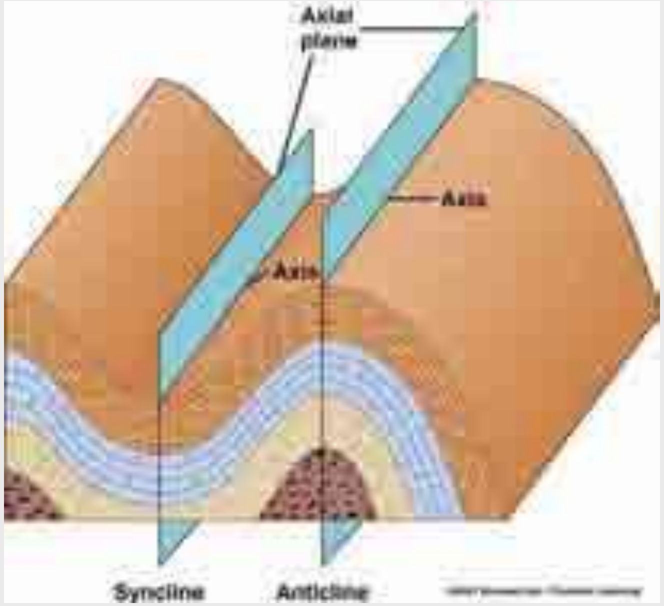
Anticlines

Anticlines are arched or convex-upward folds with the oldest rocks in the core of the fold. (is a fold arching upward),

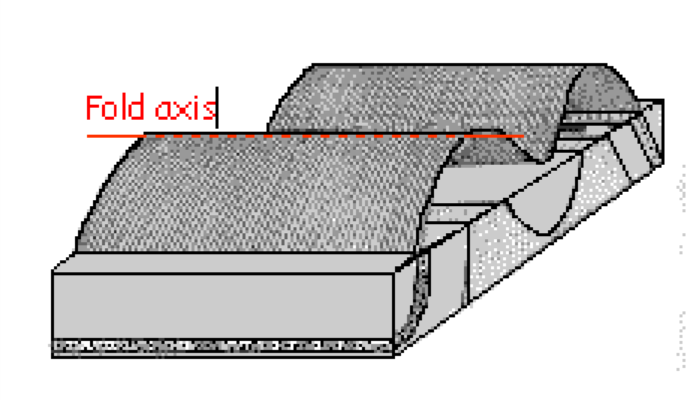


Synclines

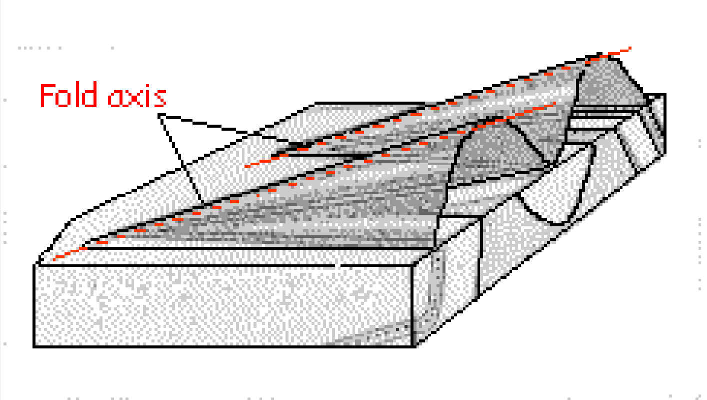
Synclines are trough-like or concave downward folds with the youngest rocks in the core of the fold.(a fold arching downward.)



The sides of these folds are called limbs. Where the two limbs meet is called the axis



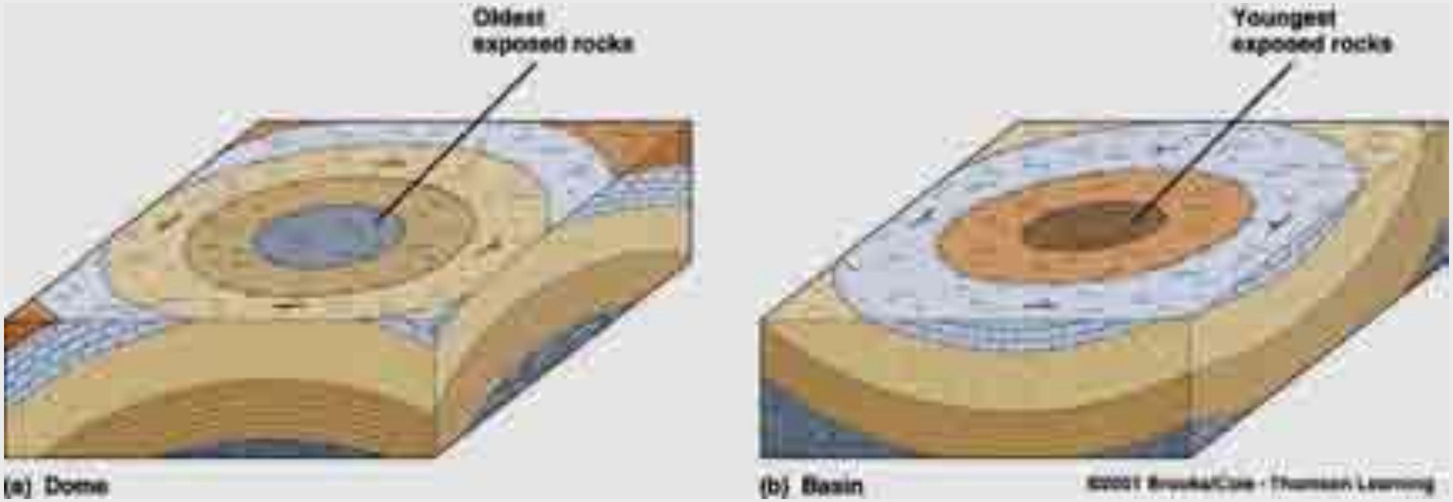
A non-plunging fold is a fold where the axis does not tilt at an angle.

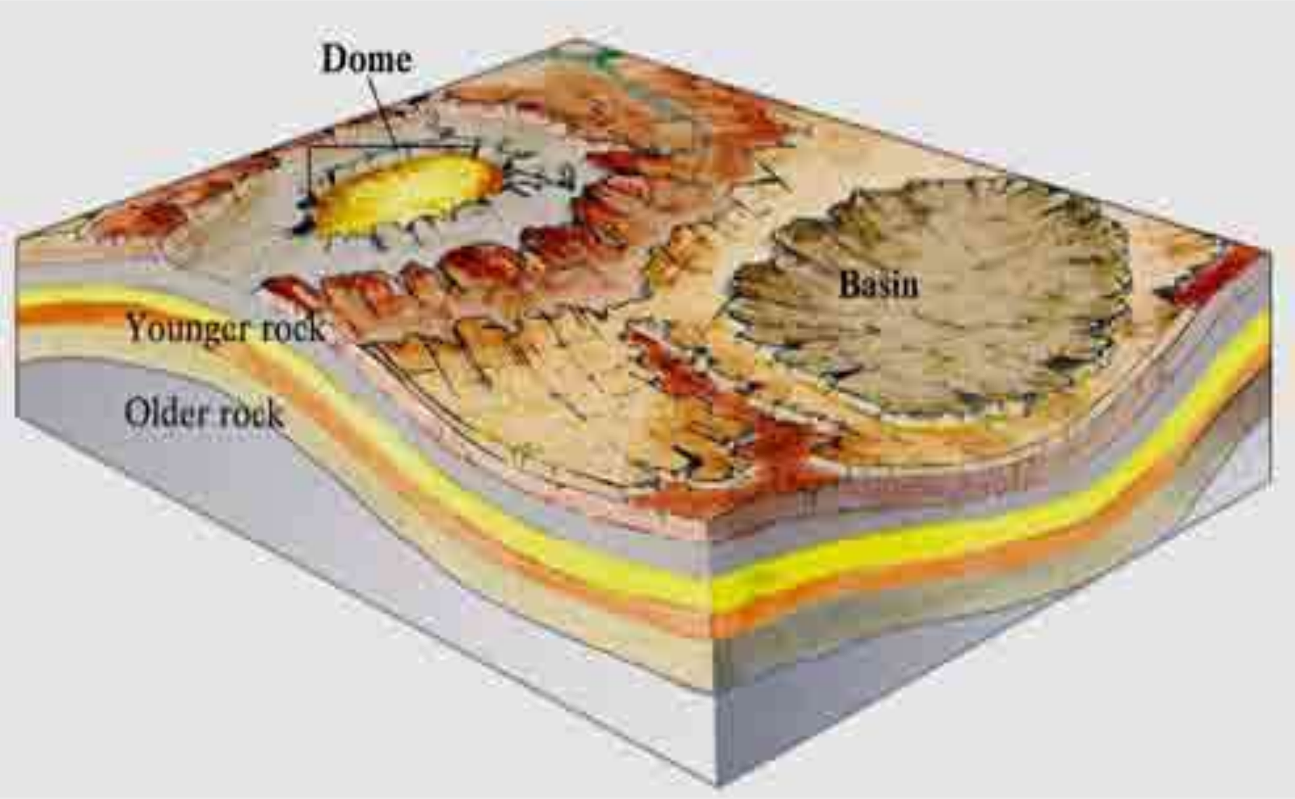


A plunging fold is a fold where the axis tilts at an angle.

Domes and Basins

Domes and basins are circular- to oval-shaped folds.
• In eroded domes, the oldest rocks lie at the middle of a bull's eye map pattern and all layers dip away from the center.
• In basins the youngest rocks lie at the middle of a bull's eye map pattern and all layers dip toward the center.




Dome
Basin
Younger rock
Older rock

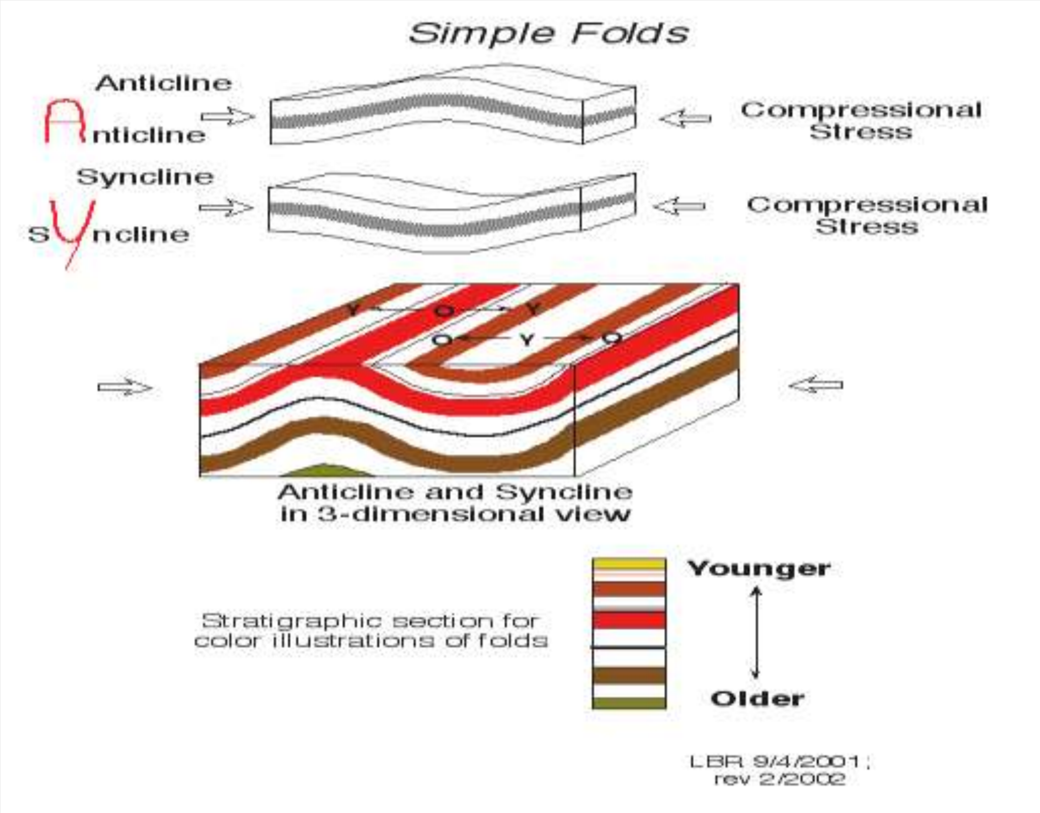
Engineering Geology

Why folds are important to be studied by engineers?

1-At the upper surface of an anticline folds there will be tensile stresses causing cracks in rocks or layers.

The changes of the stresses in rocks may change its behavior under load

2-The syncline folds can collect water and so changing its behavior



Mountains

Mountains Any area of land that stands significantly higher than the surrounding country. Mountain ranges are linear associations of peaks and ridges that are related in age and origin. Mountain systems consist of several mountain ranges and represent linear zones of intense deformation and crustal thickening. **Types of Mountains. Mountains can be produced in several different ways**:

- **Volcanic Mountains** - Produced by hot spot activity. May be isolated or in a chain.
- **Mountains Formed by Igneous Intrusions** - Intrusion of batholith causes uplift and erosion. Pluton forms small mountains.
- **Block-Fault Mountains** - Produced by normal faulting in areas subjected to tensional stress. Horst and graben blocks are produced. Horst blocks form mountains.
- **Mountains formed by compression at convergent plate margins**
- **Mountains formed by accretion of micro plates**

Unconformity

An **unconformity is a contact between two rock units in which the upper unit is usually much younger than the lower unit. Unconformities are typically buried erosional surfaces that can represent a break in the geologic record of hundreds of millions of years or more**

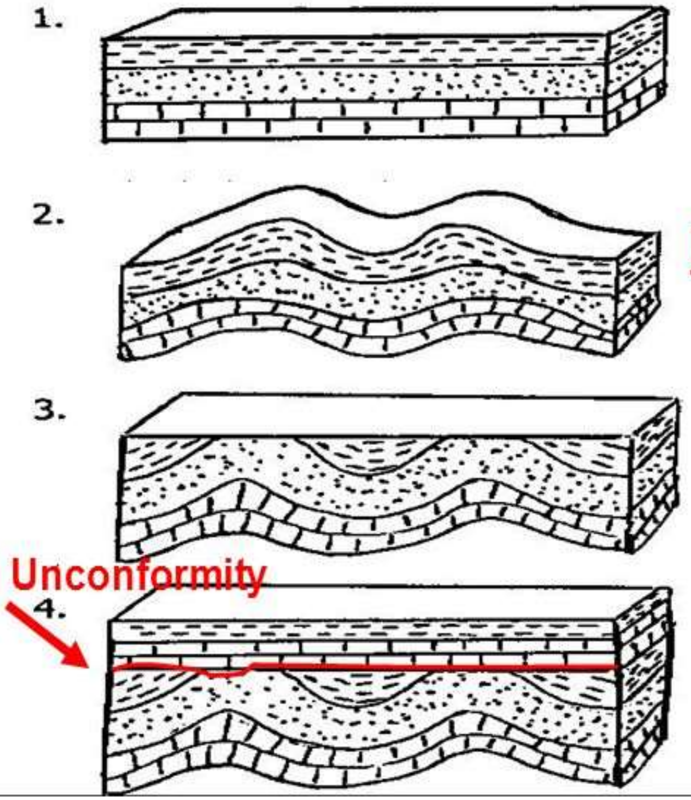
- Unconformities represent a break (missing time/period) in rock record
- Three types of unconformity
  - Dis-conformity
  - Angular unconformity
  - Non-conformity

Unconformity

- An erosional surface might become buried by the deposition of younger rocks.
- This buried erosional surface results in a gap in the rock record.

E. Unconformity- A buried erosional surface separating two rock layers of different ages that show that sediment deposition was not continuous.

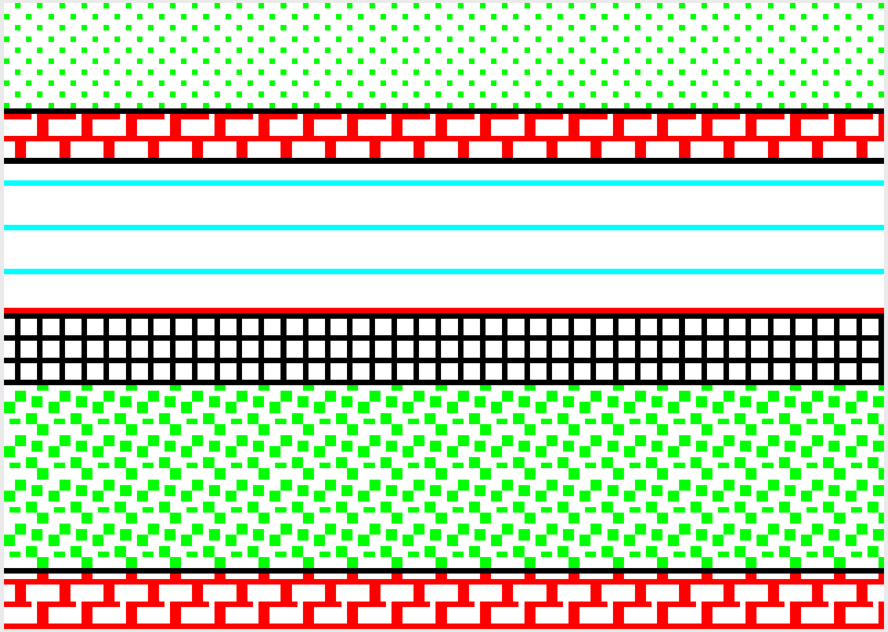
Formation of an Unconformity:



1. **Deposition- formation of horizontal rock layers**
2. **<u>Uplifting/ folding</u>**
3. **Erosion of surface layers**
4. **<u>Subsidence</u>- sinking down of earth's layers followed by deposition of new sedimentary layers**

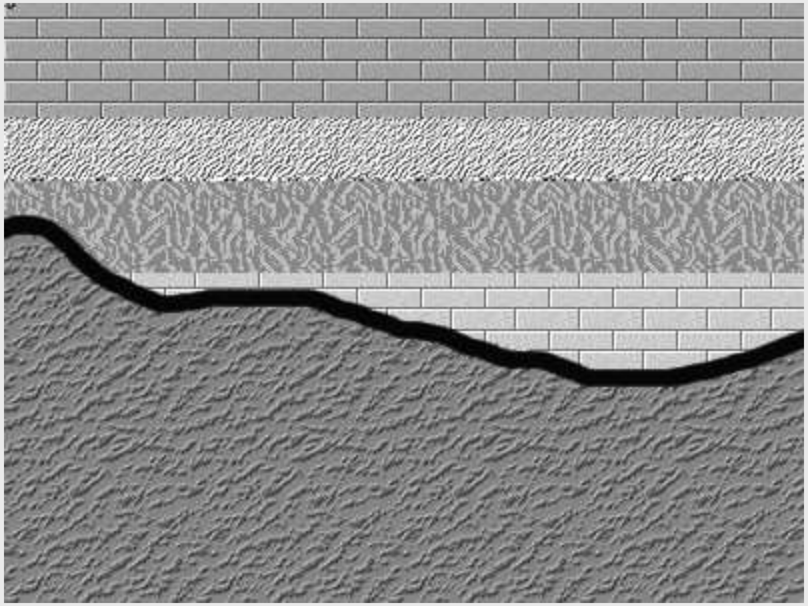
1-Conformity(para conformity)

Bedding and contacts parallel. No physical evidence for erosion or deformation. The beds were probably laid down during deposition followed by intervals when nothing happened -- no sign of disturbance, uplift, or erosion

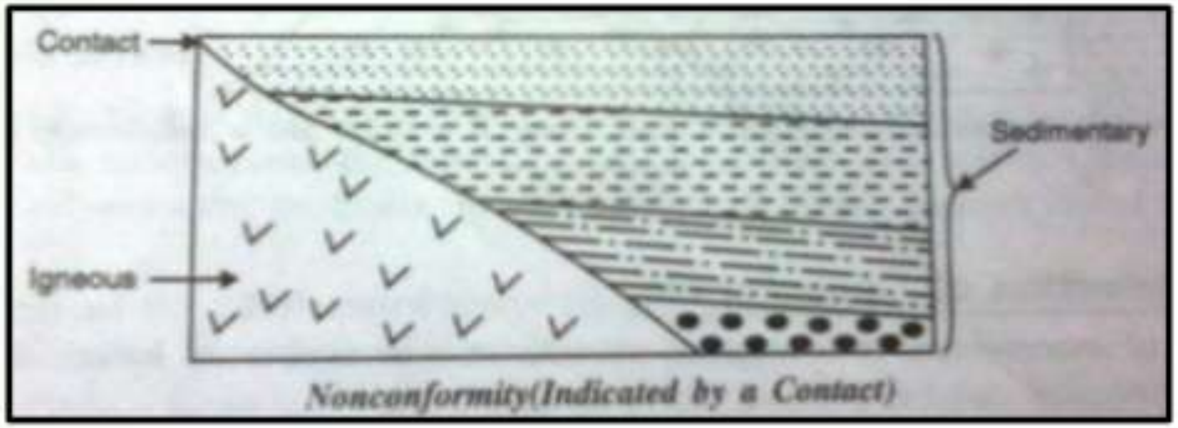


2-Nonconformity

: exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above the pre-existing and eroded metamorphic or igneous rock.



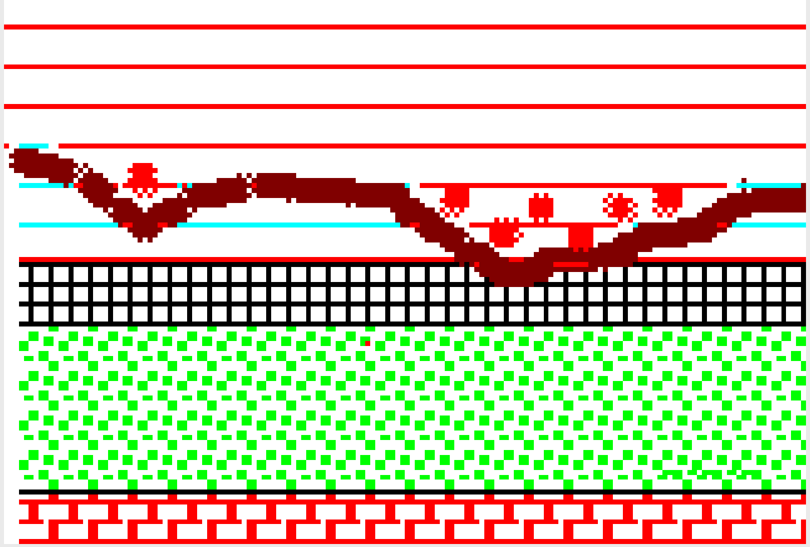
Non-conformity: it is the term used for unconformity in the sequence of the rocks composed of plutonic igneous or metamorphic rocks as older and sedimentary rocks as younger or newer.

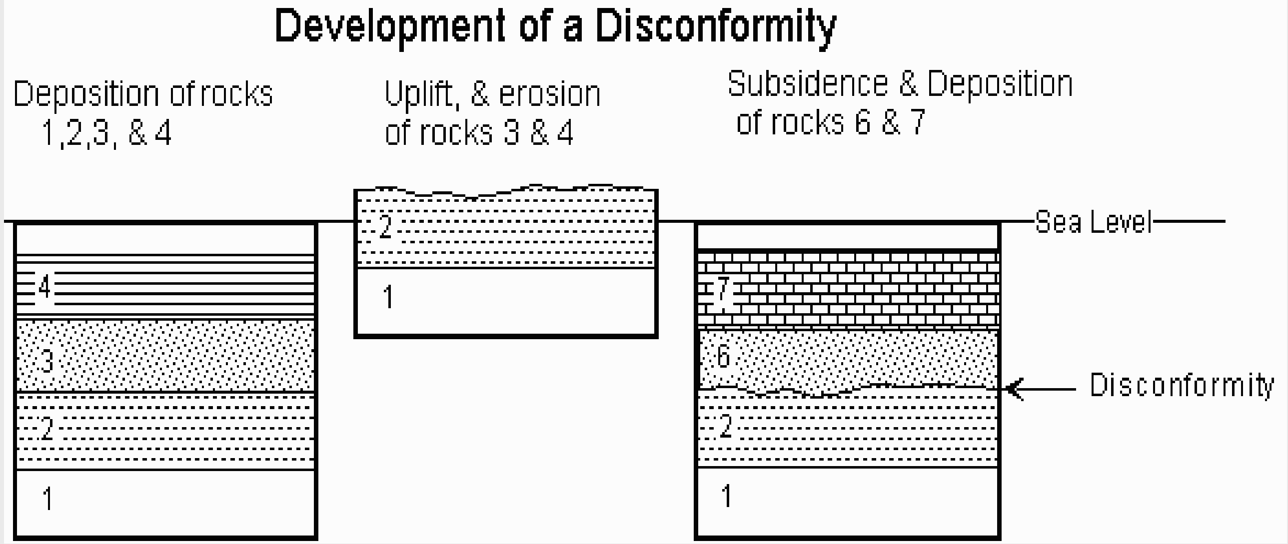


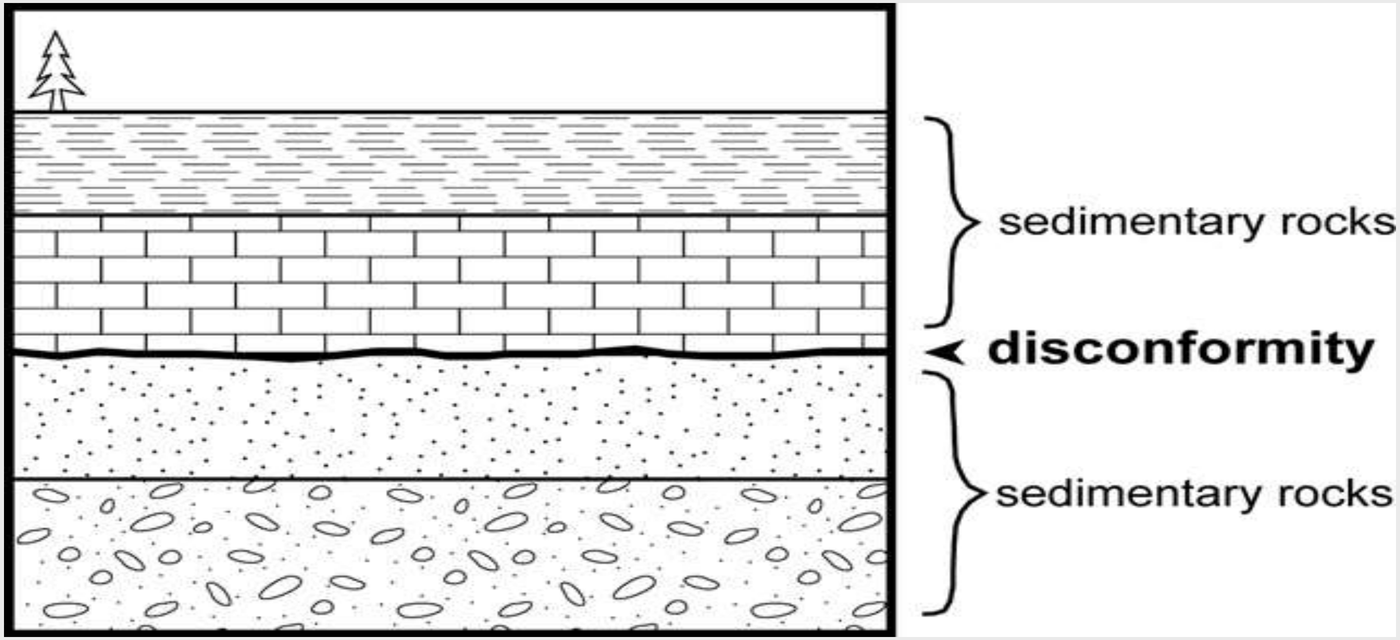
Nonconformity

3-Disconformities

Bedding is parallel on both sides of the contact but evidence shows a break (erosion, uplift) has occurred. In this sketch the break is evident in the erosional relief at the contact and by the clasts of older rocks in the younger strata. In some cases the surface is flat and there are no clasts but there could be subtle signs that weathering has occurred. Some passage of time is needed for the uplift and erosion. Additional time may be represented by any rocks that were once present but removed by the erosion.

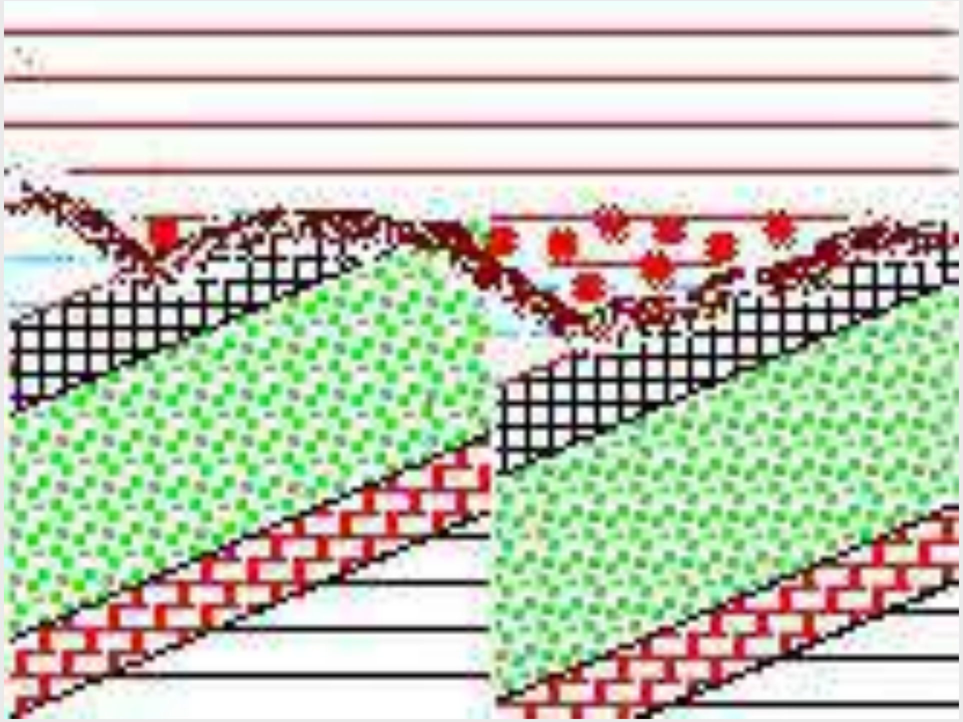



Development of a Disconformity
Deposition of rocks
1,2,3, & 4
Uplift, & erosion
of rocks 3 & 4
Subsidence & Deposition
of rocks 6 & 7
Sea Level
Disconformity
4
3
2
1
2
1
7
6
2
1


sedimentary rocks
disconformity
sedimentary rocks

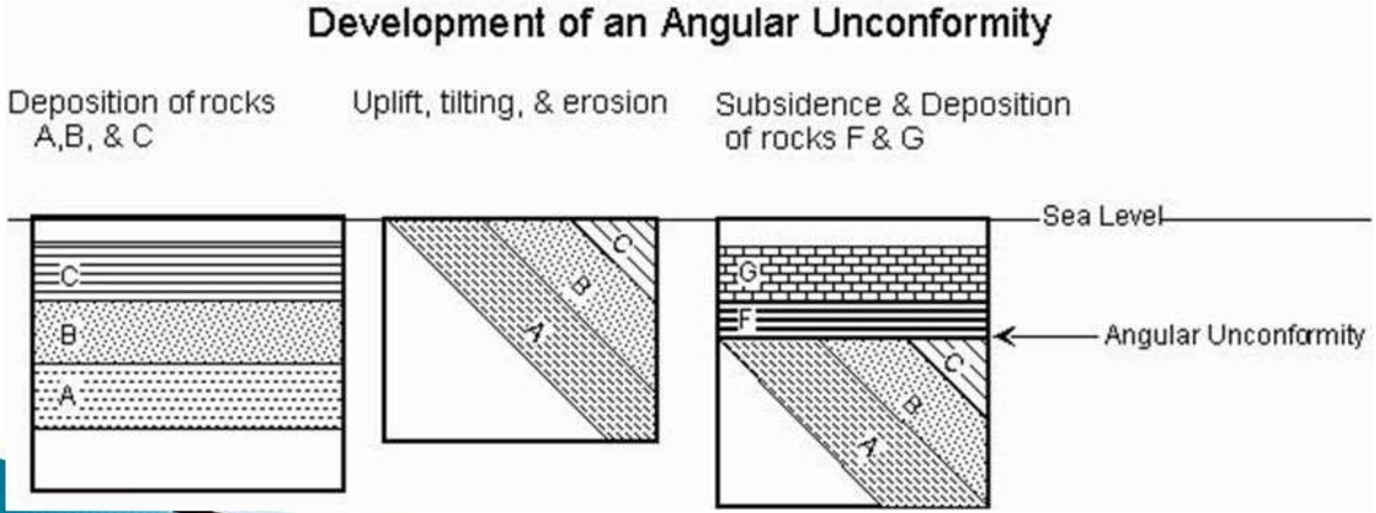
4-Angular unconformity

Bedding below the contact is NOT parallel to bedding above the contact. This indicates that deformation of the older beds occurred before the upper beds were deposited. In this sketch the deformation consists of tilting and faulting. Either could occur by itself or the beds could be folded..

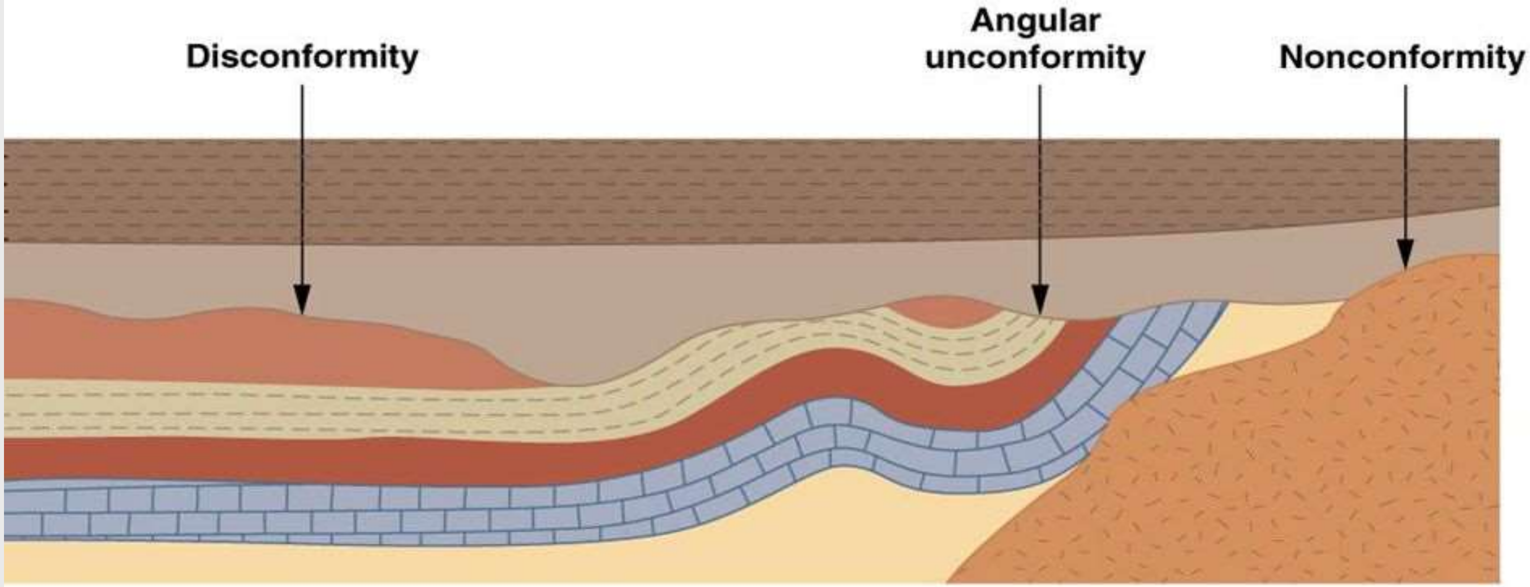


1) Angular Disconformity

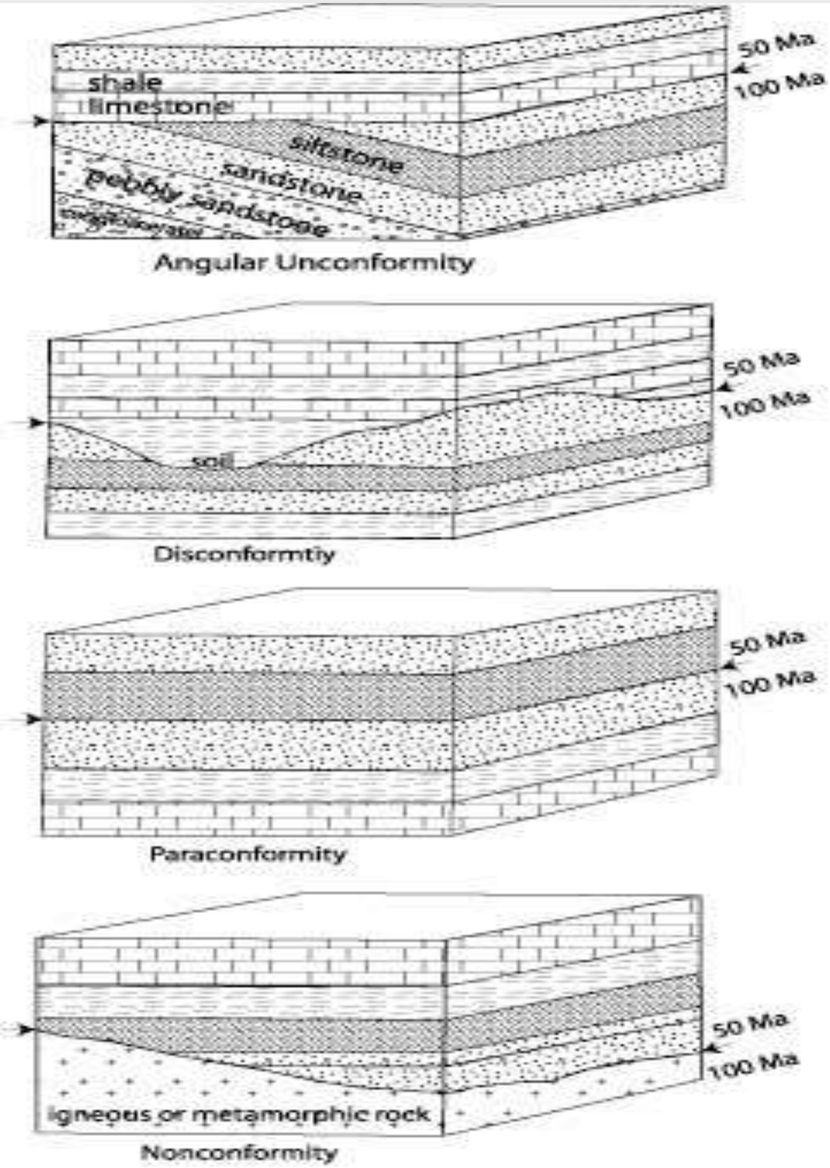
- **Angular Disconformity -** This is an unconformity between strata that are not parallel with one another. Usually when one set is folded or tilted and the above layers are not.



