Engineering Geology is Backbone of Civil Engineering

Engineering Geology
1. Introduction

2nd semester - 2012-2013

Eng. Iqbal Marie

The Hashemite University
Faculty of Engineering
Course Syllabus

Course Title: **Engineering Geology** **Course Number:** **110401436**
Department: Civil Engineering **Designation:** Compulsory
Prerequisite(s): (0103107+0401212
Instructor: Iqbal Marie **Instructor's Office:** E 3005
Instructor's e-mail: iqbal@hu.edu.jo
Office Hours: Mon 8-9:30,. Sun. + Tue 11-12
Time: 12:30-1:30 **Class Room:** E2019
Mon & Wed

Course description: Earth material, rock minerals and their characteristics, rock types and classification, rock cycle, engineering properties of rocks, weathering and weathered rocks, geologic structures, site investigation, mass movement and rock slopes, earthquakes, surface and underground water.

Lab.: Site investigation, rock minerals, rocks Identification, geologic structures, abrasion of rock, rock deformation and strength, topographic maps .

Textbook(s): Principles of Engineering Geology, by: Robert B … , John Wiley & Sons

Topics covered:

1. Introduction { course objectives and relevance to engineering}
2. Structure and composition of earth
3. Minerals (composition, characteristics, groups)
4. Rocks cycle, and the three rock families
   Igneous Activity and Igneous Rocks . Weathering, Sediments, and sedimentary rocks
   Metamorphism and Metamorphic rocks
5. Engineering Properties of rocks (foundation and materials as aggregates)
6. Structural features (folds, Joints, Faults)
7. Mass movements and slope processes
8. Site investigation
9. Surface water and ground water
10. Subsurface geology, condition of stress at depth (for excavation, tunneling highways, …)
11. Earthquakes, (interpreting earthquakes, effect of earthquakes on structures)
12. Geology of Jordan

Laboratory :

- Mineral properties and identification
- Igneous rock identification (ID)
- Sedimentary rock ID
- Metamorphic rock ID
- Slake Durability
- Strength of rocks (point load test) , indirect tensile strength , Indirect Tensile Strength (Brazilian disc method
- RQD
- Site investigation and sample preparation
- Geological maps (surfer software)

Class/laboratory schedule:
- **2 class sessions each week; 50 minutes each + three-hour laboratory session per week.**

Grading Plan:

First Exam	(20 Points)	**Wed 20 /3/2013 (12:30-1:30) pm**
Second Exam	(20 Points)	**Wed 24/4 / 2013 (12:30-1:30) pm**
Lab	(20 points)	
Final Exam	(40 Points)	Will be announced by the registrar

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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**

Geology

Geology is the science of the Earth, its composition and structure, its history, and its past plant and animal life.

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.

Geology is further divided into a number of branches according to the subject matter that is covered or to the industrial or commercial applications

Geology Branches

- ***Petrology***. → study of rocks and their origin. It consists of ***Petrography:*** (identification, description, and classification of rocks) & ***Petrogenesis*** (origin of rocks)
- ***Mineralogy*** → study of rock constituents or minerals
- ***Geochemistry*** → chemistry of rocks
- ***Geomorphology*** → landforms, their origin and development
- ***Geophysics*** → application of principles of physics to the study of the Earth.: **Geomagnetics** (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 geology, military geology, etc.

The civil engineer should have at least one course in geology that provides familiarity with the basic Earth materials, processes, an awareness of change through time, and ideally how this knowledge applies to the success of an engineering project.
Only this minimal training can permit communication with geologists who will perform the actual site characterization.

- **As an engineer – You must be able to recognize the risk or problem**
- **If the problem is known then you can suggest an engineering solution**
- **If you do not recognize the geological problems the engineering construction can be at great risk**

Engineers use knowledge of geology to design, protect and correct structures

Definition and scope of engineering geology

Engineering geology:

Scientific discipline concerned with the application of geologic knowledge to engineering problems such as:

- **reservoir design and location,**
- **determination of slope stability for construction purposes,**
- **determination of earthquake, flood, or subsidence danger in areas considered for roads, pipelines, bridges, dams, or other engineering works.**

Engineering geologic studies may be performed during:

- **the planning,**
- **environmental impact analysis,**
- **civil or structural engineering design, value engineering and construction phases of projects**

Some of the major activities of Engineering Geologists include the following:

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**.
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 assist in establishing the bases for remedial actions for mitigation of related environmental threats from un-engineered and uncontrolled waste disposal.

Exploration of a site

1. Preliminary investigation using published information and other existing data
2. A detailed geological survey of the site , with a photography study
3. Applied geophysical survey to provide information about the subsurface geology
4. Boring, drilling and excavation to provide confirmation of previous results and quantitative detail, at critical points on the site
5. Testing of soils and rocks to assess their suitability , specially their mechanical properties either is situ or from sample

Assessment of geologic hazard and risk caused by proposed human activities (feasibility and site selection)

Dams
Railway
highways

Highway engineering considerations example

1. Highway alignment, locations
2. Subsurface exploration along highway centerline and bridge foundations;
3. Classification of materials for excavation, rock versus common borrow soil
4. Cut and fill volumes determined to minimize the need of offsite borrow pits or rock waste areas;
5. Recommend angle of back slope (rock cut slope) based on rock conditions;
6. Groundwater aspects related to construction;
7. Evaluation of landslide-prone areas;
8. Recognition of compressible soil materials;
9. Construction materials, location and inventory;
10. highway effects on adjacent landowners;

Role of Engineer in Geological Hazards:

Assessing Risks

Avoiding Risks

Preventing damage

Predicting Impact

Civil engineering works are all carried out on or in the ground. Its properties and processes are therefore significant – both the strengths of rocks and soils, and the erosional and geological processes which subject them to continual change.

Civil engineering design can accommodate almost any ground conditions which are correctly assessed and understood.

SOME ENGINEERING RESPONSES TO GEOLOGICAL CONDITIONS

Geology	Response
Soft ground and settlement	Foundation design to reduce or redistribute loading
Weak ground and potential failure	Ground improvement or cavity filling; or identify and avoid hazard zone
Unstable slopes and potential sliding	Stabilize or support slopes; or avoid hazard zone
Severe river or coastal erosion	Slow down process with rock or concrete defences (limited scope)
Potential earthquake hazard	Structural design to withstand vibration; avoid unstable ground
Potential volcanic hazard	Delimit and avoid hazard zones; attempt eruption prediction
Rock required as a material	Resource assessment and rock testing

Engineering Geology

2- Earth Structure

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Physical Geology: focuses on processes that operate at or near the surface and those that operate within the Earth -- and the response of Earth materials to those processes.

With Geology try to answer questions such as the following:

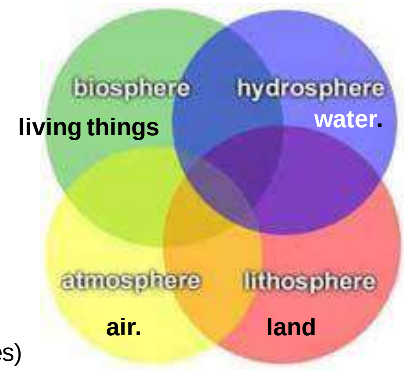
- **What are the soils and rocks, and where are the boundaries?**
- **Where is the groundwater and how is it moving?**
- **How do the soils and rocks respond to different loading, unloading, exposure, flows of fluids, changes in temperature?**
- **Why do these materials respond this way?**
- **How can we beneficially control or modify the response of these materials?**
- **How do we relate the answers to the engineering problem at hand?**

Geology is applicable in:

- Foundation engineering - assessment of soil conditions
- Construction materials engineering - quality of stones, lime, cement *etc*.
- Infrastructure engineering - location of bridges, tunnels, river meandering zones
- Disaster mitigation - seismic resistant structural design, flood control, river training, waterway of bridges
- Land-use engineering - soil erosion control, natural drainage
- Water Resources engineering - hydrogeology (reservoir capacity for *e.g.*), source and quality of aquifer
- Environmental engineering - ecological balance, solid waste management by landfill

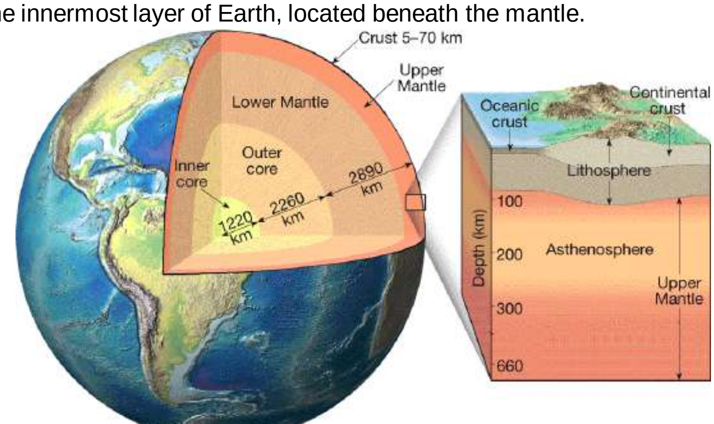
Earth major spheres

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

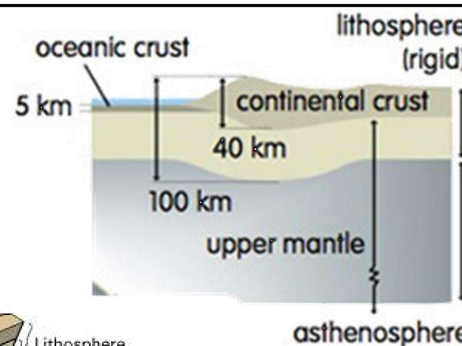


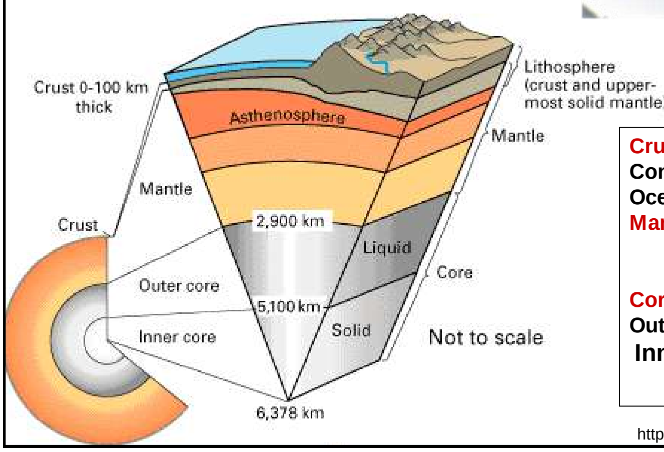
2. **Atmosphere**
   - Thin, blanket of air
   - One half lies below 5.6 kilometers (3.5 miles)
3. **Biosphere**
   - Includes all life
   - Concentrated near the surface in a zone that extends from the ocean floor upward for several kilometers into the atmosphere

4. **Geosphere**
   - Based on compositional differences, it consists of the crust, mantle, and core.
     - **Crust—**the thin, rocky outer layer of Earth.
     - **Mantle—**the 2890-kilometer-thick layer of Earth located below the crust.
     - **Core—**the innermost layer of Earth, located beneath the mantle.



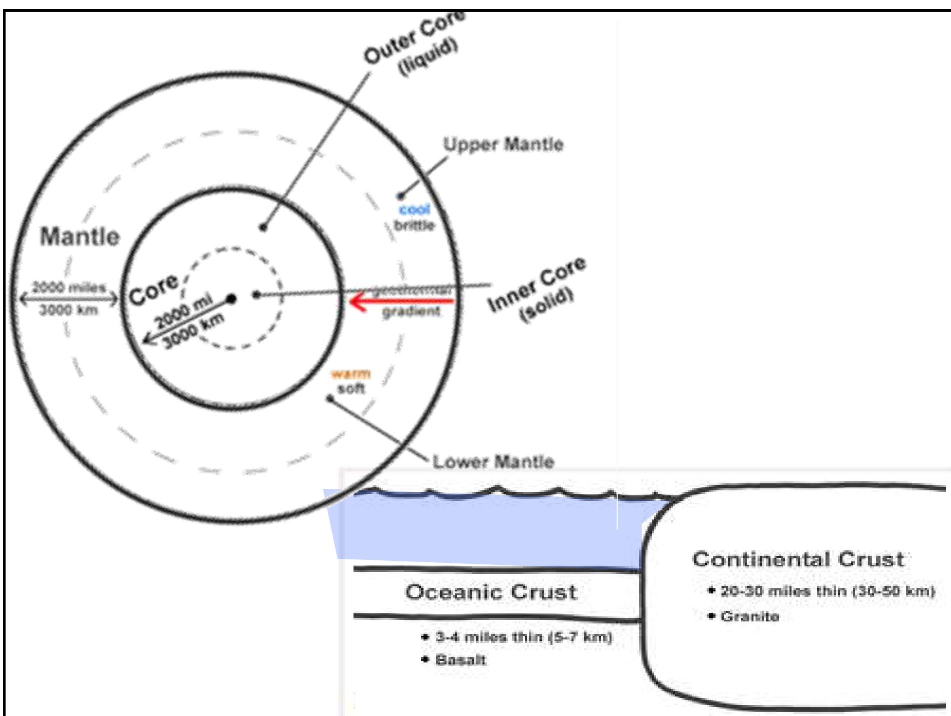
Interior Structure of the Earth





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)

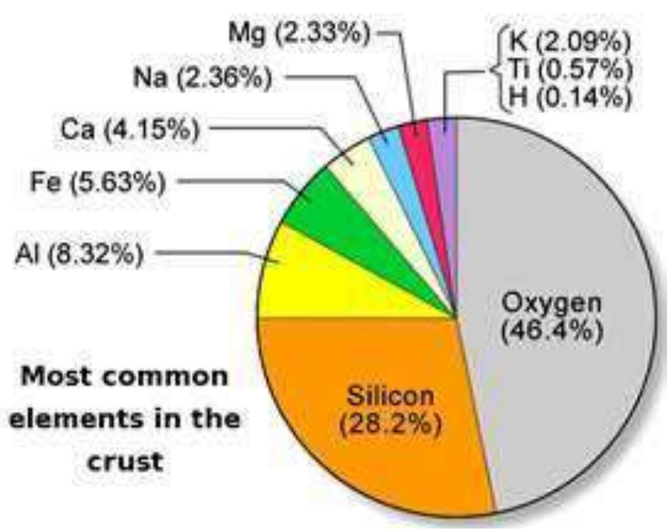
http://aboutcivil.com/interior-of-the-earth.html



Materials of the earth crust

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 basalt. 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.

Basic knowledge of earth materials (rocks) is essential to the understanding of all geologic phenomena



http://www.suu.edu/faculty/colberg/Hazards/Append2.html

Mantle — the 2890-kilometer-thick layer of Earth located below the crust. It is composed of very hot ,dense rock. This layer of rock even flows like asphalt under a heavy weight. This flow is due to great temperature differences from the bottom to the top of the mantle. The movement of the mantle is the reason that the plates of the earth move. The temperature of the mantle varies from 1600 °F at the top to about 4000 °F near the bottom.

Core—the innermost layer of Earth, located beneath the mantle.

Outer core: it is so hot that the metals in it are all in the liquid state. The outer core is composed of the melted metals nickel and iron

Inner core: It has pressure and temperature so great (9000°F) that the metals are squeezed together and are not able to move about like a liquid. But forced to vibrate in place like a solid.