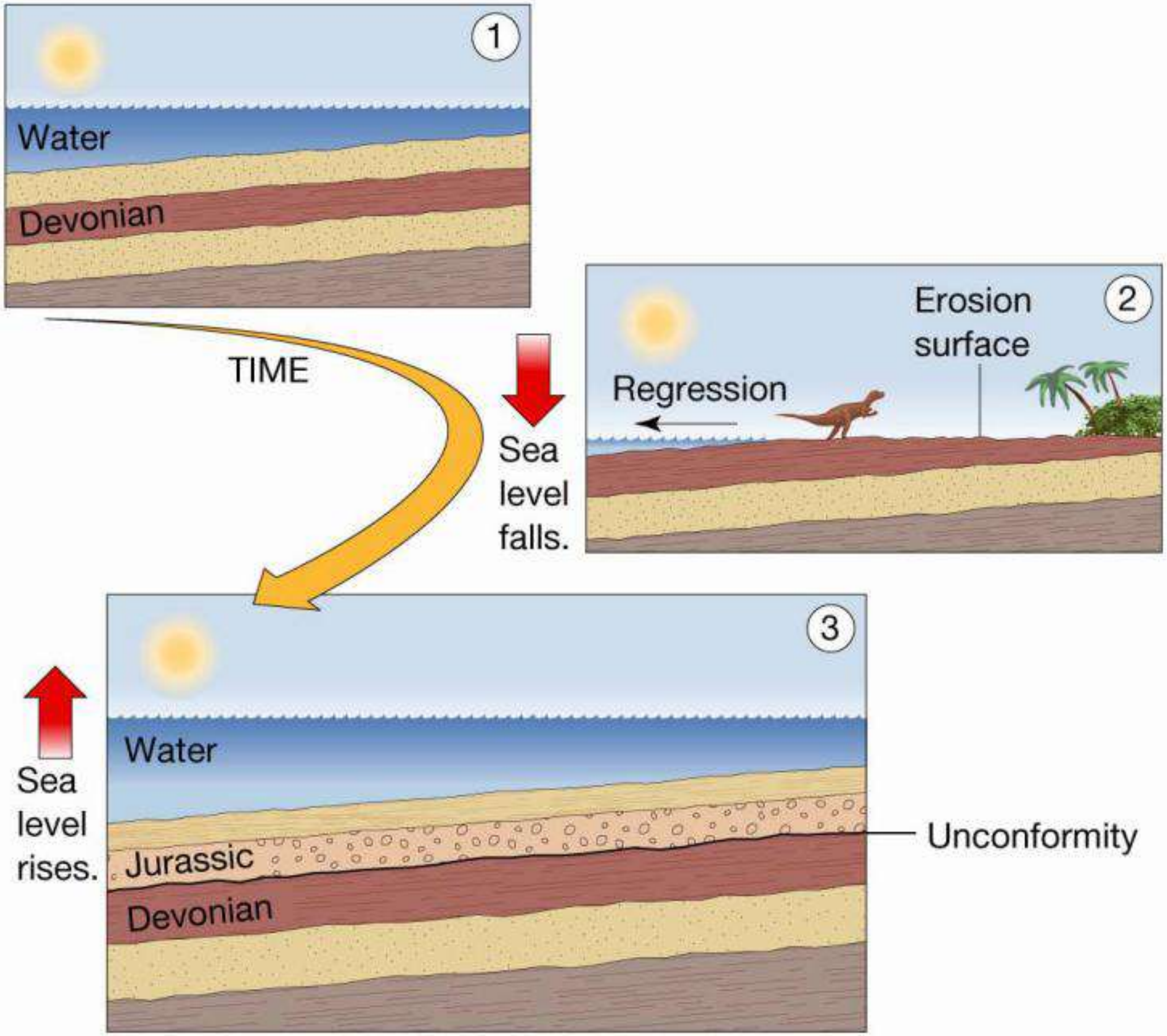
Types of Unconformities



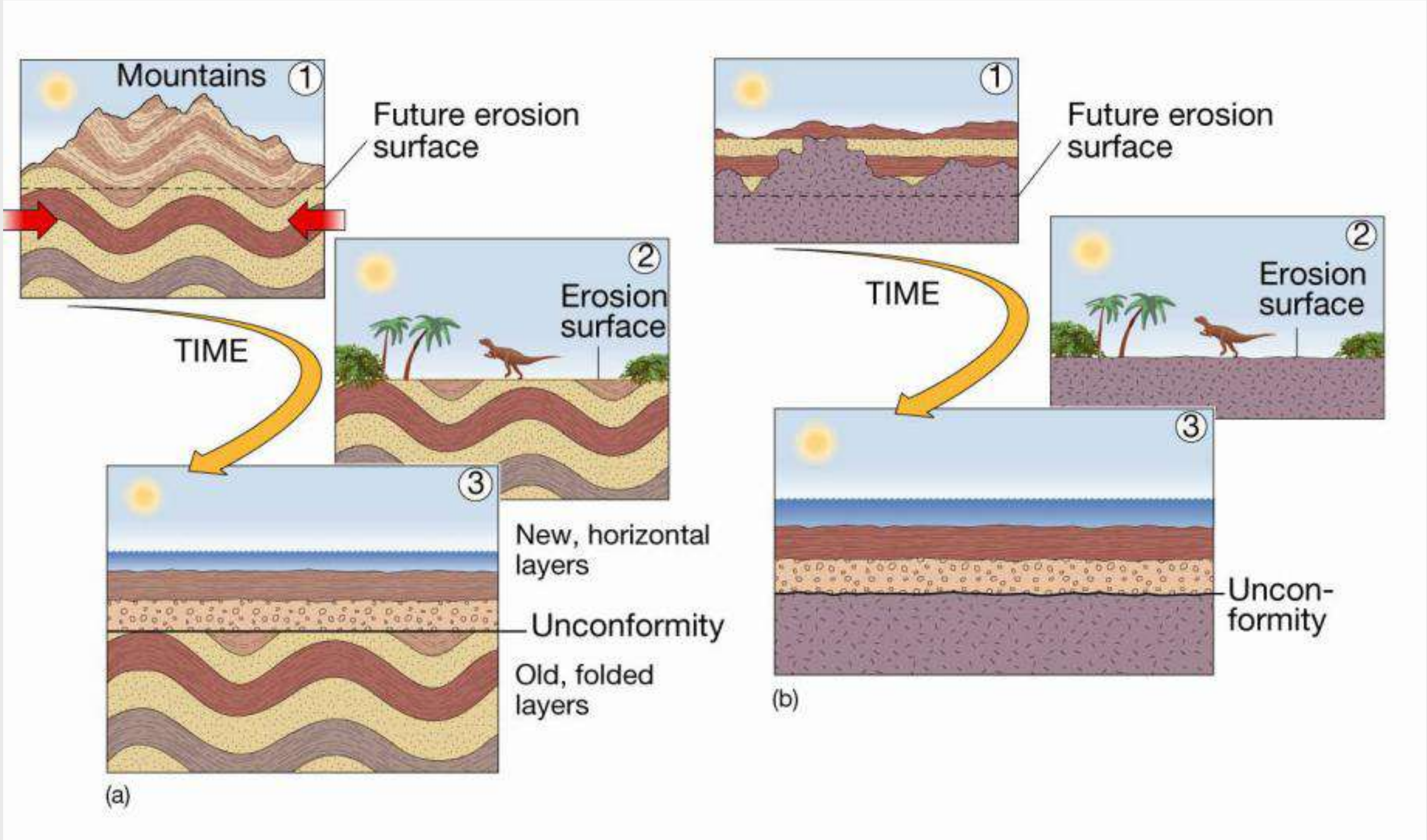
- Unconformities of regional extent may change from one type to another
- They may not represent the same amount of geologic time everywhere



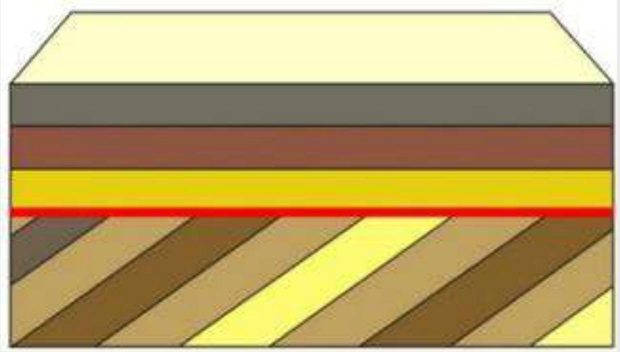
Unconformities (redrawn from Boggs, 2001)


1
Water
Devonian
TIME
Sea
level
falls.
2
Erosion
surface
Regression
3
Sea
level
rises.
Water
Jurassic
Devonian
Unconformity

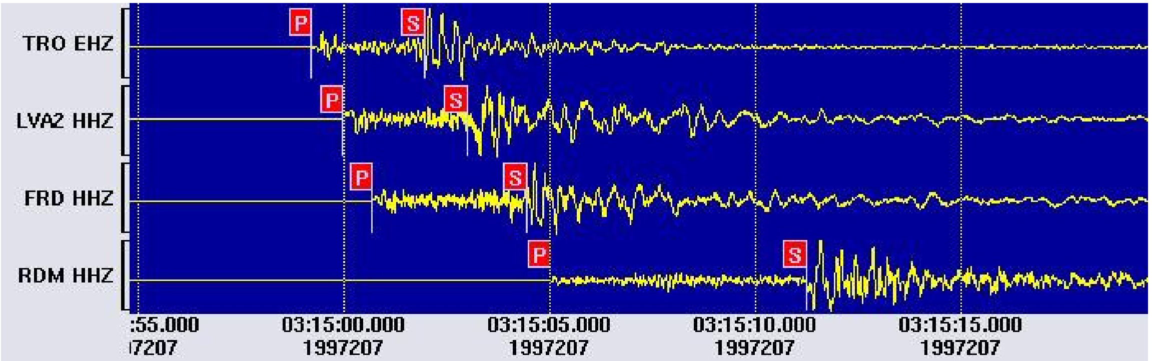
Formation of angular unconformity and nonconformity



Angular unconformity



Earthquake



- Hussien aldeeky

Definition

An earthquake is the vibration of Earth produced by the rapid release of energy.

Can cause catastrophic destruction to humans and our civilizations.

Damage in San Francisco's Marina District following the 1989 Loma Prieta Earthquake

Earthquake Engineering: Studies of the effects of earthquakes on people and their environment, with methods of reducing these effects.

Earthquake Engineering involves:

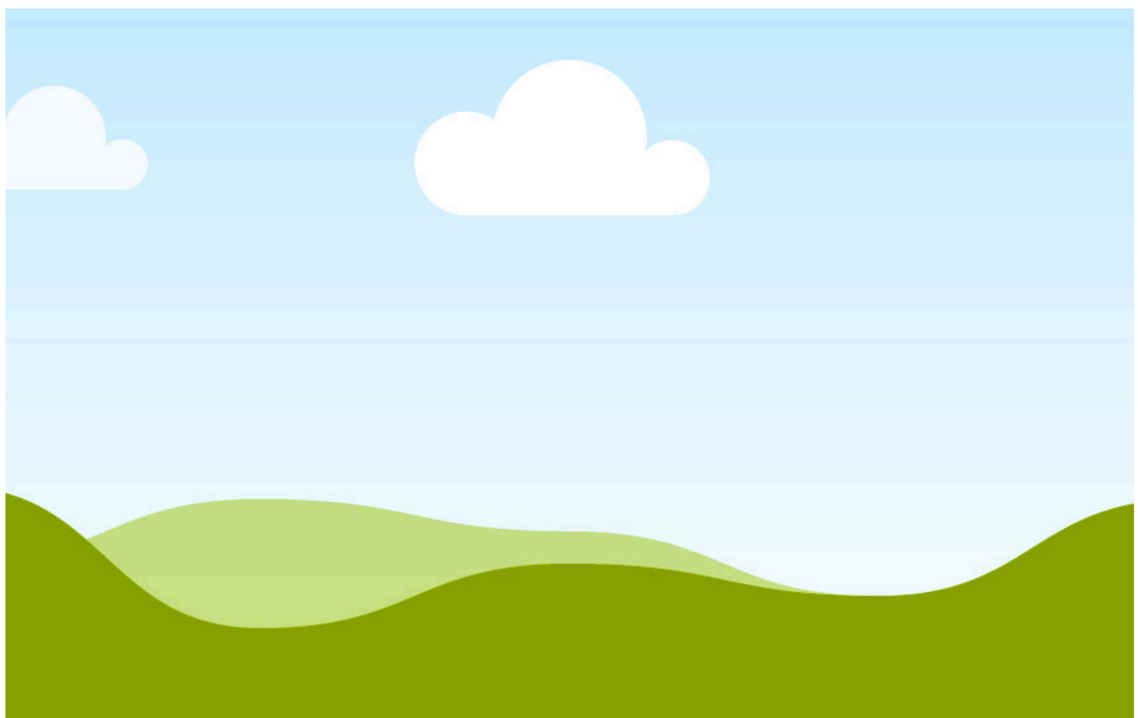
geology,
seismology,
geotechnical engineering,
structural engineering,
risk analysis with also social, economic, and political factors.

Seismic Hazards: Natural hazards associated with the occurrence of earthquakes.

Inside of the earth The inner core is solid and consists of heavy metals (nickel and iron), while the crust consists of light materials (basalt and granites). The outer core is liquid and the mantel has the ability to flow.

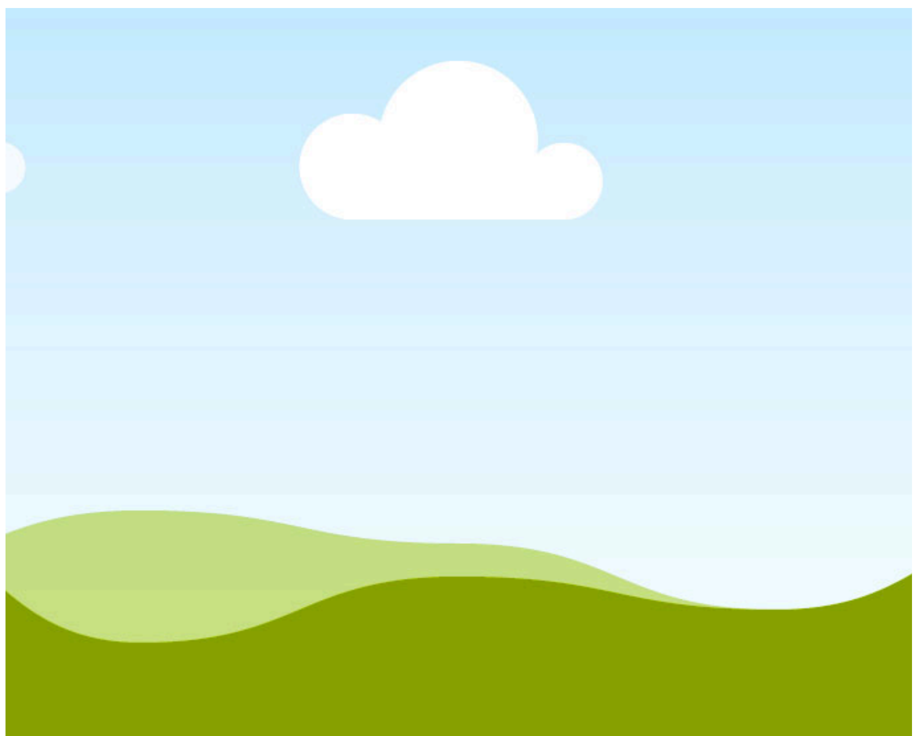
Core properties: temperature= 2500⍰ C pressure: ~ 4million atmosphere density: ~13.5 gm/cc

Earth surface [properties]: temperature= 25⍰ C pressure: 1 atmosphere density: ~1.5 gm/cc



Convection Currents:

Heat from deep inside the Earth heats up the lower mantle. This increase in heat results in a decrease in density. This decrease in density causes the lower mantle material to rise. Mantle material near the crust comes in contact with cooler material. During this contact, heat energy is transferred from the warmer material to the cooler material. Once cooled, the material is denser, causing it to sink and come into contact with the heat from the interior of the Earth where it heats up, becomes less dense, and rises once again.



Seismology: is the study of earthquakes and seismic waves that move through and around the earth

Earthquakes: is a natural geologic phenomenon caused by the sudden and rapid movement of a large volume of rock. Most earthquakes are caused by slippage along fractures in Earth's crust called faults.

Terminology:

The point on the fault where slip starts is the Focus or Hypocenter, and the point vertically above this point on the surface of the earth is the Epicenter.

The depth of the focus from the epicenter is called the Focal Depth (it is an important parameter in determining the damaging potential of an earthquake.

Most of the damaging earthquakes have shallow focus with focal depth less than 70km

Distance from epicenter to any point of interest is called the Epicentral Distance

Earth’s Major Roles

According to the **plate tectonics** theory, the uppermost mantle, along with the overlying crust, behaves as a strong, rigid layer. This layer is known as the lithosphere.

The Earth's outermost surface is broken into rigid plates which are 60-200 km thick and float on top of a more fluid zone

The boundaries along each plate are referred to as margins A **plate** is one of numerous rigid sections of the lithosphere that move as a unit over the material of the asthenosphere.

Different types of stresses are associated with each type of margin

Types of Plate Boundaries

Divergent boundaries (also called spreading centers) are the place where two plates move apart. divergent-plate margins have tensional stresses

Convergent boundaries form where two plates move together. (For example, the Rockies in North America, the Alps in Europe, the Pontic Mountains in Turkey, the Zagros Mountains in Iran, and the Himalayas in central Asia were formed by plate collisions)-compressional stresses

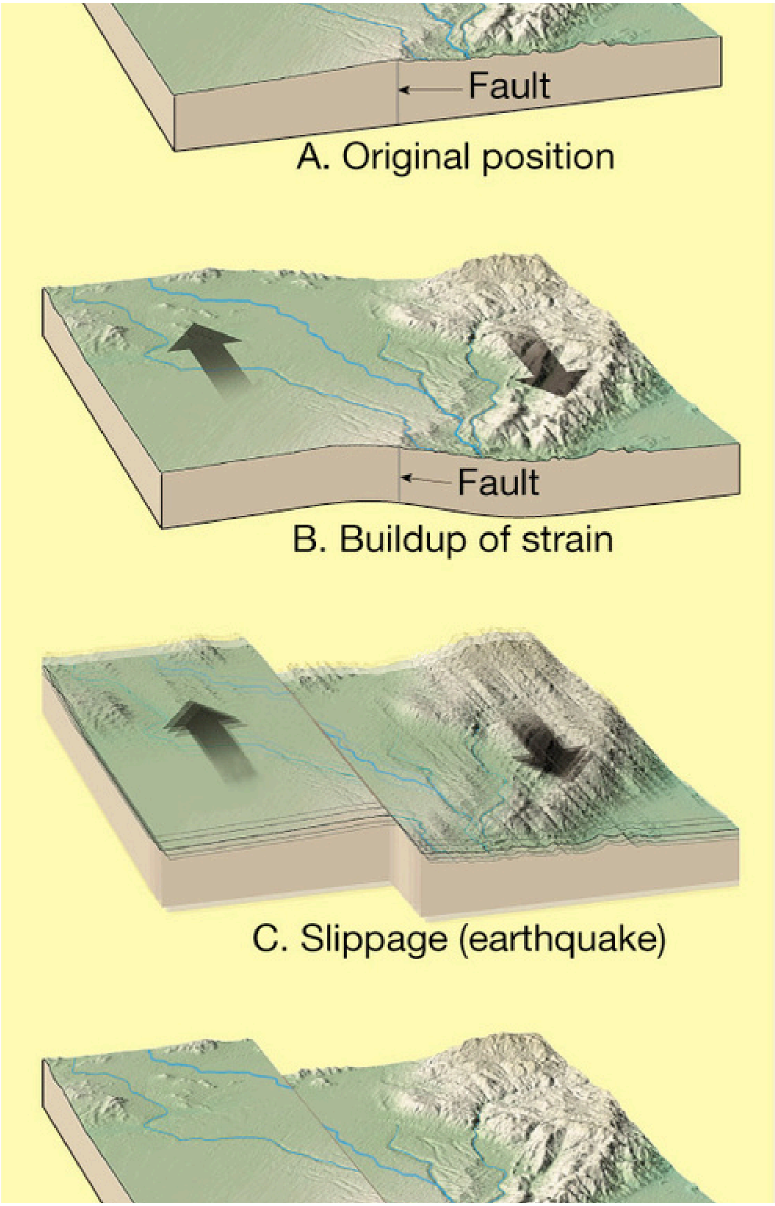
Transform fault boundaries are margins where two plates grind past each other without the production or destruction of the lithosphere.(As

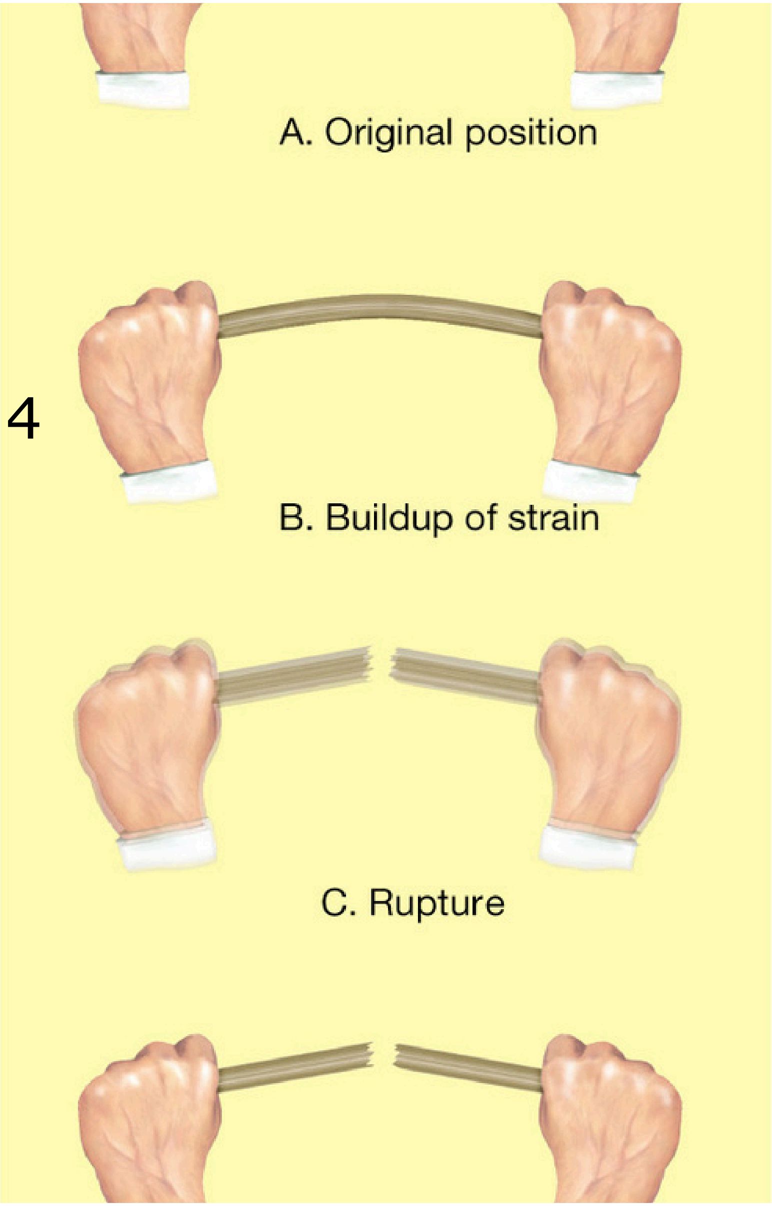
Causes an Earthquake

The Plate Tectonic Theory shows that the lithospheric plates of the Earth are in continual motion. **Lithospheric movements produce faults that cause earthquakes**

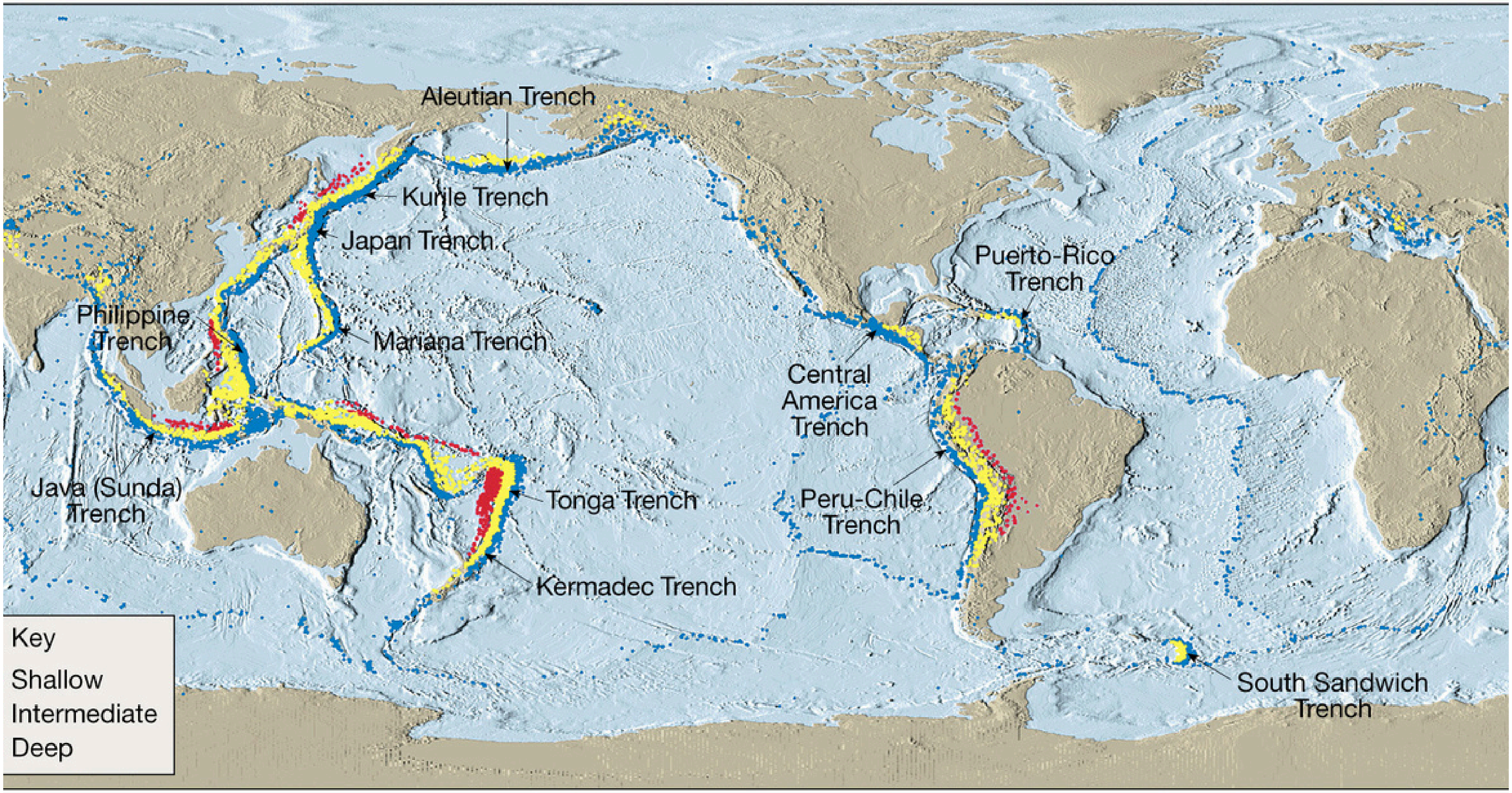
Elastic Rebound

As rocks deform along the fault
They bend,
Storing elastic energy
Once strained beyond the breaking point,
Frictional resistance holding the rocks together is overcome.
The rock cracks, releasing its stored-up energy in the form of earthquake waves.
Vibrations (earthquakes) occur as the deformed rock “springs back” to its original shape (elastic rebound).

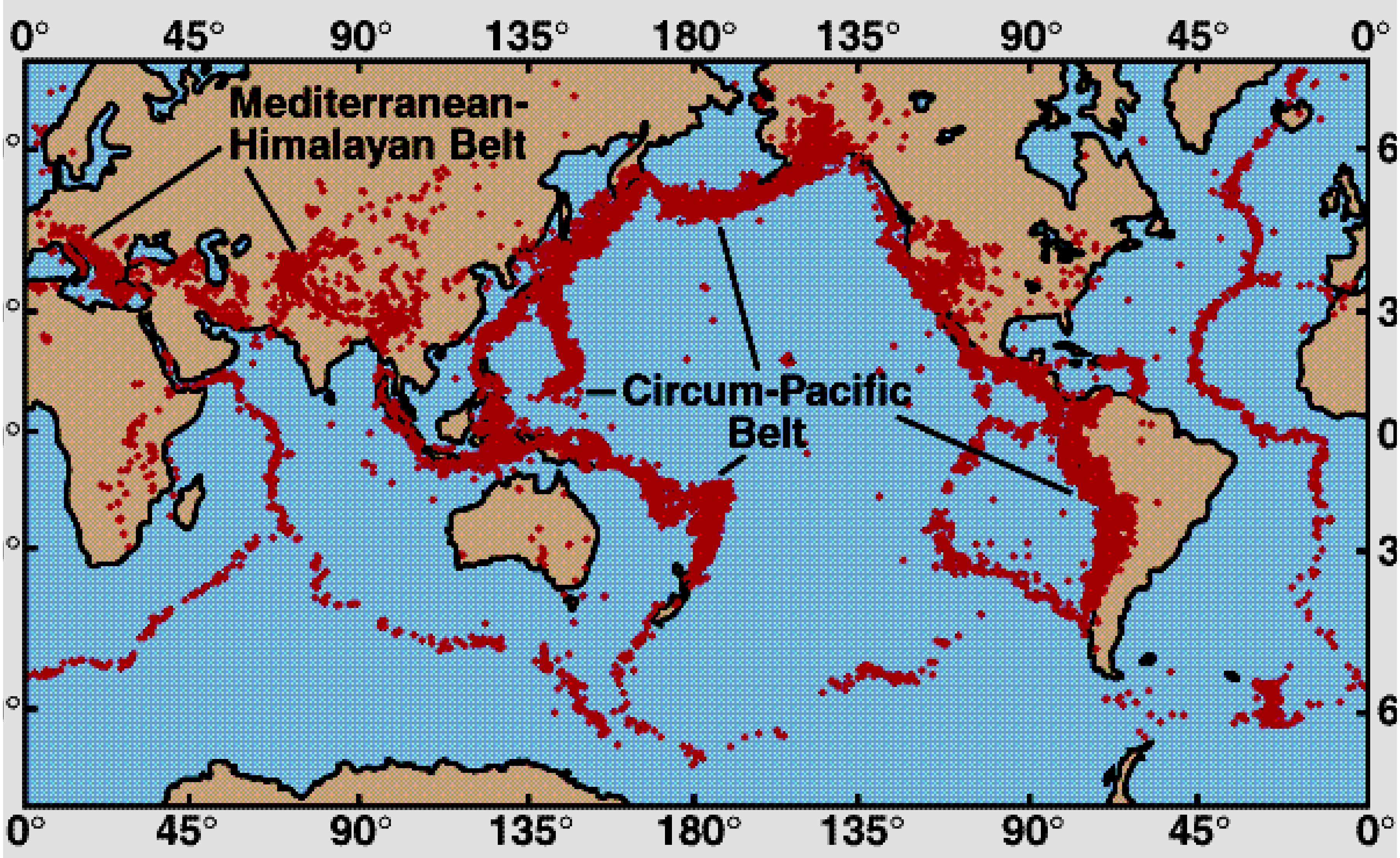

Fault
A. Original position
Fault
B. Buildup of strain
C. Slippage (earthquake)


A. Original position
B. Buildup of strain
C. Rupture

4

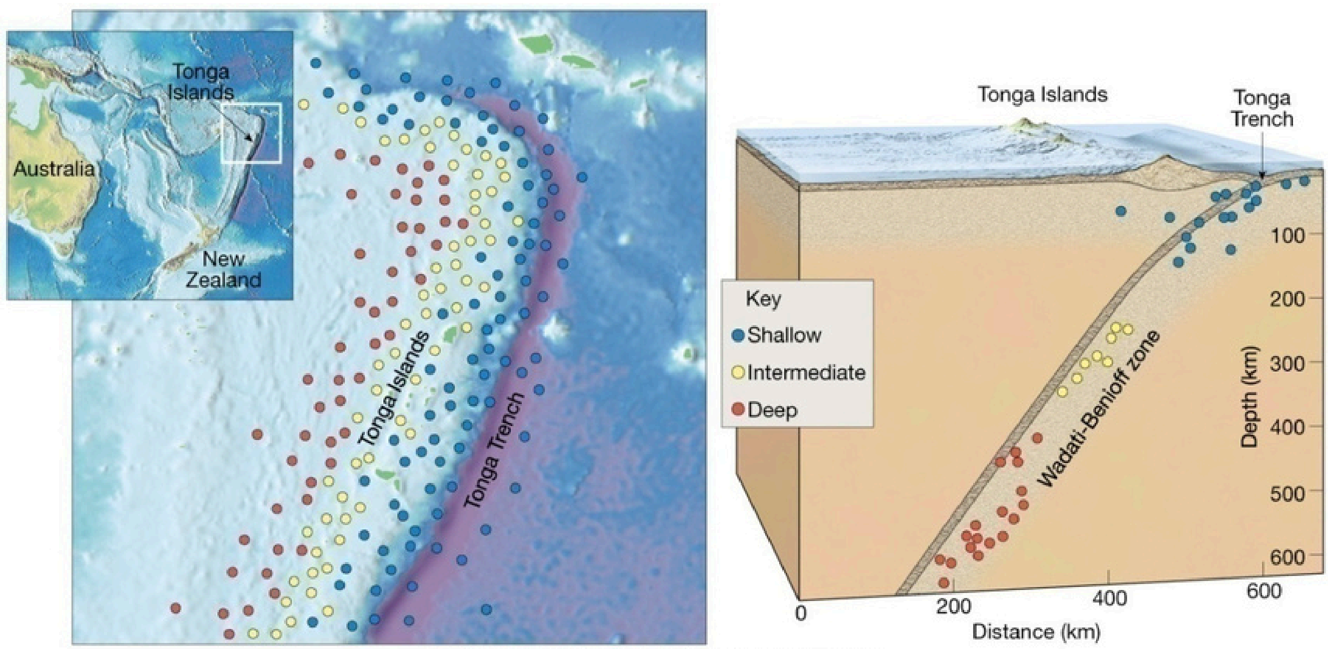

Aleutian Trench
Kurile Trench
Japan Trench
Philippine Trench
Mariana Trench
Java (Sunda) Trench
Tonga Trench
Kermadec Trench
Central America Trench
Peru-Chile Trench
Puerto-Rico Trench
South Sandwich Trench
Key
Shallow
Intermediate
Deep

Engineering Geology



Earthquakes originate at depths ranging from 5 to nearly 700 km

Shallow (surface to 70 kilometers)
Intermediate (between 70 and 300 kilometers)
Deep (over 300 kilometers)



80% of all earthquakes occur in the circum-Pacific belt, a zone of seismic activity that nearly surrounds the Pacific Ocean basin. Along this belt, most quakes are associated with convergent plate boundaries but also occur along divergent and transform boundaries.

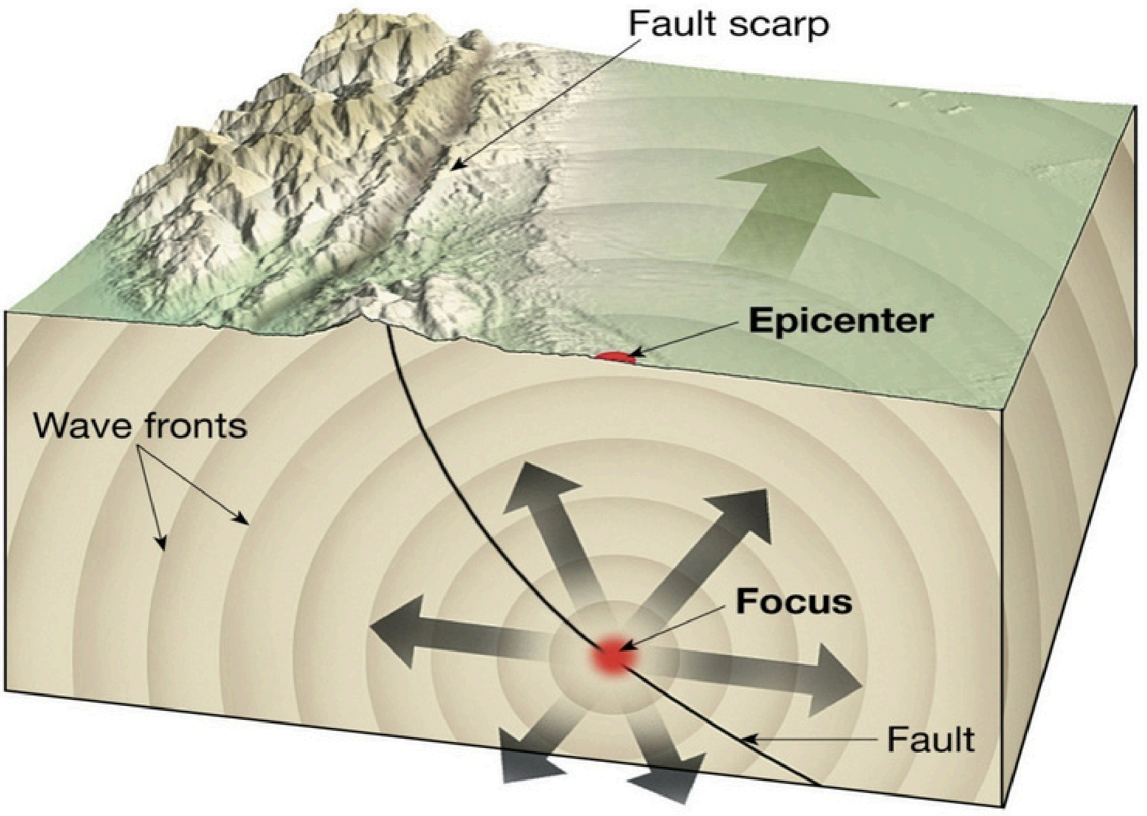
• 15% of all earthquakes occur along the largely convergent Mediterranean-Asiatic belt.

• The remaining 5% of earthquakes occur in plate interiors and along divergent margins. Intraplate earthquakes take place along ancient faults commonly associated with ancient, buried plate margins.

• On average, 150,000 earthquakes strong enough to be felt are recorded each year. Another 900,000 are recorded but are too small to be cataloged

What Happens During an Earthquake?

Energy is released in the form of waves and radiates in all directions from its source, the focus.



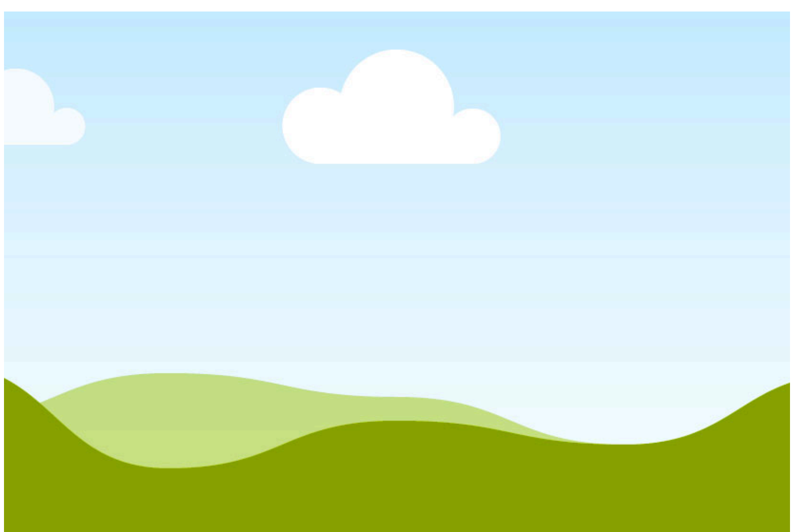
Types of Seismic Waves

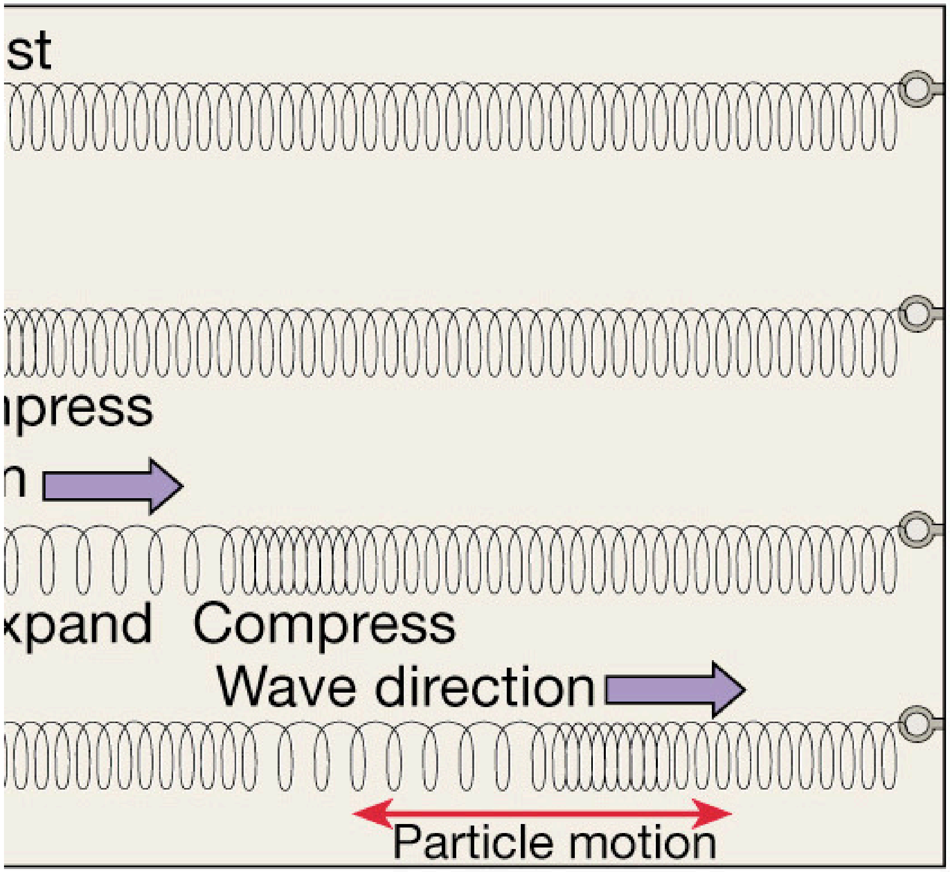
Body Waves

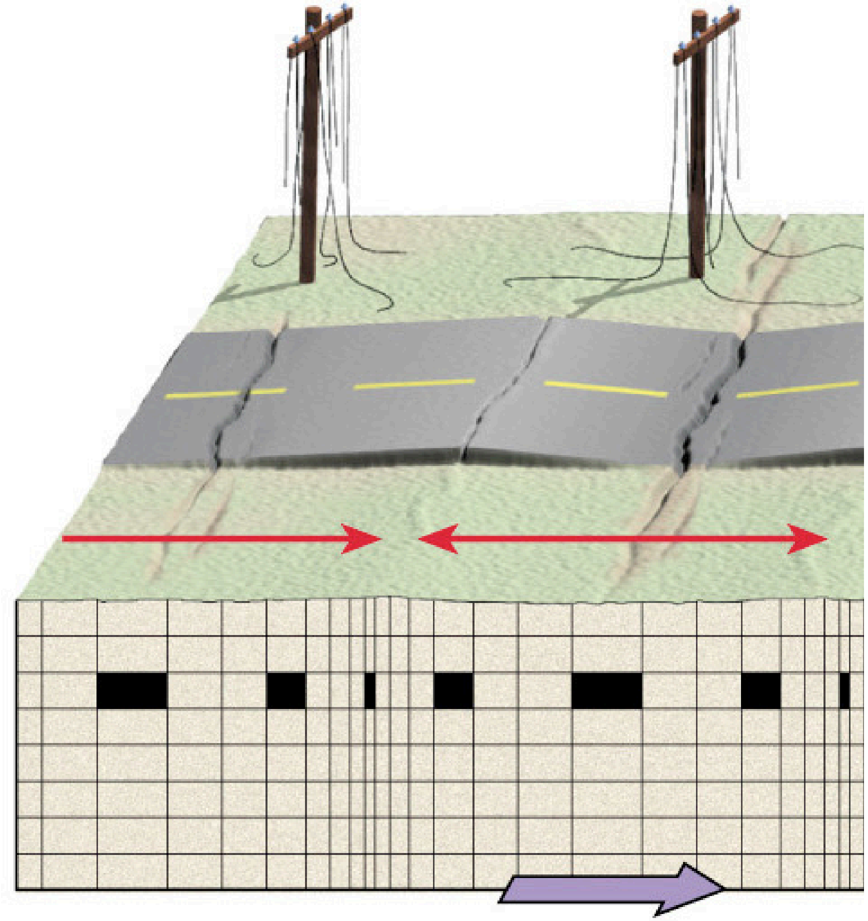
Travel through Earth's interior.
Two types based on mode of travel.

1-Primary (P) Waves

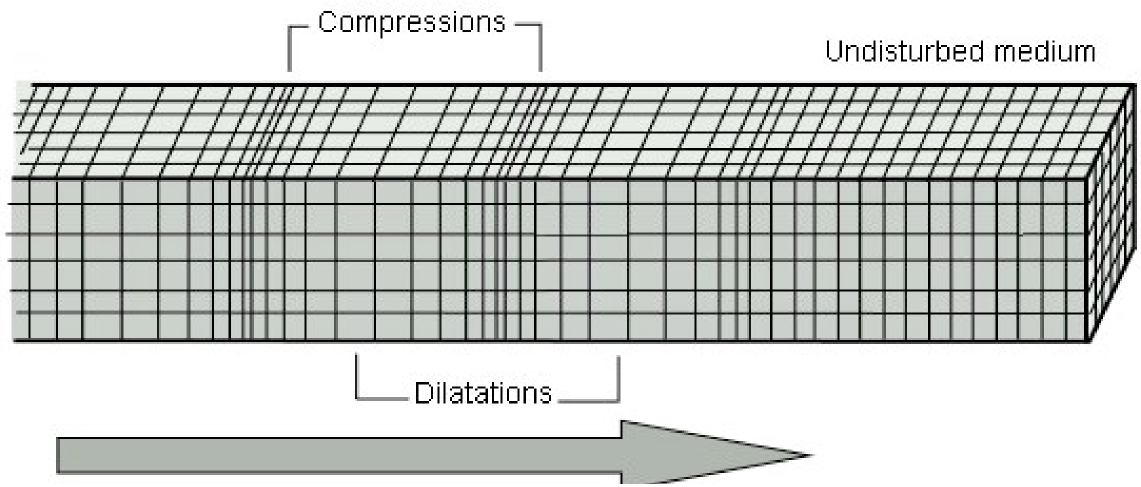
1-Push-pull (compress and expand – compressional waves) motion,
2-changing the volume of the intervening material.
3-Therefore, can travel through solids, liquids, and gases.
4-Generally, in any solid material, P waves travel about 1.7 times faster than S waves

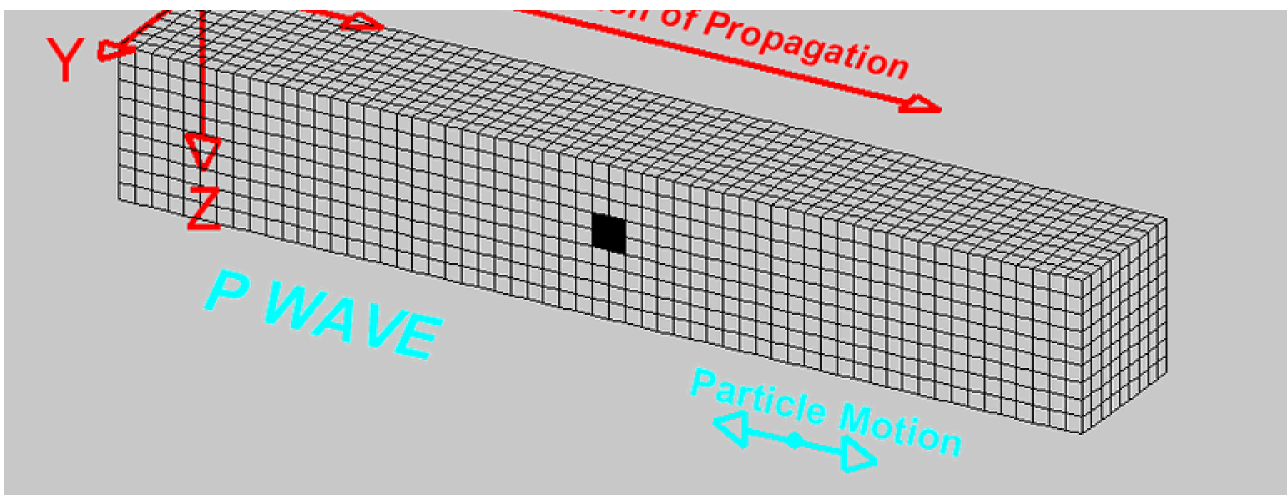



st
ıpress
ı
xpand Compress
Wave direction
Particle motion



P Wave


Compressions
Undisturbed medium
Dilatations


of Propagation
Y
Z
P WAVE
Particle Motion

Body Waves

2-Secondary (S) Waves

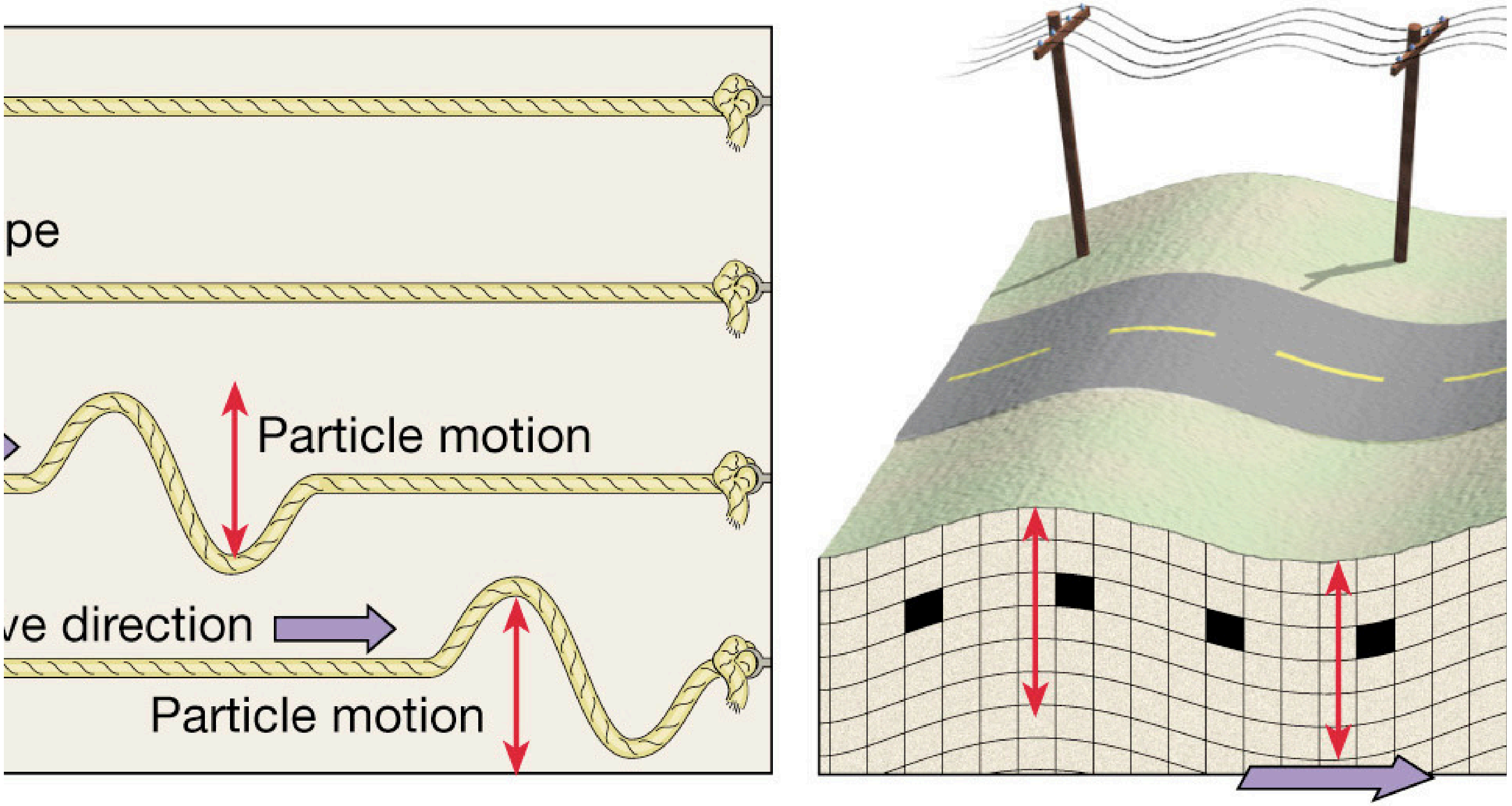
1-"**Shake" motion at right angles to their direction of travel that changes the shape of the material transmitting them (shear waves).**

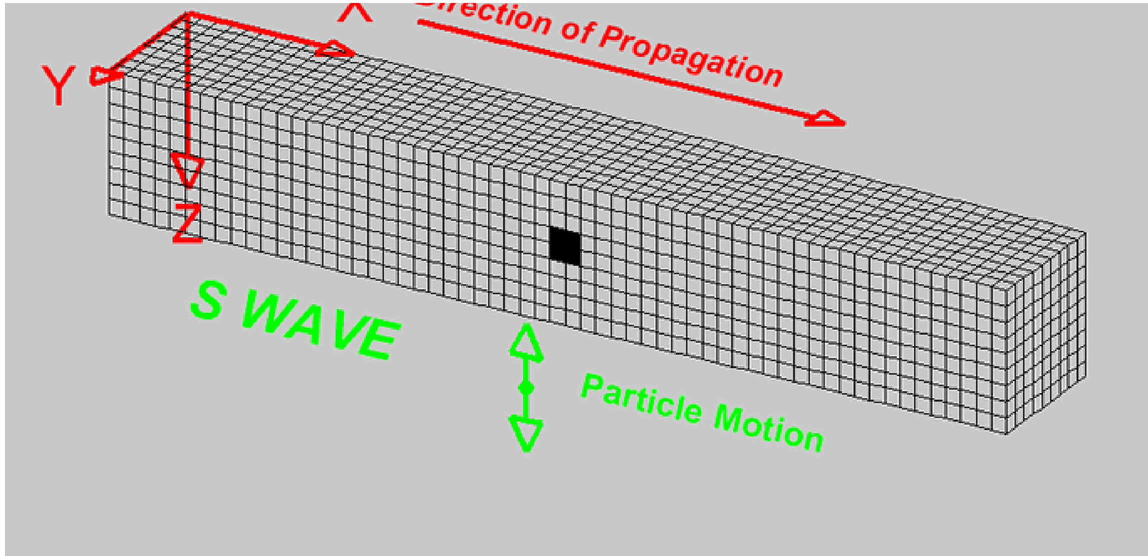
2-Therefore, can travel only through solids.

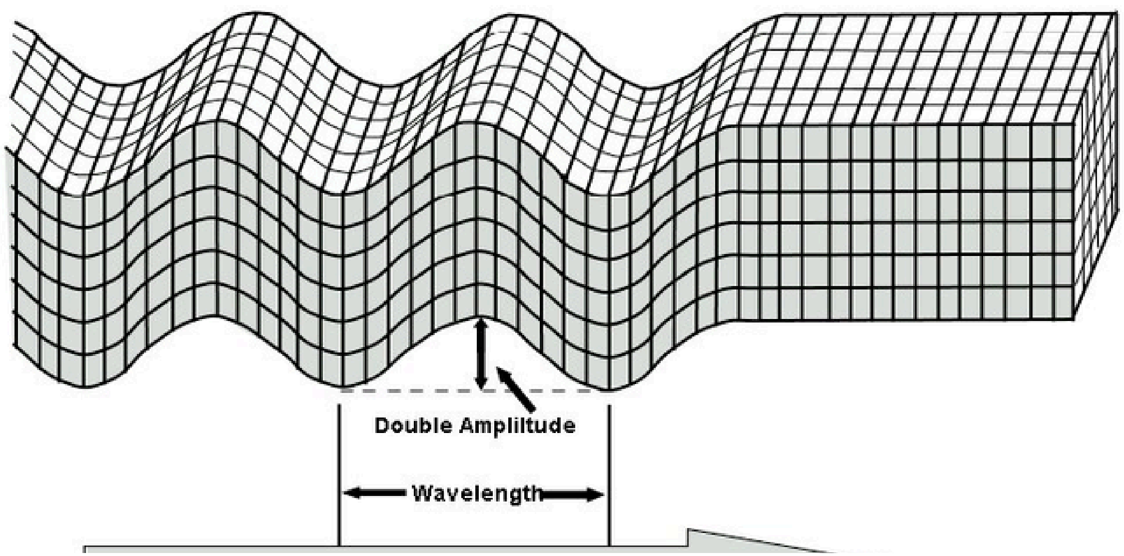
3-Slower velocity than P waves.

4-Slightly greater amplitude than P waves.
Lesser amplitude than L Wave.

Engineering Geology

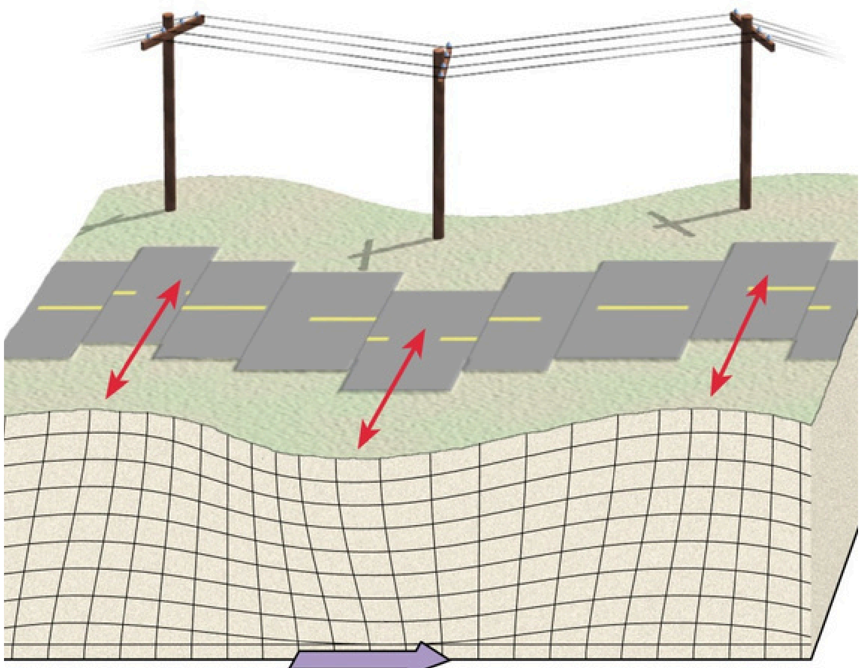



X
Direction of Propagation
Y
Z
S WAVE
Particle Motion

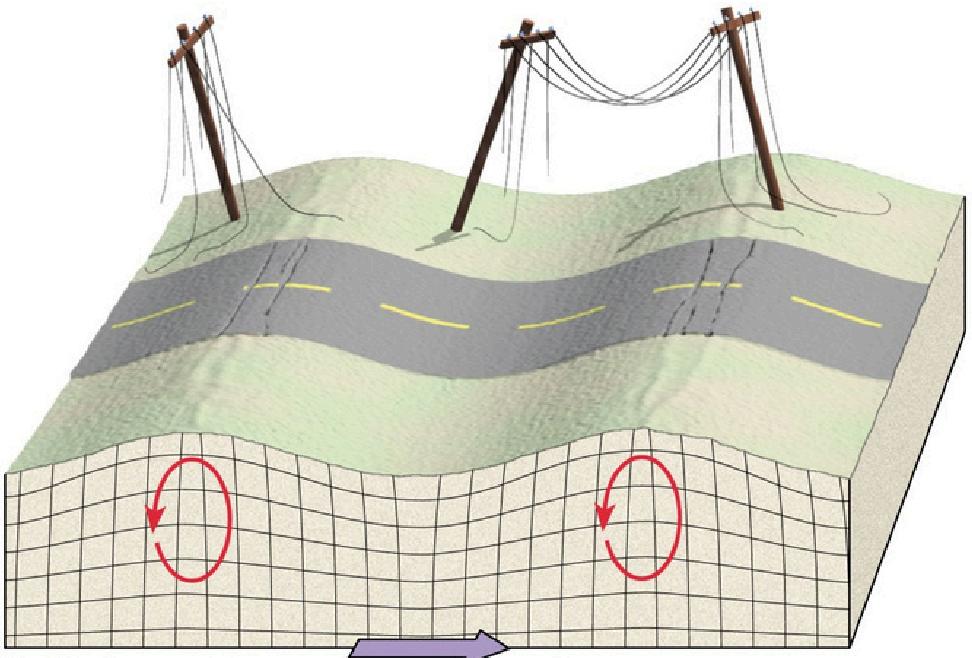

Double Amplitude
Wavelength

Surface Waves

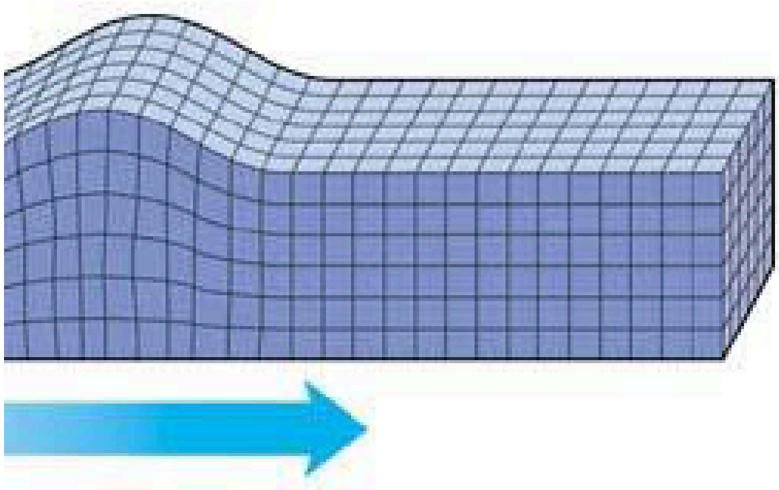
1-Travel along outer part (surface) of the Earth.
2-Complex motion (up-and-down motion as well as side-to-side motion).
3-Cause greatest destruction.
4-Exhibit greatest amplitude and slowest velocity.
5-Waves have the greatest periods (time interval between crests).
Often referred to as long waves, or L waves.

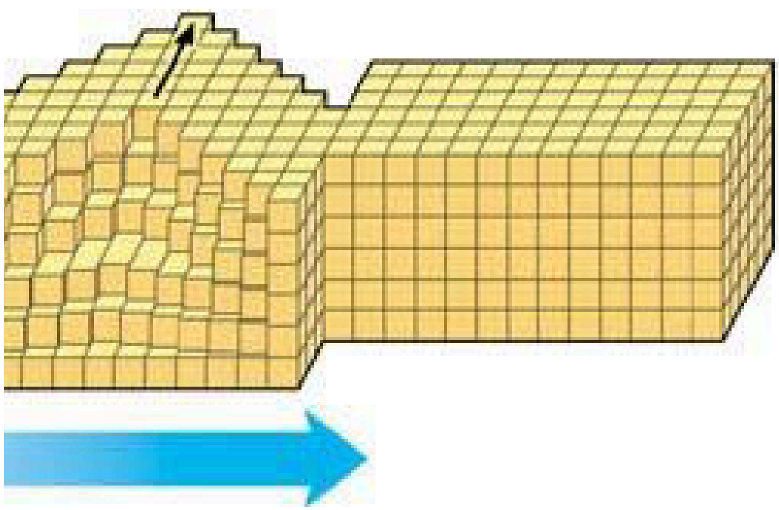


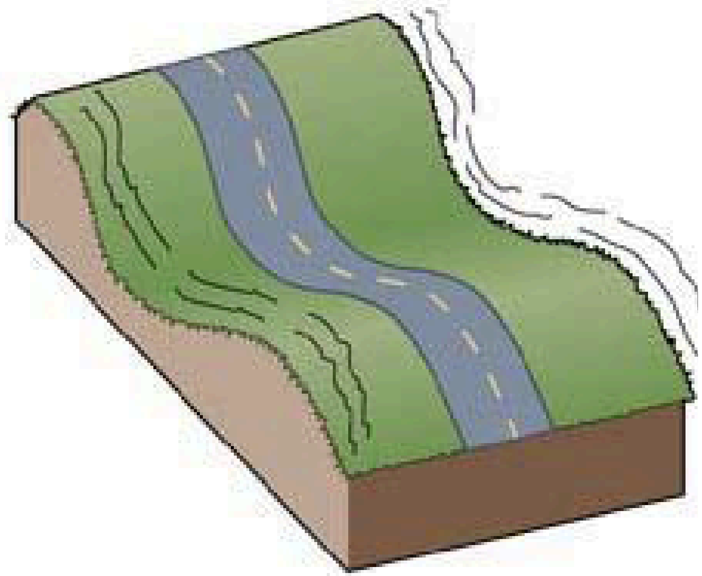
Surface wave



D. Surface wave







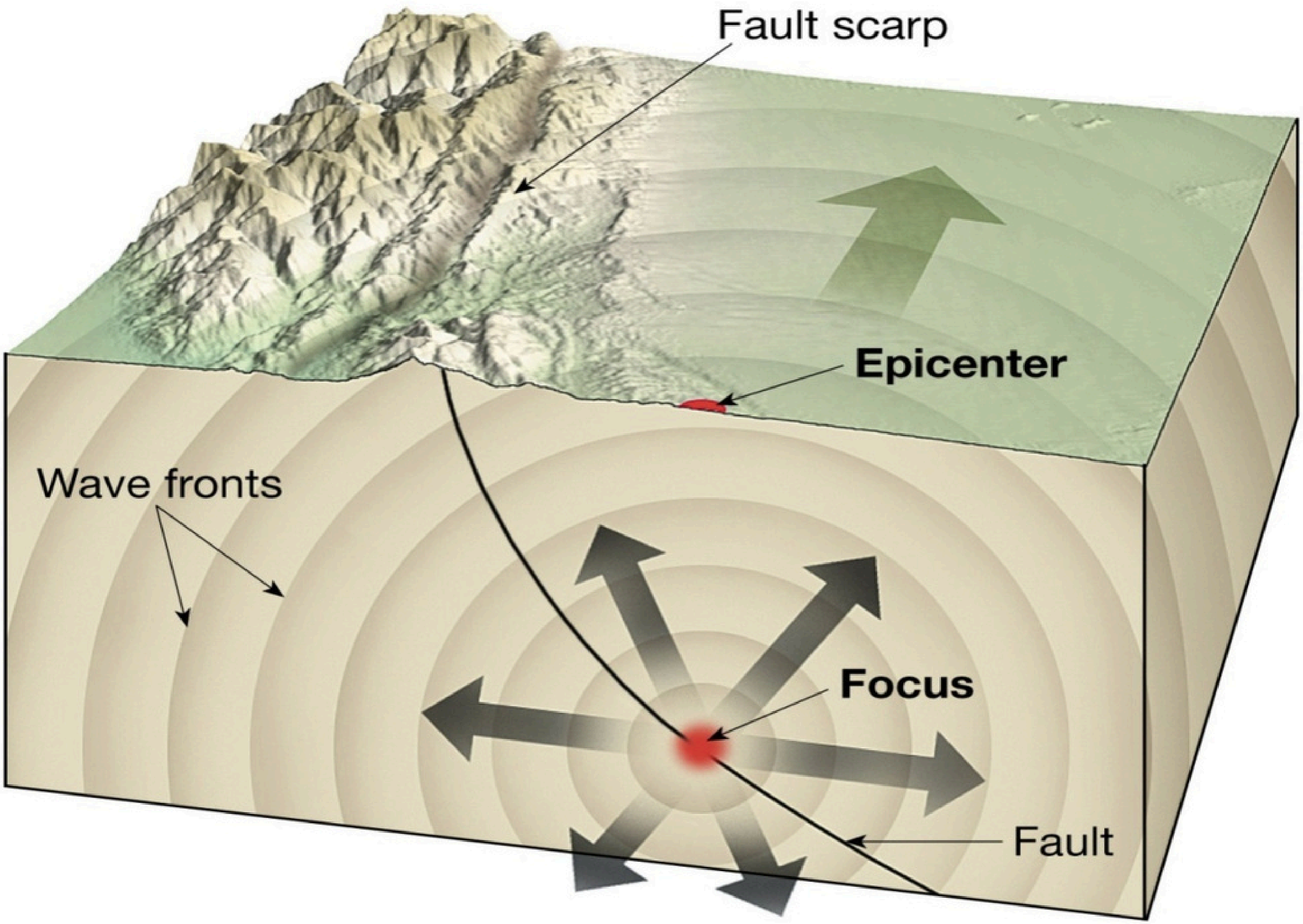
Rayleigh wave

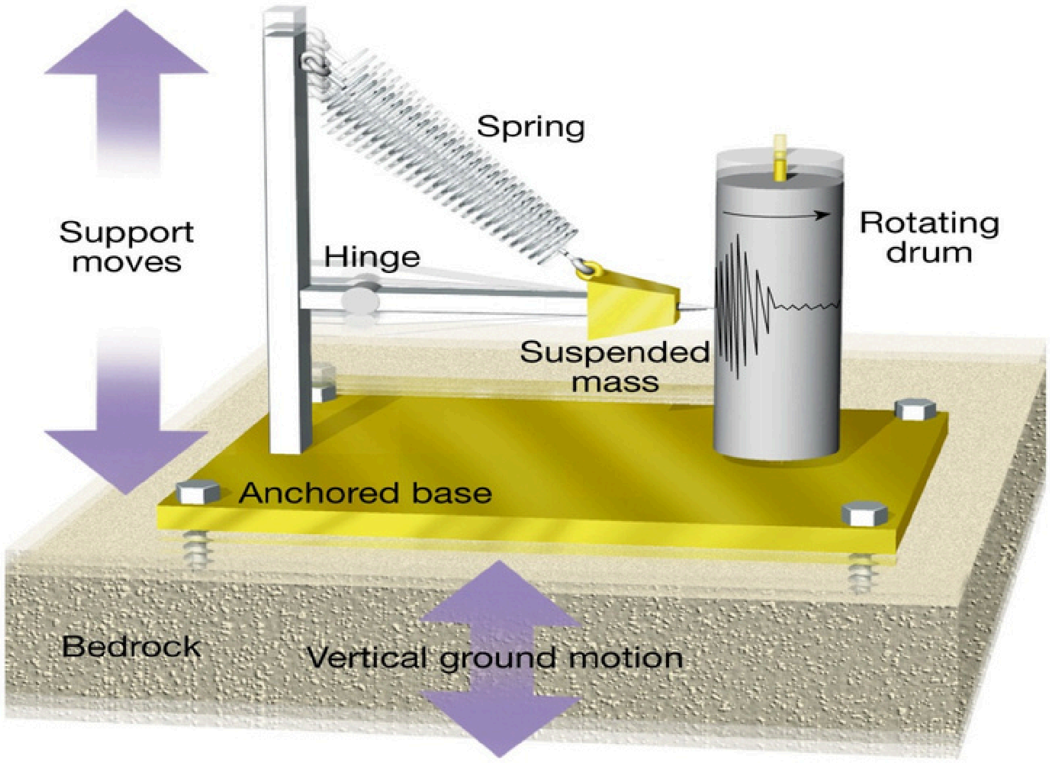
Locating the Earthquake's Epicenter

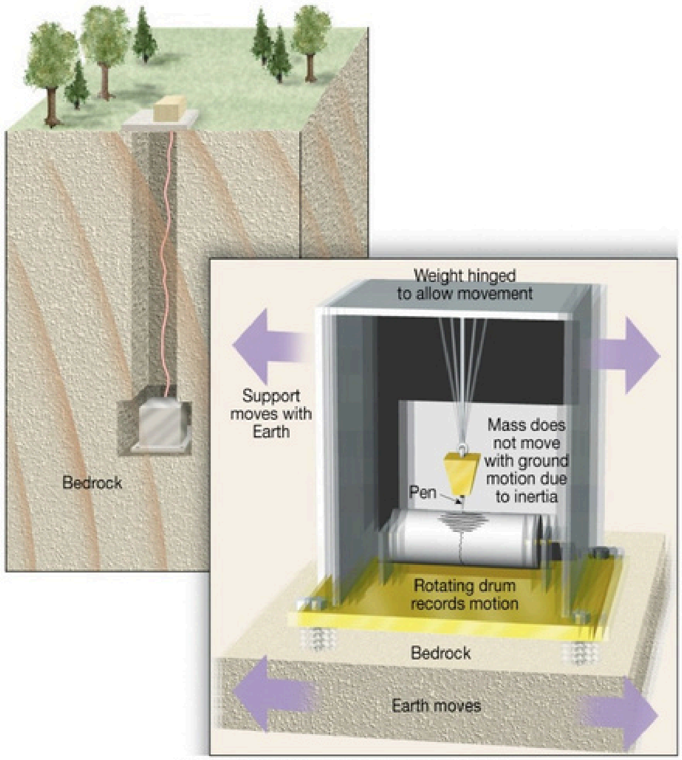
Sensitive instruments, called seismographs, around the world record the earthquake event.

Seismographs record seismic waves.

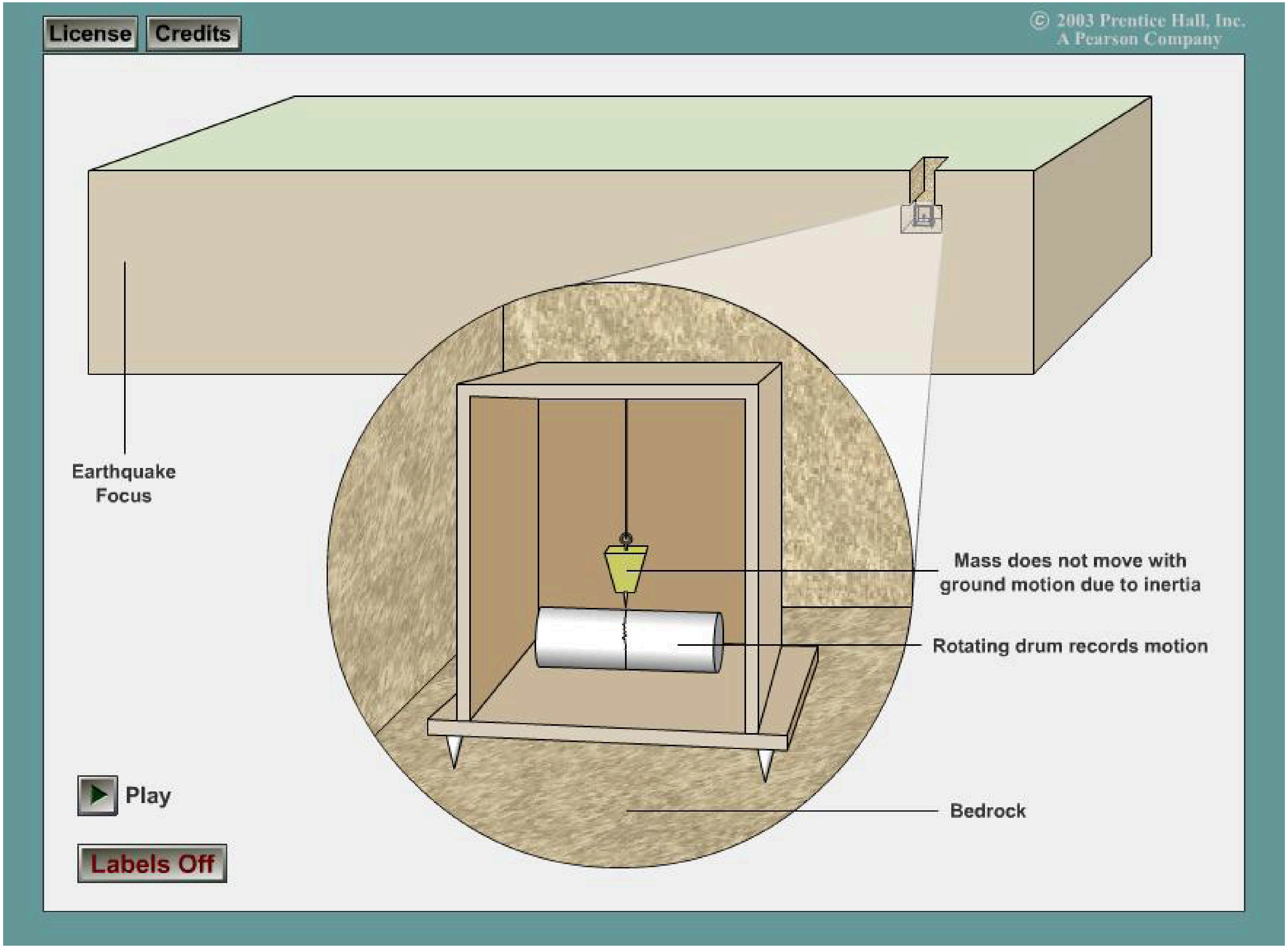
Seismographs record the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape.
More than one type of seismograph is needed to record both **vertical and horizontal ground motion.**


Fault scarp
Epicenter
Wave fronts
Focus
Fault


Support moves
Spring
Hinge
Rotating drum
Suspended mass
Anchored base
Bedrock
Vertical ground motion


Bedrock
Weight hinged to allow movement
Support moves with Earth
Mass does not move with ground motion due to inertia
Pen
Rotating drum records motion
Bedrock
Earth moves

Engineering Geology

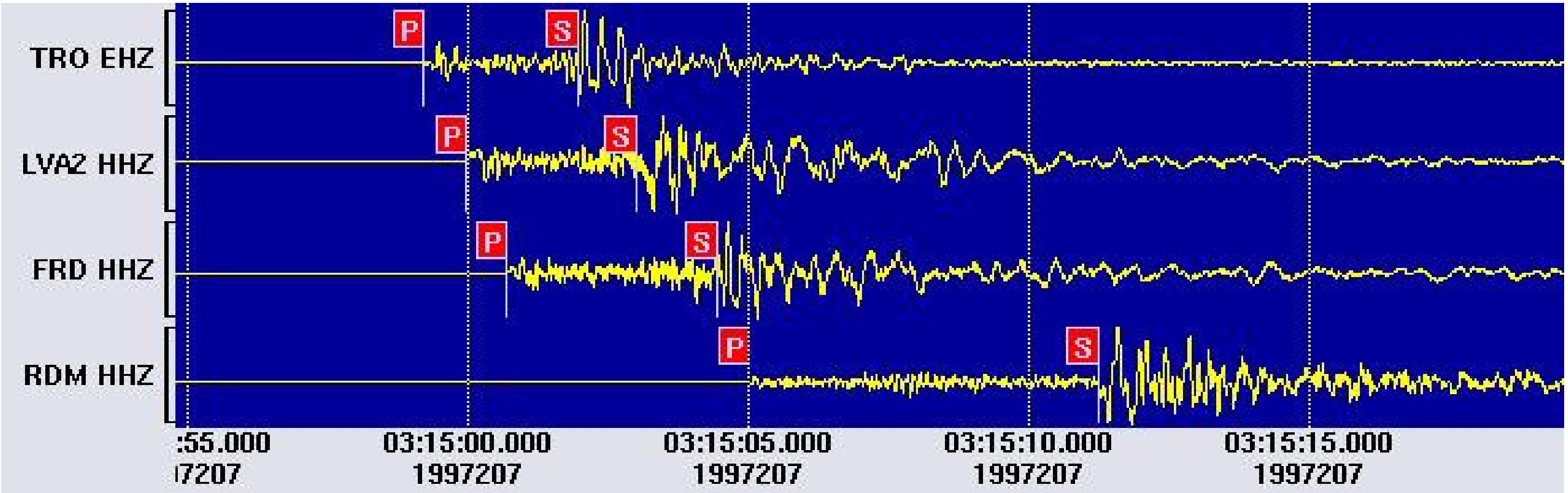


Records obtained are **called seismograms.**

Seismogram Showing P, S, and L Waves

By determining the time of arrival for both the P and S waves at a location we can determine how far away the Earthquakes epicenter is from the seismograph.