Relevance of geology to civil engineering

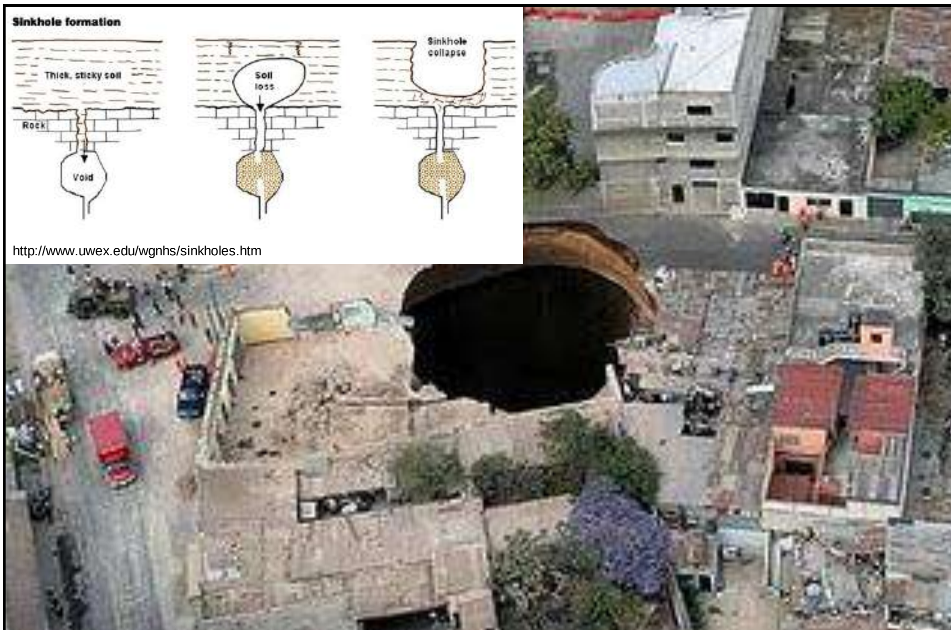
Most civil engineering projects involve some excavation of soils and rocks, or and hazards created by geologic materials. In some cases the excavated rocks may be used as constructional materials, and in others rocks may form a major part of the finished product, such as a motorway cutting or the site for a reservoir

Civil engineers design structures that are built on or in the ground. As such an understanding of how the ground behaves is fundamental to civil engineering design.

Earth materials can pose significant problems that need to be predicted, planned and designed for.

landslide in Taiwan

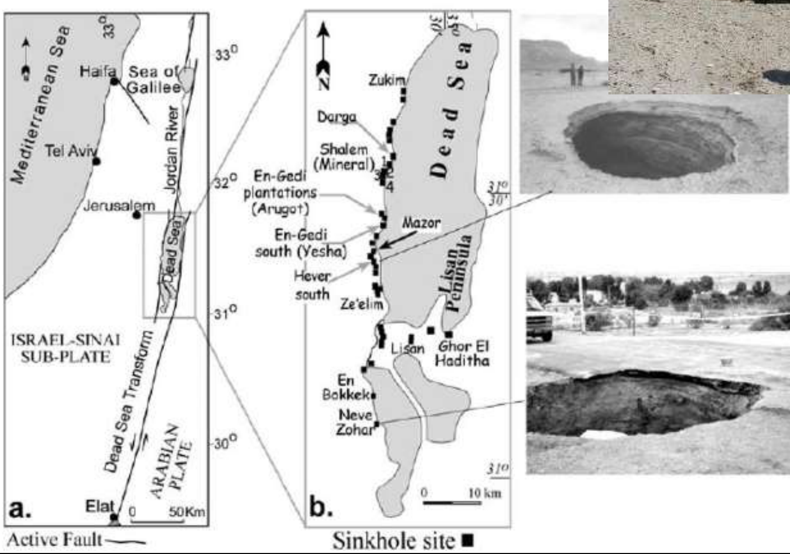
Land Slides

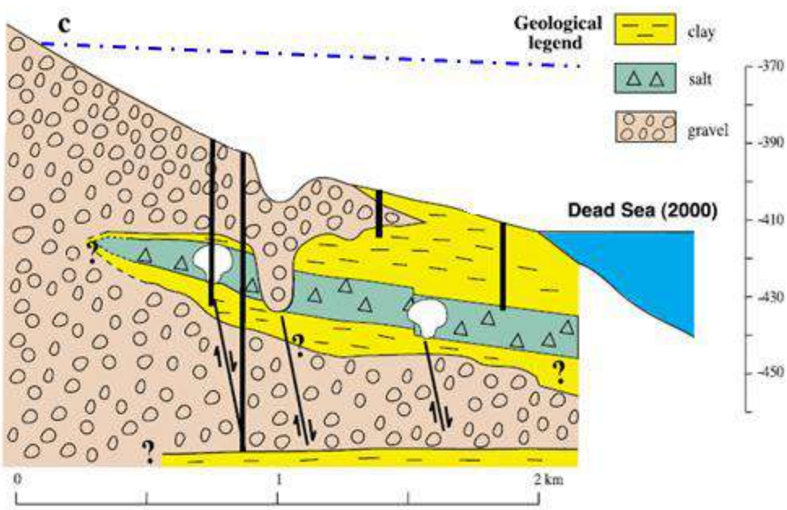

Sinkhole formation
Thick, sticky soil
Rock
Void
Soil loss
Sinkhole collapse
http://www.uwex.edu/wgnhs/sinkholes.htm

Sink holes


Guatemala, 2010
Germany, 2009
China, 2010
Sweden, 2012
Florida, 2006

Dead sea area face sink holes problems





The formation of sinkholes at the Dead Sea area reflects subsurface cavities formed by salt dissolution

Salt deposits in the dead sea

http://whatiscivilengineering.csce.ca/structural_earthquakes1.htm

Overturning of a building due to liquefaction failure of the foundation soil during the Kocaeli earthquake, Turkey, August 17, 1999, Magnitude 7.4

Engineering Geology

3. Minerals

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- **Element**
  – A form of matter that cannot be broken down into simpler form by heating, cooling, or chemical reactions
- **Mineral**
  – a naturally occurring inorganic element or compound having an orderly internal structure and characteristic chemical composition, crystal form, and physical properties
- **Rock**
  - rocks are composed of one or more minerals and minerals are composed of one or more elements.

Definition of a Mineral:

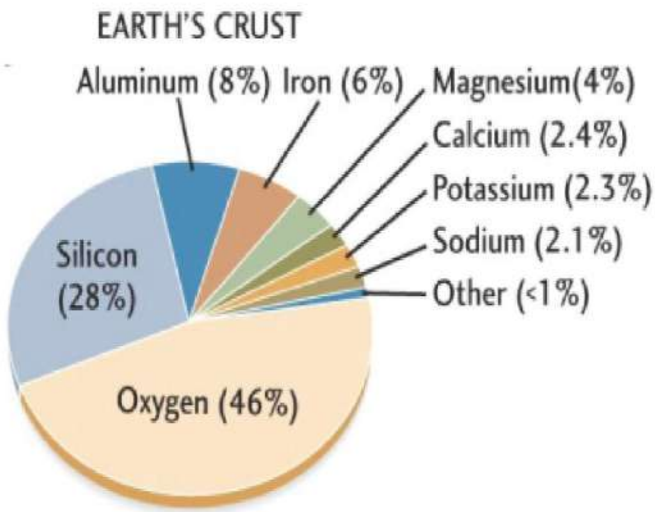
A mineral is:

1. **Naturally occurring**
2. **Solid substance**
3. **Orderly crystalline structure**
4. **Definite chemical composition**
5. **Generally considered inorganic**

How Minerals Form

1. Crystallization from magma
2. Precipitation
3. Pressure and temperature
4. Hydrothermal solutions

More than different 3000 minerals are present in the earth's crust. They can be identified by their physical and chemical properties; by standard tests; or by examination under microscope



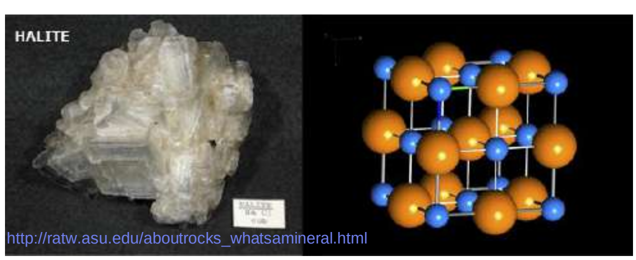
The common rock-forming minerals are formed mainly of combinations of these important elements, and most of them are silicates.

Crystal structure is a continuous ordered arrangement of one or more elements.

Elements have very different properties depending on how they are stacked together

Eg 1. Salt

composed of two elements; Sodium (Na) and Chlorine (Cl). Sodium and chlorine are strongly attracted to each other and stack together into a cubic crystal structure



Eg.2 carbon; graphite and diamond

The importance of crystal structure can be shown by the difference between two minerals made out of only one element; carbon; graphite and diamond.

Graphite is the soft, dark colored material, is composed of carbon that forms loosely bonded sheets in their crystal structure.

diamonds are very hard, often transparent and colorless, and very expensive. It is composed of carbon atoms stacked tightly together in a cubic crystal structure, making it a very strong material

The reason that graphite and diamond are so different from each other is because the carbon atoms are stacked together into two different crystal structures.

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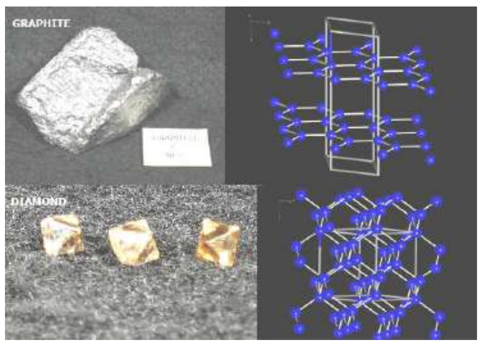
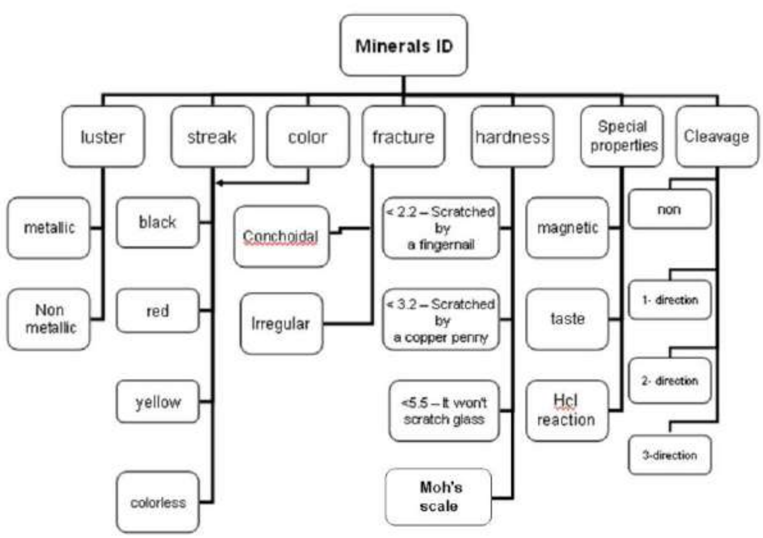


Minerals Identification

Mineral identification is based on performing several tests that determine the physical properties of an unknown mineral and comparing the results of those tests with the physical properties of known minerals as listed in identification tables. At least initially, mineral identification proceeds by a process of elimination; an initial test (e.g. luster) eliminates large groups of minerals, thereby narrowing the choice



Properties used to identify minerals

Color: Some minerals have characteristics color due to composition of the minerals
and the arrangement of the constituent atoms:

magnetite: black color of
chlorite: green
pyrite : brassy yellow
quartz and calcite: have variable color

Color can't be sole identification property

Streak: Color of mineral in powder form obtained by crushing the mineral.
Color of the streak may differs from color of mineral:

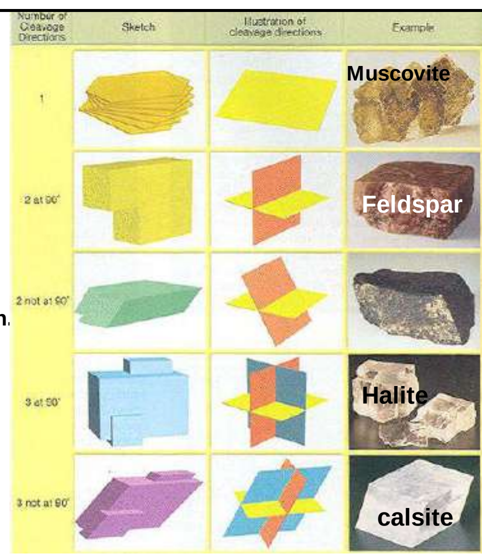
color of pyrite is brass yellow and its streak is dark green.
lead ore, galena, has a metallic grey color but a black streak.

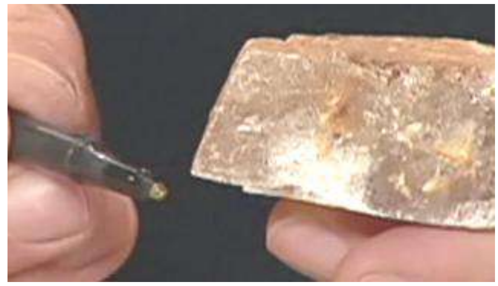
Cleavage: capacity to split in certain directions along certain specific directions which are related to planes of weakness in the atomic structure of the mineral than in others.

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

mica : have perfect cleavage in one direction.
feldspars, have two cleavages.
quartz and garnet, possess no cleavages
galena: three directions
fluorite: four directions

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





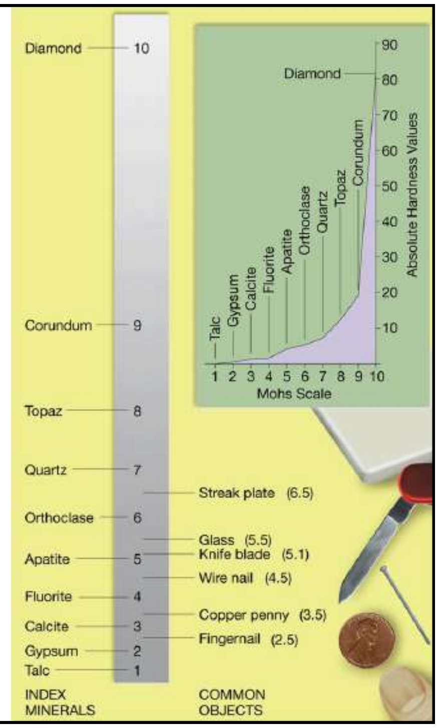
Fracture: A surface formed by breaking the mineral along a direction which is not a cleavage is called a **fracture** and is usually more irregular than a cleavage plane. A curved, rippled fracture is termed **conchoidal** (shell-like).

Luster: Appearance of mineral in ordinary light. Luster may be:

- **metallic,** (galena and pyrite)
- **glassy,** (quartz)
- **earthy**, (*Kaolinite* - $Al_2Si_2O_5(OH)_4$)
- **pearly** , (talc)
- **silky** : like strands of fibers parallel to surface-(asbestos)
- **vitreous** : (broken glass)

Hardness: **measured by its ability to resist scratching.**
If a mineral is scratched by a knife, it is softer than the knife.

Mohs scale **: standard scale for expressing hardness of minerals, In sequence of increasing hardness from 1 to 10,**



fingernails have hardness values of 2.5, based on Mohs' scale of hardness. Thus, a mineral with a hardness less than 2.5 will not scratch a fingernail, but it will be scratched by a fingernail. In contrast, a mineral with a hardness greater than 2.5 will scratch a fingernail, but a fingernail will not scratch the mineral.

A penny has a hardness values of 3 on Mohs' scale of hardness. Thus, a mineral with a hardness less than 3 will not scratch a penny, but it will be scratched by a penny. In contrast, a mineral with a hardness greater than 3 will scratch a penny, but a penny will not scratch the mineral

Glass has a hardness value of 5.5, based on Mohs' scale of hardness. Thus, a mineral with a hardness less than 5.5 will not scratch the glass plate, but it will be scratched by the glass plate. In contrast, a mineral with a hardness greater than 5.5 will scratch the glass, but the glass will not scratch the mineral.

The porcelain streak plate has a hardness value of 7, based on Mohs' scale of hardness. Thus, a mineral with a hardness less than 7 will not scratch the streak plate, but it will be scratched by the streak plate. In contrast, a mineral with a hardness greater than 7 will scratch the streak plate, but the streak plate will not scratch the mineral.

Other Characteristics:

Specific Gravity is meant the weight of a substance compared with the weight of an equal volume of water. The specific gravity of quartz is 2.65. Some minerals are heavy than the others. The specific gravity of majority minerals range from 2.55 to 3.2.

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

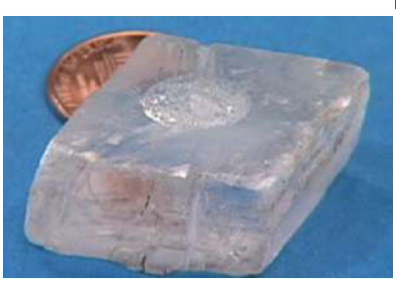
Tenacity is a measure of how the mineral deforms when it is crushed or bent

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

Specific gravity

SG Description	SG	Mineral examples
Very light	<2	borax
light	2 - 3	Quartz, calcite, halite , dolomite, gypsum, talc, muscovite, biotite
heavy	3 – 5	Barite, Fluorite, apatite,
Very heavy	5 - 10	Nickel-iron, galena, pyrite, magnetite
Extreamly heavy	> 10	Silver, gold

Some minerals are known to react with acid. This can be a very diagnostic test for some minerals.



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 crystal 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

QUARTZ

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

TALC

0-1 cleavage plane, light apple green/grey/white color, pearly luster, hardness of 1, may have light grey streak, greasy feel.

FELDSPAR

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

GALENA-PbS (lead sulfide

3 excellent cleavages, metallic luster, hardness of 2.5, black/grey streak,

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

$Fe_2O_3.H_2O$ (hydrated iron oxide)

Luster/Color: non-metallic/yellow brown Cleavage: absent Hardness: 5 to 5.5 :

yellow-brown streak, moderate to high sepcific gravity (3.5-4),

PYRITE- FeS_2 (iron sulfide) metallic luster, a streak of greenish black to black, a hardness of 6-6.5 - cubic crystals, high specific gravity (5) – no Cleavage:

MICA BIOTITE

black to brownish black, vitreous luster, hardness of 2.5-3, may have faint brown/grey streak, perfect cleavage, transparent, thin sheets

Hematite- Fe_2O_3 (iron oxide)

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

LUSTER	HARD-NESS	CLEA	FRAC	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)	$CaSO_4 \cdot 2H_2O$
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**	$K(Mg,Fe)_3 AlSi_3O_{10}(OH)_2$
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 Cl = chlorine H = hydrogen Na = sodium S = sulfur

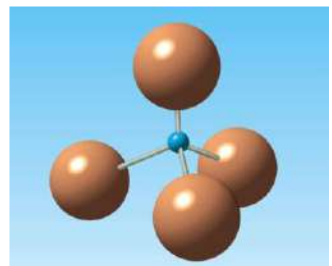
Mineral Groups

Can be classified based on their composition

Silicates & Non- Silicates

1. Silicates

- Silicon and oxygen combine to form a structure called the **silicon-oxygen tetrahedron.** This silicon-oxygen tetrahedron provides the framework of every silicate mineral.



The Silicon-Oxygen Tetrahedron $(SiO_4)^{-4}$

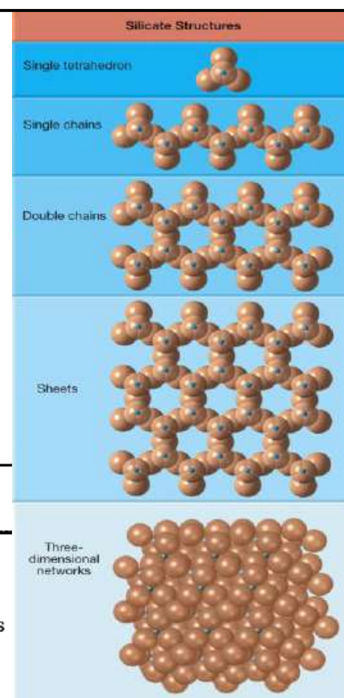
Silicate structures

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

Non-Silicates

2. Carbonates

- Minerals that contain the elements carbon, oxygen, and one or more other metallic elements

calcite	$CaCO_3$	white or colourless	2.7	3	three (parallel to rhombohedron faces)
dolomite	$CaMg(CO_3)_2$	off-white	3	4	three (parallel to rhombohedron faces)

3. Oxides

- Minerals that contain oxygen and one or more other elements, which are usually metals

4. Sulfates and Sulfides

- Minerals that contain the element sulfur

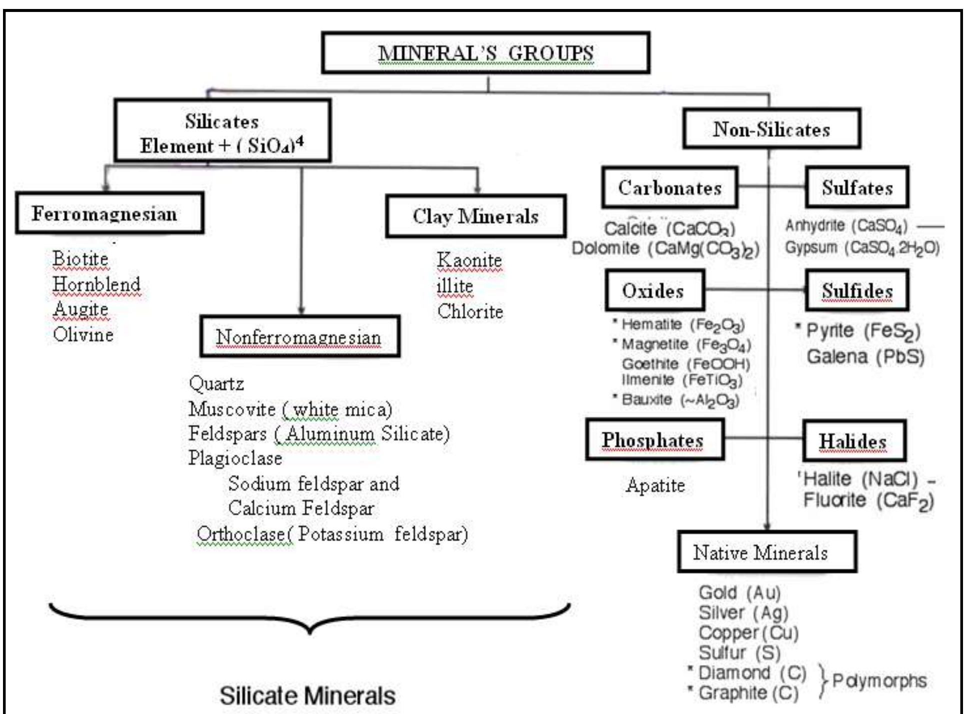
In the Middle East, limestone is widespread and may be the only material available to use as a crushed rock aggregate for concrete or roads. Limestone is the most important constituent in the manufacture of cement.

5. Halides

- Minerals that contain a halogen ion plus one or more other elements

6. Native elements

- Minerals that exist in relatively pure form



Rock Forming Minerals

1. Feldpars:
Feldspar 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: 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.

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.

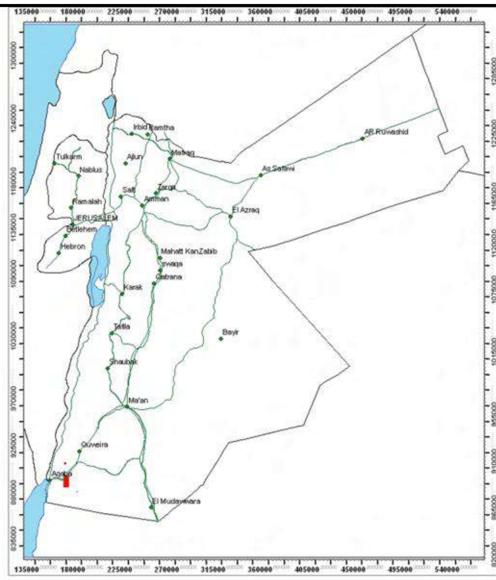
4. Ferromagnesian minerals: A class of minerals, all of which contain both iron and magnesium. This class includes pyroxene, amphibole, hornblende and olivine. These minerals are dark color and a moderate hardness.

5. Calcite: A mineral made of calcium carbonate (CaCO3). 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.



Location map for the feldspar ore deposits in Jordan

Feldspar is used in the manufacture of glass products (70%), in ceramic and other products (30%).

سلطة المصادر الطبيعية

http://www.nra.gov.jo/index.php?option=com_content&task=view&id=5&Itemid=39

Engineering Geology

Engineering Geology is backbone of civil engineering

4. Rocks

Igneous Rocks

Eng. Iqbal Marie

Minerals and Rock

Minerals are naturally occurring inorganic substances of definite chemical composition, displaying definite physical properties.

Rocks:

Geologist define rock as aggregates or mass composed of one or more commonly, several of minerals. There are few exceptions to this rule: not all rocks are composed of minerals-for example, coal.

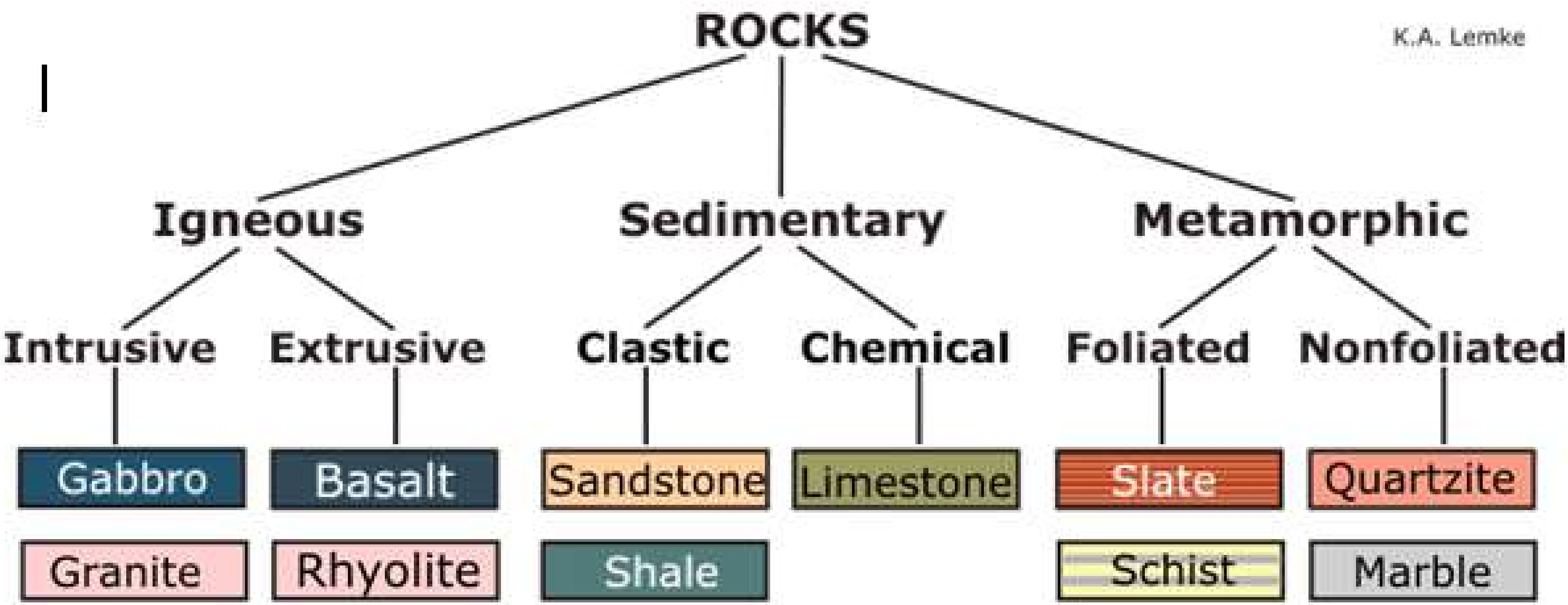
Engineers (or contractor) define rock to be a ‘hard, durable material that can’t be excavated without blasting. The definition is based on strength and durability.

Minerals: as the basic constituent of rock, control much of rock behavior. Some minerals are very strong and resistant to deterioration producing rocks with similar properties, while others are much softer and produce weaker rock.

.

There are three kinds of rocks, that are defined on the basis of how they formed

1. **Igneous Rocks:** formed from the solidification of molten rock or magma.
2. **Sedimentary Rocks** form through when materials at the earth's surface (sediments) are buried and hardened (lithified).
3. **Metamorphic Rocks** are formed when older rocks are changed by heat and pressure without being melted.

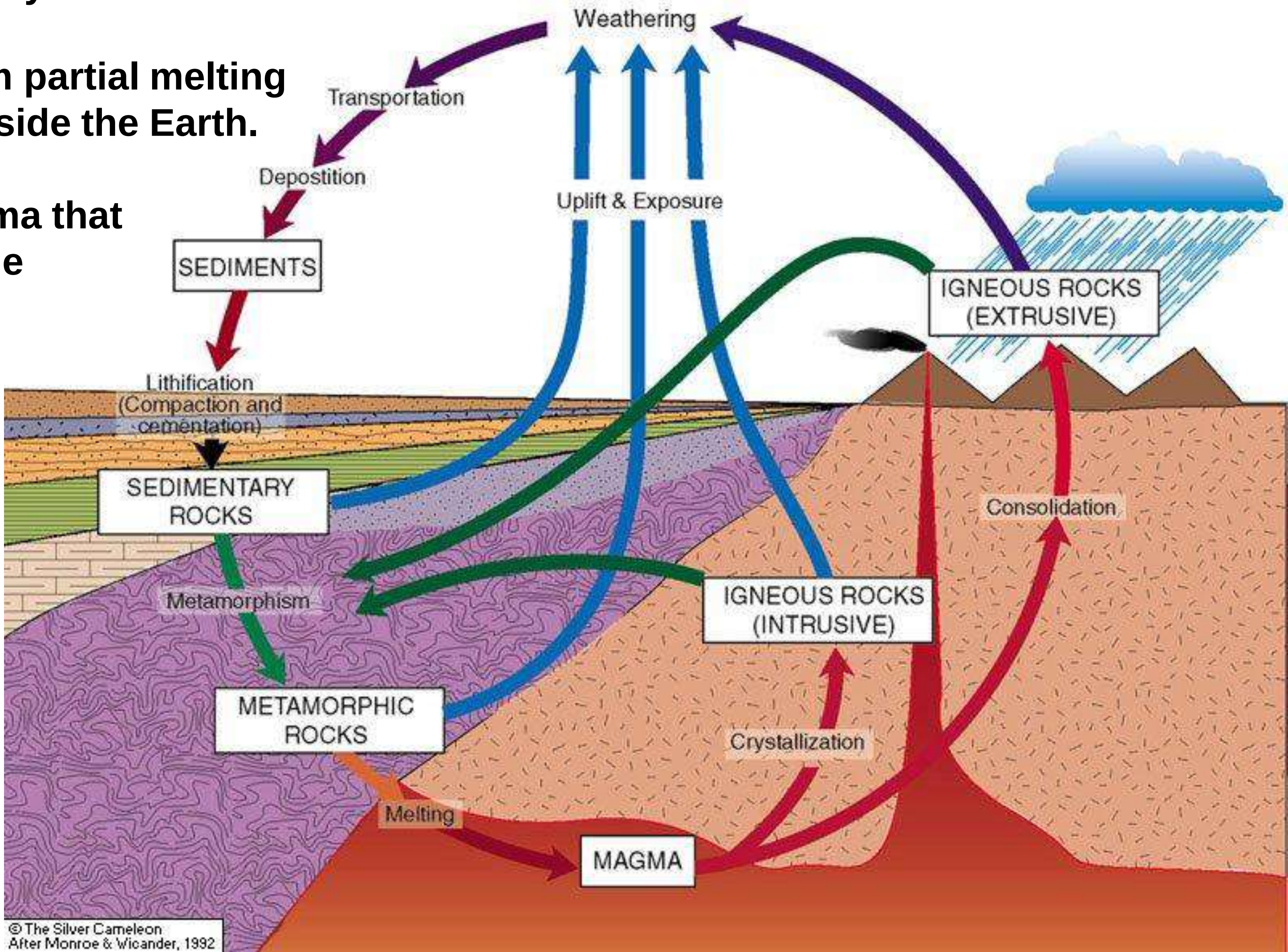


http://www.uwsp.edu/geo/faculty/lemke/geog101/lectures/17_earth_composition_structure.html

Rock Cycle Diagram

Magma:
Parent material of igneous rocks usually are 900 to 1300 °C,
Forms from partial melting of rocks inside the Earth.