This **does NOT tell us what direction** the waves are coming from.



Part I: Finding the distance to the epicenter

Step 1:

Determine the difference in arrival time for your P-wave, and your S-wave. **For example**

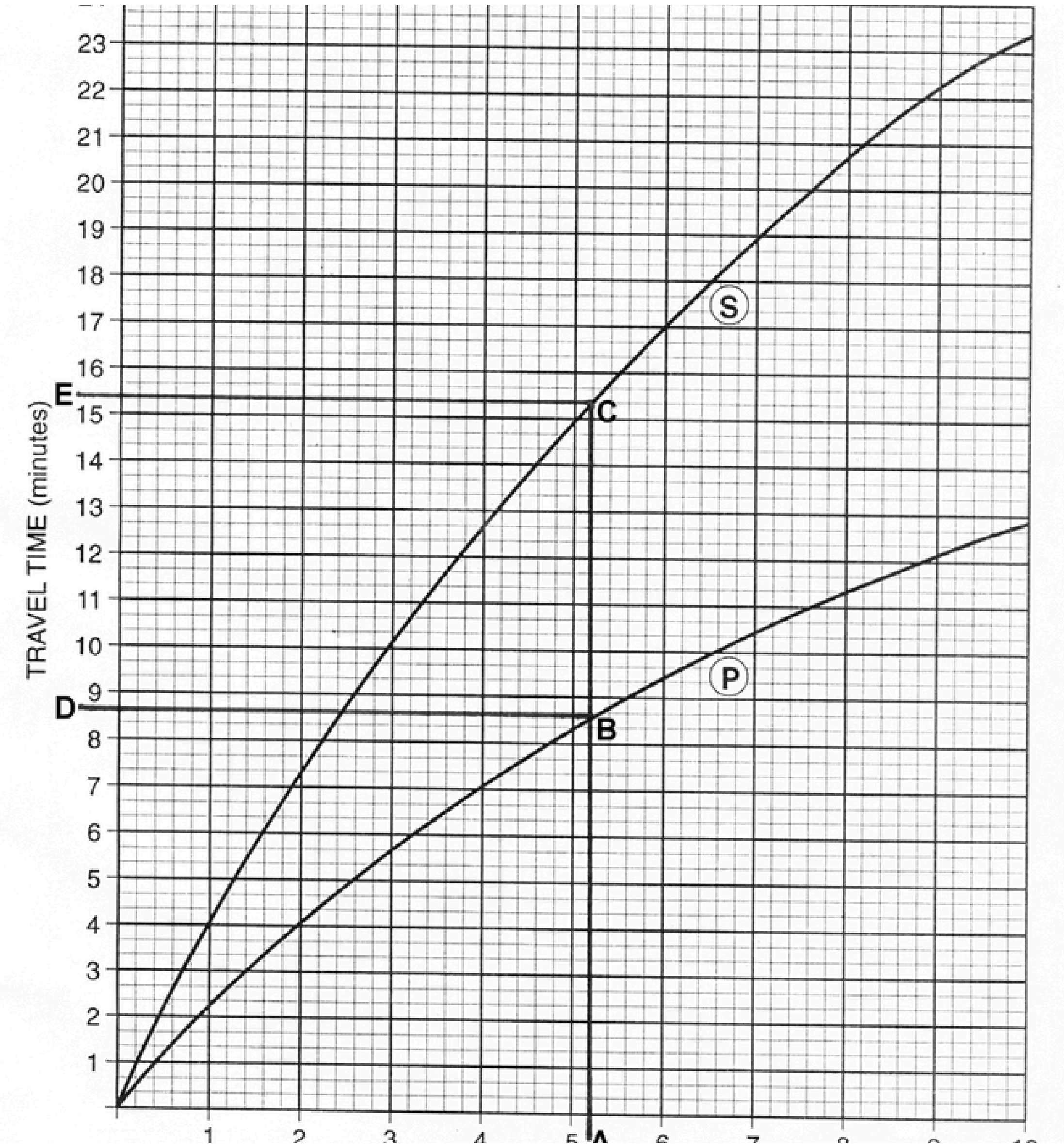
S-wave
03:27:15

P-wave
03:21:15

<u>Calculation</u> – difference in arrival time

03:27:15
<u>-03:21:15</u>
00:06:00 minutes

Step 2
Go to the Travel Time Graph



A travel-time graph is used to determine each station’s distance to the epicenter.

Step 3:

Use the vertical scale (time) to mark off the difference in arrival time on a scrap sheet of paper.

Step 4:

Make sure to keep your scrap paper **vertical**! Slide it along the curves until it lines up on each of the curves.

Be very accurate!!!!!

Step 5:

Read off the distance from the horizontal axis that corresponds to this spot. **This is the distance between the epicenter and your seismograph location**.

This distance is the radius of a circle around the seismograph

Step 6:

Repeat steps 1-5 for **at least 2 other seismograph locations**.

It is necessary to have **at least 3 stations**, if you do not you can not be sure of the exact location of the epicenter.

Part II Locating the Epicenter

Step 1:

Find the location of your first seismographic station on the map.

Step 2:

Use a compass or string to create a circle with its center at your seismograph location, and a radius equal to the distance you found

Step 3:

Repeat this procedure around two other seismographic stations.

Where the three circles all **intersect** (cross) is where your epicenter is located.

If the circles do not all intersect, but form a small triangle, **the epicenter is the center of the triangle**

Epicenter Location


BERKELEY
HONOLULU
SAN JUAN
EPICENTER
SEISMIC STATION

>

Part III: Origin time of the Earthquake

Step 1:

From the distances determined in Part I, determine how long it would take a P-wave to travel that distance

Step 2:

Find the distance on the horizontal axis.
Go up to the point where you hit the P-wave travel line.
Go over to the vertical axis and read off the travel time for the P-wave.

P-wave Travel Time = 00:07:40

Distance = 4,400 km

We have the P-wave arrival time at the seismograph, and the time that it took to get there, so we need to find the time the wave left the focus of the earthquake (origin time of the seismic waves).

Step 3:

Taking the time found in step 1, subtract this from the arrival of the P wave and that is the original time of the earthquake.

Calculation

03:21:15 - P-wave Arrival Time

-00:07:40 - Travel Time for P-wave @ 4,400km

03:13:35 - Origin Time (when the earthquake occurred)

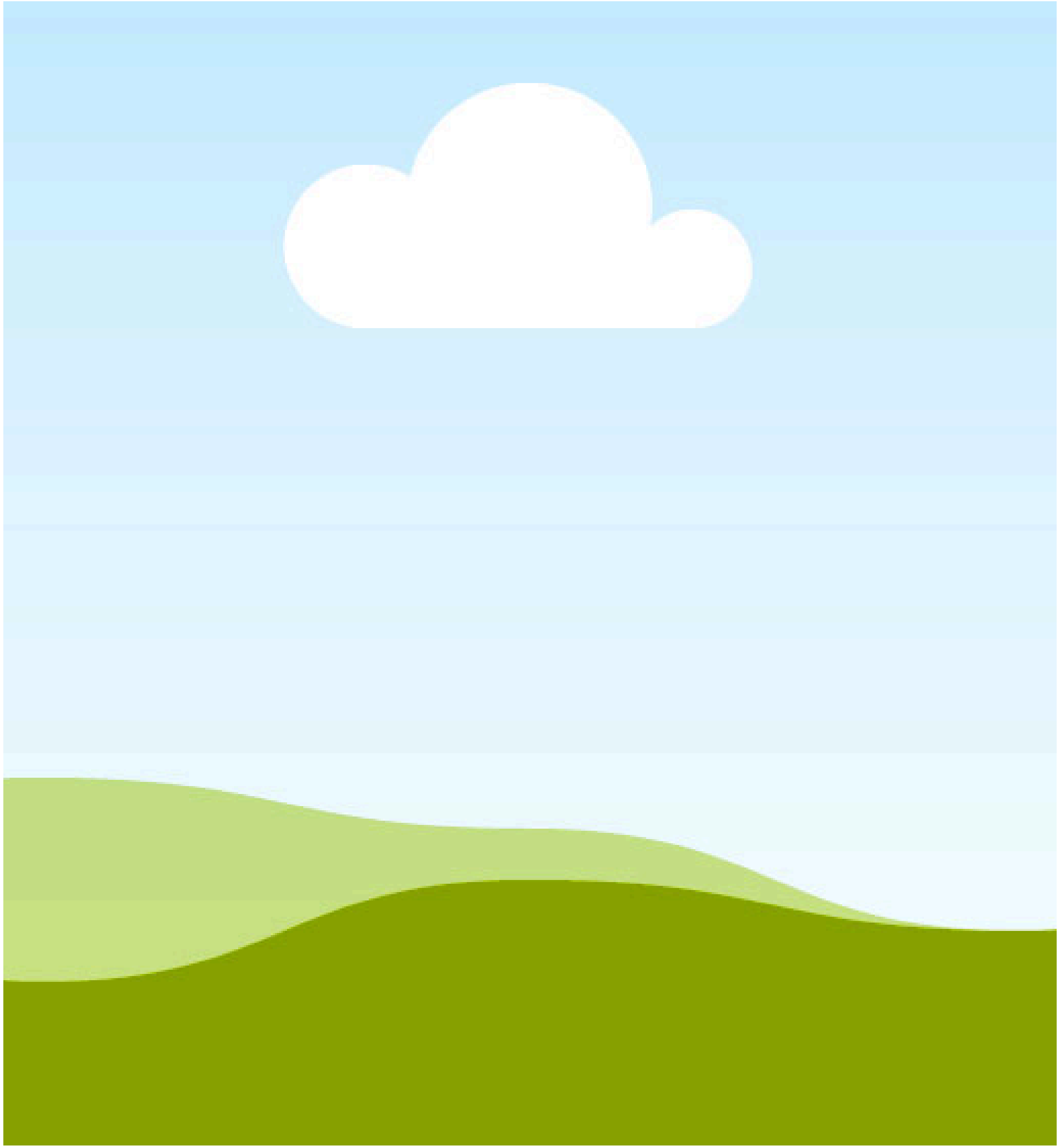
Part IV : Earthquakes Measured

Prior to 1935 **the estimation of the(intensity) of** an earthquake was base on a qualitative and subjective interpretation of the **Mercalli Intensity Scale.**

Charles Richter (1935) devise a quantitative(**Magnitude**) method based on the amplitude of the largest waves recorded on a seismogram.
the size of the amplitude depends on:-
The distance from the epicenter.
The intensity or magnitude of the earthquake.
(Note - the amplitude can vary many thousands of times)

1.1 Modified Mercalli Intensity Scale

elt except by a very few under especially favorable circumstances.
nly by a few persons at rest, especially on upper floors of buildings.
uite noticeably indoors, especially on upper floors of buildings, but many people d
nize it as an earthquake.
g the day, felt indoors by many, outdoors by few. Sensation like heavy truck striking
y nearly everyone, many awakened. Disturbances of trees, poles, and other tall obj
times noticed.
y all; many frightened and run outdoors. Some heavy furniture moved; few instanc
er or damaged chimneys. Damage slight.
body runs outdoors. Damage negligible in buildings of good design and constructi
rate in well-built ordinary structures; considerable in poorly built or badly designed
ge slight in specially designed structures; considerable in ordinary substantial buil
l collapse; great in poorly built structures (fall of chimneys, factory stacks, columns
ments, walls).
ge considerable in specially designed structures. Buildings shifted off foundations.
ed conspicuously.
well-built wooden structures destroyed. Most masonry and frame structures destr
nd badly cracked.
if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in g
ge total. Waves seen on ground surfaces. Objects thrown upward into air.



Factors affecting the amount of damage:

- the building designs,
- the distance from the epicenter,
- the type of surface material (rock or dirt) the buildings rest on.

- Richter scale, anything below 2.0 is undetectable to a normal person and is called a microquake. Moderate earthquakes measure less than 6.0 on the Richter scale. Earthquakes measuring more than 6.0 can cause significant damage. The biggest quake in the world since 1900 scored a 9.5 on the Richter scale. It rocked Chile on May 22, 1960.

Principle of intensity Measure (Mercalli Intensity Scale)

- **Low: Human effects**
- **Intermediate: Building effects**
- **High: Change in landscape**

Problems :

Many influences: focal strength, distance, attenuation, direction to focus, site effects

- **Damages are sometimes secondary effects**
- **Significant only in densely populated areas**

Strength classification in the focus : Magnitude

The fathers of magnitudes

B. Gutenberg

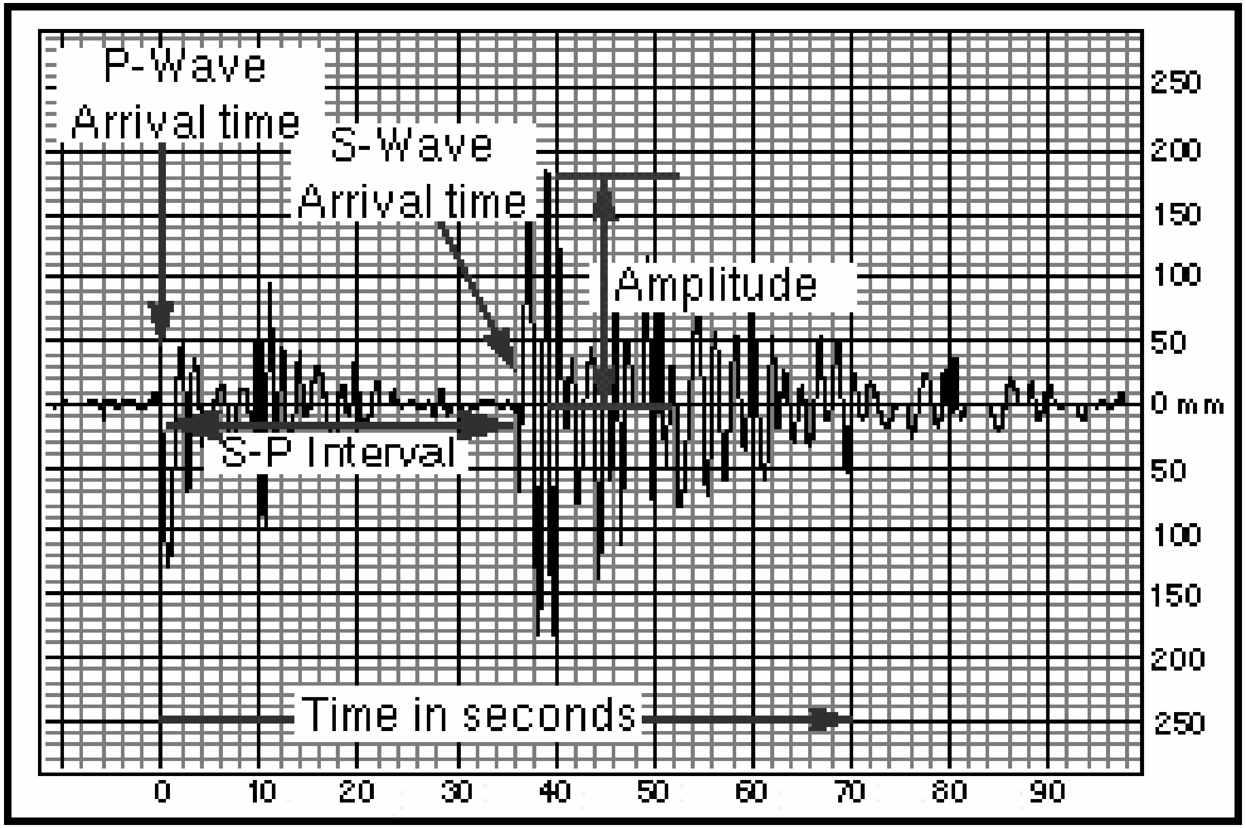
C. F. Richter

TABLE 11.2 Earthquake Magnitudes and Expected World Incidence

Richter Magnitudes	Effects Near Epicenter	Estimated Number per Year
<2.0	Generally not felt, but recorded.	600,000
2.0–2.9	Potentially perceptible.	300,000
3.0–3.9	Felt by some.	49,000
4.0–4.9	Felt by most.	6200
5.0–5.9	Damaging shocks.	800
6.0–6.9	Destruction in populous regions.	266
7.0–7.9	Major earthquakes. Inflict serious damage.	18
8.0	Great earthquakes. Cause extensive destruction to communities near epicenter.	1.4

Step 1:

Amplitude is measured in millimeters (mm) from the center of the seismic record to the maximum on the trace.



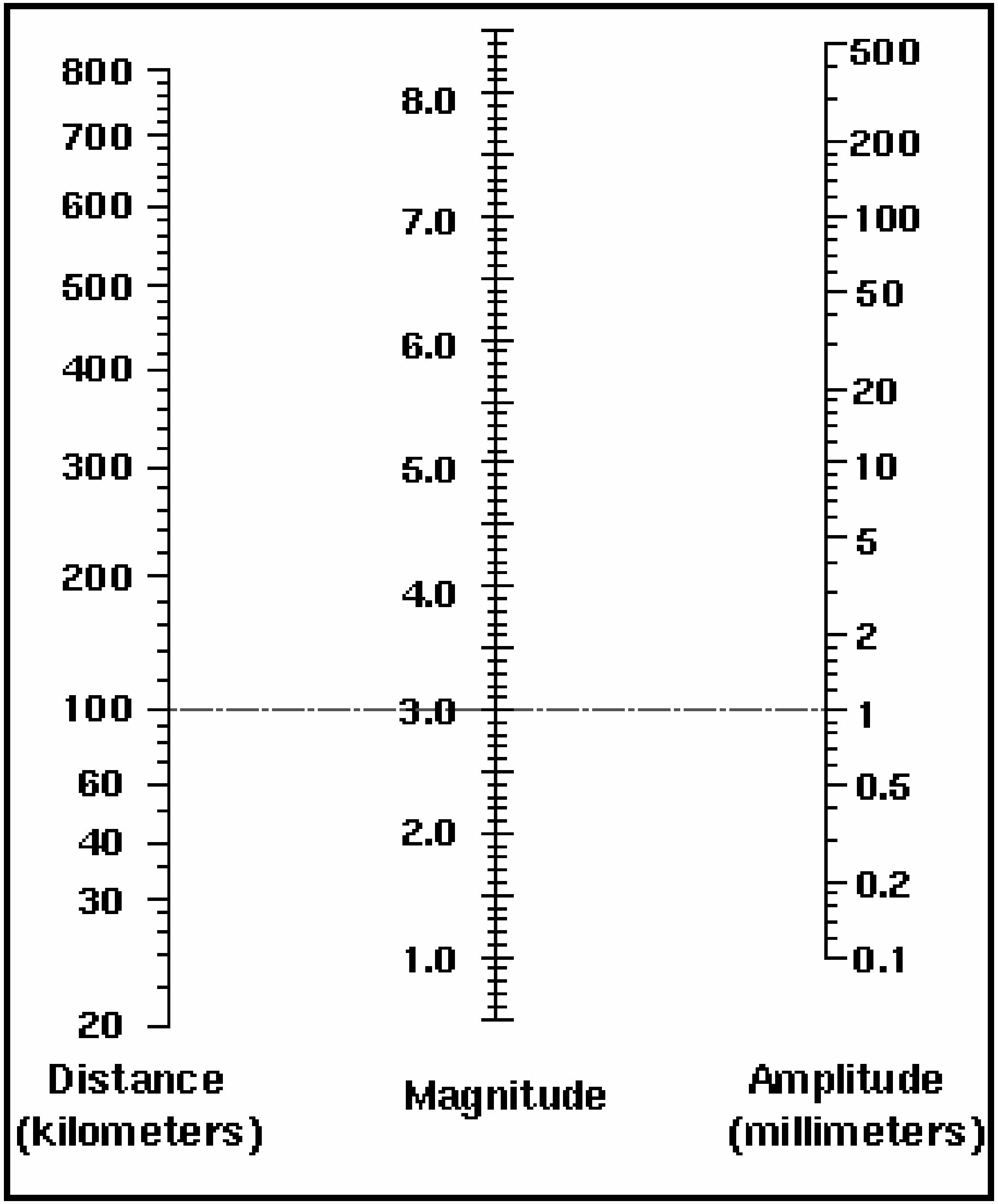
In this case the amplitude is 180 mm

Step 2:

The Richter Scale
The scale is LOGARITHMIC and ranges from 1 to 8
Therefore, an earthquake of magnitude 6 on the Richter scale is ten times larger than an earthquake that registers 5 on the Richter scale, and one hundred times larger than one that register 4 on the Richter scale

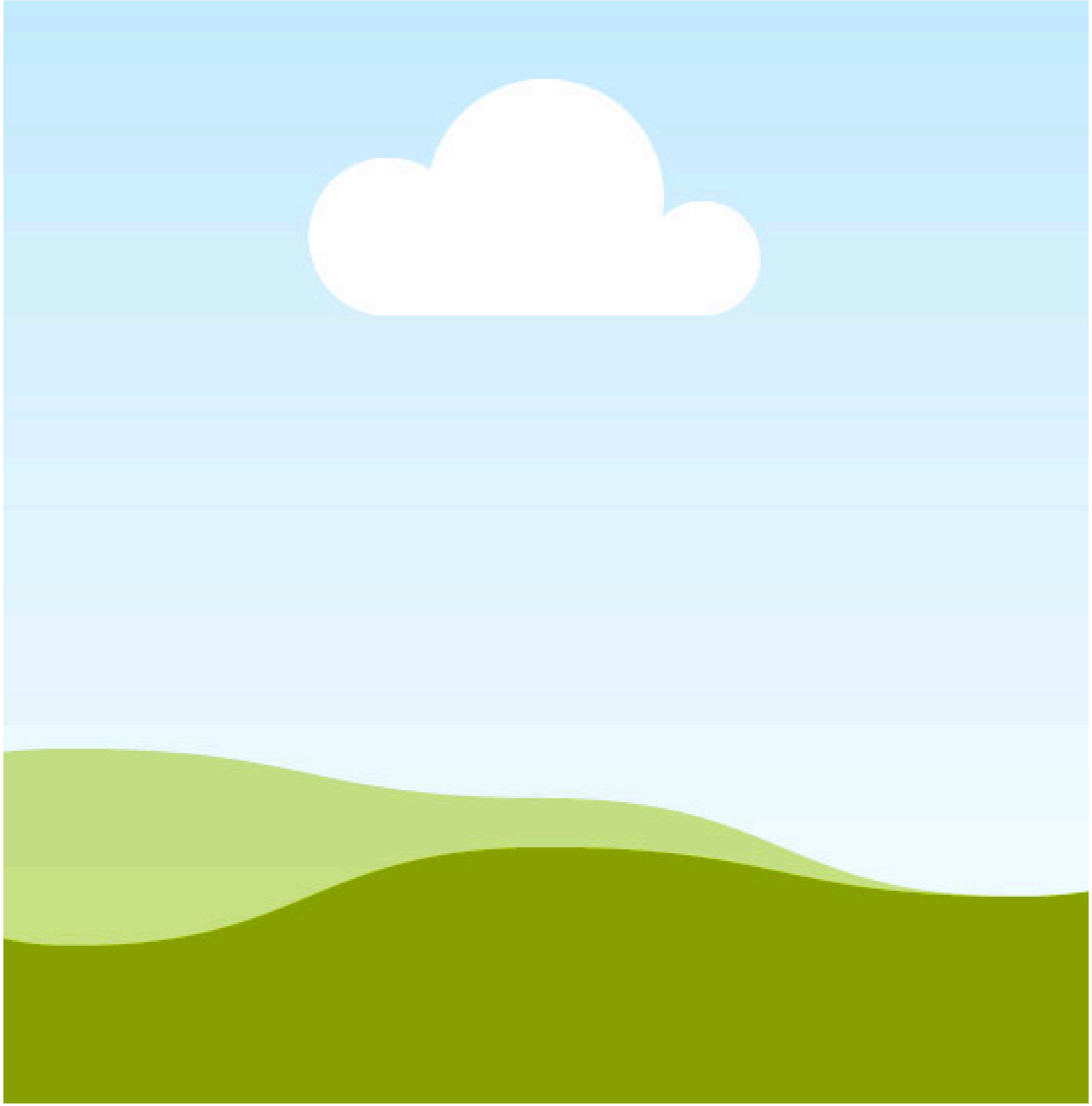
Step 3

Draw a line connecting a distance with an amplitude. The magnitude on the Richter scale of the earthquake is given by where this line intersects the center line of the nomogram.

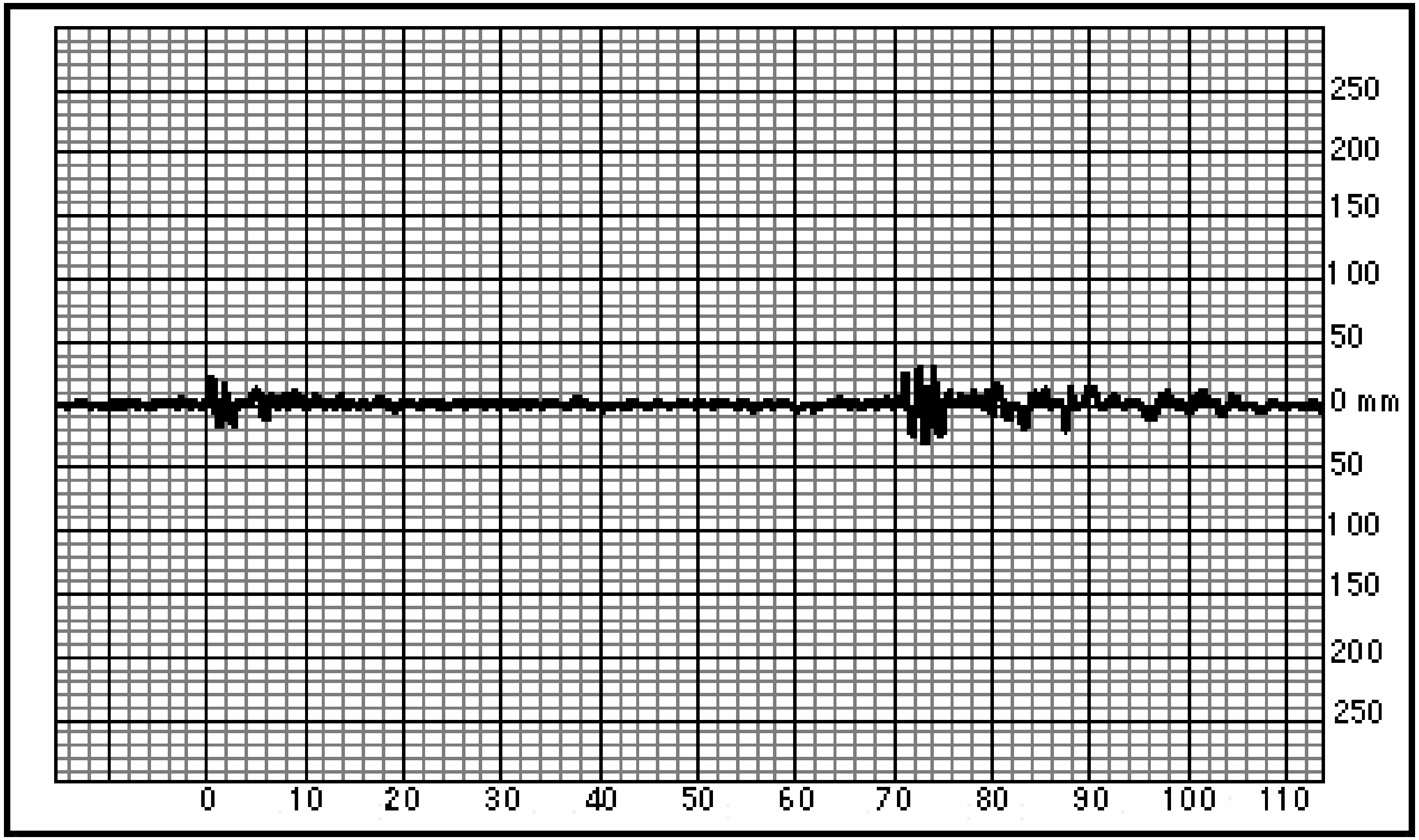

800
700
600
500
400
300
200
100
60
40
30
20
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
Distance
(kilometers)
Magnitude
Amplitude
(millimeters)

.