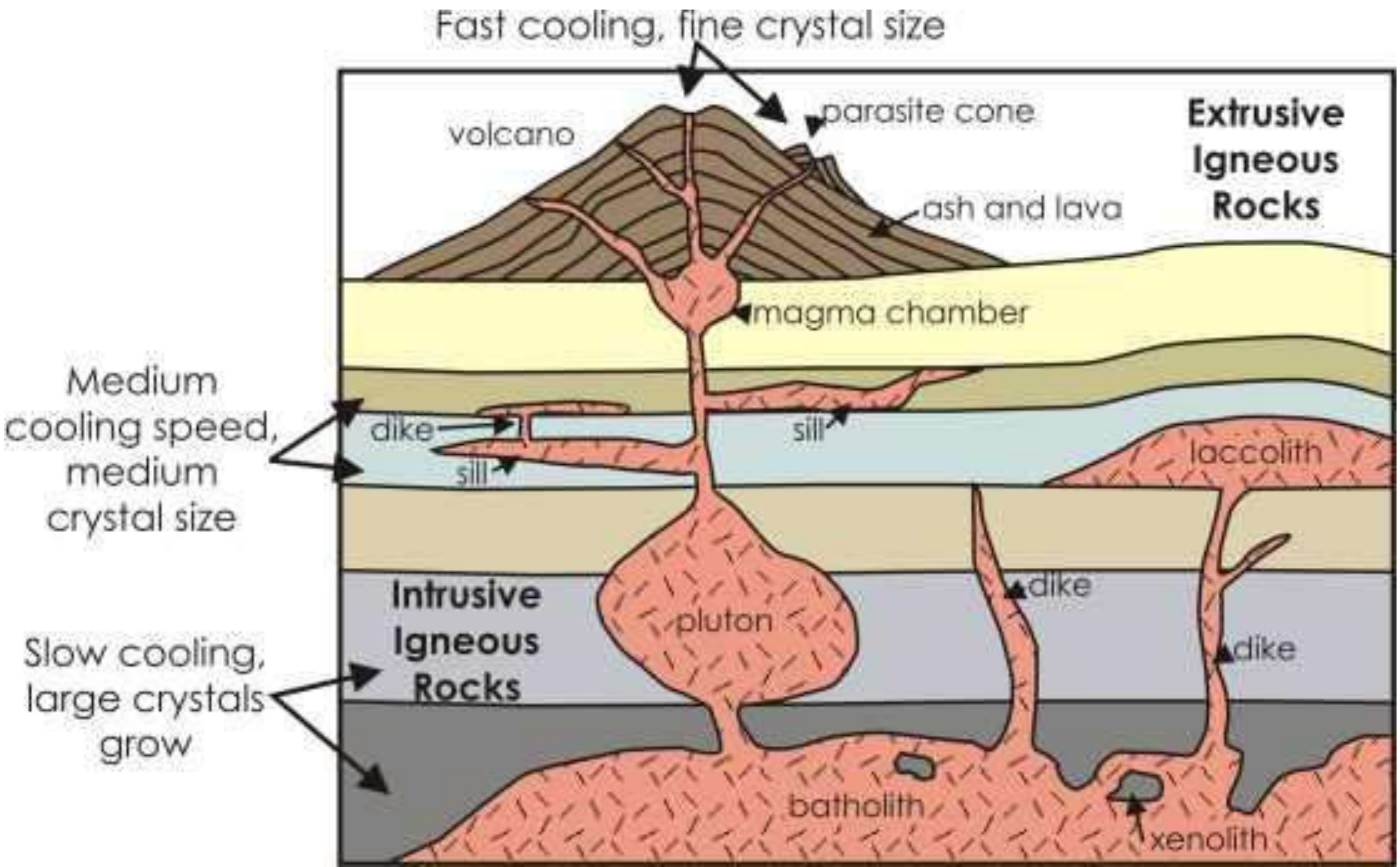
lava : Magma that reaches the surface



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.

Engineering geologic classification of igneous rocks are based on composition or grains (crystals) size .

Mineralogy and texture combine to cause high strength and excellent elastic deformation

Crystal size inversely affects strength.

At the surface:

LAVA hardens to form EXTRUSIVE rocks with tiny (FINE-GRAINED) crystals or GLASSY (no crystal) TEXTURES

Beneath the surface:

MAGMA hardens to form INTRUSIVE rocks with easily visible (COARSE-GRAINED) crystal texture

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. T*he crystals formed early have a higher specific gravity than the remaining liquid of the magma***

The content of silica (as SiO_2) 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.

3. Mica: Translucent thin sheets or flakes. Muscovite is potassium aluminum 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 <u>soluble in water</u>, 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 than quartz or feldspar. The hardness is 3. Have <u>vigorous reaction to hydrochloric acid.</u>

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

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 <u>distinctive rusty color to some rocks</u> and soils and can <u>act as cementing agents</u>. The compact varieties have a hardness of 5.5-6, but earthy form are soft.

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

Texture: describes the overall appearance of a rock based on the size, shape, and arrangement of interlocking minerals.

Factors affecting crystal size

* Rate of cooling

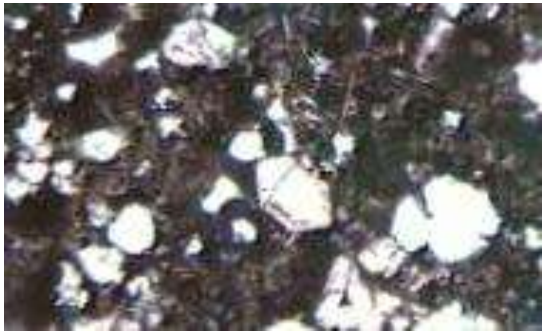
- Slow rate promotes growth of fewer but larger crystals
- Fast rate forms many small crystals
- very fast forms glass

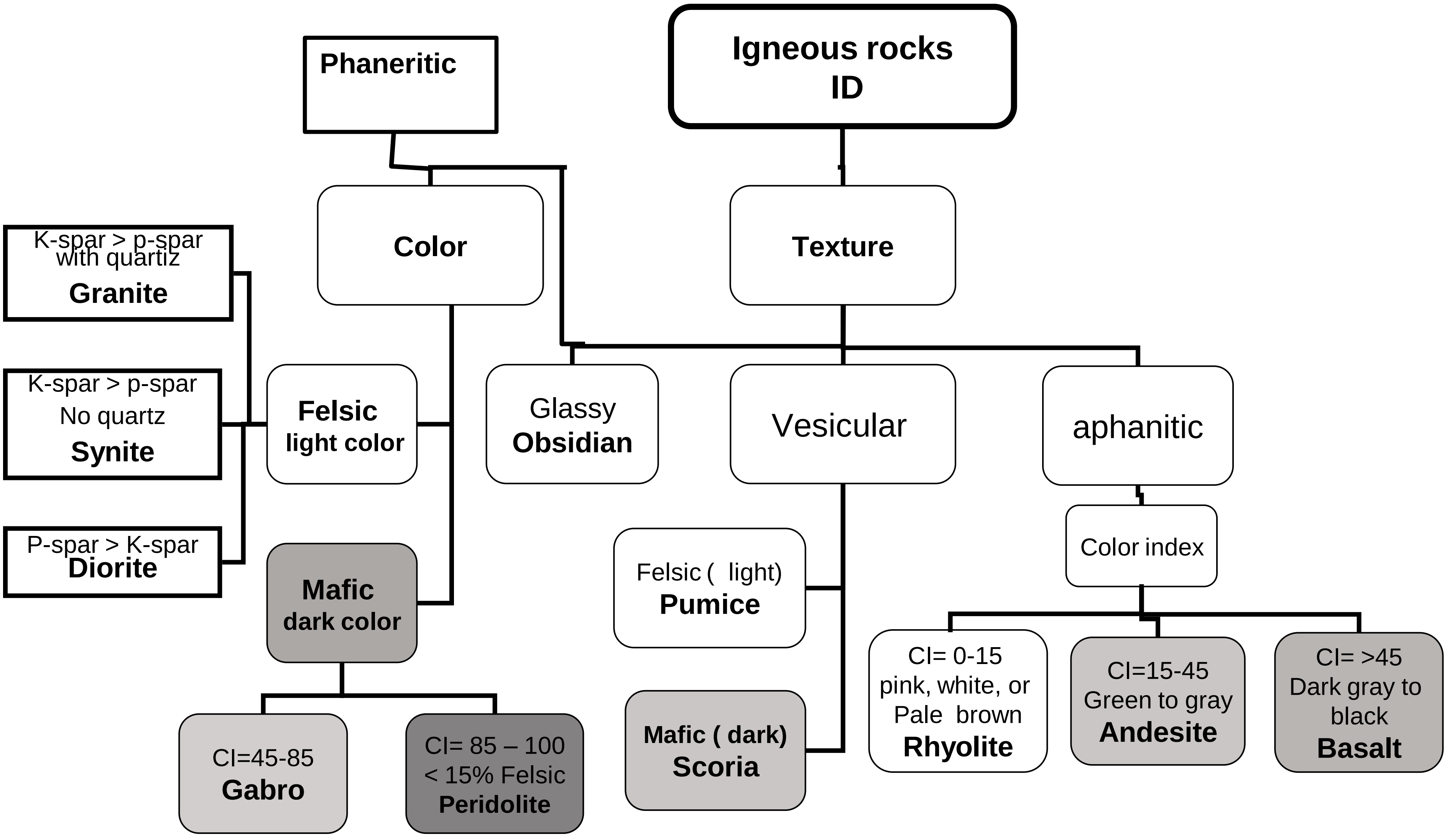
* Amount of silica (SiO_2) present

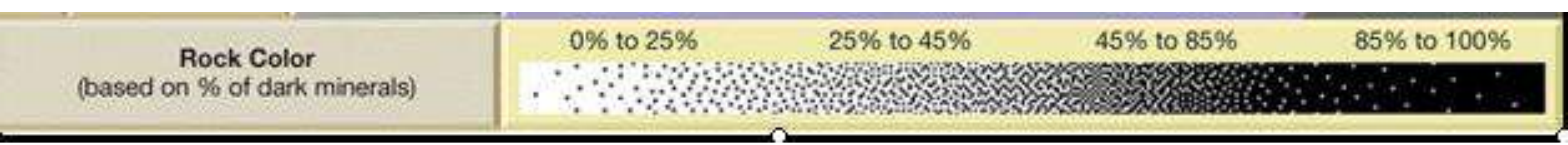
* Amount of dissolved gases

IGNEOUS ROCK TEXTURES

Phaneritic Texture	large crystals that are clearly visible to the eye . This texture forms by slow cooling of magma deep underground in the plutonic environment.	
Aphanitic Texture	consists of small crystals that cannot be seen by the eye or with hand lens . This texture results from rapid cooling in volcanic or hypabyssal (shallow subsurface) environments.	
Glassy Texture	are non-crystalline meaning the rock contains no mineral grains. Glass results from cooling that is so fast that minerals do not have a chance to crystallize. This may happen when magma or lava comes into quick contact with much cooler materials near the Earth's surface. Pure volcanic glass is known as obsidian	
Vesicular Texture	holes, pores, or cavities within the igneous rock. Vesicles are the result of gas expansion (bubbles), which often occurs during volcanic eruptions. Pumice and scoria are common types vesicular rocks	

Fragmental Texture	**blown out into the atmosphere during violent volcanic eruptions. These rocks are collectively termed fragmental . <u>feel grainy like sandpaper</u> or a sedimentary rock.**	
Porphyritic Texture	**composed of at least two minerals having a conspicuous (large) difference in grain size.. Porphyritic rocks are thought to have *undergone two stages of cooling*; one at depth where the larger phenocrysts formed and a second at or near the surface where the matrix grains crystallized.**	


Igneous rocks ID
Phaneritic
Color
Texture
K-spar > p-spar with quartiz
Granite
K-spar > p-spar
No quartz
Synite
P-spar > K-spar
Diorite
Felsic
light color
Mafic
dark color
CI=45-85
Gabro
CI= 85 – 100
< 15% Felsic
Peridolite
Glassy
Obsidian
Vesicular
Felsic (light)
Pumice
Mafic (dark)
Scoria
aphanitic
Color index
CI= 0-15
pink, white, or
Pale brown
Rhyolite
CI=15-45
Green to gray
Andesite
CI= >45
Dark gray to
black
Basalt

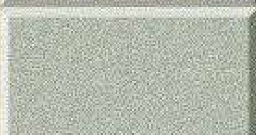

Rock Color
(based on % of dark minerals)
0% to 25%
25% to 45%
45% to 85%
85% to 100%