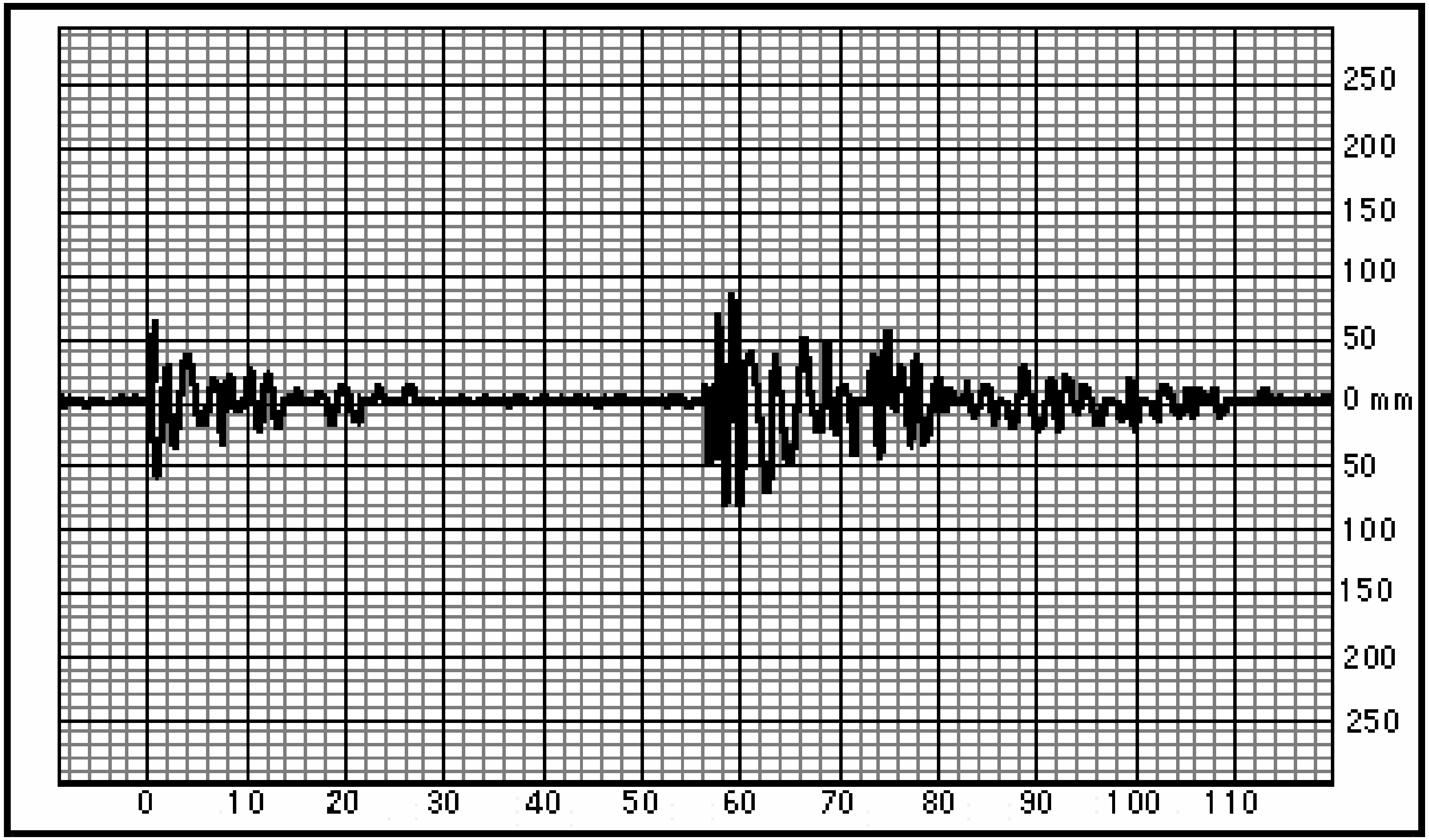
Example



A Real Example

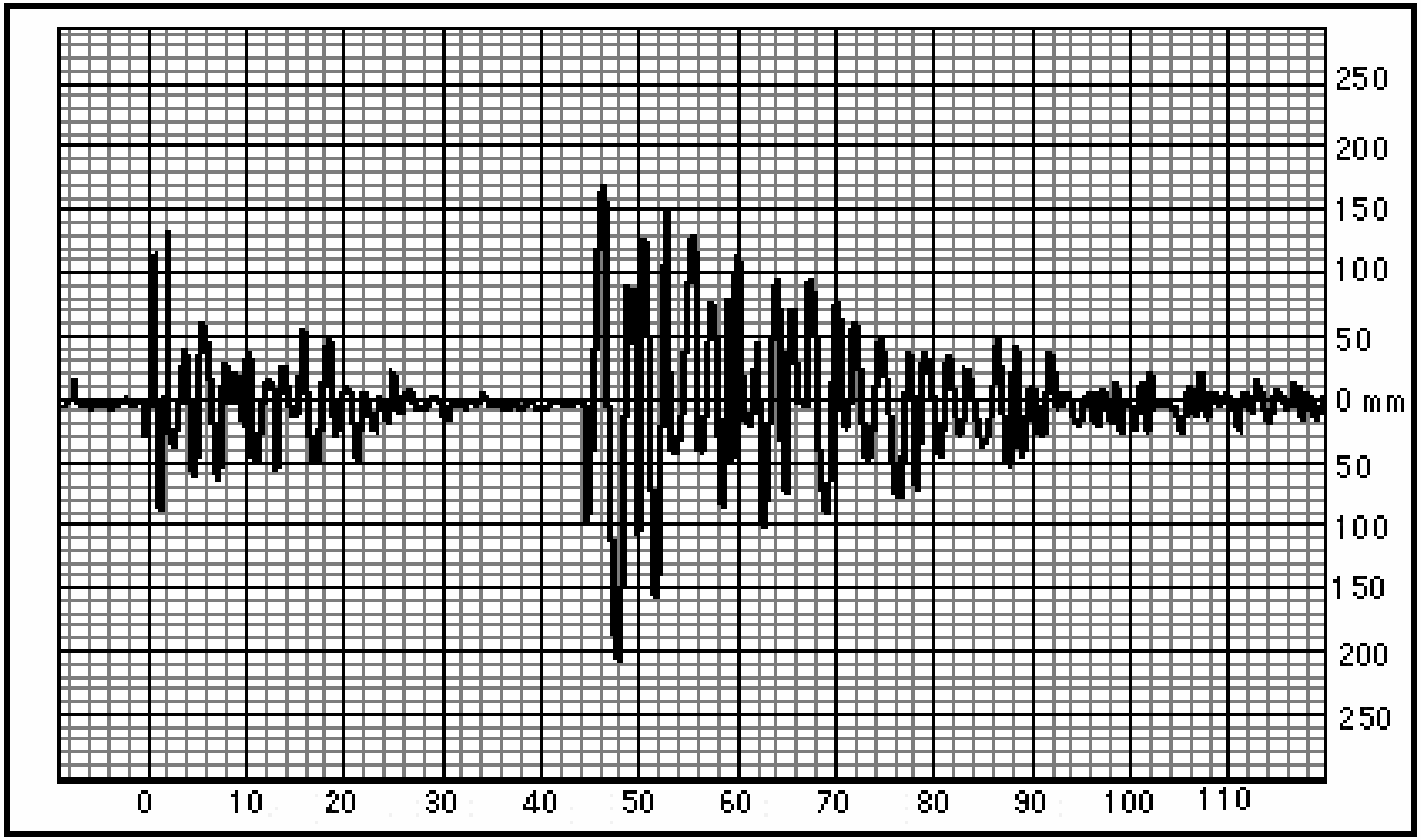


Akita, Japan P - S = 71 seconds

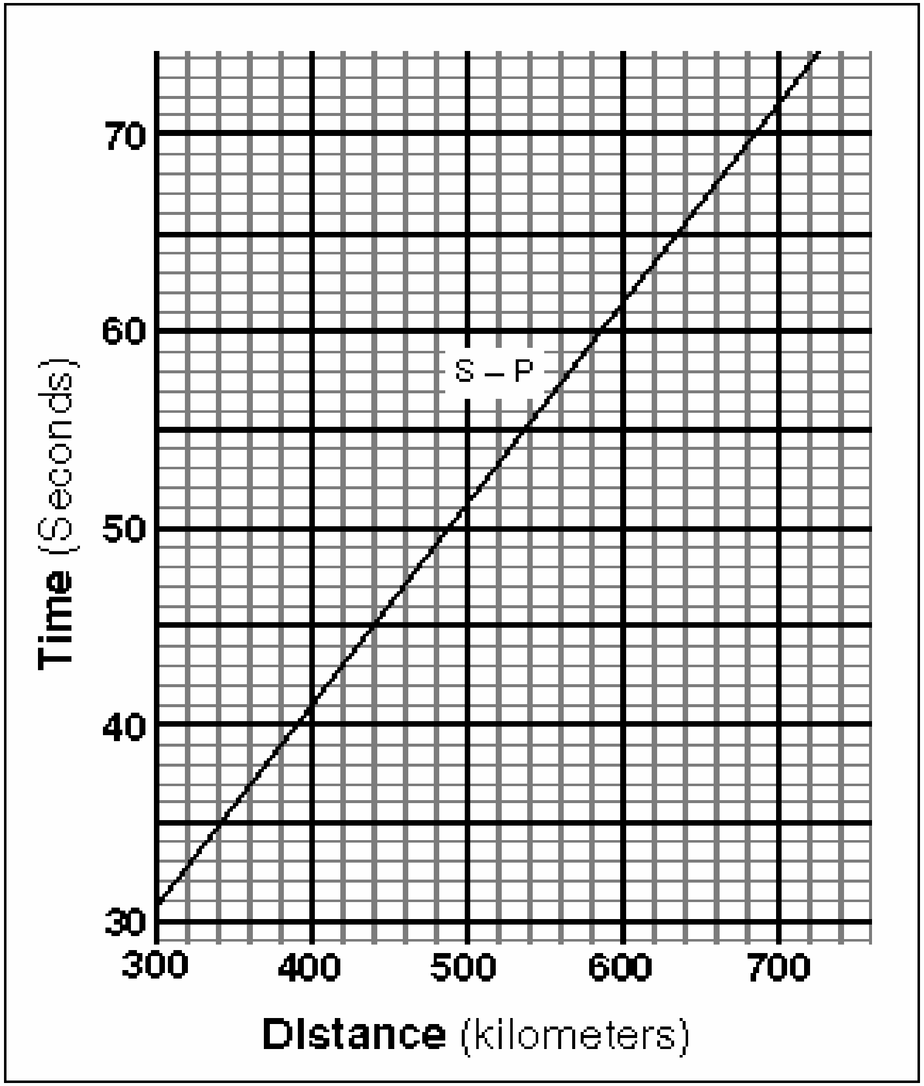


Pusan, South Korea

P - S = 56 seconds



Tokyo, Japan
P - S = 44 seconds



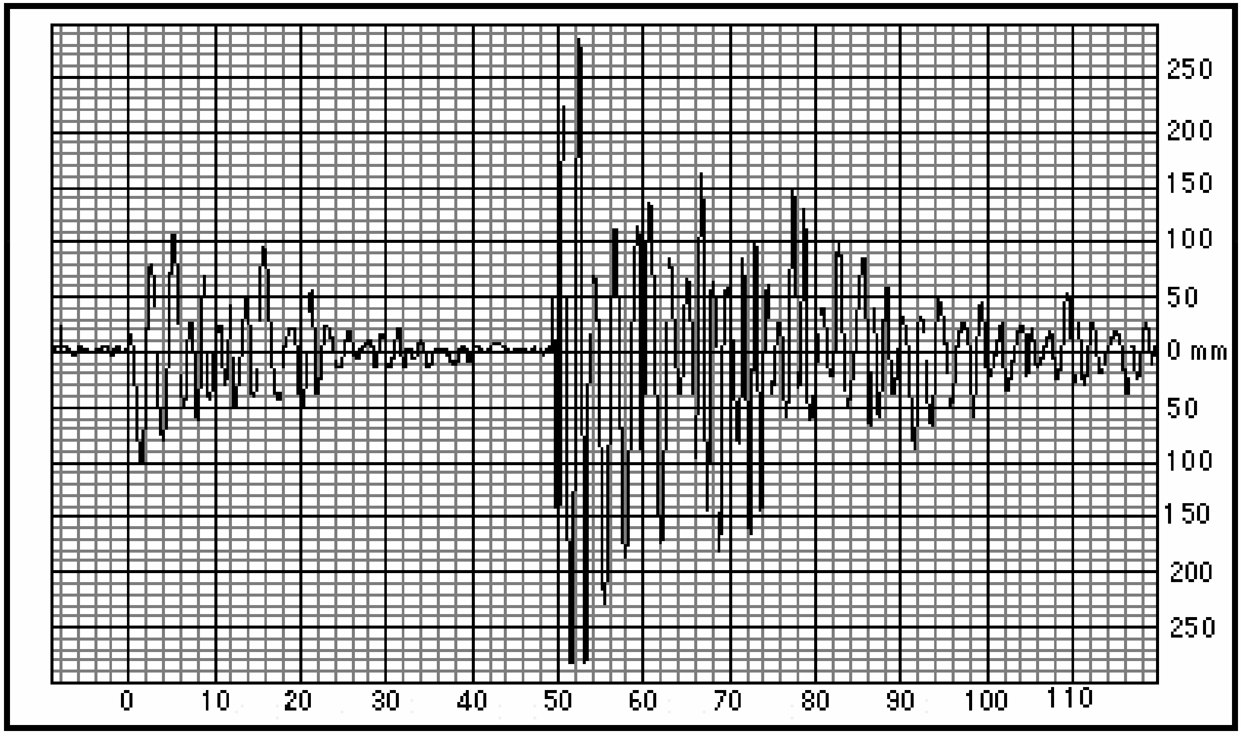
Akita, Japan
P - S = 71 seconds
Distance = 695 km

Pusan, South Korea
P - S = 56 seconds
Distance = 540 km

Tokyo, Japan
P - S = 44 seconds
Distance = 430 km

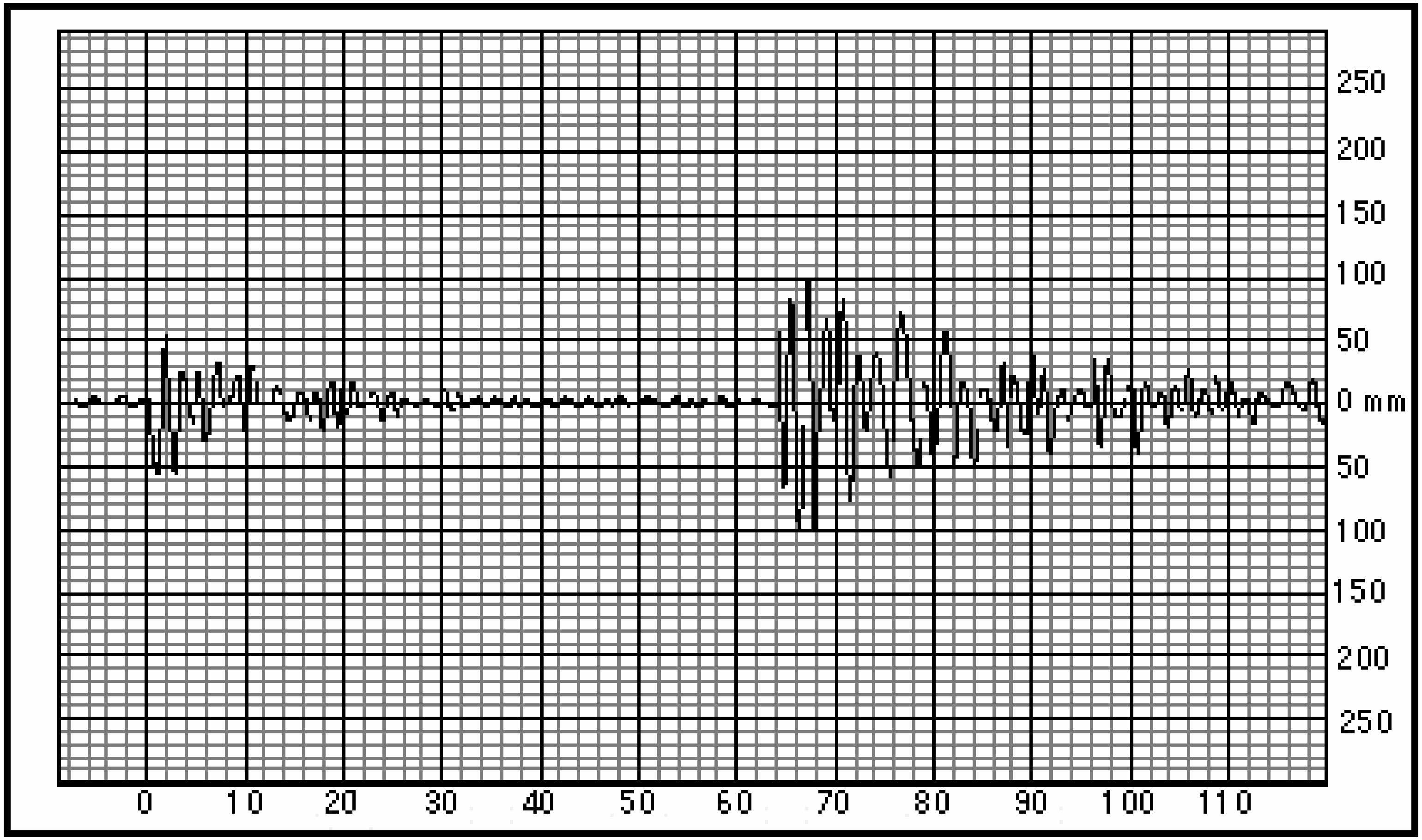

Vladivostok
Hakodate
North Korea
Kuji
Sea of Japan
Akita
Sendai
South Korea
Toyama
Japan
TOKYO
North Pacific Ocean
Nagoya
Pusan
Hiroshima
Kobe
Osaka

A Real Example - Loma Prieta (1989)



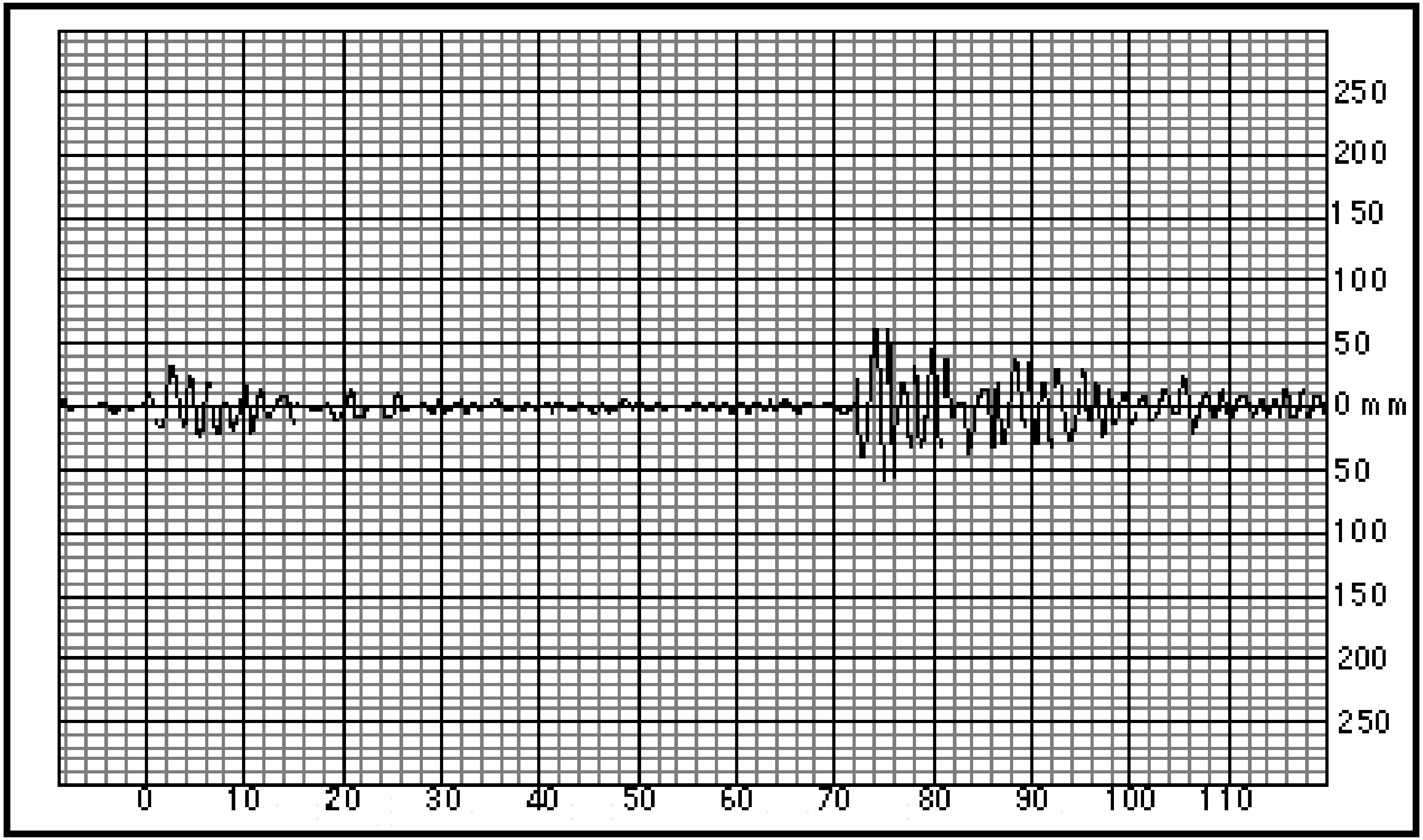
Eureka,CA

S - P = 49 seconds , Distance = 480 km
Amplitude = 280 mm



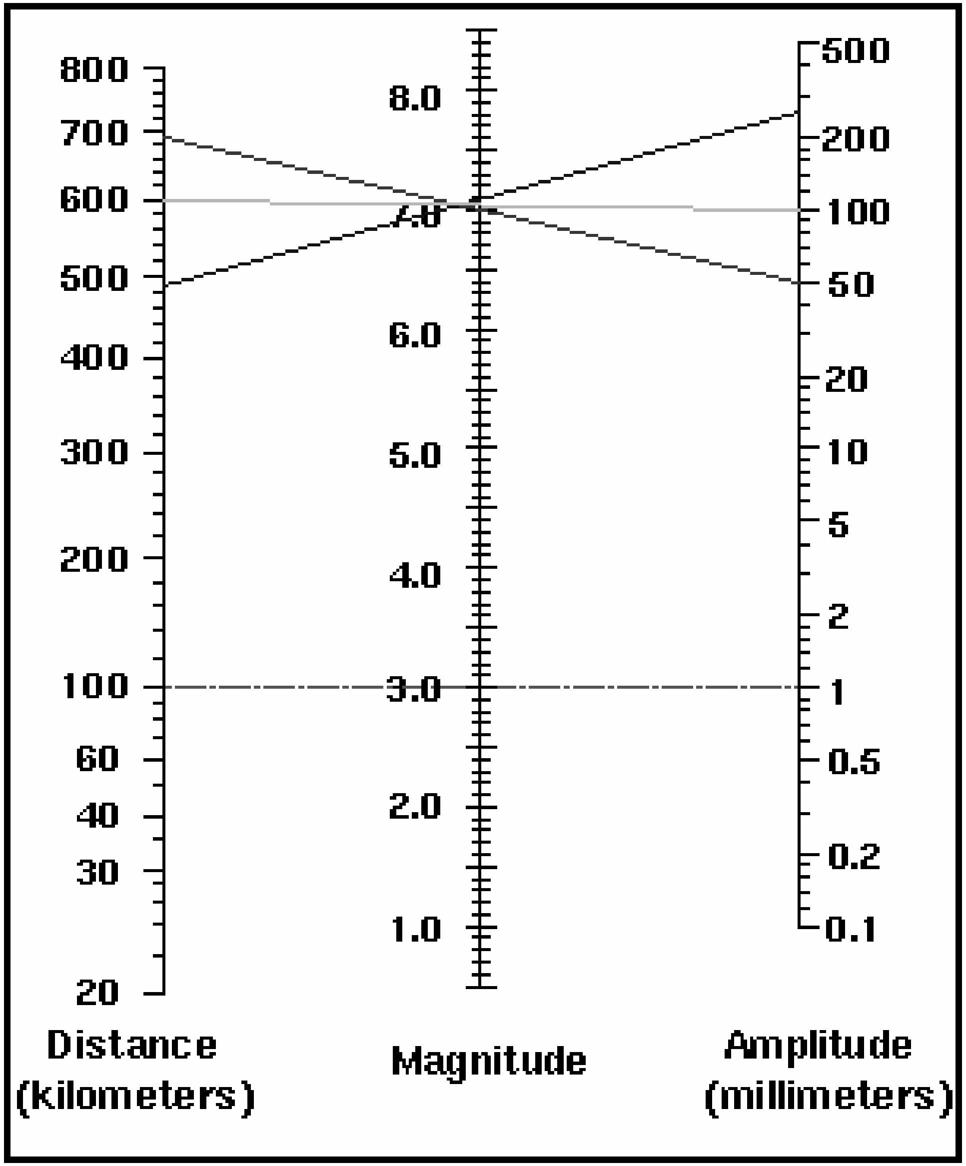
S - P = 64 seconds , Distance = 600 km
Amplitude = 100 mm

Las Vegas, NV



S - P = 72 seconds , Distance = 690 km
Amplitude = 60 mm

Elko, NV



All 3 records give the same magnitude (as they should) of about 7.0 on the Richter scale.

Earthquake Destruction

The destructive effects of earthquakes include:

- **1- Ground shaking**
- **2- Fire**
- **3- Tsunami**
- **4- Aftershocks**
- **5- Landslides**
- **6-Panic, disruption of vital services, and shock**

The hazards

The numbers of deaths and injuries depend on several factors: **magnitude, duration of shaking, local geology, population density, distance from epicenter, construction practices, and disaster response planning**.

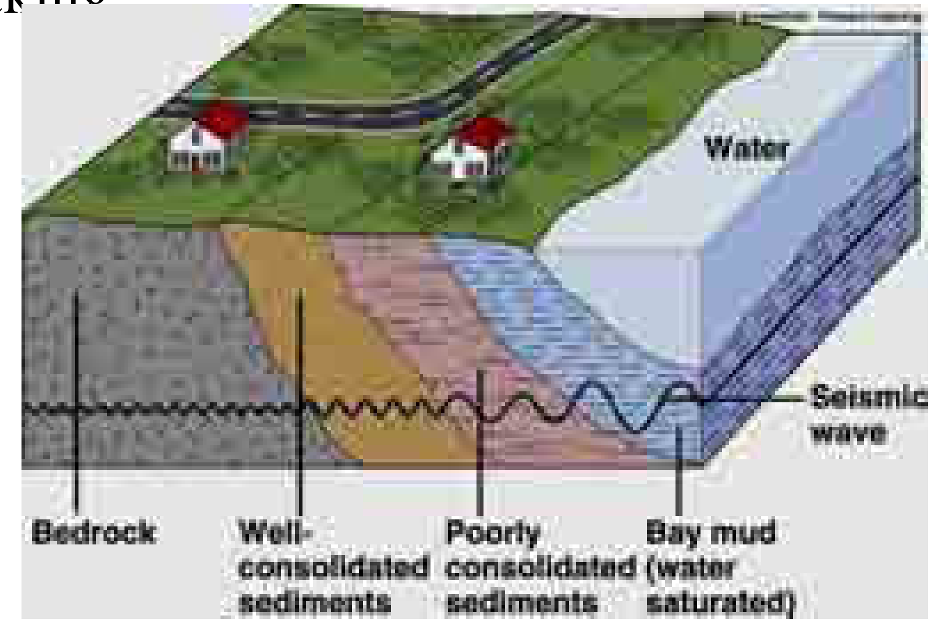
- Even the time at which an earthquake occurs affects its destructiveness. Earthquakes during working hours in populated urban areas are most destructive and cause most fatalities and injuries.
- When the above factors are considered, it is obvious why small earthquakes are sometimes more destructive than larger ones.

Earthquake damage

Ground Shaking

The effects of ground shaking, toppling buildings, falling glass, etc., cause more
injuries than any other earthquake hazard. In addition to magnitude and distance to epicenter, earth materials beneath a site (bedrock versus sediment) strongly influence the amplitude and duration of seismic waves, and thus ground shaking

Amplitude and duration of S-waves is greater in poorly consolidated or water-saturated material than in bedrock. Structures built on bedrock suffer less ground shaking than those built on poorly consolidated or water-saturated material



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Buildings must be designed to withstand the maximum horizontal ground shear (base shear) expected

- **Base shear is expressed as a % age of the acceleration of gravity**

Building failure

Flexible framed buildings may be deformed or knocked off their foundations

Building material and type of construction can also affect the amount of damage done by ground shaking.

- **Adobe and mud-walled buildings are most susceptible and nearly always collapse.**
- **Unreinforced brick and poorly built concrete structures are easily destroyed as occurred in Tangshan, China, in 1976. The entire city was nearly leveled when buildings, mostly unreinforced brick, collapsed.**

Liquefaction

The passage of seismic waves can cause the material on which buildings are constructed to behave as a fluid. This process, known as liquefaction, **is especially prevalent in fill and water-saturated sediment, which tend to liquefy when shaken.** Structures are tilted or toppled when liquefaction causes the material on which they are founded to flow.

Fire

In urban areas fires sparked by severed electrical and gas lines pose a great hazard. Fire caused 90% of the damage in the San Francisco earthquake of 1902. In 1923 an earthquake caused fire that destroyed 75% of all the houses (most of which were wood) in Tokyo

Tsunami

The "tidal wave," or more correctly, tsunami, is an ocean wave produced
by an earthquake. In the open ocean, tsunami are less than 1 m high, but
can rise to 30 m or more as they enter the shallow water of coastal areas.
Tsunami cross the oceans traveling at several hundred kilometers/hour
and can de miles from their

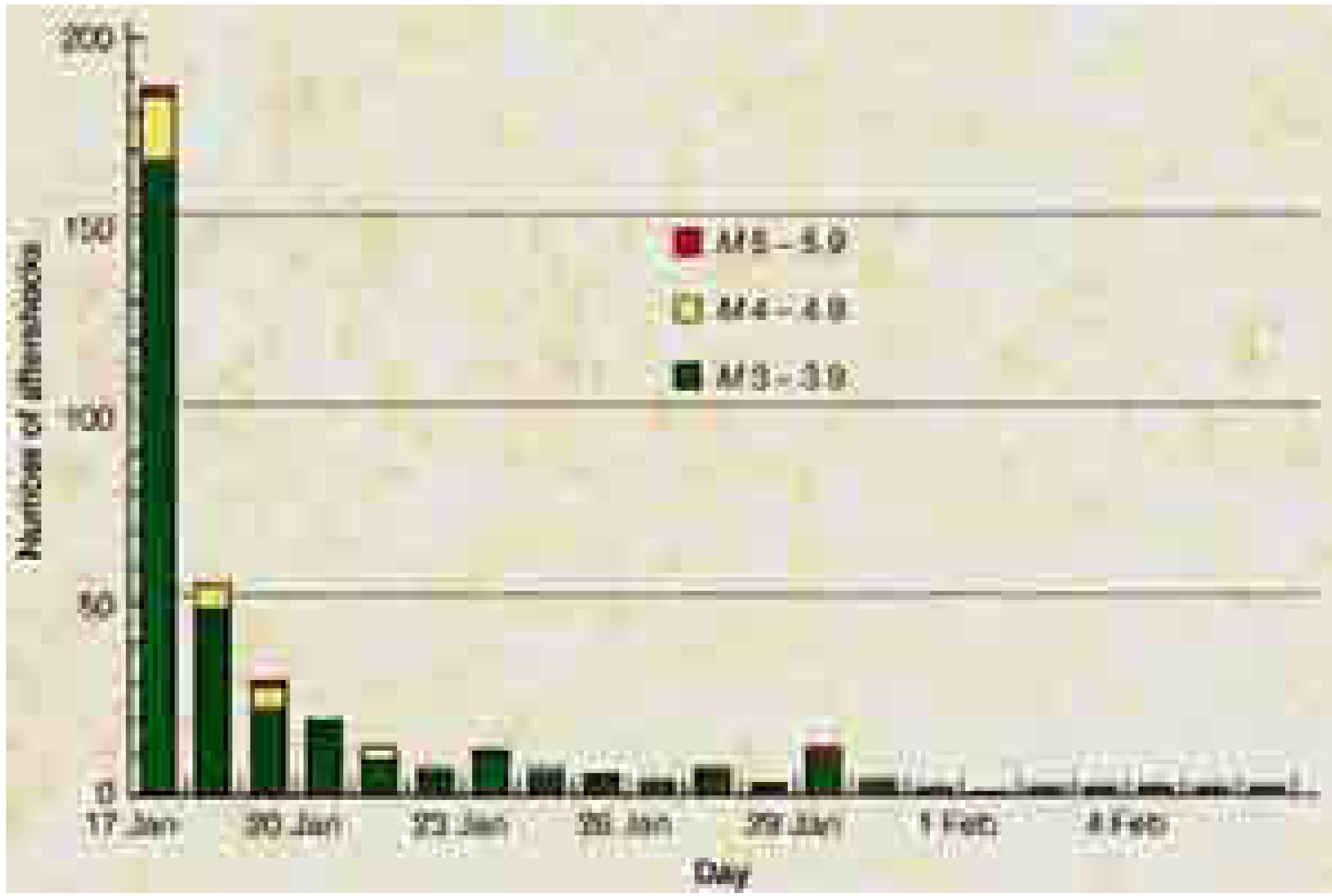
Ground Failure - landslides

In mountainous areas, earthquake-triggered landslides are a particular hazard and have caused much destruction and many deaths.

• Of the 100,000 killed in the earthquake of 1920 in Ganso, China, most died when cliffs of wind-laid silt collapsed. In 1970, an earthquake-induced avalanche killed 66,000 in Peru.

Aftershocks

- **Aftershocks can be a major problems as structures are already weakened**
  - **2500 after Northridge, 3 > M5**



Can Earthquakes Be Predicted?

• Successful earthquake prediction includes the location, strength, and time frame for occurrence of the quake. Successful predictions remain rare.

• Only three quakes have been predicted since the 70’s

• Haicheng, 1975

• Songpan-Pingwu, 1976

• Longling, 1976

• At Haicheng a rapid increase in ground tilt and microearthquakes led to the evacuation of several million people. 9 hours later a major earthquake destroyed many buildings, but killed no one.

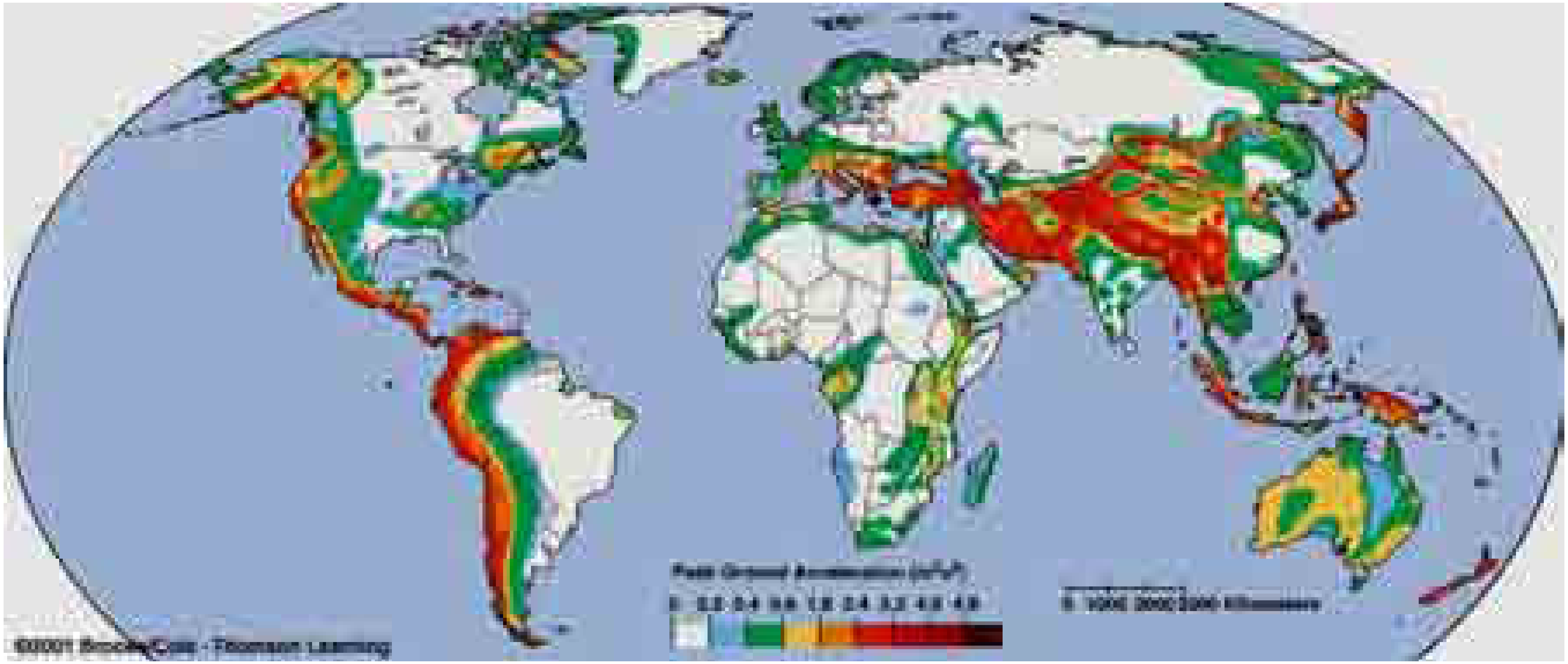
• In contrast at Tangshen they could only say that an earthquake would occur in the next couple of months, no evacuation took place and the M = 8 quake killed 250,000

Three methods can be applied to earthquake prediction

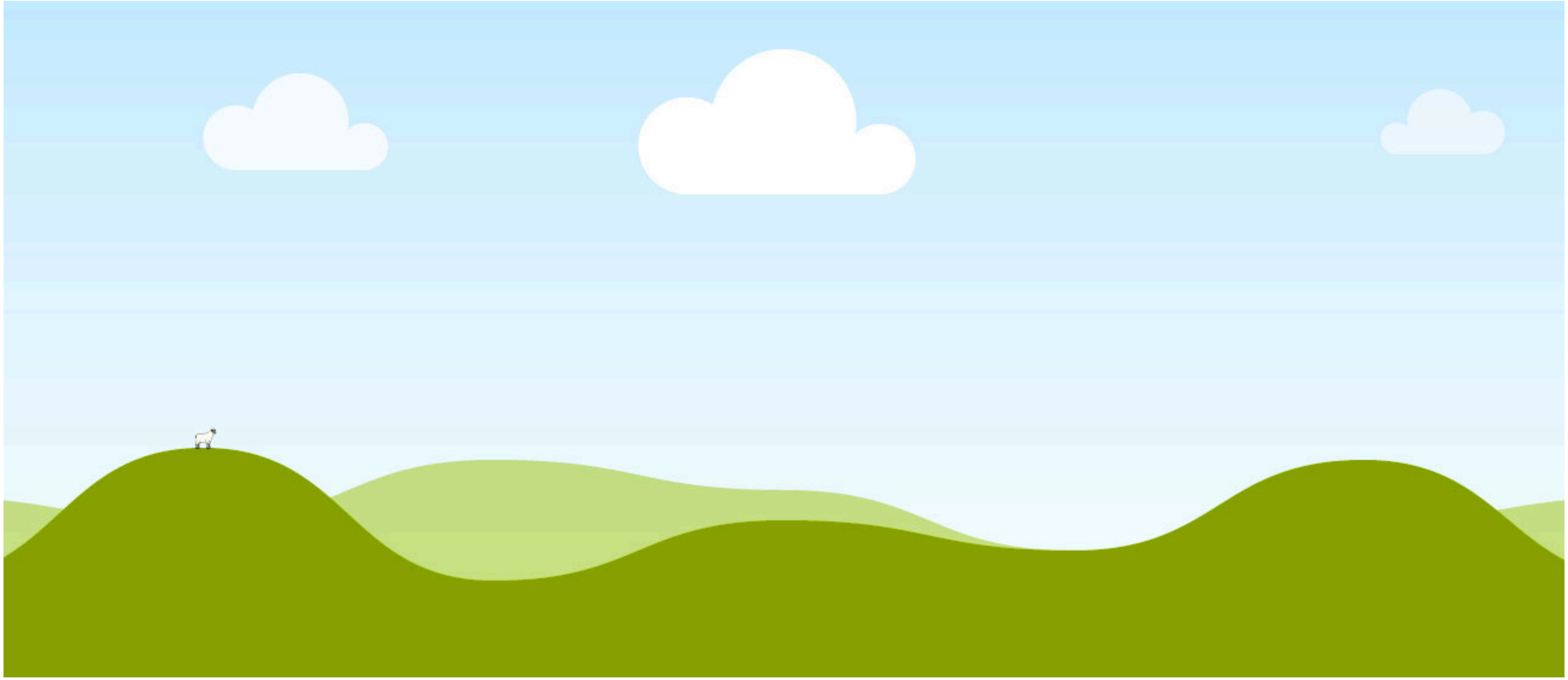
- **Statistical**
- **Geophysical**
- **Geological**

Statistical

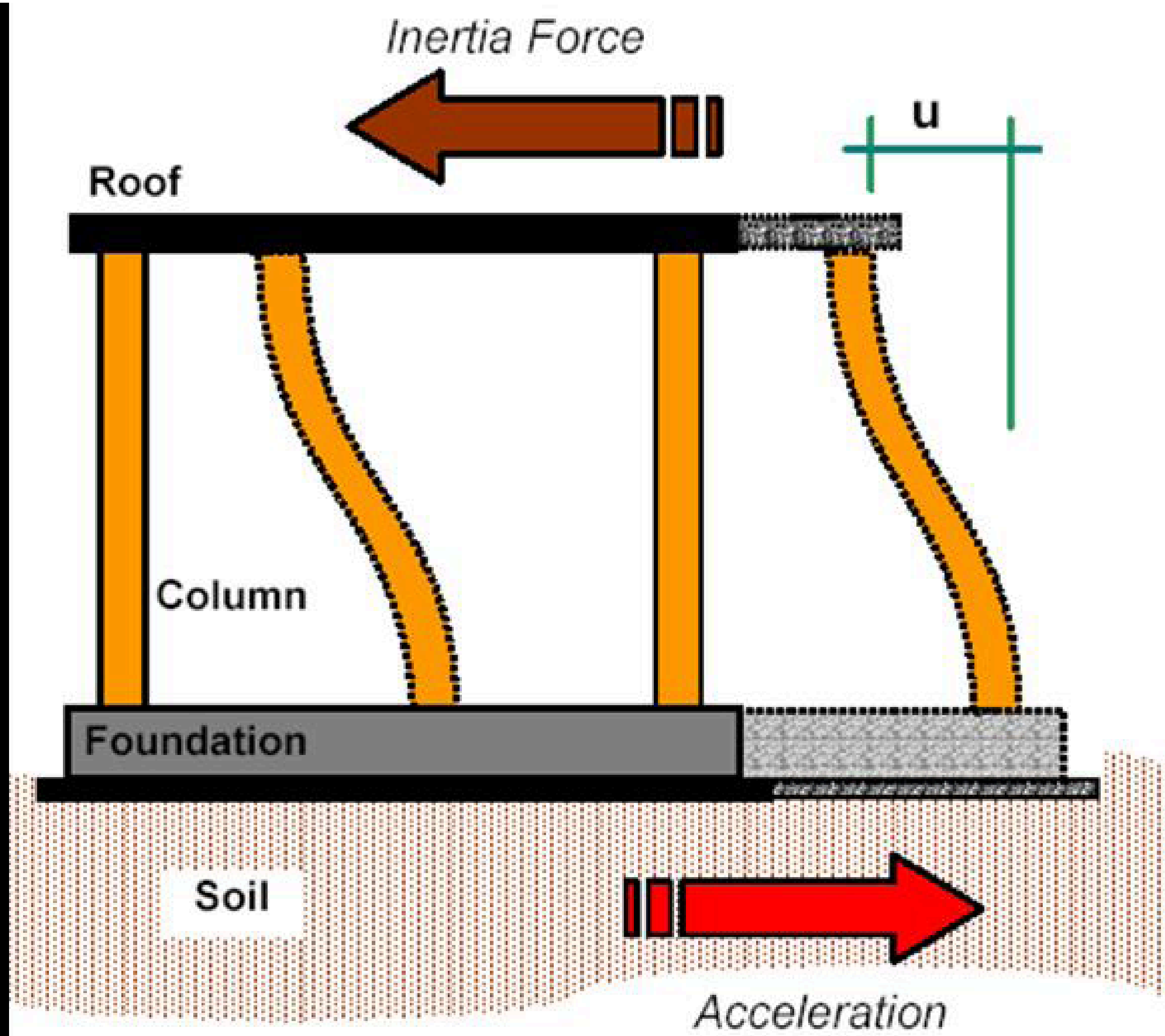
Seismic risk maps, constructed based on historic records and the distribution of known faults, can be used to assess the potential severity and likelihood of future earthquake