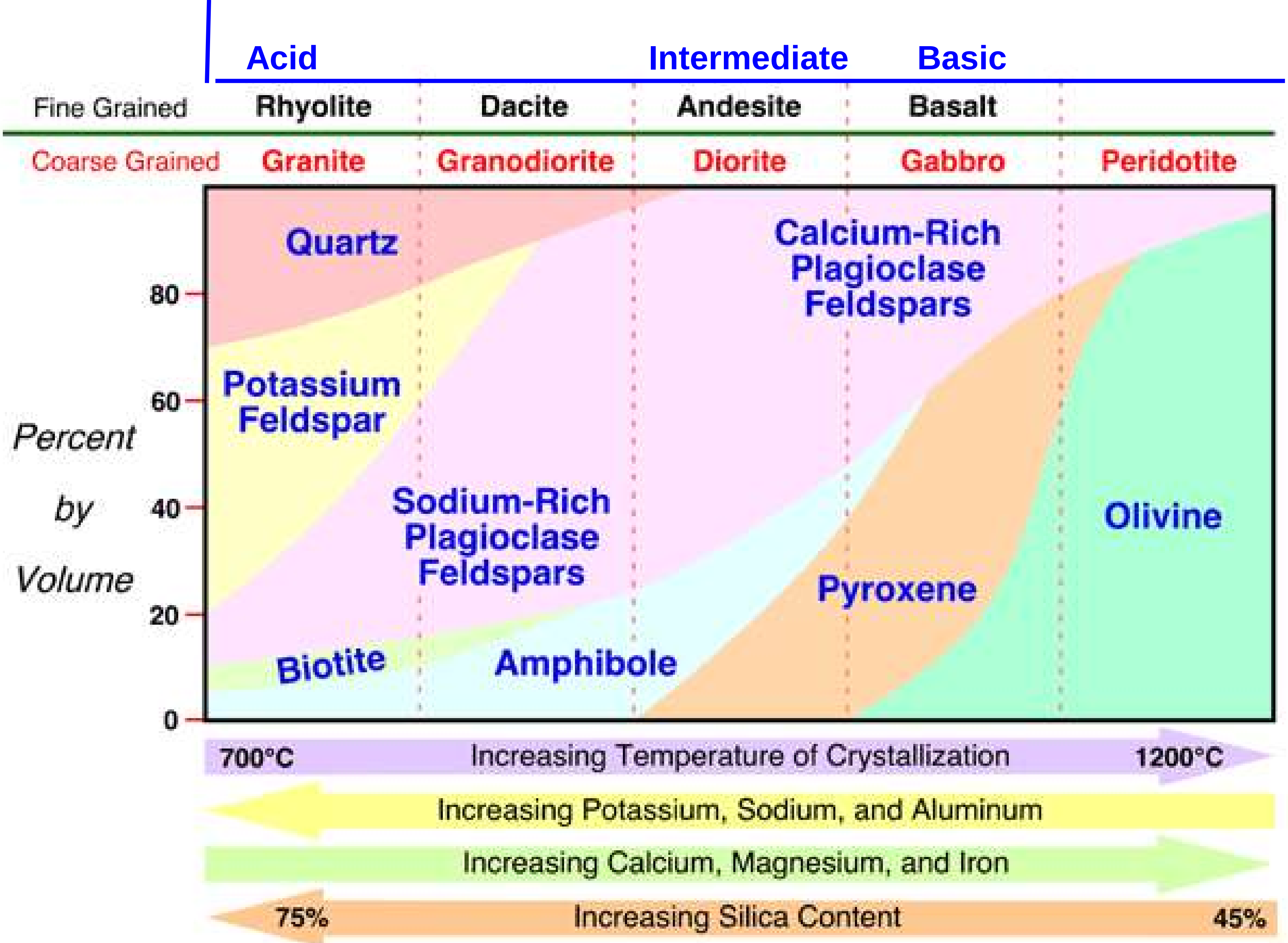
Classification of Igneous Rocks

Texture

Color

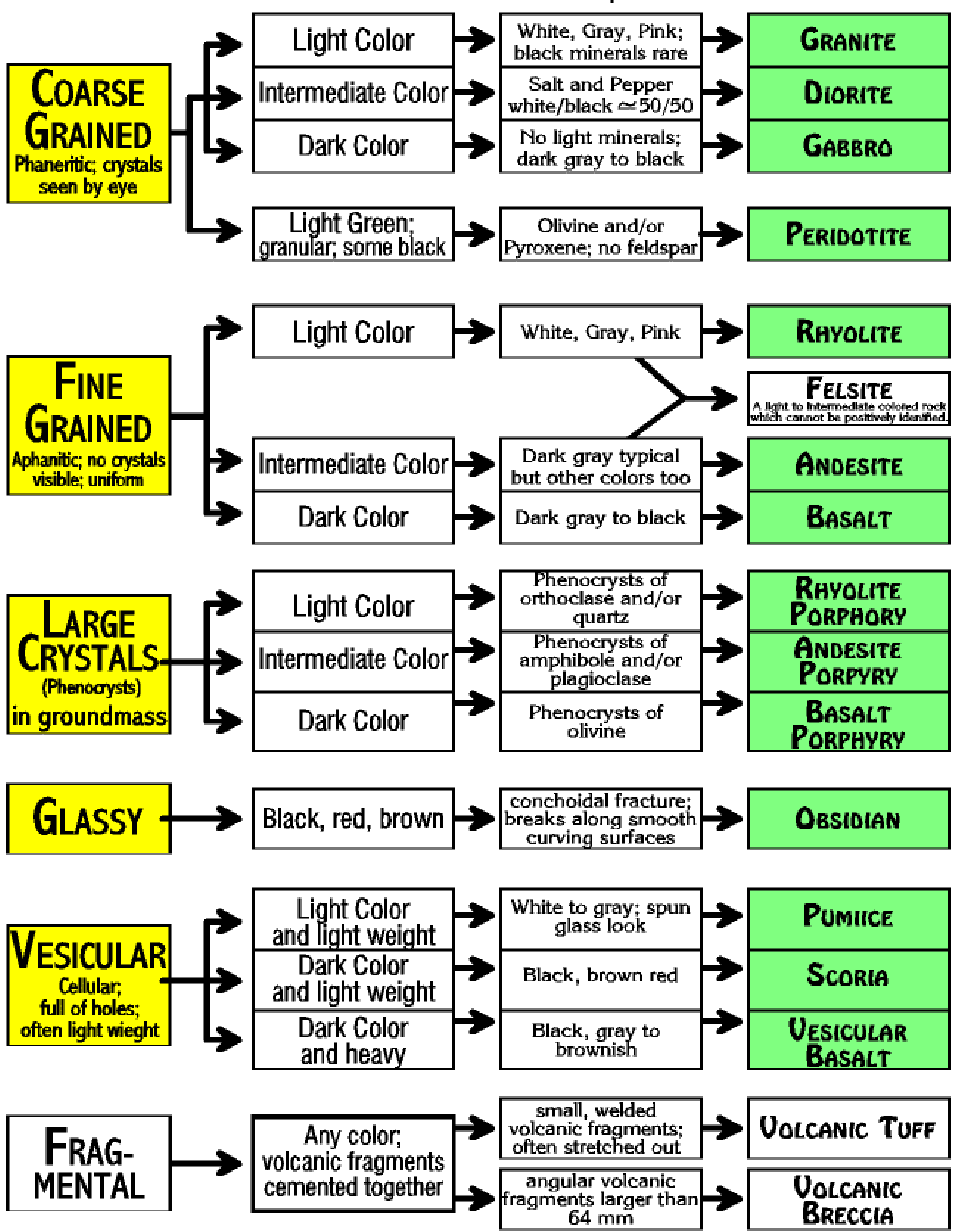
Minerals present

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)			
Rock Color (based on % of dark minerals)		0% to 25%	25% to 45%	45% to 85%	85% to 100%



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

Color-Texture Classification of igneous rocks



http://csmres.jmu.edu/geollab/Fichter/IgnRx/igkey.html

Andesite is a fine-grained, extrusive igneous rock composed mainly of plagioclase with other minerals such as hornblende, pyroxene and biotite

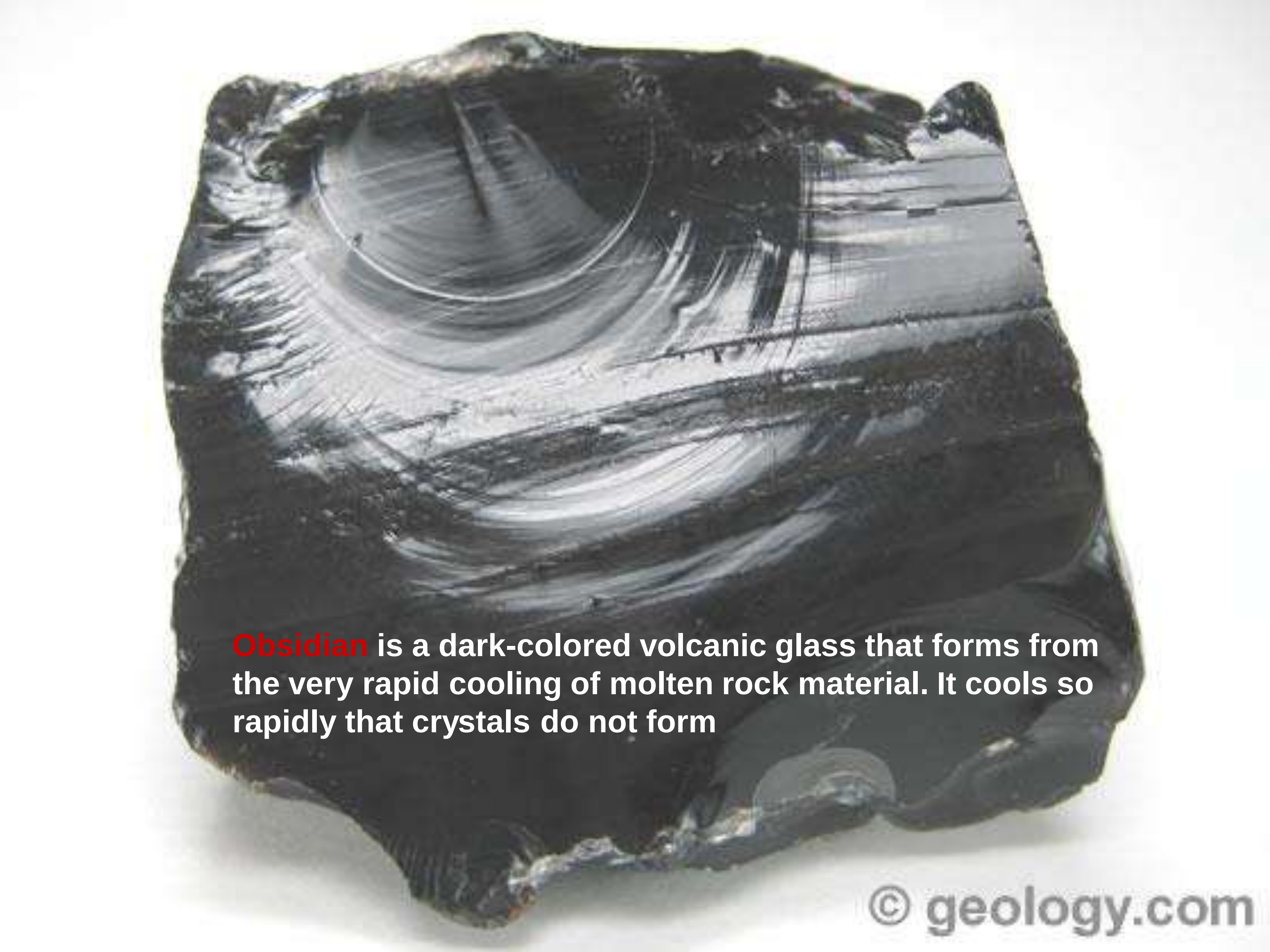
Basalt is a fine-grained, dark-colored extrusive igneous rock composed mainly of plagioclase and pyroxene.

Vesicular Basalt

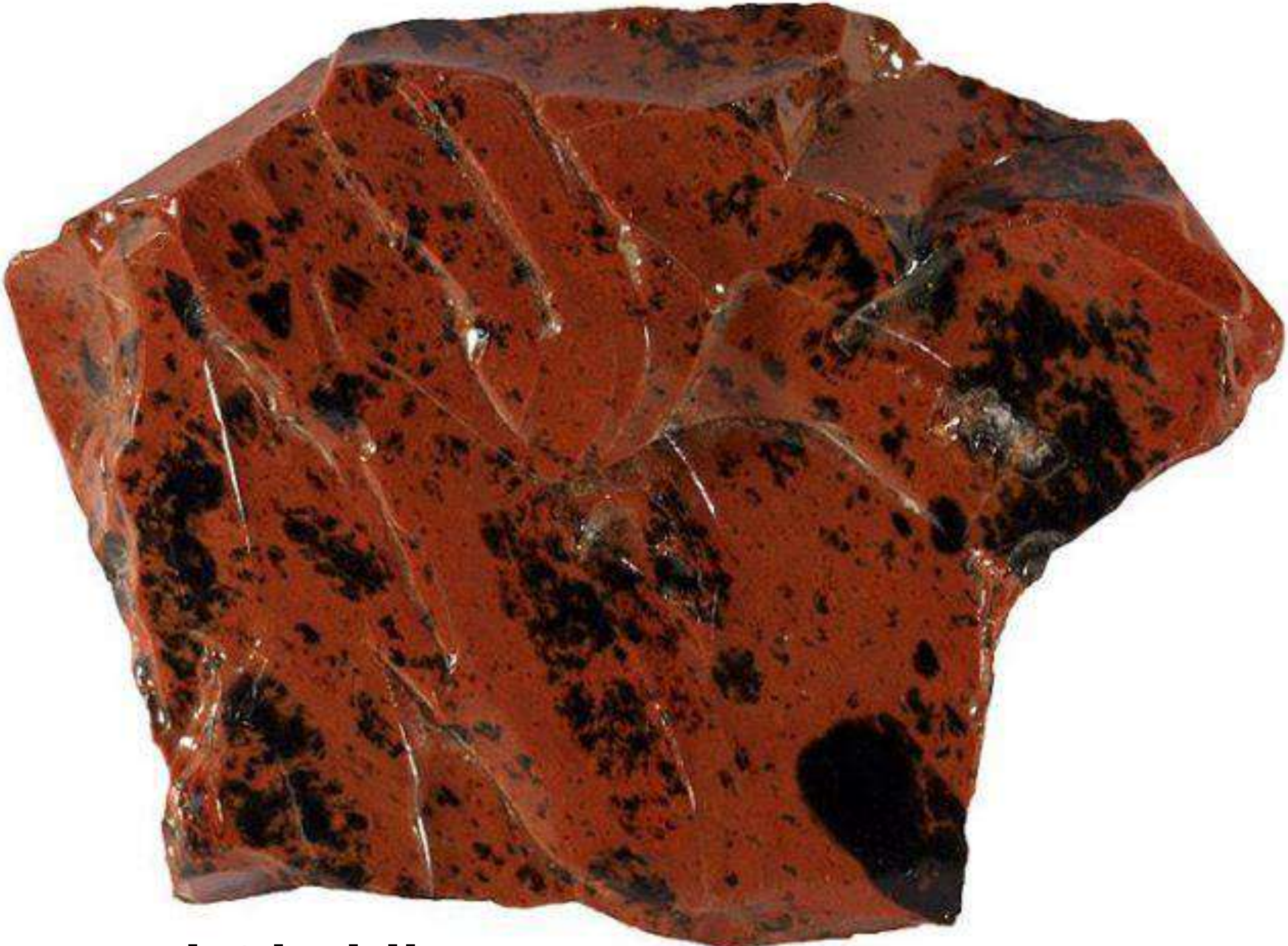
Diorite is a coarse-grained, intrusive igneous rock that contains a mixture of feldspar, pyroxene, hornblende and sometimes quartz

Gabbro is a coarse-grained, dark colored, intrusive igneous rock that contains feldspar, augite and sometimes olivine

Granite is a coarse-grained, light colored, intrusive igneous rock that contains mainly quartz and feldspar minerals



Obsidian is a dark-colored volcanic glass that forms from the very rapid cooling of molten rock material. It cools so rapidly that crystals do not form



Red Obsidian

Pegmatite is a light-colored, extremely coarse-grained intrusive igneous rock. It forms near the margins of a magma chamber during the final phases of magma chamber crystallization. It often contains rare minerals that are not found in other parts of the magma chamber

Pumice is a light-colored vesicular igneous rock. It forms through very rapid solidification of a melt. The vesicular texture is a result of gas trapped in the melt at the time of solidification

Rhyolite is a light-colored, fine-grained, extrusive igneous rock that typically contains quartz and feldspar minerals

Scoria is a dark-colored, vesicular, extrusive igneous rock. The vesicles are a result of trapped gas within the melt at the time of solidification. It often forms as a frothy crust on the top of a lava flow or as material ejected from a volcanic vent and solidifying while airborne

Welded Tuff is a rock that is composed of materials that were ejected from a volcano, fell to Earth, and then lithified into a rock. It is usually composed mainly of volcanic ash and sometimes contains larger size particles such as cinders

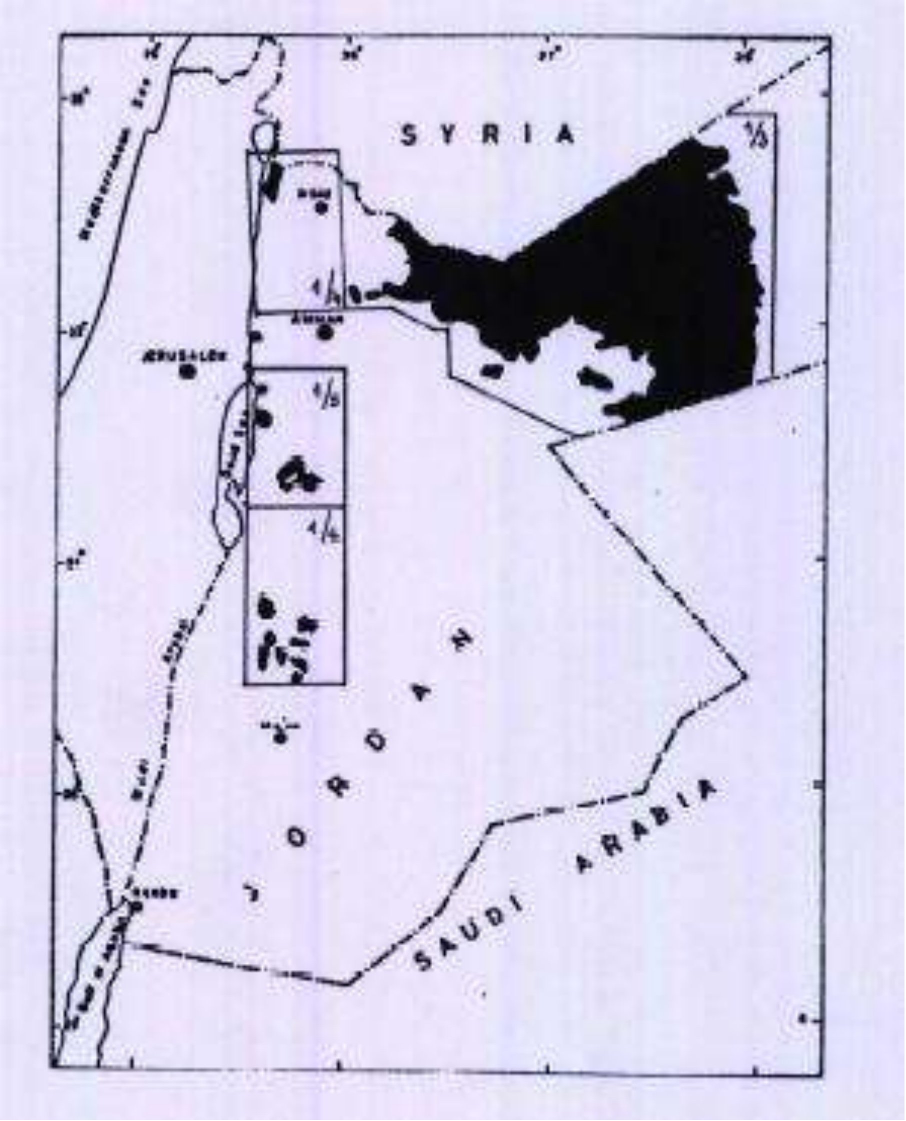
Basalt occurrence in Jordan (natural recourses authority)

uses

Rock Wool Industry

As Aggregates and Building Stones

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



Mould 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.

Engineering Geology

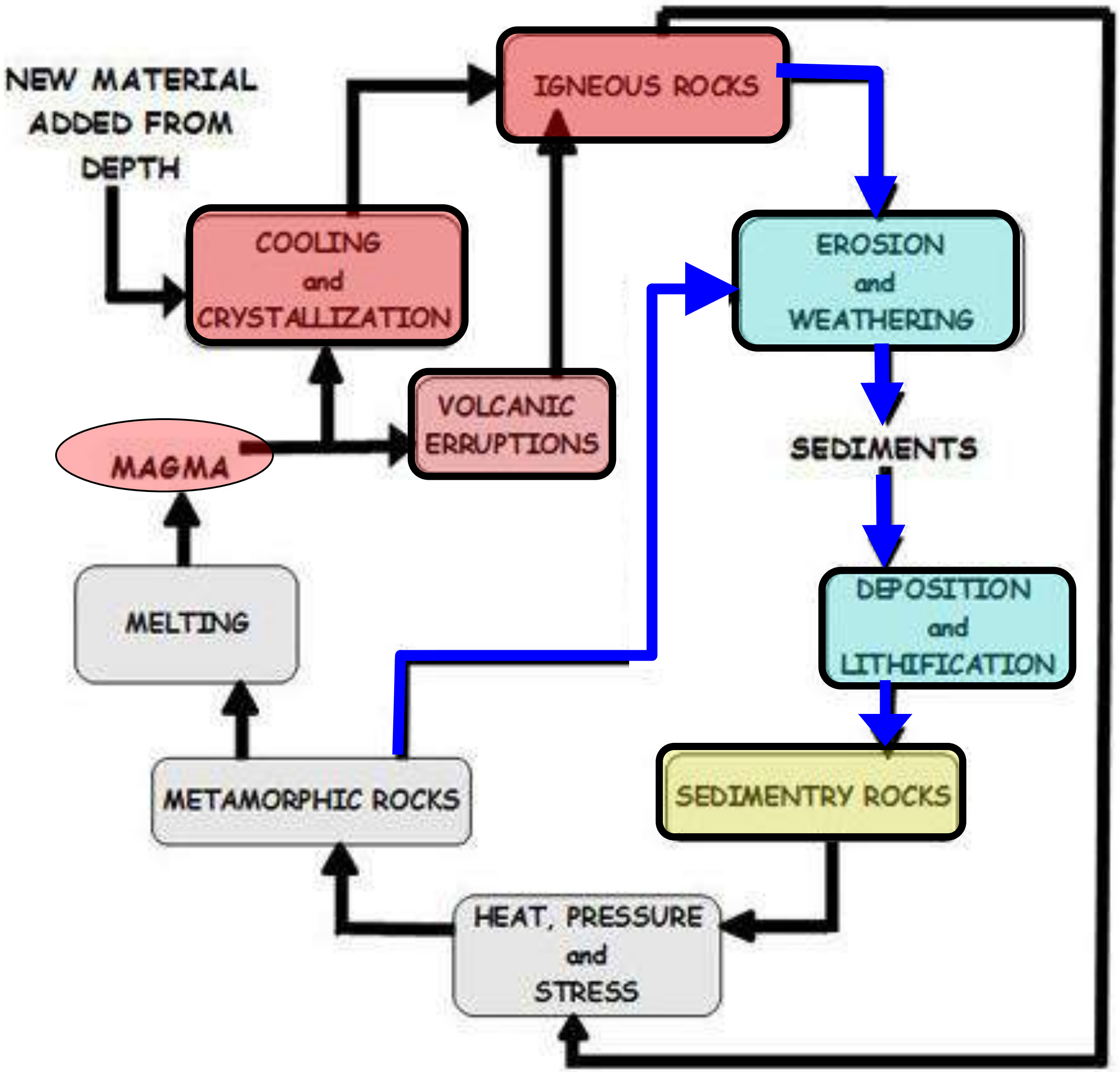
Engineering Geology is backbone of civil engineering

Rocks

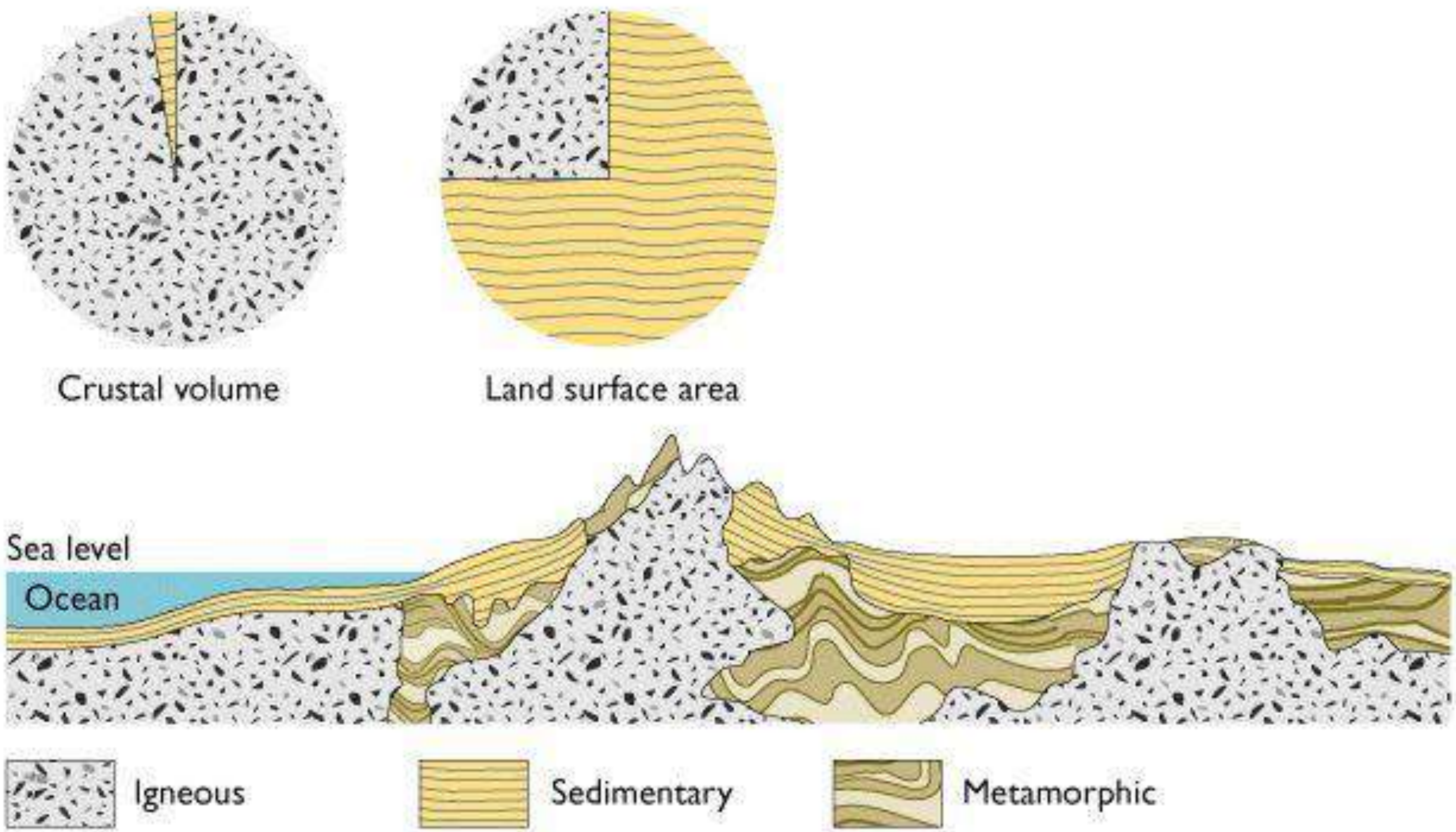
2. Sedimentary Rocks

Eng. Iqbal Marie

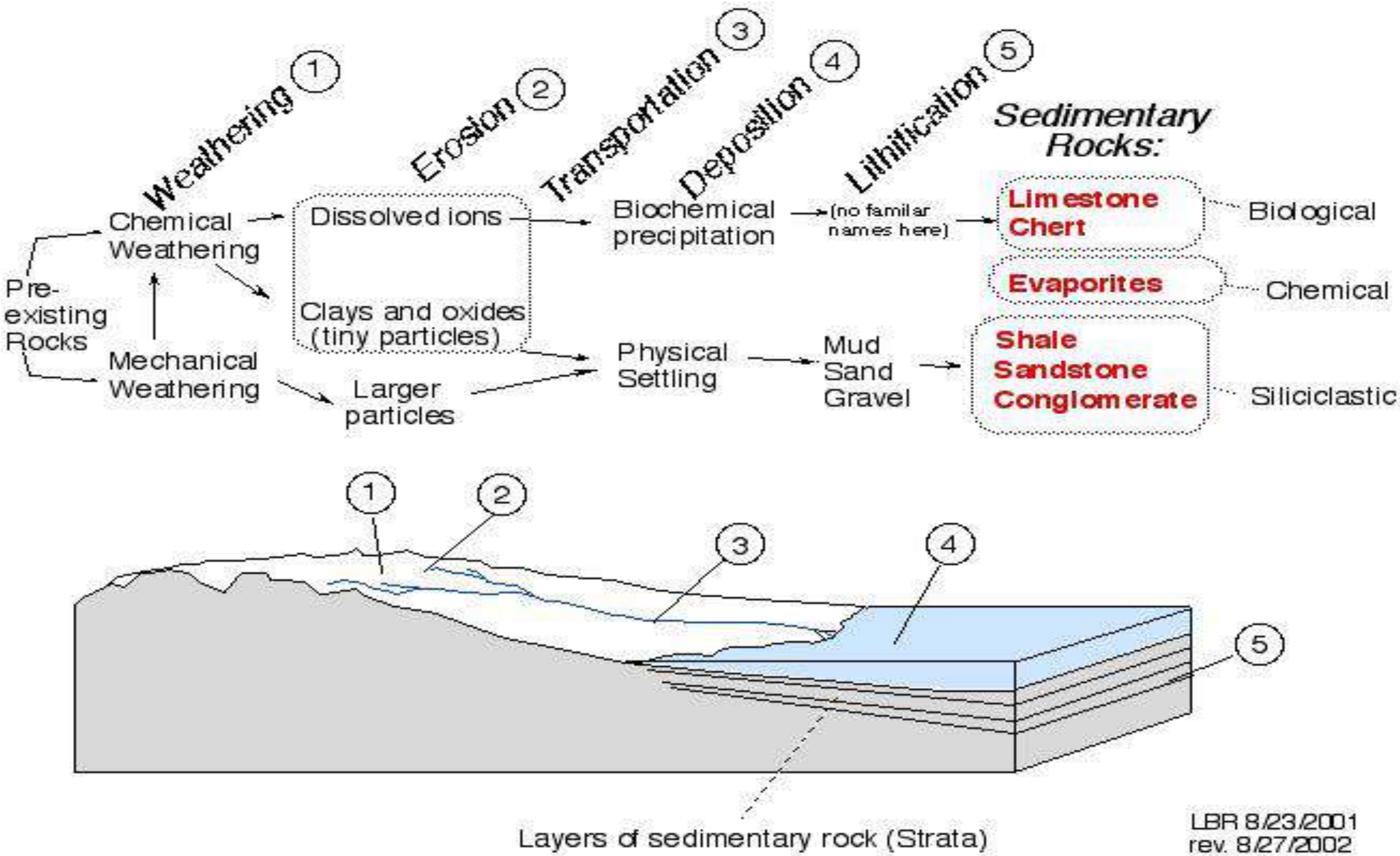
Rock Cycle Diagram



How common are sedimentary rocks?



Sedimentary rocks go through the following stages on the way to becoming a rock: (sedimentary rocks cycle)



Weathering

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

weathering causes deterioration of building materials. It also weaken rocks, a great concern when weathered rocks are used for foundation

Two types of weathering:

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.

Main causes of Mechanical weathering:

- Frost action
- Heating and cooling
- Organisms

a. Frost action:

Freezing of water in the cracks of rocks tends to disintegrate them because volume of water increases 1-11 times of its actual volume. It exerts a great pressure on the wall having cracks. By this process, angular fragments of rocks are broken off from the main body of the rock,

b. heating and cooling:

Heating of rocks causes expansion and cooling cause contraction of rocks. This repeated heating and cooling helps to develop cracks in rocks and the rock will be disintegrated.

c. Organisms:

Plants and insects like earthworms, ants, and snakes play an important role in mechanical weathering. Plants also grow in joints and cracks of the rocks and push them further apart.

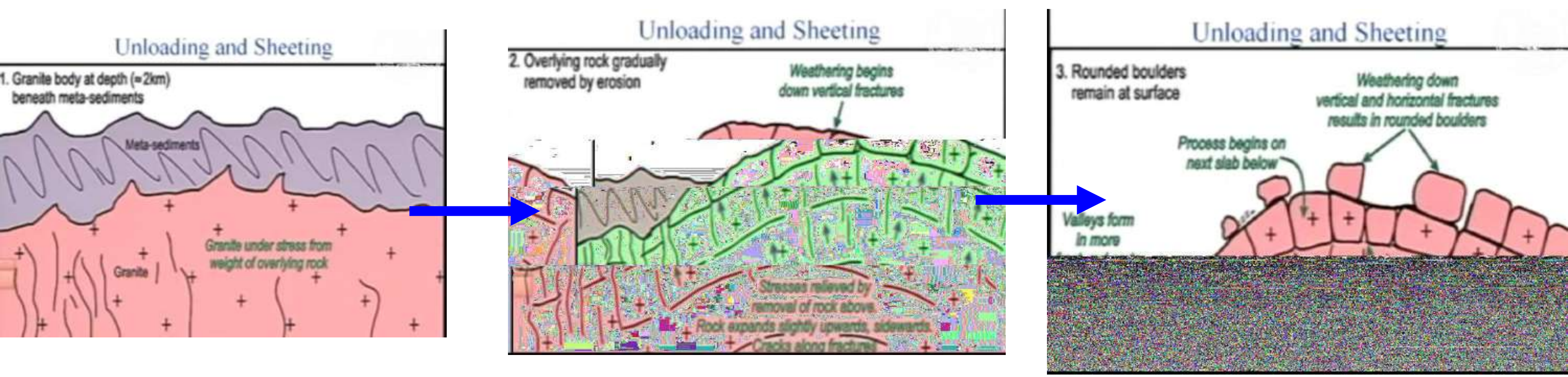
Similarly, man activities like breaking rocks for his construction.