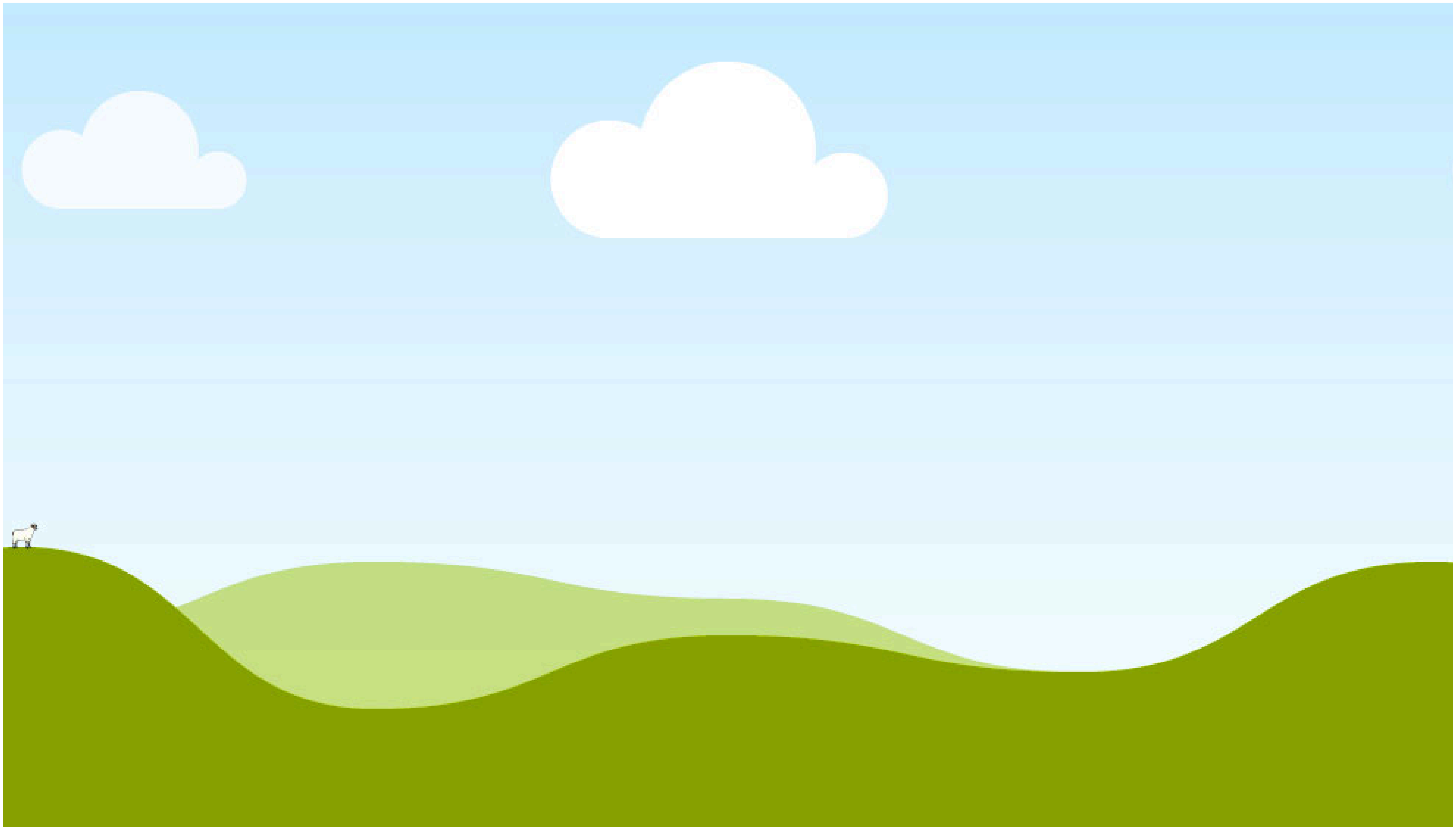
Seismic effects on Structures

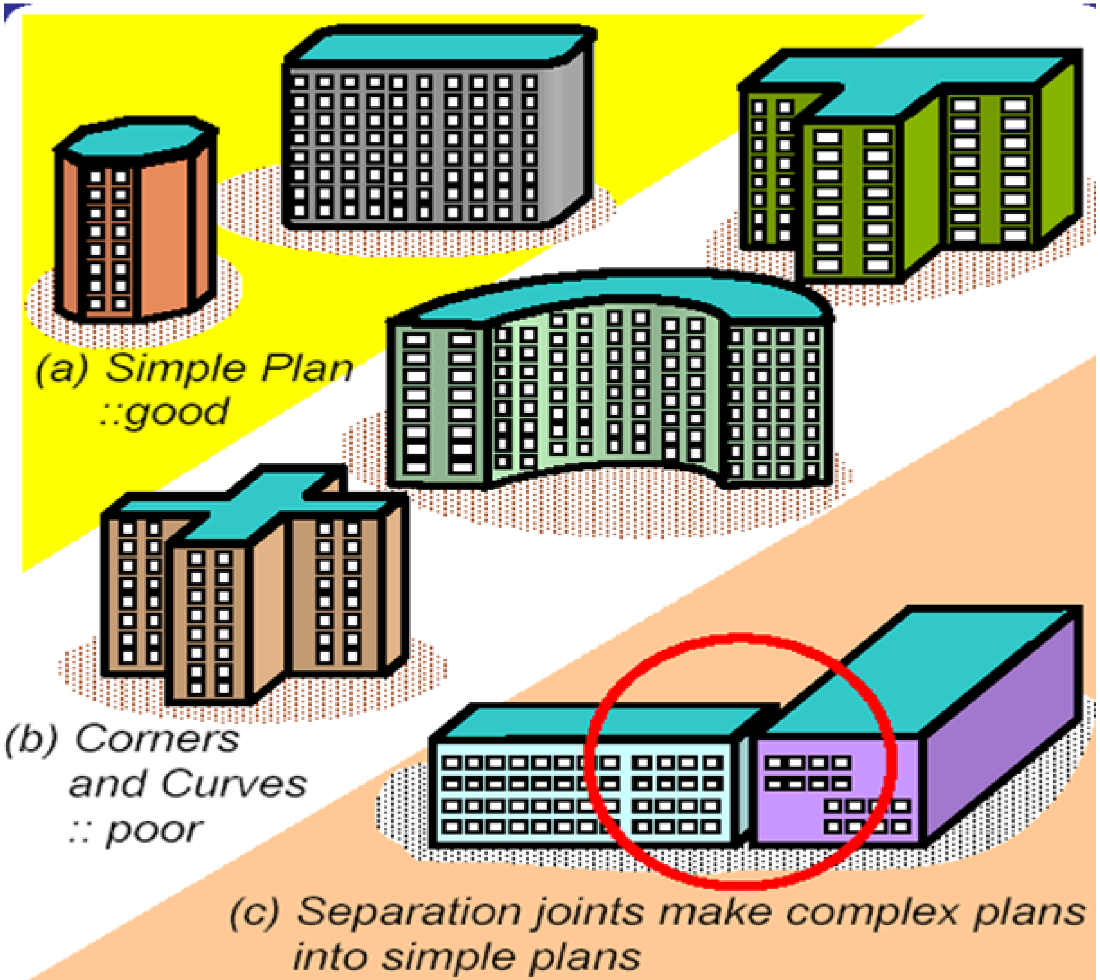


Effect of inertia is a building when shaken at its base

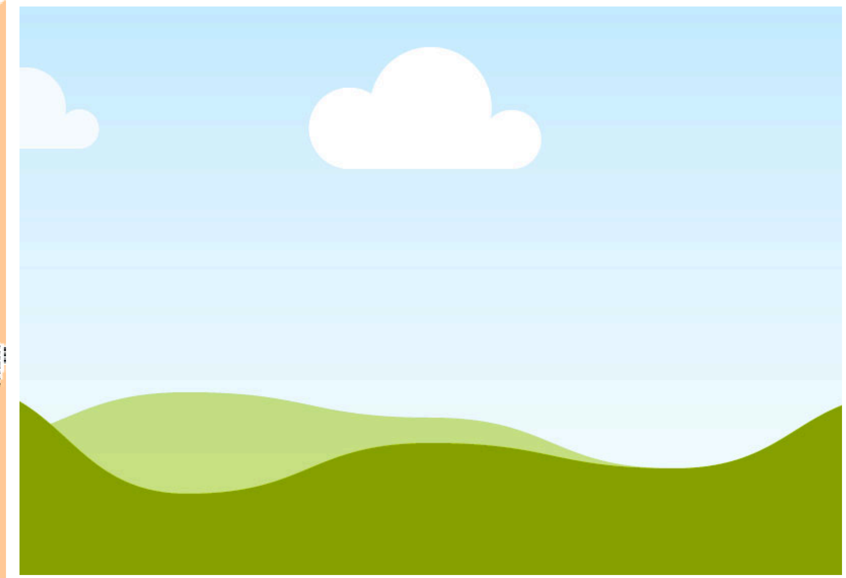


Inertia force and relative motion within a building





Simple plan shape buildings do well during earthquakes.

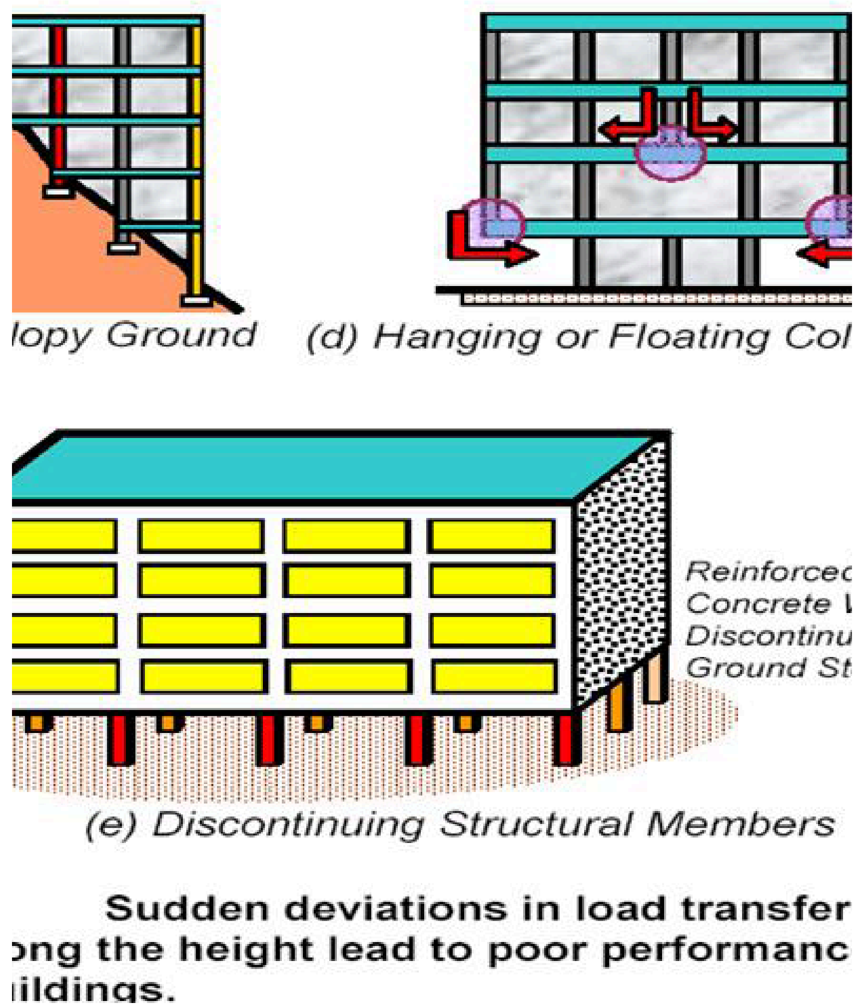


Some engineering designs have poor behavior in earthquakes:

1. Buildings on slops with unequal columns lengths will cause twisting and damage in the shorter columns.

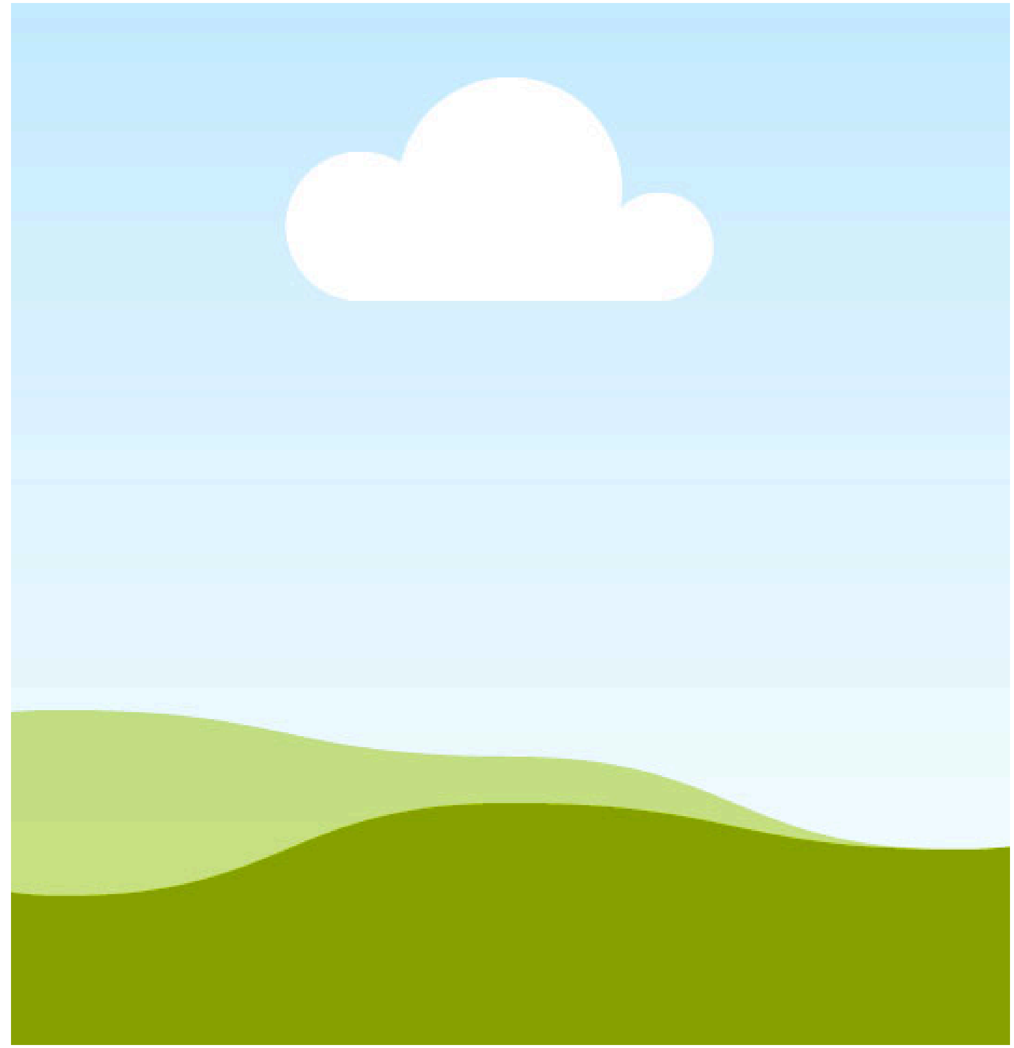
2. Buildings with columns ends at intermediate stories and do not go all the way to the foundation (have discontinuity in the load transfer path)

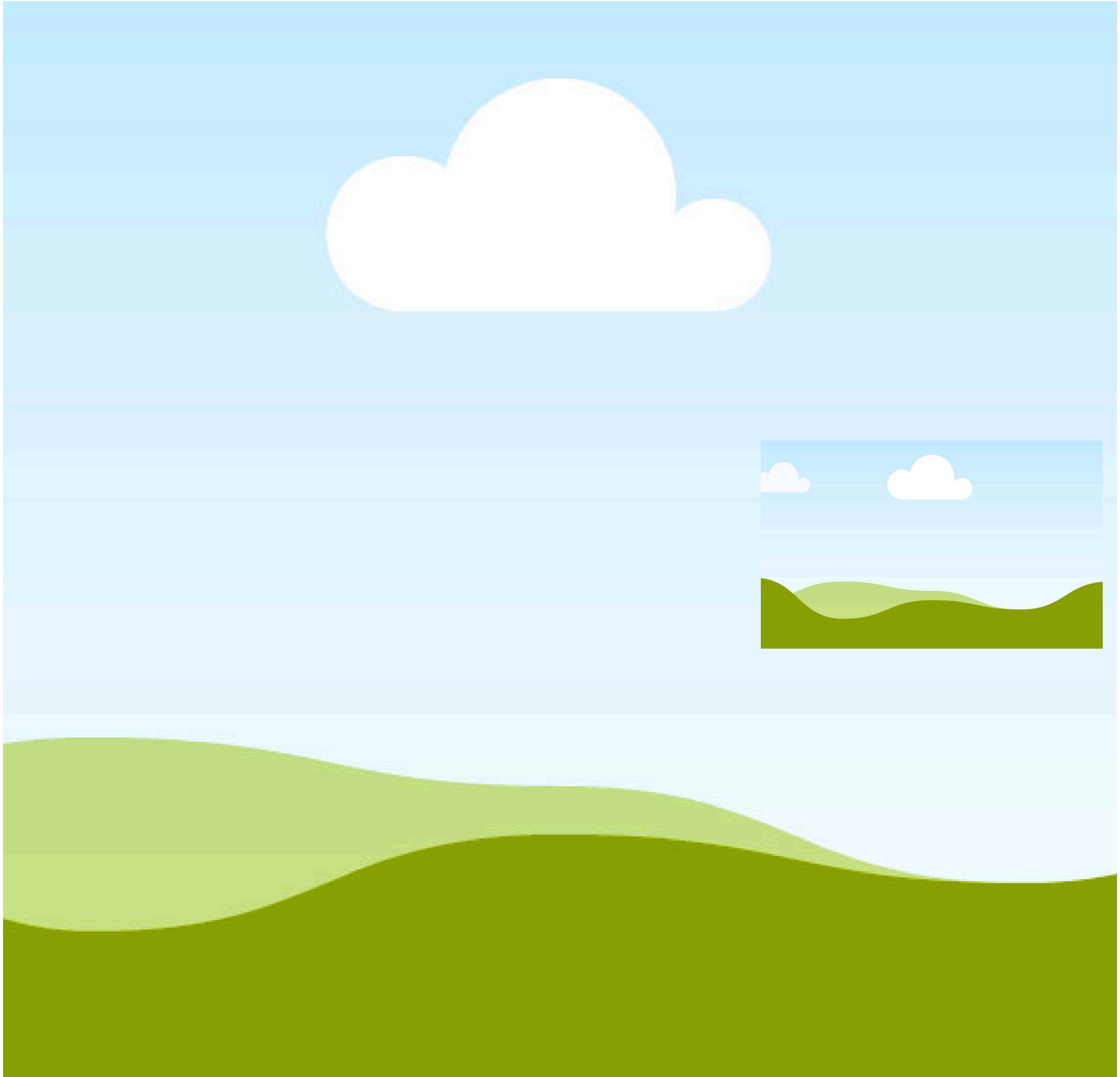
3. Buildings with reinforced walls that do not go all the way to the ground and stop at an upper level are liable to get severely damaged during earthquakes



Earthquake resisting buildings

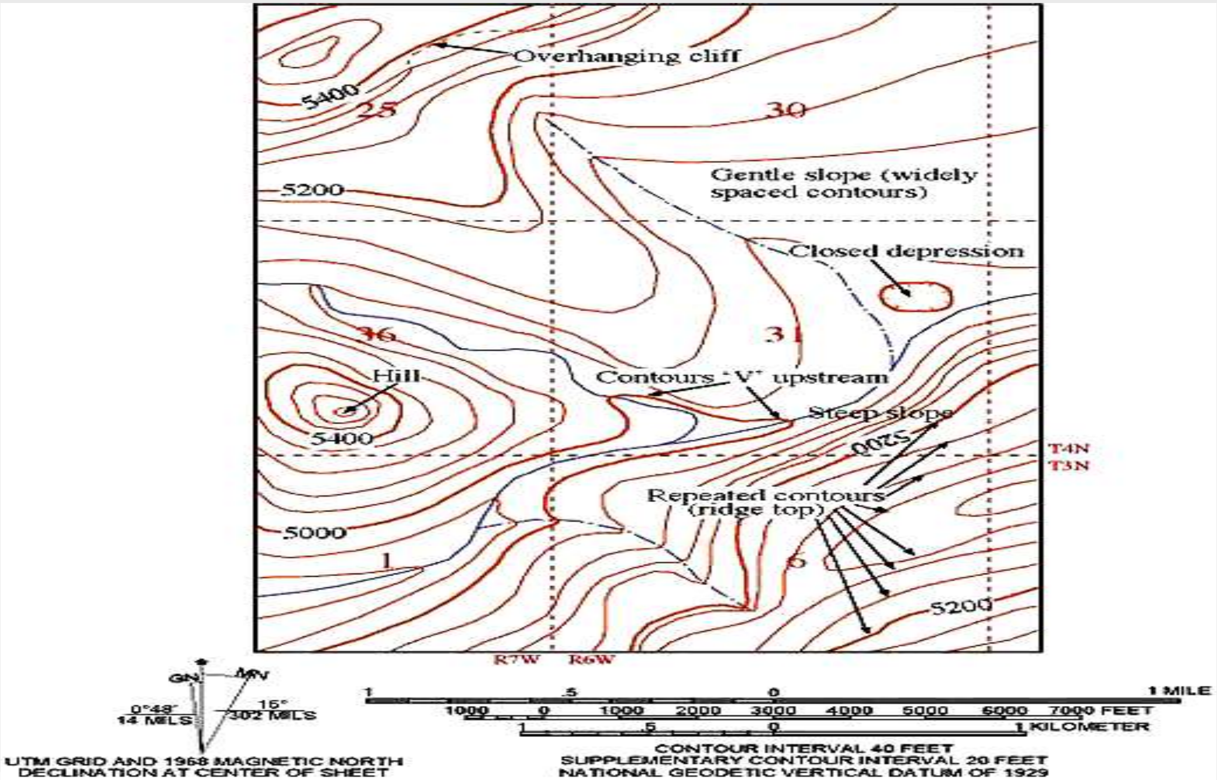
Engineering does not looking for completely earthquake resisting buildings that will not be damaged even during the rare strong earthquake. Such building will be too expensive. The engineering intention is to make buildings earthquake resistant, that resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus safety of people and content is assured in earthquake- resistant buildings. .





Engineering Geology

Topographic Maps



- Hussien aldeeky

Maps are a two dimensional representation, of an area or region. There are many types of maps, each with a specific function. As an example:

Bathymetric maps, illustrate the topography of the ocean floor

topographic maps show the topography of the earth's surface above sea level.

Street maps show the locations of streets, highways and roads.

Demographic maps: used to show statistical changes in a population (age, race, education, etc) for a specific region.

geologic maps: shows the distribution of various types of bedrock in an area maps may vary in content, scale, and size,

they all have several things in common: publishing information (title, the author of the map, year printed), the contour interval, the scale of the map, a North indicator, and a legend stating what each of the symbols and lines on the map represent

A geologic map

involves three levels of information:

1. The information that any map needs to function as a scale model of the world, including

A scale : compares distances on the map with distances on earth.

An indication of the location in the real world that it represents.

Representations of roads, bodies of water, buildings, etc.

2. Information about the surface topography of the mapped region:

Topographic counter lines

3. Information about the bedrock:

The identity of the rocks

The orientation of strata

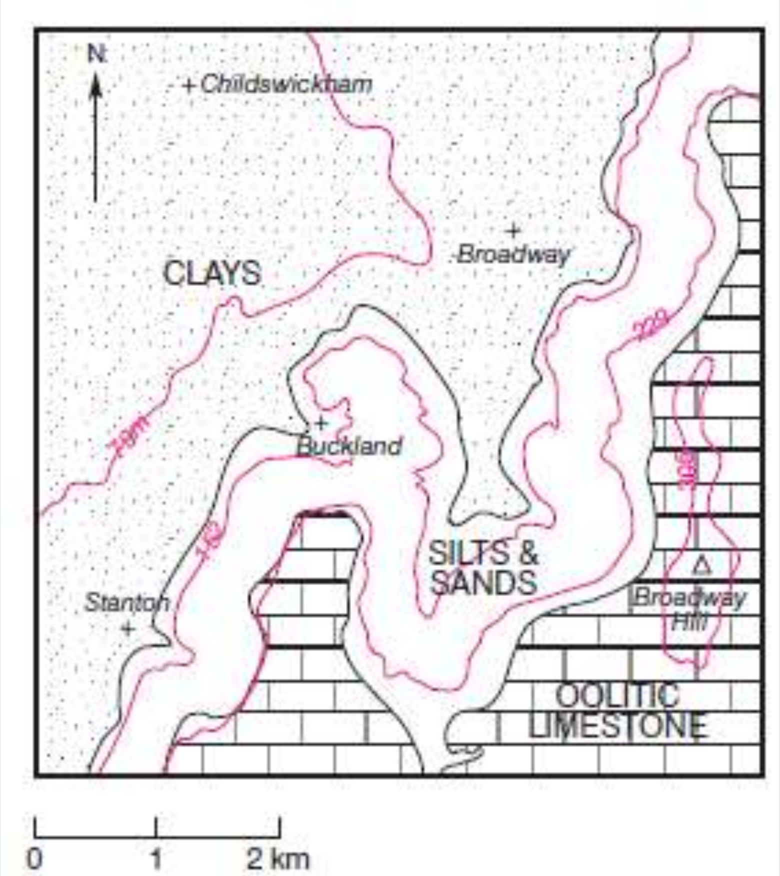
The presence of structures such as faults, folds, domes, and basins

What is a geological map used for?

a geological map is to indicate the nature of the near-surface bedrock. This is of great importance to :

• civil engineers who, for example, have to advise on the excavation of road cuttings or

• geographers studying the use of land
• companies exploiting minerals



contour map:

consists of lines . Each of these lines, called contour line, which is a line along which some quantity (temperature, for example) is everywhere the same. Contour lines bear more specific names depending on what quantity the contour map shows:

Each contour line has a value associated with it and is usually labeled with that value.

Contour maps show contour lines with values at regular intervals, including some standard reference value. The contour interval is arbitrary but should be chosen so that the contour map shows enough contours to reveal the pattern clearly without being crowded with too many contour lines

contour map should always include a title or caption that identifies the quantity shown and the contour interval used.

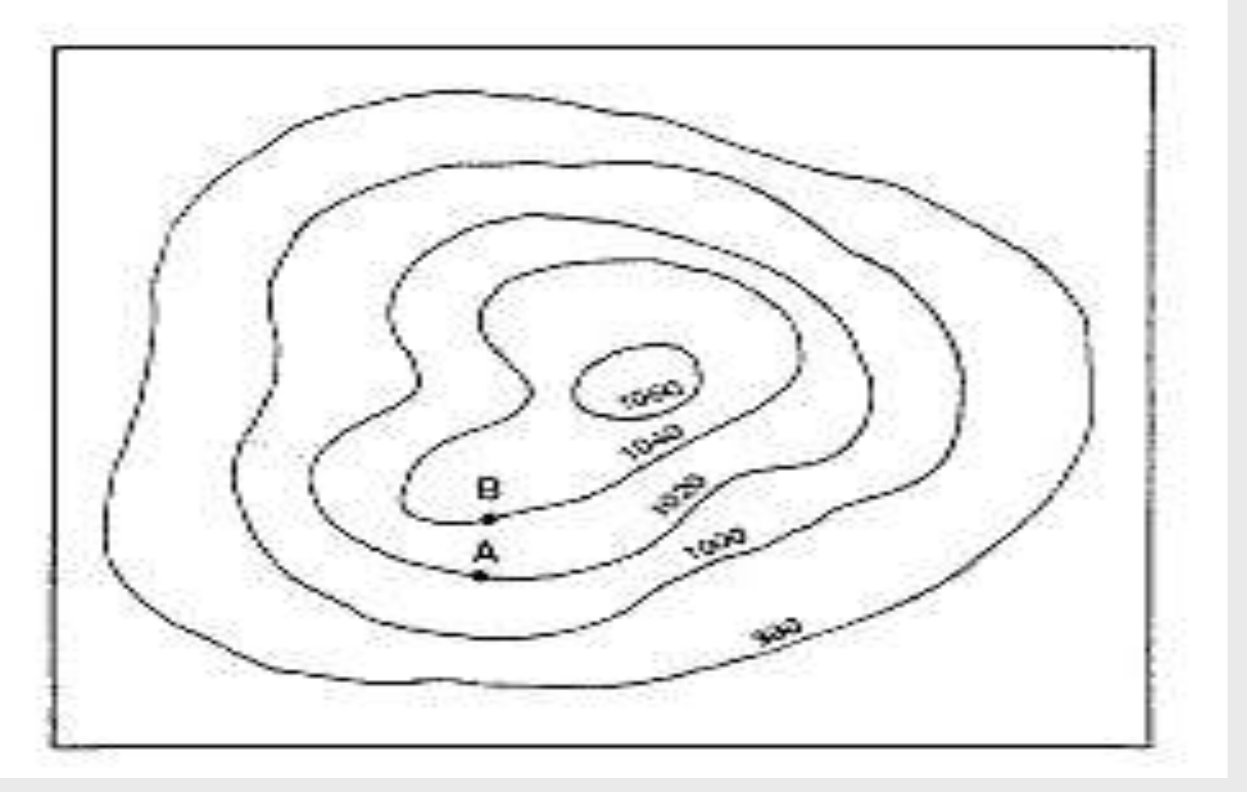
topographic map

A topographic map, also known as a contour map, is a map that shows the shape of the land using contour line.
It is a map that shows and elevation field, meaning how high and low the ground is in relation to sea level.

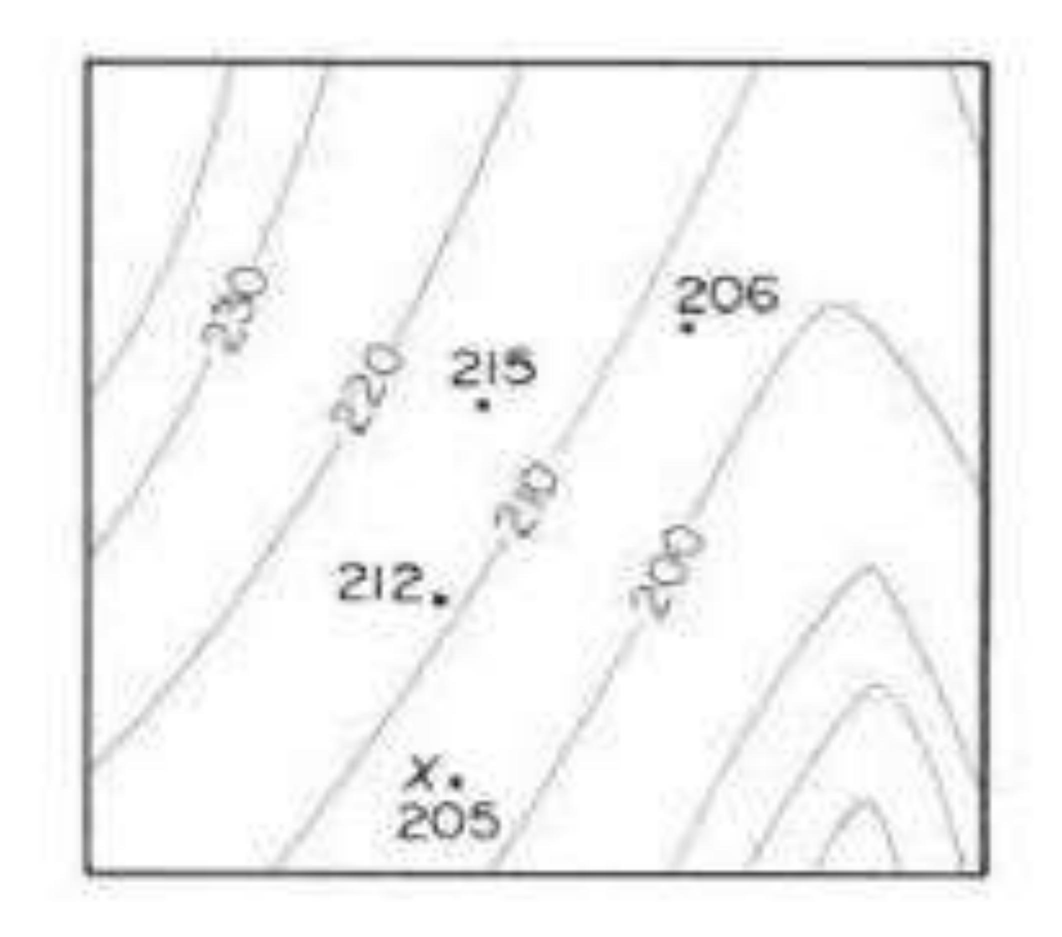
Contour lines

Contour lines are lines that connect points that are of the same elevation. They show the exact elevation, the shape of the land, and the steepness of the land’s slope.

Contour lines never touch or cross



Contour lines are generally drawn as black or brown lines on a map. Usually, every 5th contour is printed with heavier print than the others and is labeled with the elevation of the contour above sea level it is called an index contour line.



A benchmark

- **A benchmark is a point where exact elevation is known and is marked with a brass or aluminum plate. It is marked BM on the map with the elevation numbers given in feet.**
- **Benchmarks are useful to help determine contour lines.**

Map scale – compares distances on the map with distances on earth.
Legend – explains symbols used on the map.

Index contours – contour lines that are labeled to help you find the contour interval.

A contour interval

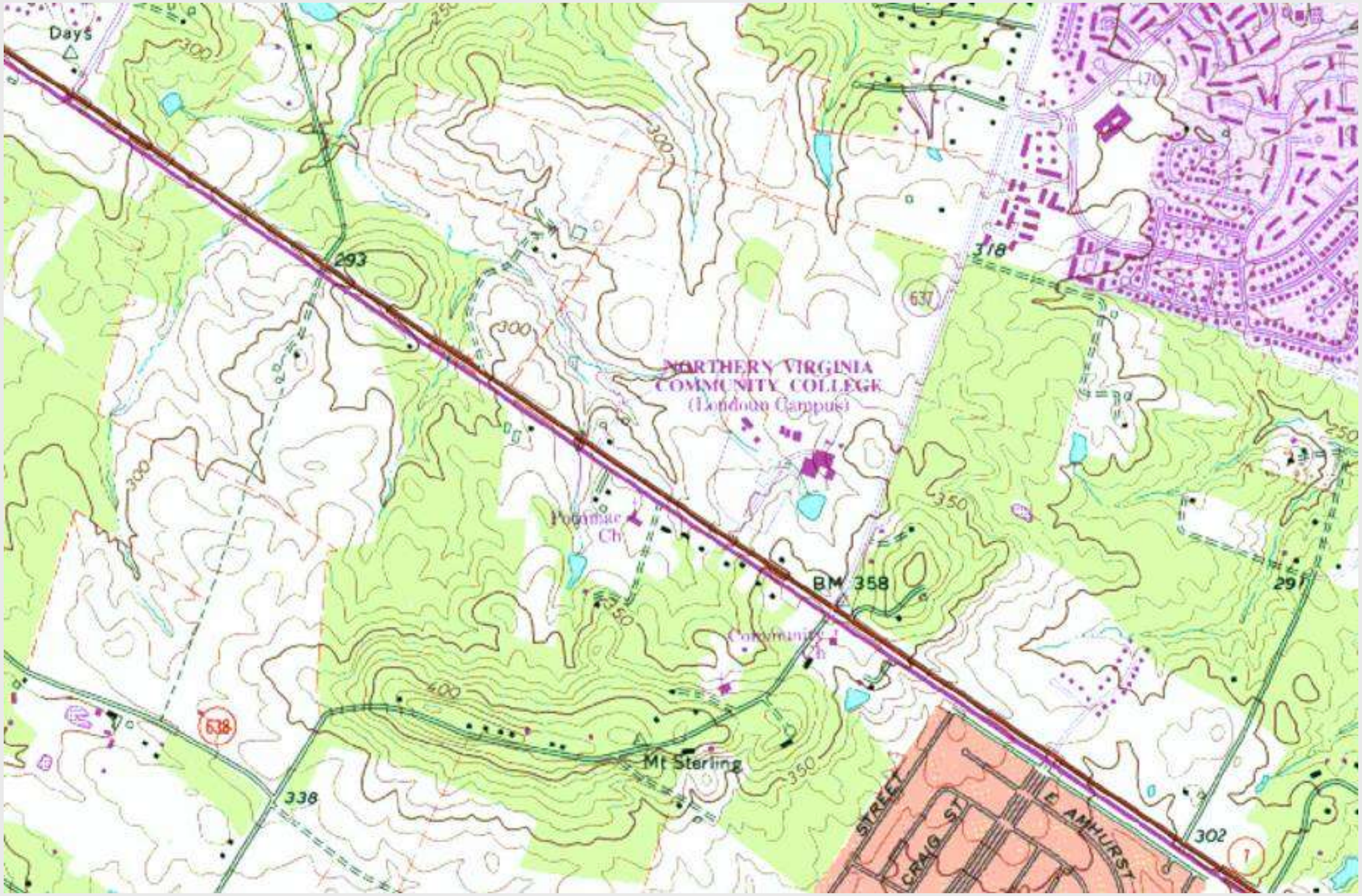
A contour interval is the difference in elevation between two contour lines that are side by side.

Remember that a contour interval is not the distance between the two lines – to get the distance you need to use the map scale.

Understanding Topographic Maps

Cartographers solve the problem of representing the three-dimensional land surface on a flat piece of paper by using contour lines, thus horizontal distances and vertical elevations can both be measured from a topographic map.

Local Topographic Map



Aerial Photo

Topographic Quadrangles

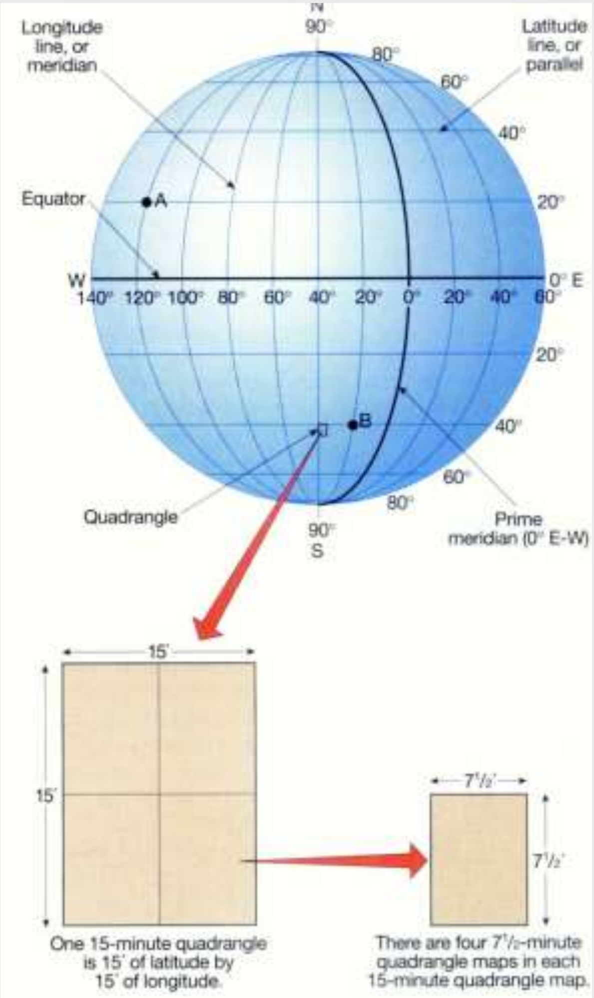
Quadrangles are sections of the Earth that are bounded by lines of

Latitude at the top (**north**) and bottom (**south**)
Longitude on the right (**east**) and left (**west**)

.