Unloading: Jointing, exfoliation and sheeting

Removal of overburden → the rock expands

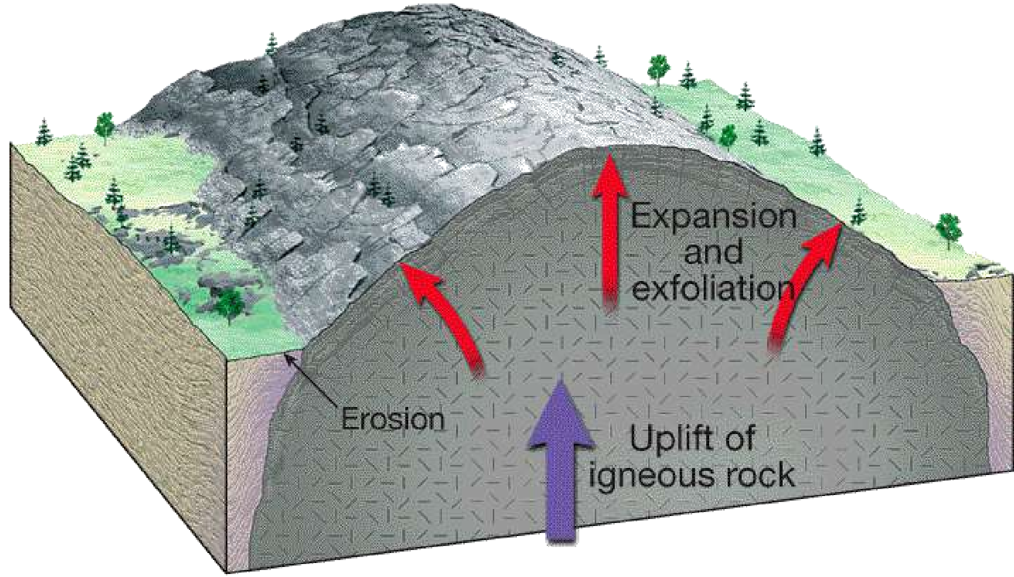
The unloading may occur when the overlaying rocks are eroded or rocks are removed from a quarry. The expansion caused by naturally formed cracks are known as joins

Typically, large plutons (bodies of igneous rock) or metamorphic bodies split into sheets that are parallel to the mountain face, a process known as exfoliation. It is also known as sheeting if the expansion from unloading occurs in granite to form rock slabs.



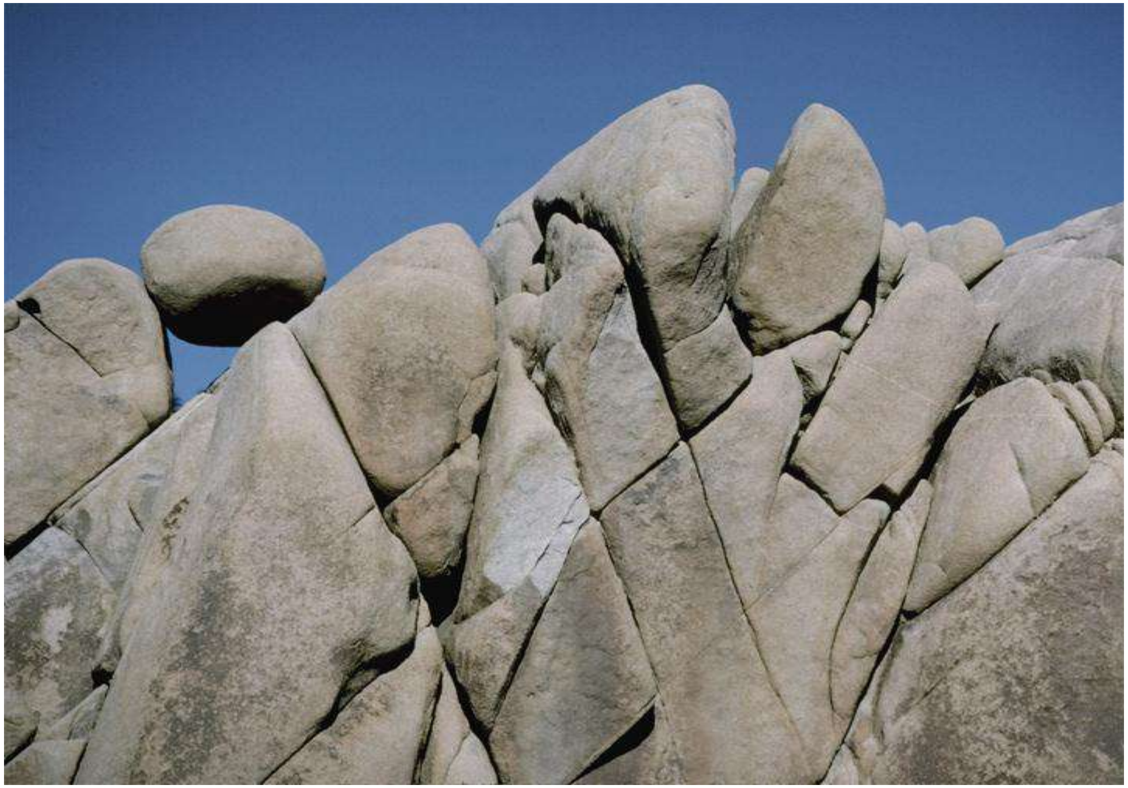
, Sheeting and exfoliation

When subsurface confining stress is released fast, and the rock exposed to the surface, if the rock has large residual stress, it will be broken into blocks. The fracture in vertical direction form exfoliation. If the fracture is in horizontal direction, it calls sheeting.



Spheroidal Weathering

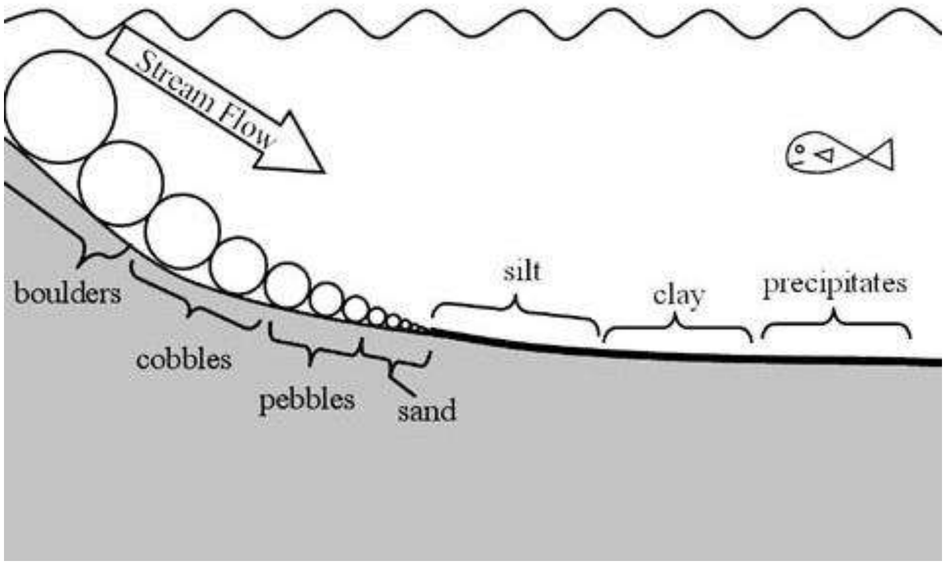
- Causes the corners and edges of rock to be more rounded



Particles size and angularity

Erosion- the process of moving sediment from one location to another. The most important **FORCE of erosion is GRAVITY**. The most important **AGENT of erosion is WATER**.

The amount of erosion by a stream depends on the velocity and volume of water



- 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.

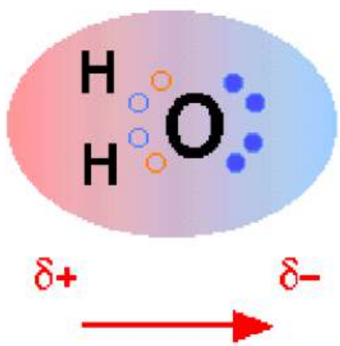
1. **Quartz** the most common mineral. Chemically stable and hard enough to resist abrasion as it is transported (**Conglomerate and Sandstone**)
2. **Clay** (**Shale and Mudstone**)
3. **$CaCO_3$** (**Limestone and Dolomite**)

Chemical weathering: **Dissolve and decay earth materials that exposed to air and water**

Mechanical weathering could enhance chemical weathering by disintegration, which accelerate the chemical weathering

Chemical weathering rate depends on

1. Temperature
2. Amount of surface area
3. Availability of water or natural acid



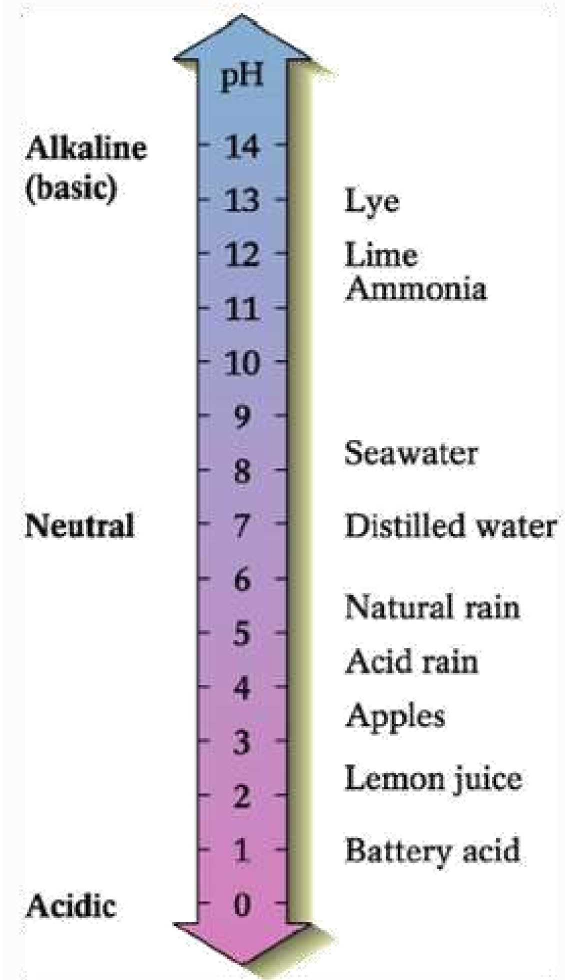
Because of its dipolar nature water is able to dissolve many chemical compounds. In addition to the solution effect, water aids decomposition through acid action, oxidation, and hydrolysis.

Solution (or dissolution)

*** Several common minerals dissolve in water**

i), halite; ii), calcite

*** Limestone and marble contain calcite and are soluble in acidic water.**



Chemical Weathering of Granite

- Weathering of potassium feldspar produces clay minerals, soluble salt (potassium bicarbonate), and silica in solution.
- Quartz remains substantially unaltered.

Weathering of Silicate Minerals

- Produces insoluble iron oxides and clay minerals

Rock salt, evaporative: formed in a saline body of water

Peat, biochemical/organic: dark mud, plant fragments indicates it was formed in a swamp environment

Hydrolysis: Hydration-reaction between mineral and water

Since many igneous rocks contain feldspar minerals (K-feldspar and plagioclase) as a major component in mafic, intermediate, and felsic rocks, clays are common products of chemical weathering of igneous rocks. Clays are a group of minerals that are all sheet silicates with various amounts of water in their crystal structures (added to feldspar structure, which is a framework silicate). An example is kaolinite (a chalky white mineral)

Feldspar + water -> kaolinite + silica + potassium ions

$KAlSi_3O_8 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + SiO_2 + K^+$

Minerals of Sedimentary Rocks → Products of Weathering

Original Mineral	Weathering Product
Iron-bearing silicates Olivine Pyroxene Amphibole Biotite	Clay minerals Iron oxide
Feldspar	Clay minerals K, Na, Ca ions
Quartz	Quartz
Muscovite mica	Clay minerals K ions
Calcite	Ca, CO_3 ions

http://geology.csupomona.edu/drjessey/class/Gsc101/Weathering.html

Lithification - Involves several steps.

Compaction - Squeezing out of water.
Cementation - Precipitation of chemical cement from trapped water and circulating water.
Recrystallization - Growth of grains in response to new equilibrium conditions

Sedimentary rock grains may be bonded together by a cement, which consists of any naturally deposited mineral matter.

Commonly found cements in sedimentary rocks include calcite and silica as will as hematite. (gives red color)

The name of the cement may be of importance to the engineer since it affect a rock's properties.

If the sedimentary pile is later uplifted the calcite cement re-dissolves and the sedimentary rocks will possess gaps or voids in its structure

Oxidation

Oxidation - Oxygen combines with iron-bearing silicate minerals causing "rusting". Iron oxides are produced that are red, orange, or brown in color. Iron-bearing silicate minerals that undergo oxidation include the following:

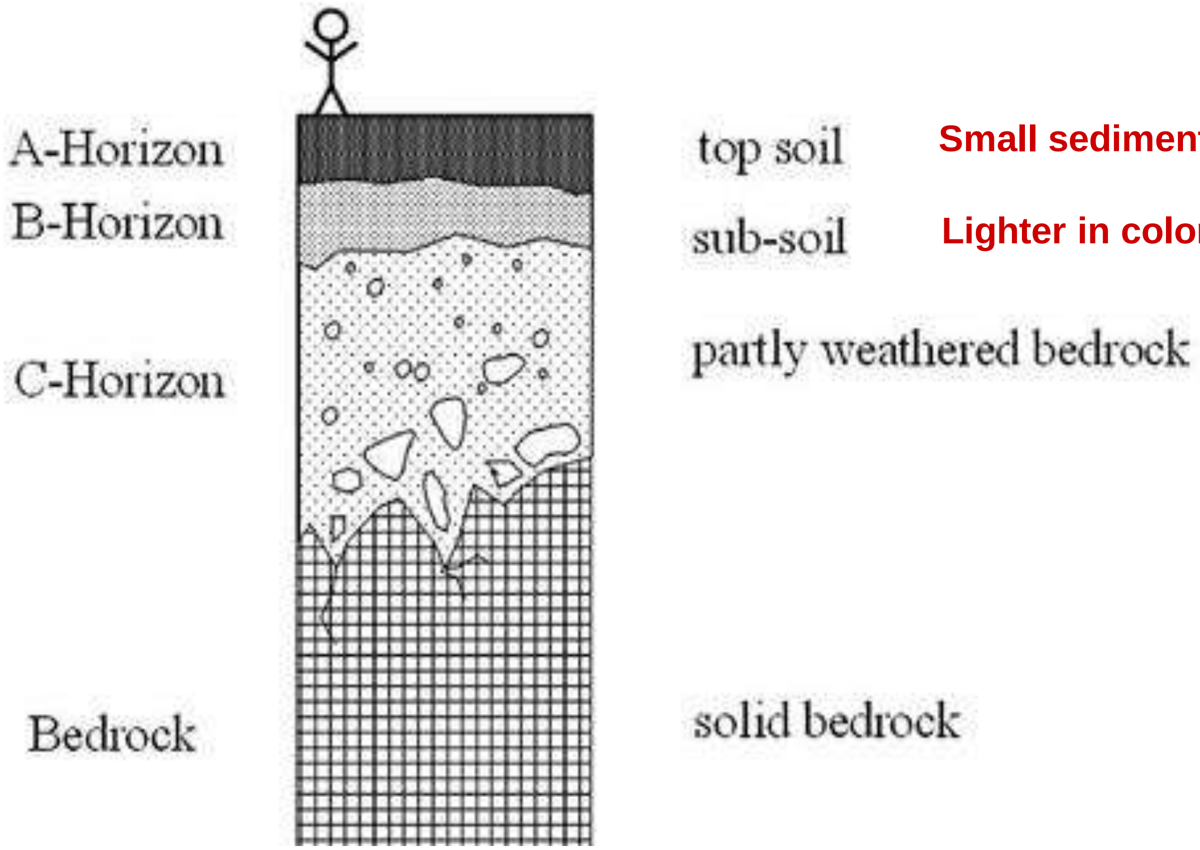
* olivine
* pyroxene
* amphibole
* biotite

Iron oxides are produced by oxidation of iron-bearing silicate minerals. These minerals are iron oxide minerals:

* limonite
* hematite
* goethite
* Iron oxides are red, orange, or brown in color
* Mafic rocks such as basalt (which may contain olivine, pyroxene, or amphibole) weather by oxidation to an orange color

Soil - The product of weathering
Soil is made from rocks, minerals (mainly sand and clay), and organic material (regolith and organic matter)
Soil forms layers of different characteristics called horizons.