Longitude and **latitude** are measured in **degrees**, **minutes** and **seconds**.

1 degree (º) = 60 minutes (‘)
1 minute = 60 seconds (“)



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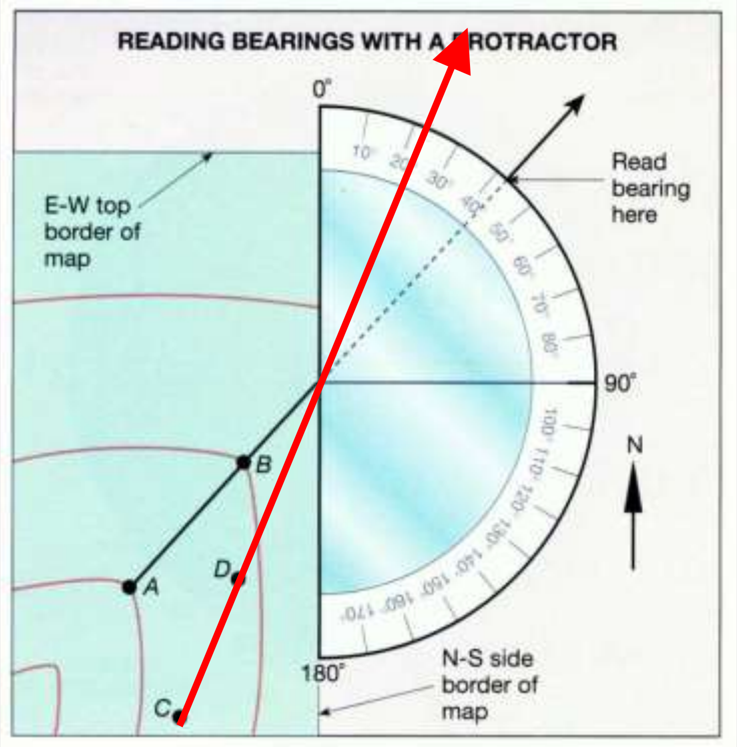
Compassing Bearing

A bearing is the *direction* from one point to another.
If direction is expressed in **degrees east or west of north**, it is called a "***quadrant bearing***."
If direction is expressed in **degrees between 0 and 360**, it is called "***azimuth bearing***."

What is the bearing from C to D?

N22°E



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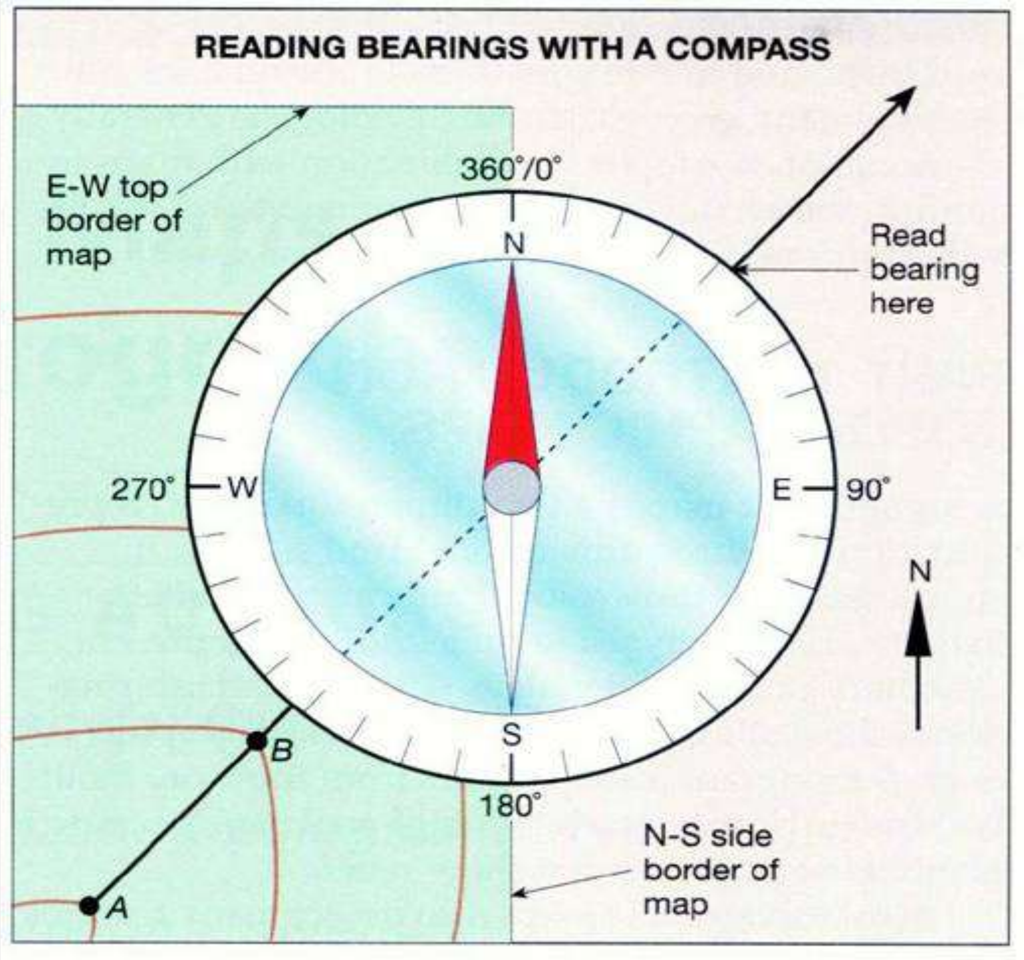
Azimuth Bearing



What is the bearing from A to B?

N45º

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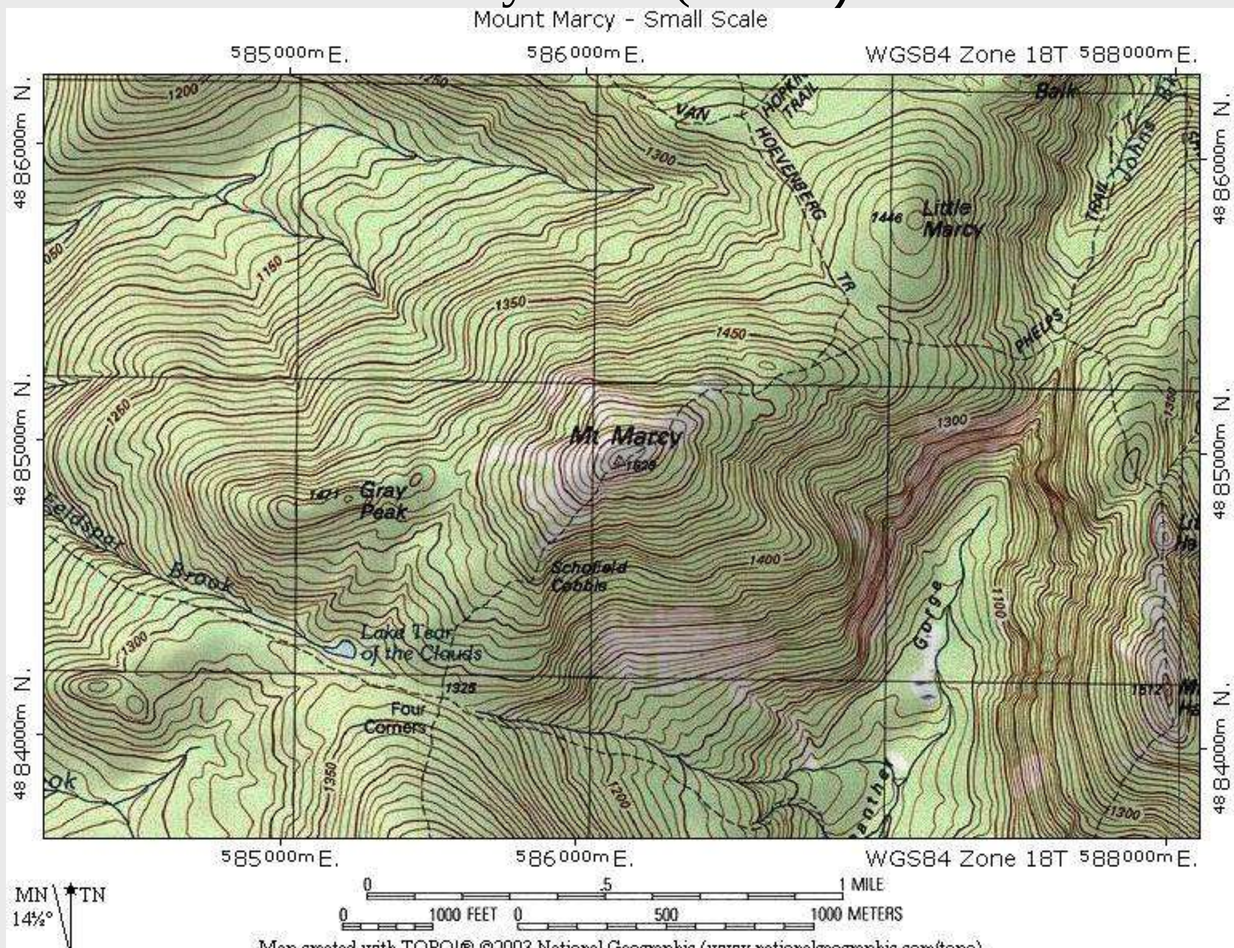
Map Scale

Map Scale: Maps come in a variety of scales, covering areas ranging from the entire earth to a city block (or less).



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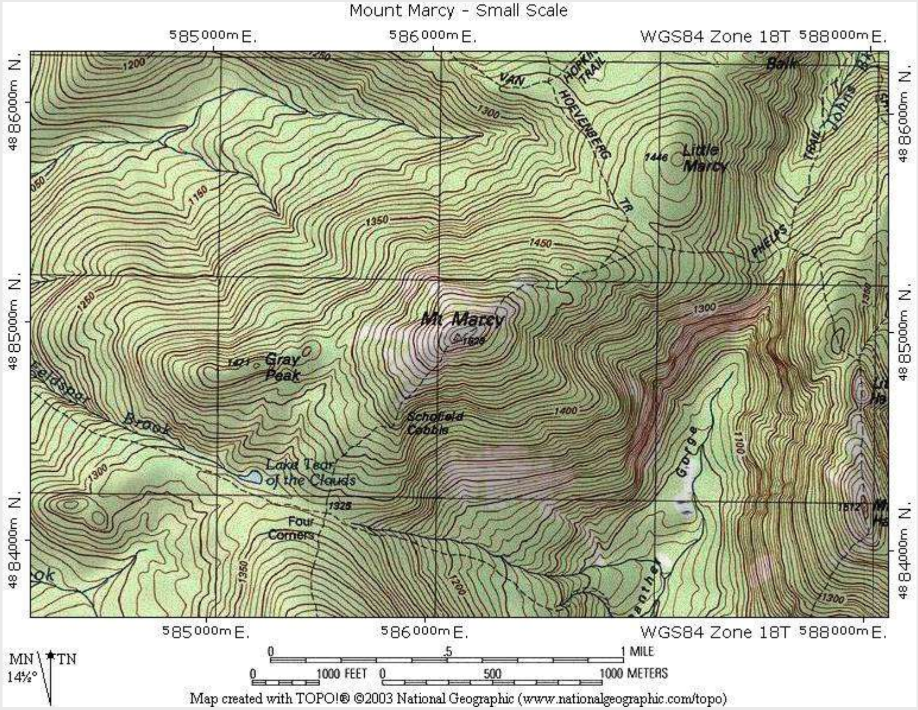
Vertical Scale (contour interval): All maps have a horizontal scale. Topographic maps also have a vertical scale to allow the determination of a point in three dimensional space.

- **Contour Lines**: Contour lines are used to determine **elevations** and are lines on a map that are produced from **connecting points of equal elevation** (elevation refers to height in feet, or meters, above sea level).



Rules for Contour Lines

1. Every point on a contour line is of the exact same elevation; that is, contour lines connect points of equal elevation.

2. Contour lines always separate points of higher elevation (uphill) from points of lower elevation (downhill). You must determine which direction on the map is higher and which is lower, relative to the contour line in question, by checking adjacent elevations.

3. Contour lines always close to form an irregular circle. But sometimes part of a contour line extends beyond the mapped area so that you cannot see the entire circle formed.

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4. The elevation between any two adjacent contour lines of different elevation on a topographic map is the *contour interval*. Often every fifth contour line is heavier so that you can count by five-times the contour interval. These heavier contour lines are known as *index contours*, because they generally have elevations printed on them.

5. Contour lines never cross one another except for one rare case: where an overhanging cliff is present. In such a case, the hidden contours are dashed.

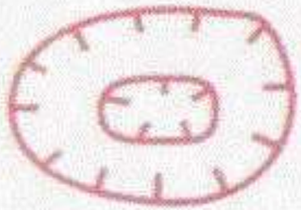
6. Contour lines can merge to form a single contour line only where there is a vertical cliff.

7. Evenly spaced contour lines of different elevation represent a uniform slope.

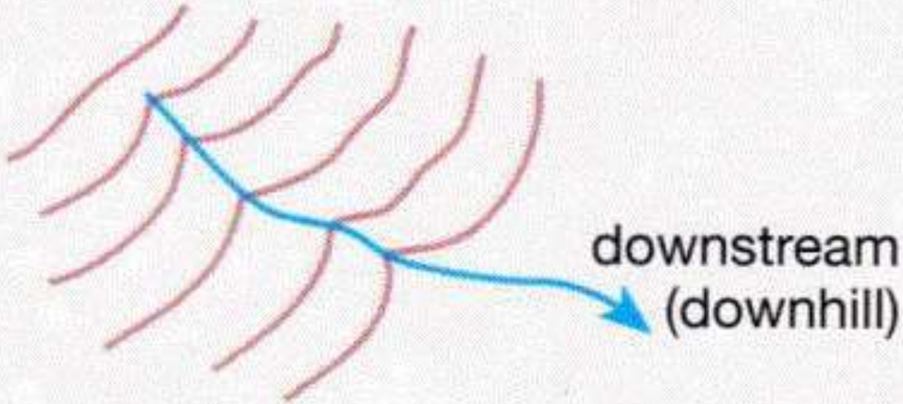
8. The closer the contour lines are to one another the steeper the slope. In other words, the steeper the slope the closer the contour lines.

9. A concentric series of closed contours represents a hill:

10. *Depression contours* have hachure marks on the downhill side and represent a closed depression:



11. Contour lines form a V pattern when crossing streams. The apex of the V always points upstream (uphill):



12. Contour lines that occur on opposite sides of a valley always occur in pairs.

13. Topographic maps published by the U.S. Geological Survey are contoured in feet or meters referenced to sea level.

Contour Lines on Ridges and Valleys

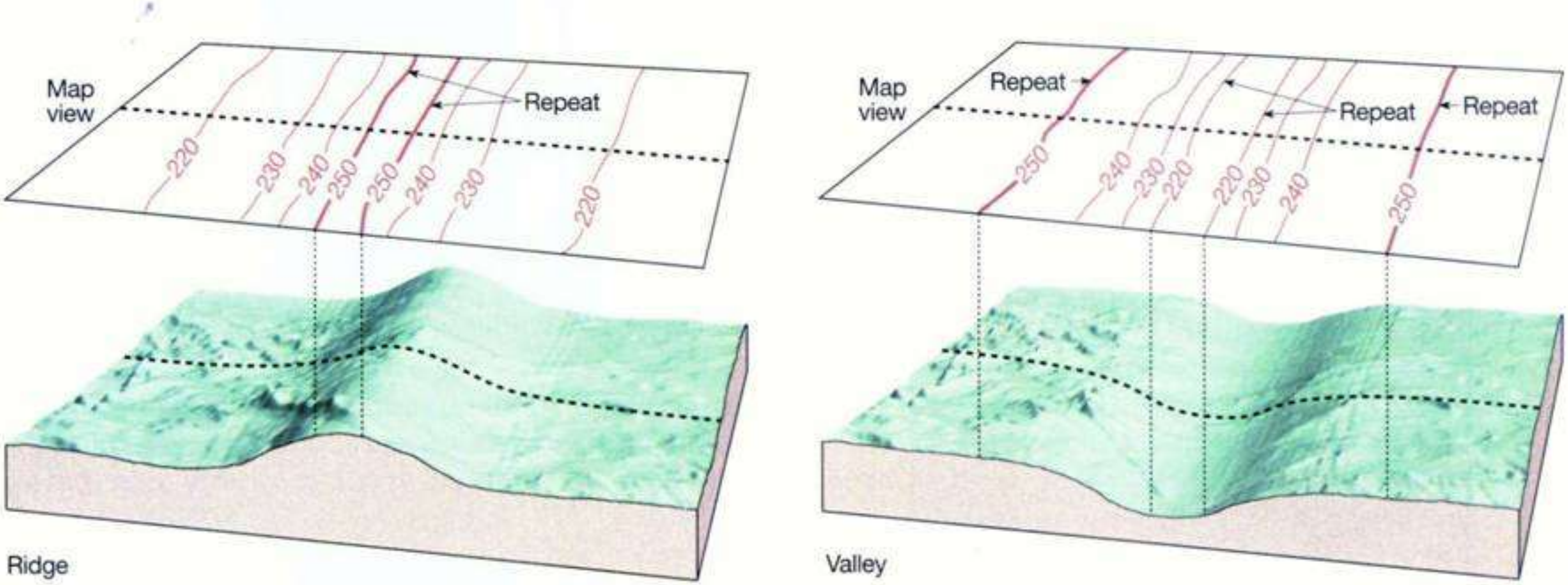


FIGURE 8.9 Contour lines repeat (occur in pairs) on opposite sides of ridges and valleys. For example, in the ridge illustration, if you walked the dashed line from right to left, you would cross the 230-foot contour line, go over the top of the ridge, and cross the 230-foot contour again as you walk down the other side.

Contour Lines on Closed Depressions

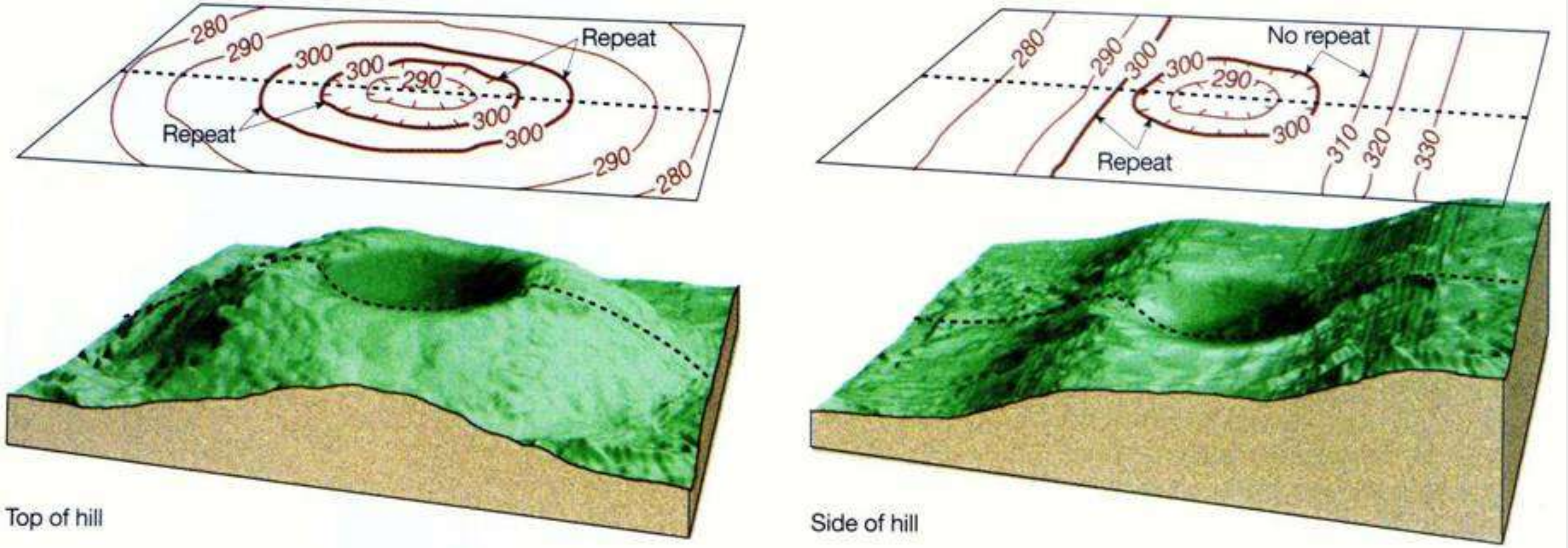
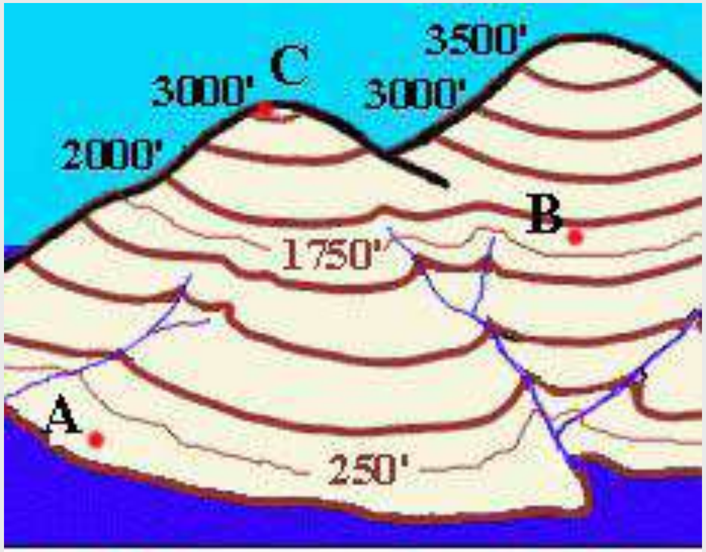
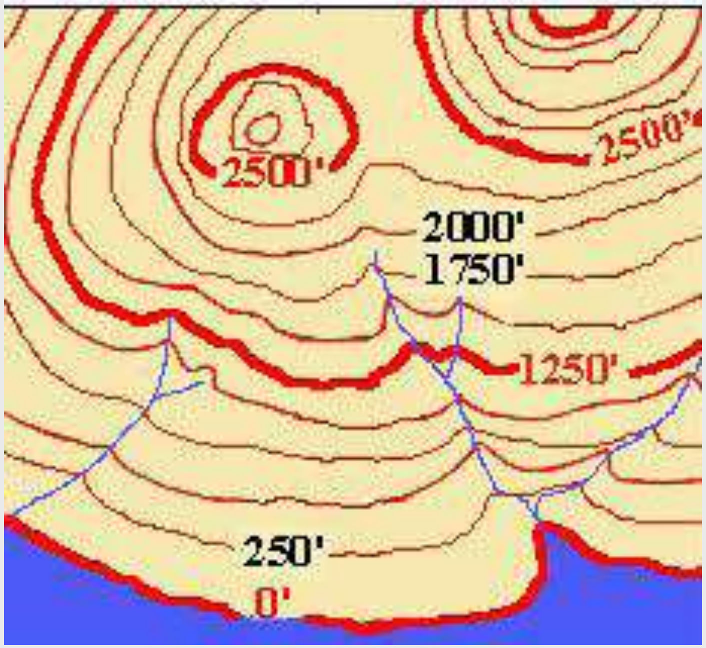
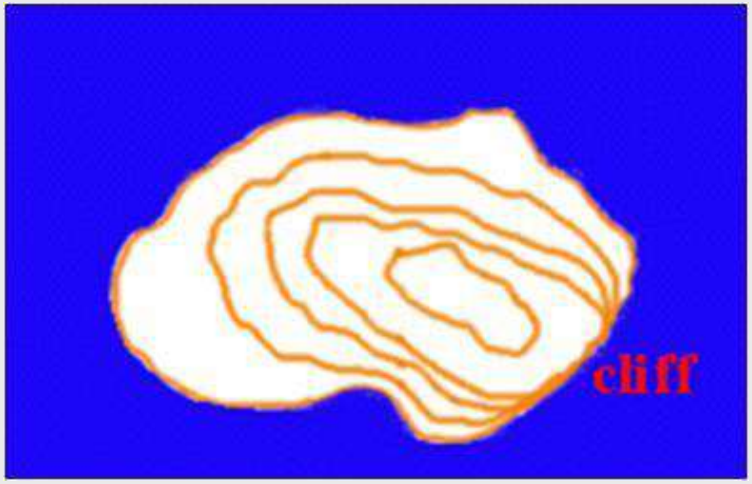


FIGURE 8.10 Contour lines repeat on opposite sides of a depression (left illustration), except when the depression occurs on a slope (right illustration).


3500'
C
3000'
3000'
2000'
B
1750'
A
250'


2500'
2500'
2000'
1750'
1250'
250'
0'


cliff


cliff

Contour Interval

The **Contour Interval** (**CI**) is the difference in elevation between two adjacent contour lines.
The **CI** can vary from map to map. Usually expressed in feet or meters.
Elevation is always referenced to **Mean Sea Level (MSL).**
MSL=0

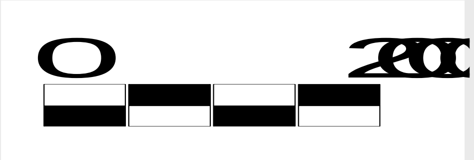
Map Scale

Several representations of scale exist:

Verbal: "one inch equals one mile"

Ratio: 1:24,000 means that the portion of the earth represented has been reduced to 1/24000th its actual size.

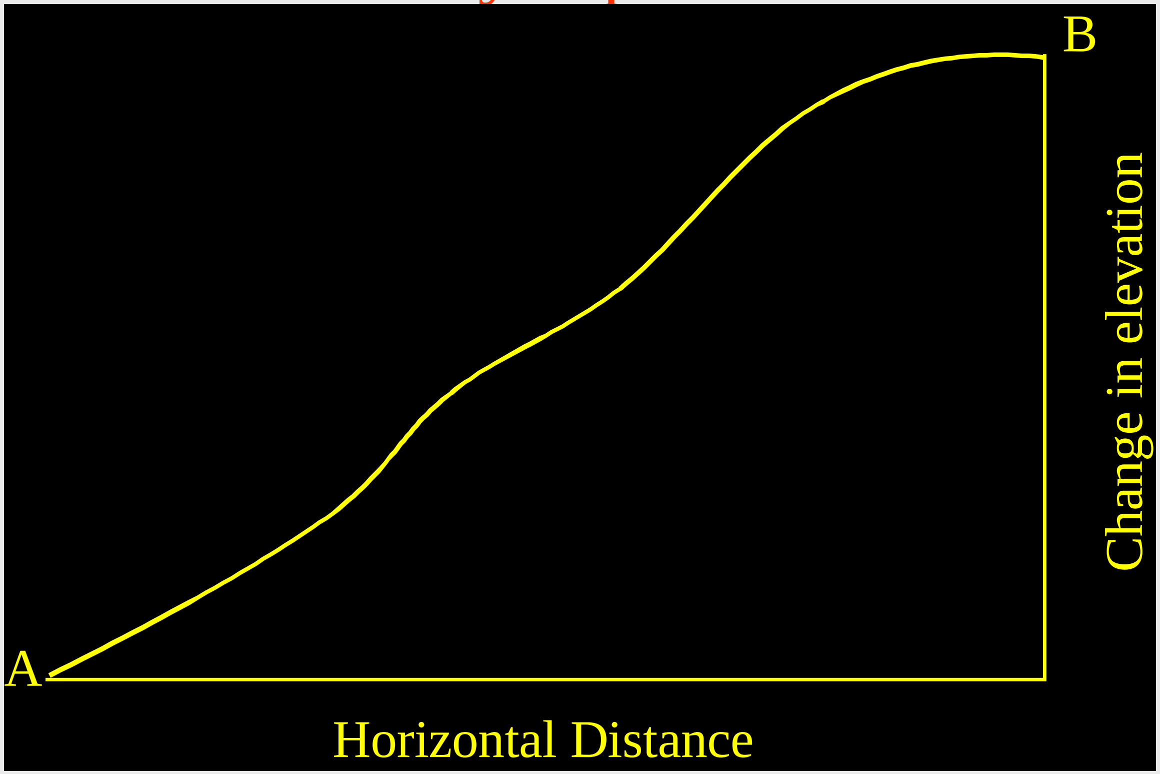
Graphic:



Calculating Gradient (or Slope)

$$\text{Gradient} = \frac{\text{Change in elevation between 2 points}}{\text{Distance between 2 points}}$$

Gradient is usually expressed as **ft/mi**.

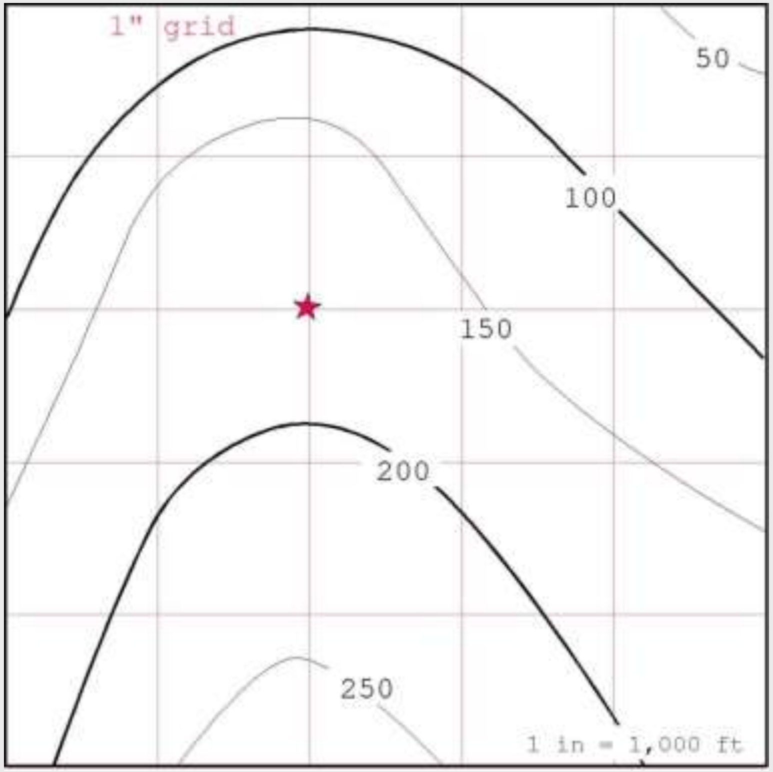


Elevation from Contours

Elevations of points between contours can be determined by interpolation.

$$Elevation = \left[150 + \{200 - 150\} \times \frac{.75}{2.0}\right]$$

$$= 168.75ft$$



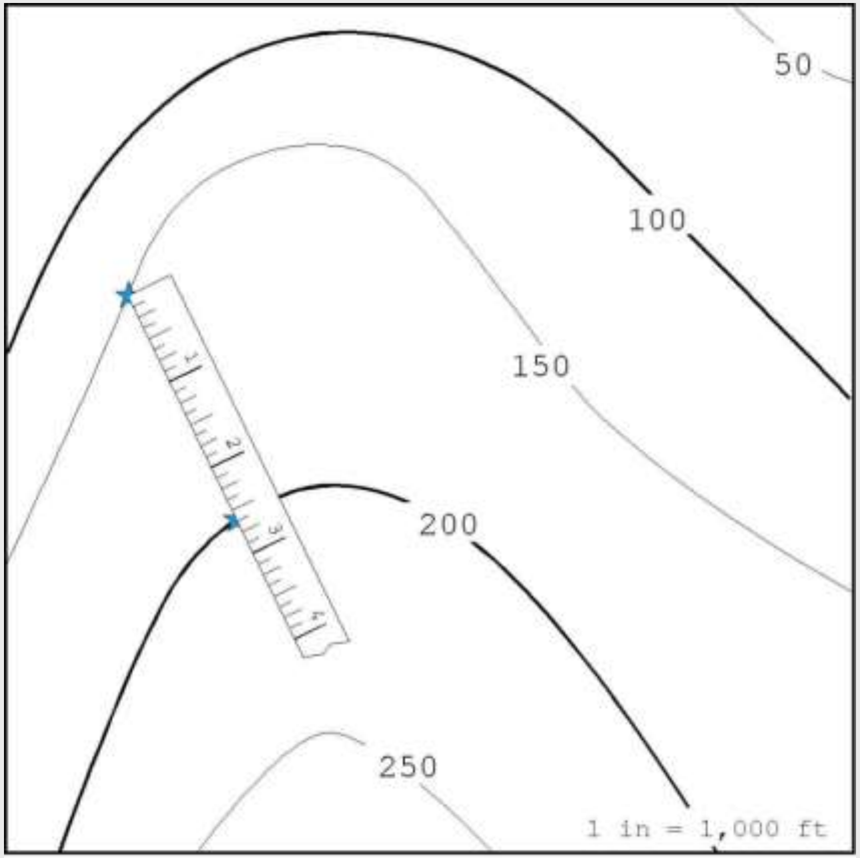
Slope from Contours

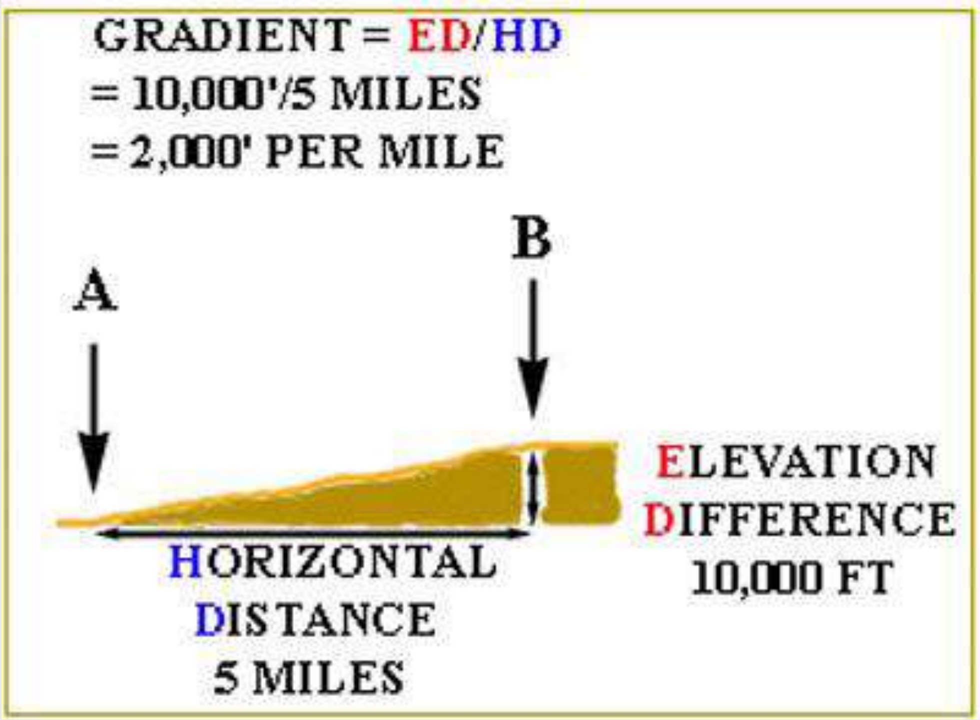
The percent slope can be determined from the contour lines on a topographic map as:

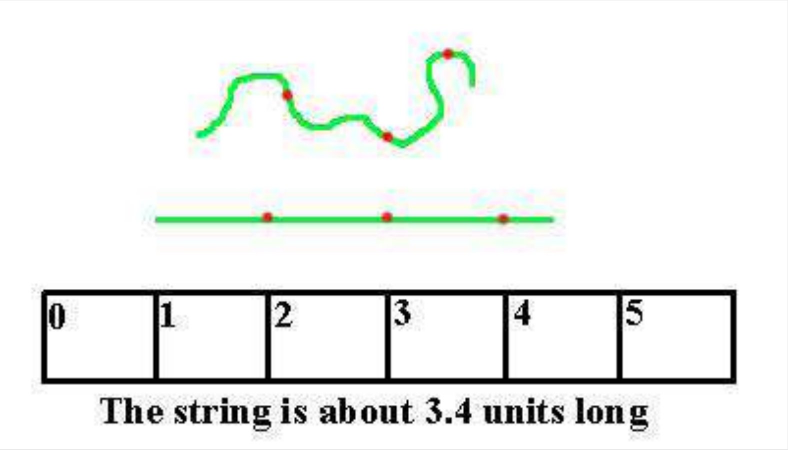
$$\% \, Slope = \left[\frac{Rise}{Run}\right] \times 100\%$$

Rise = 200 - 150 = 50 ft
Run = 2.625 in x 1,000 ft/in

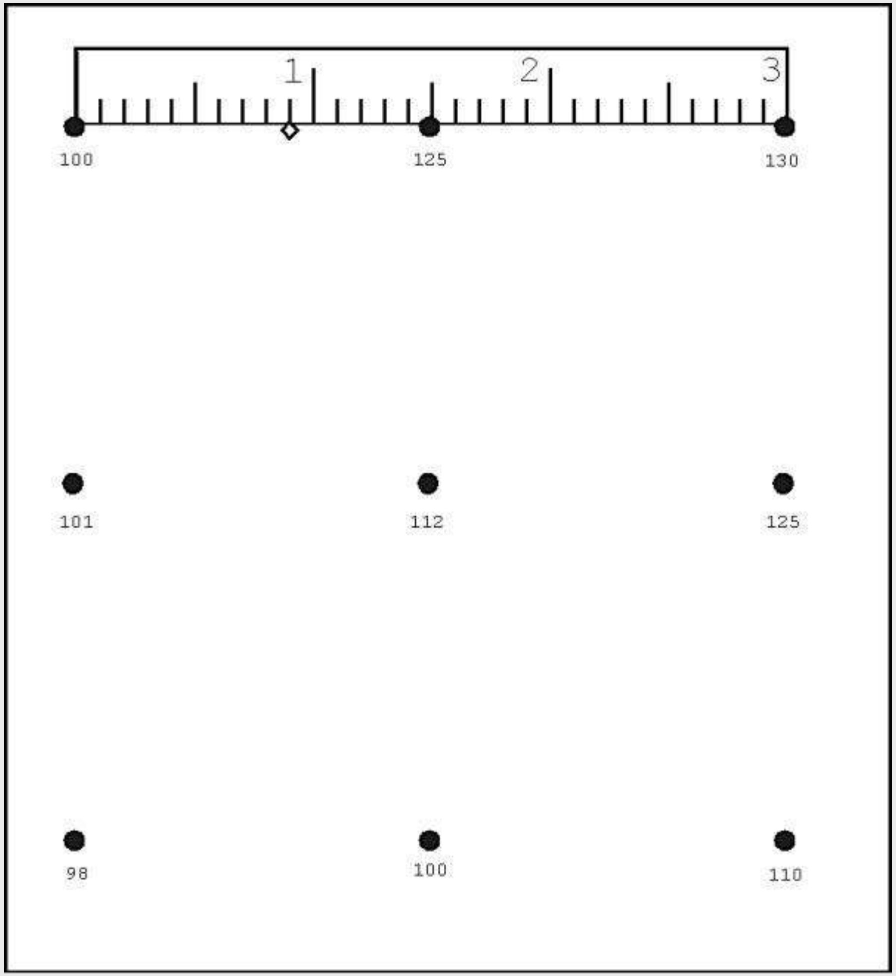
$$\% \, Slope = \left[\frac{200-150}{2625}\right] \times 100\% = 1.9\%$$




GRADIENT = ED/HD
= 10,000'/5 MILES
= 2,000' PER MILE
B
A
ELEVATION
DIFFERENCE
10,000 FT
HORIZONTAL
DISTANCE
5 MILES


0
1
2
3
4
5
The string is about 3.4 units long

Interpolation by Calculation and measurement



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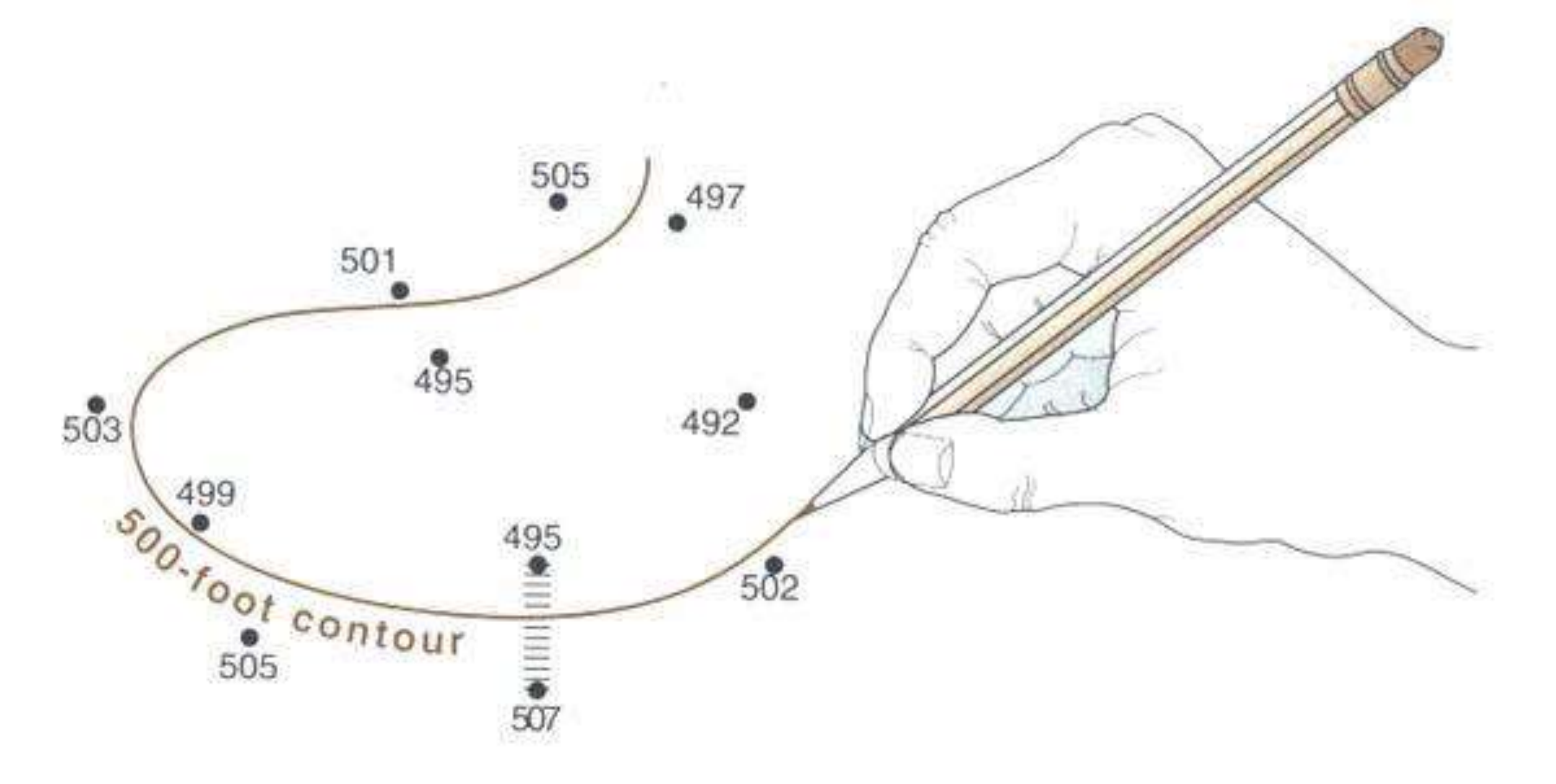

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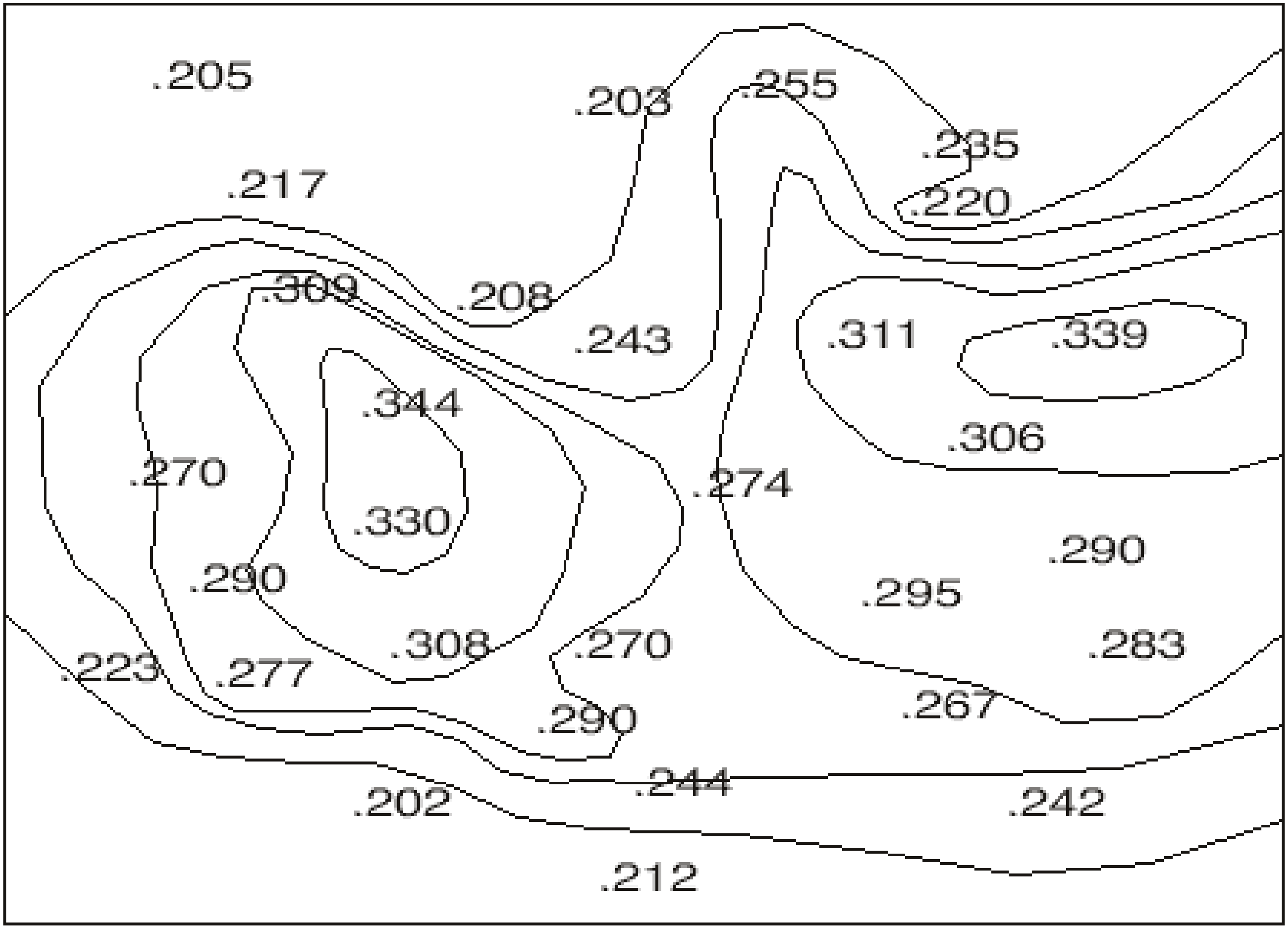


Topographic Profiles

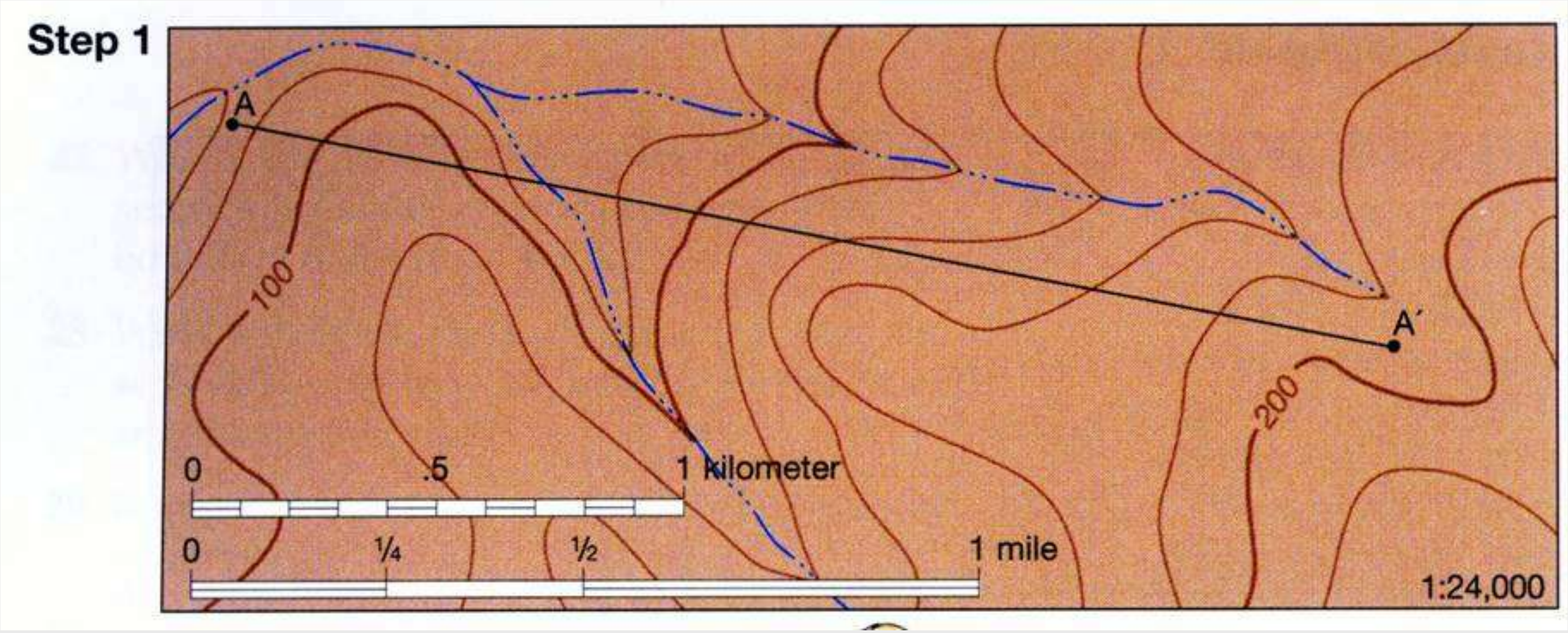
Topographic maps represent a view of the landscape as seen from above (called “map view”).

For producing a detailed study of a landform it is necessary to construct a topographic profile.

A topographic profile is a cross-sectional view along a line drawn through a portion of a topographic map.

Creating Topographic Profiles

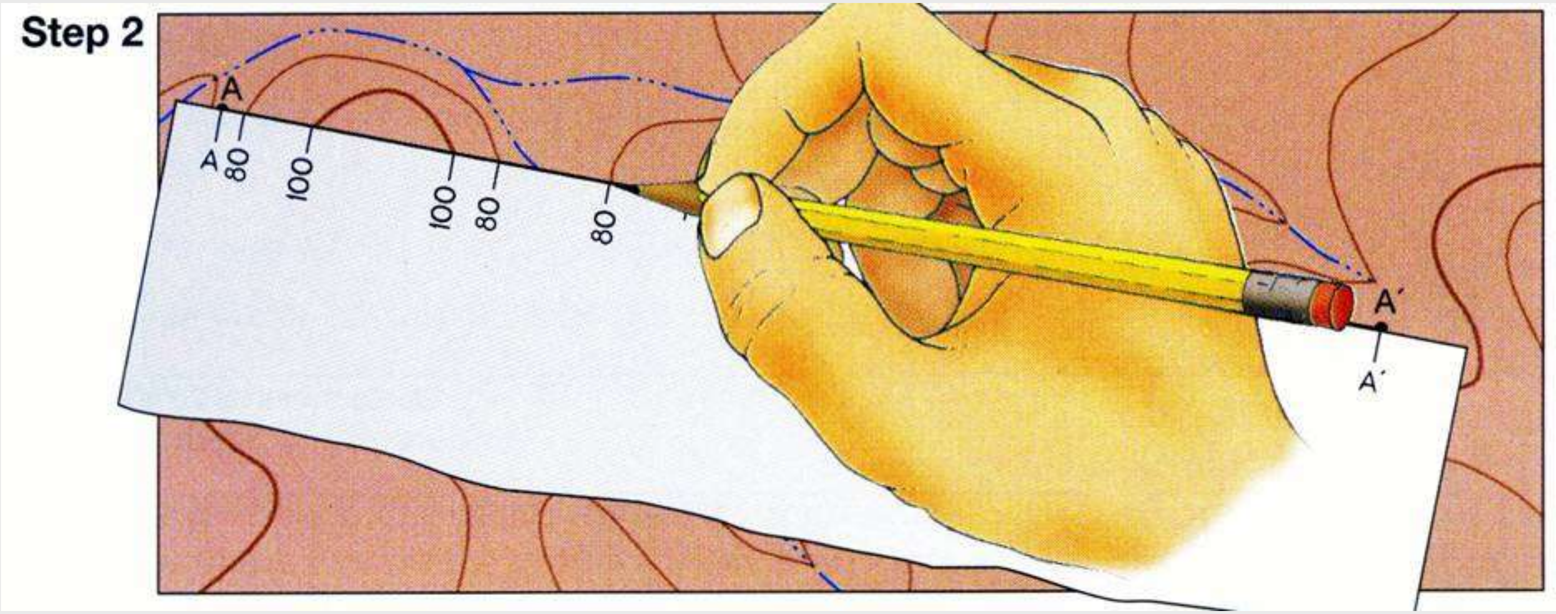
a. Draw a line from Point A to Point A′ where you want a cross-sectional view of the topography.



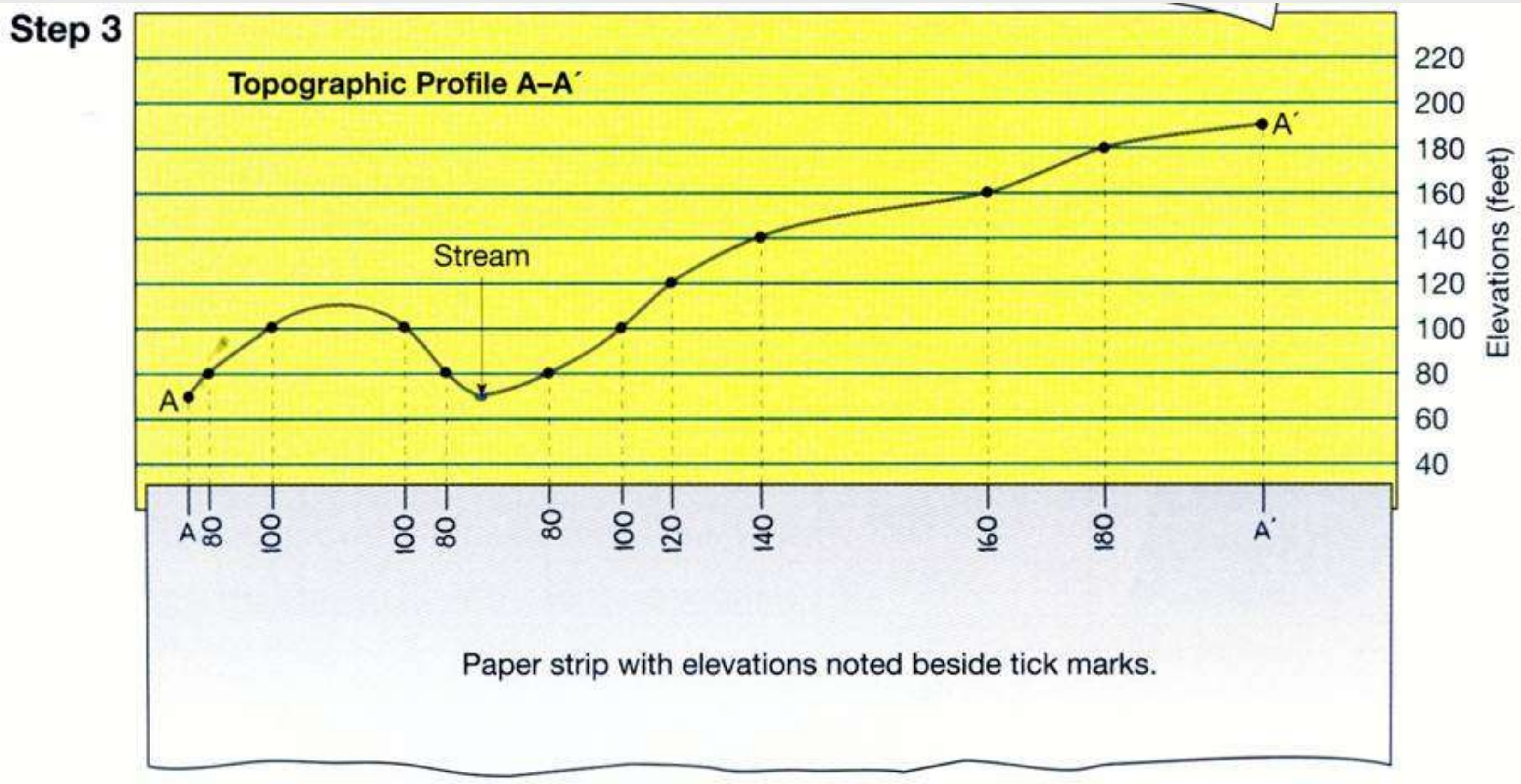
b. Lay a strip of paper along a line across the area where the profile is to be constructed.

c. Mark on the paper the exact place where each contour, stream and hill top crosses the profile line.

d. Label each mark with the elevation of the contour it represents.

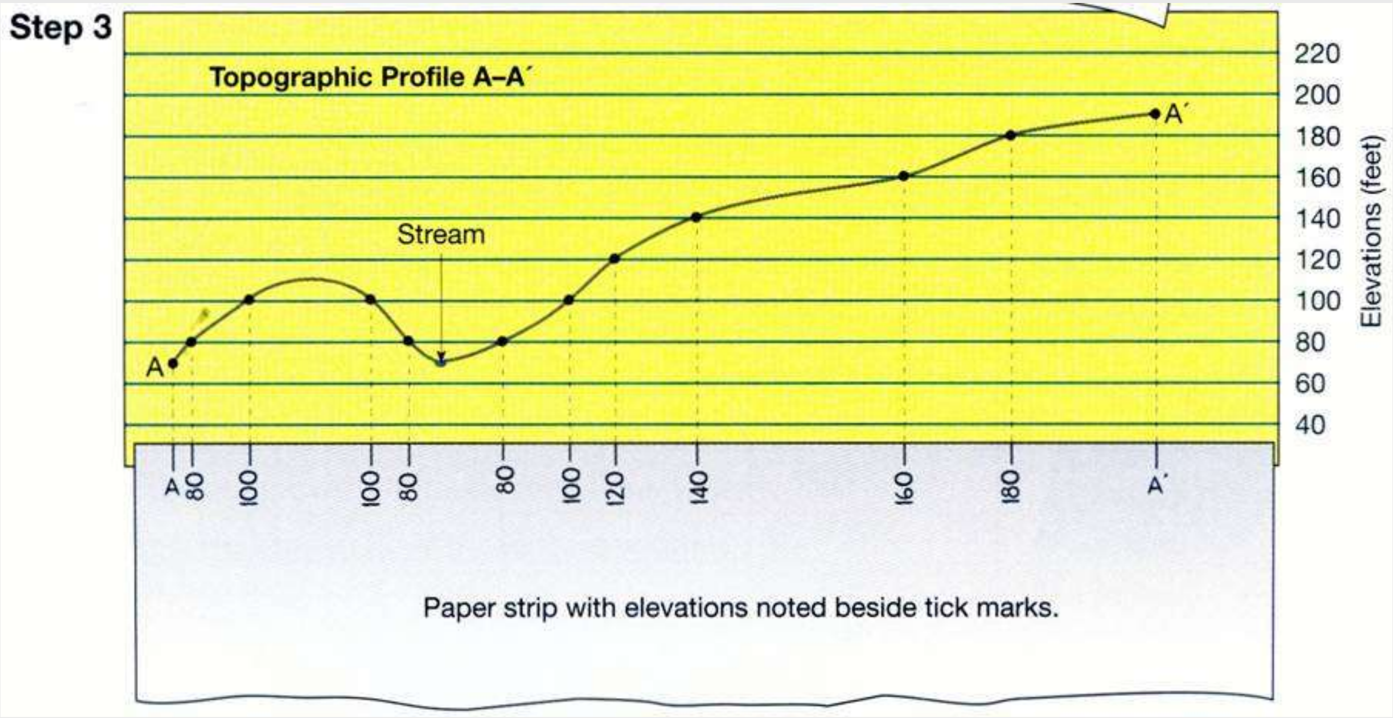


e. Prepare a vertical scale on profile paper by labeling the horizontal lines corresponding to the elevation of each index contour line.



f. Place the paper with the labeled contour lines at the bottom of the profile paper and project each contour to the horizontal line of the same elevation.

g. Connect the points.



Vertical Exaggeration

$$VE = \frac{\text{Vertical Scale}}{\text{Horizontal Scale}}$$

Example: **VE = 1:2000/1:4000 = 2**

This means... "the vertical relief of the terrain portrayed in this profile view is exaggerated two-fold relative to its actual profile in the real-world".

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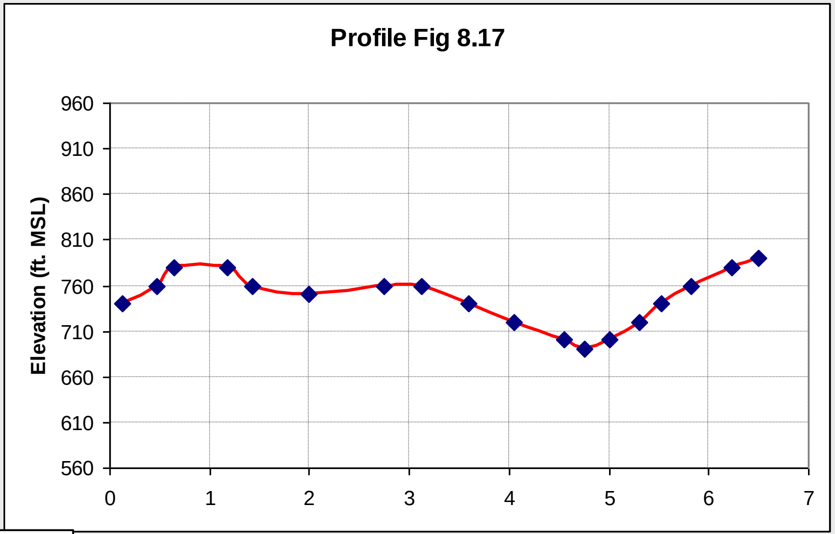
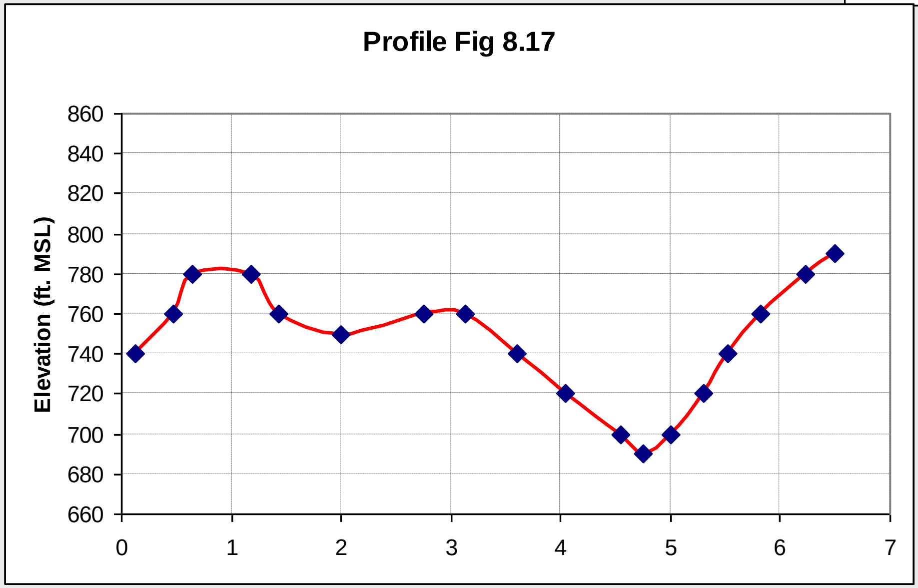




Topographic Map Symbols

Boundaries

City

Small Park

Buildings and related features

Building

School

Athletic field

Forest headquarters

Airport

Well (other than water),
windmill or wind generator

Picnic area

Campground

Winter recreation area

Contours

Contour line — 6000

Depression

River mileage marker — Mile 69

Railroads

Railroad, single track

Railroad, multiple track

Rivers, lakes and canals

Perennial river

Perennial lake/pond

Roads and related features

Primary highway

Secondary highway

Trail

Highway or road
with median strip

Vegetation

Woodland

Shrubland

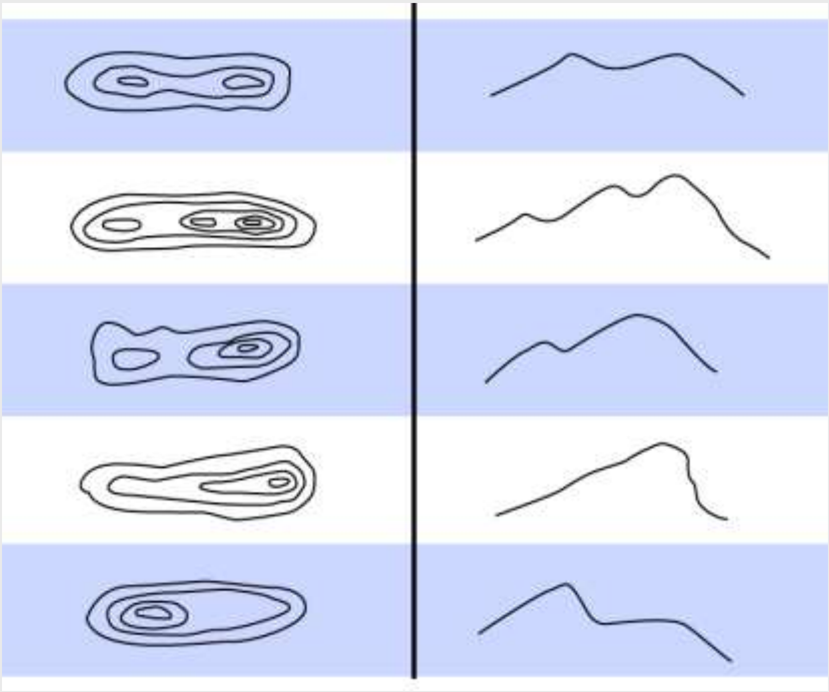
Orchard

Vineyard

U.S. Geological Survey used in compiling this information.

Colors indications on contour maps.

- **Water is shown in blue.**
- **Densely populated areas are shown in gray or pink.**
- **Wooded areas are in green and open areas in white.**
- **Individual buildings are solid black shapes**



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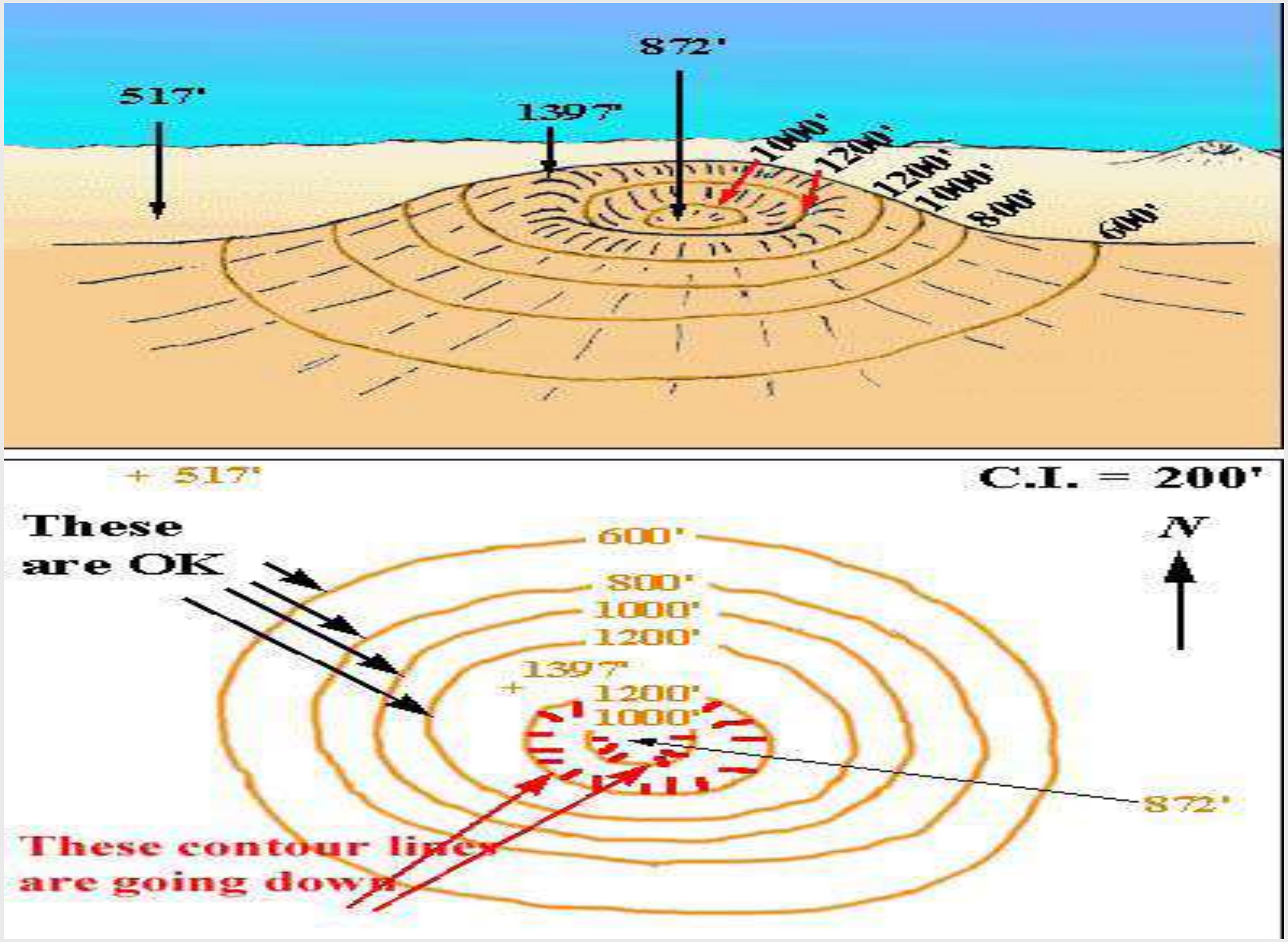

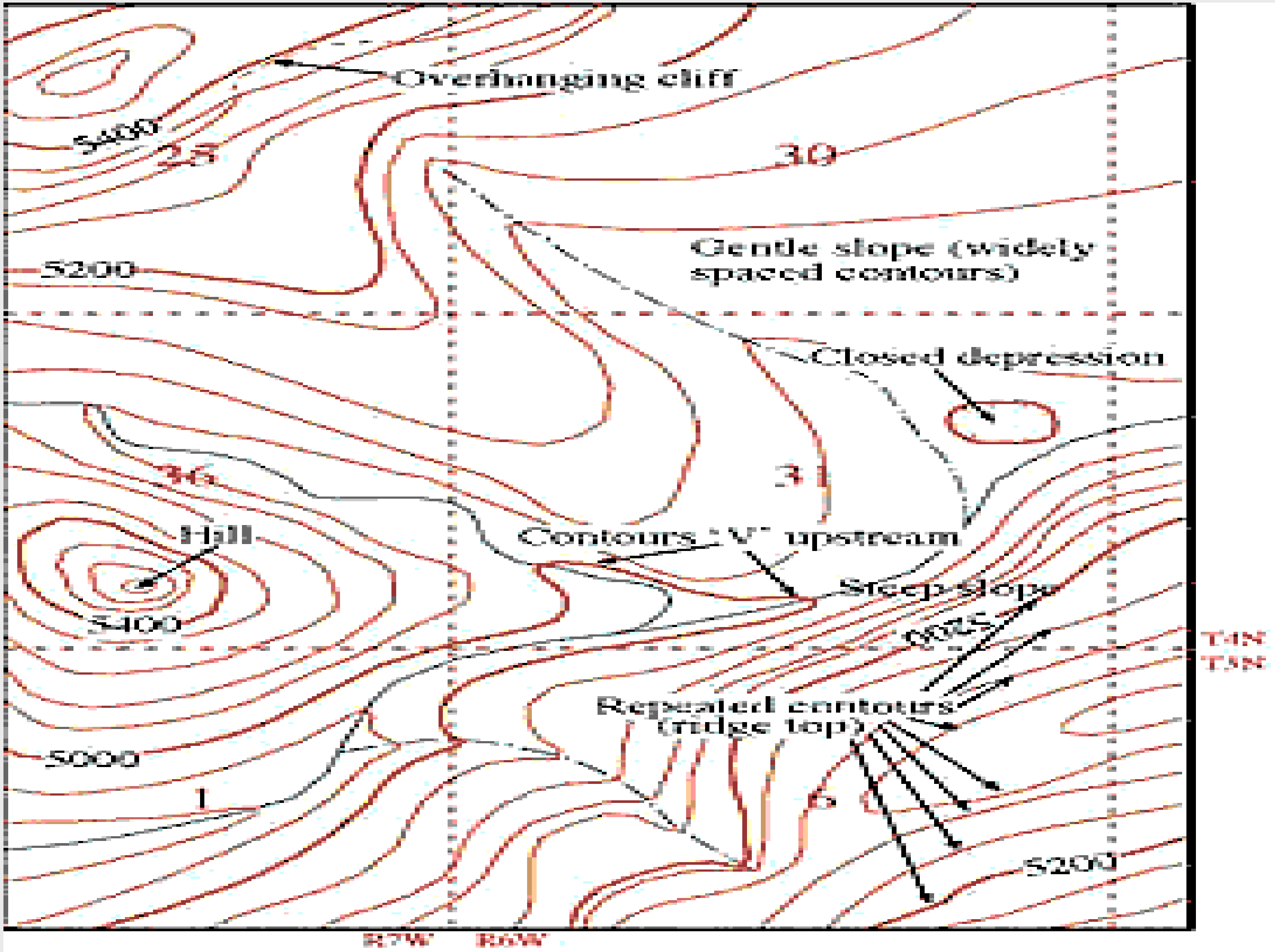
Overhanging cliff
5400
28
30
Gentle slope (widely spaced contours)
5200
Closed depression
36
31
Hill
Contours "V" upstream
Steep slope
5400
5200
T4N
T3N
Repeated contours (ridge top)
5000
1
6
5200
R7W
R6W

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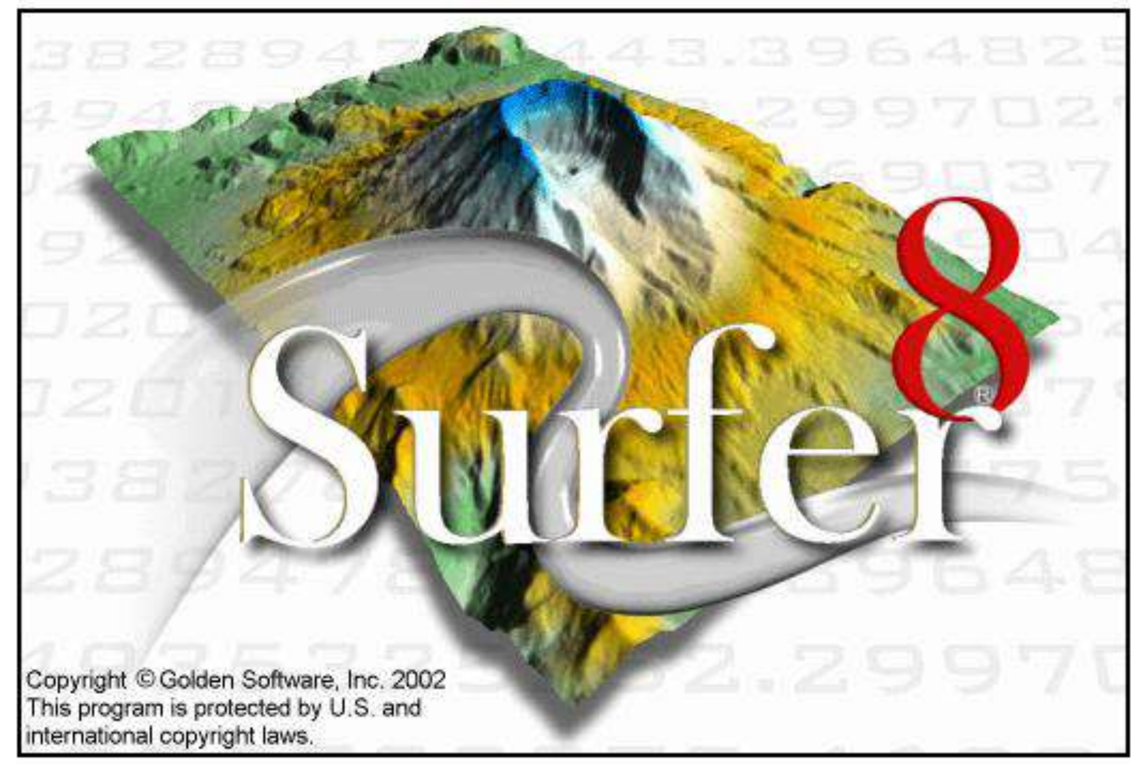

Surfer Software Surfer's outstanding gridding and contouring capabilities have made Surfer the software of choice for working with XYZ data