Classification of soils varies depending on the classifier. ***Geologists use a very simple classification based largely on materials added or removed from the soil during its formation.***

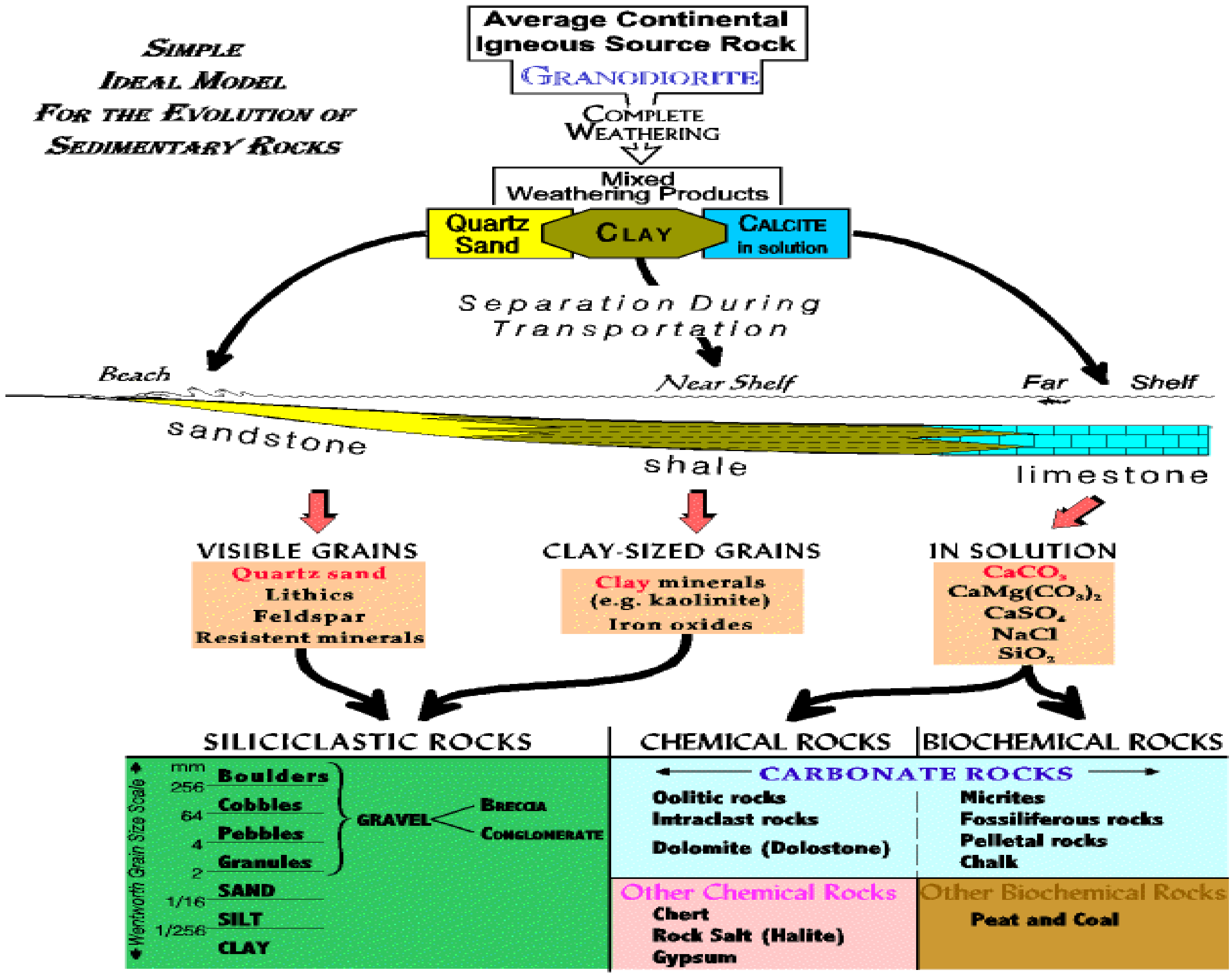


Small sediments and organic material

Lighter in color, no organic material

Larger rocks

SEDIMENTARY ROCK MODELS



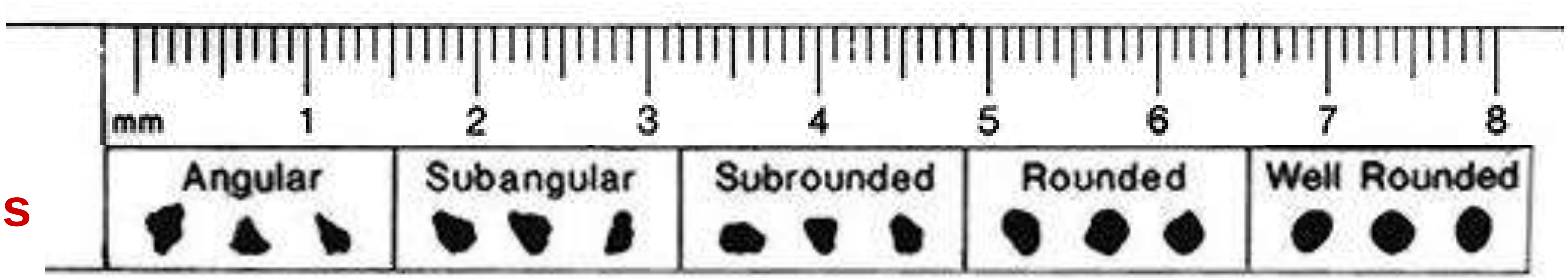
L. S. Fichter, 1993, 2000

http://geollab.jmu.edu/Fichter/SedRx/sedclass.html

clastic rock - Texture

- **Texture – description of parts of the rock and their size, shape and arrangement; sorting**

roundness



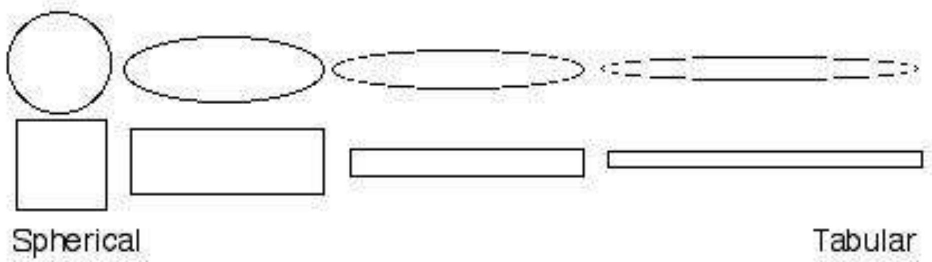
- **Grain size:**
  (a) larger than 2 mm (gravel size)
  (b) sand size; 1/16 – 2 mm (visible)
  (c) mud/silt size; <1/16 mm (not visible)
  (d) crystalline/microcrystalline –(crystals are visible/ not)

Characteristics of sediments

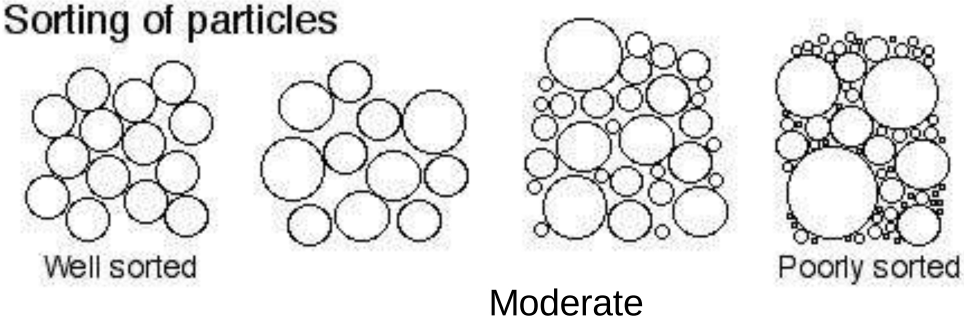
Size of particles

Rounding or angularity of particles

Sphericity of particles



Sorting of particles



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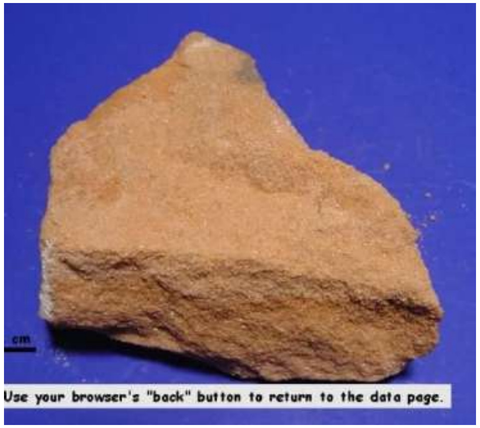


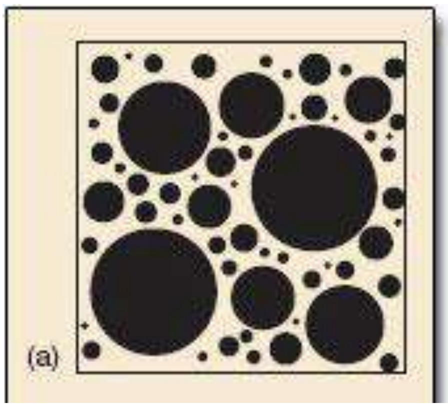
Clastic - Formed from broken or fragmented grains (**detrital**).
Rock appears grainy.
Basis of classification of the clastic rocks is the Wentworth Size Scale which was derived from studies of grain diameters.

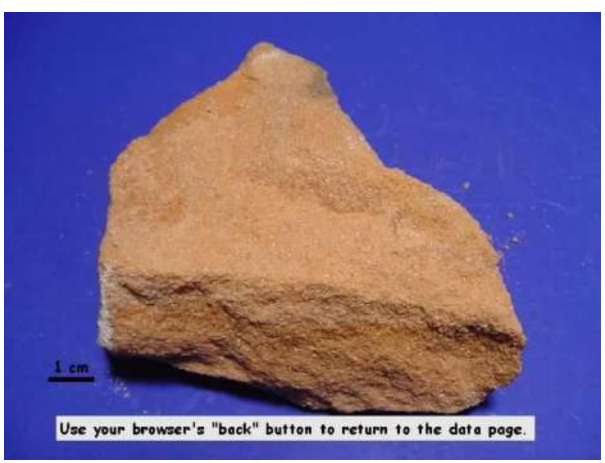
Wentworth Size Scale		
Boulder	>256 mm	Conglomerate
Cobble	64-256 mm	
Pebble	2-64 mm	
Sand	1/16-2 mm	Sandstone
Silt	1/256-1/16 mm	Siltstone
Clay	<1/256 mm	Shale

Nonclastic (chemical) - Grains are interlocked through crystallization. Has igneous appearing texture with very little open space.

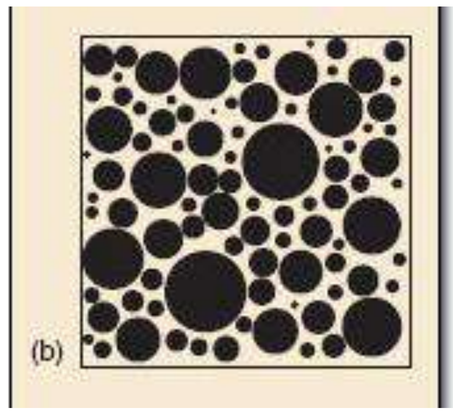
Sorting

Poorly

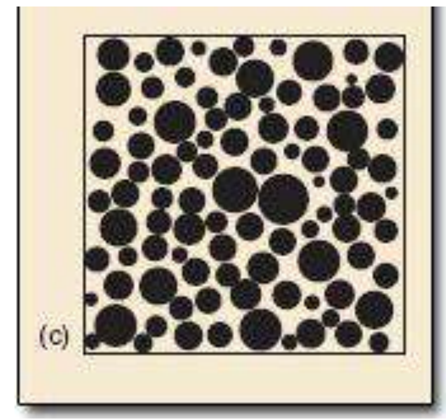




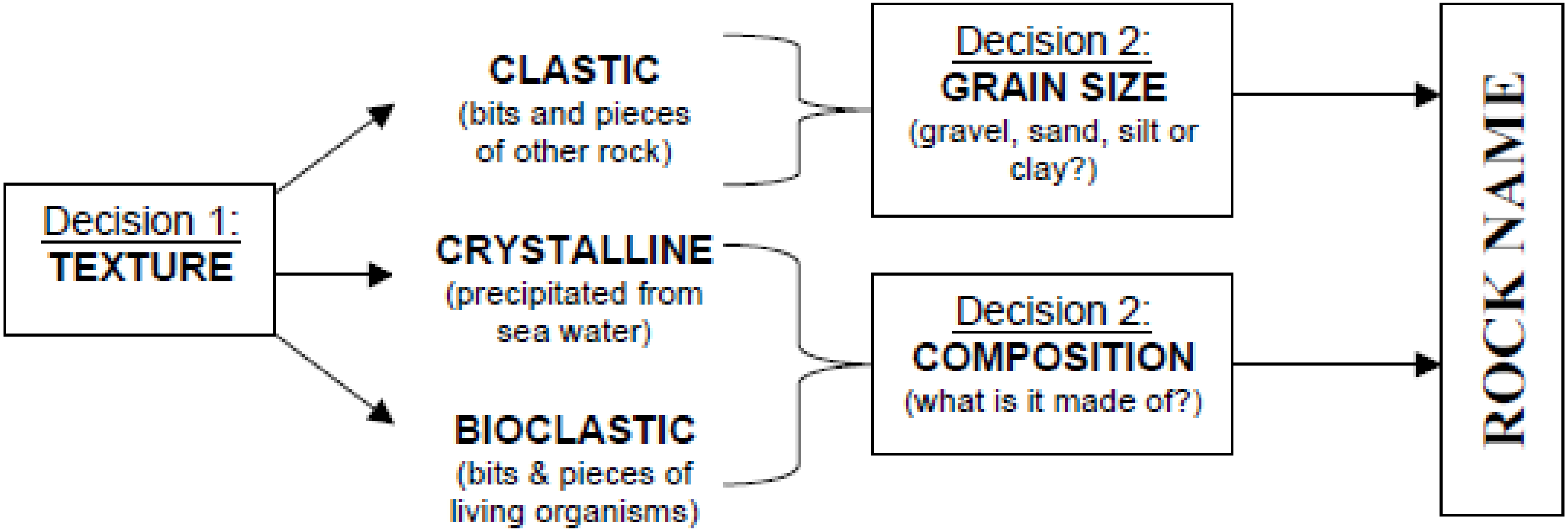
Moderate



Well

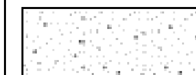
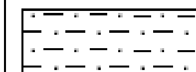
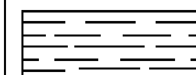


Sedimentary Rocks Classification

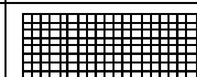
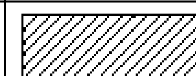
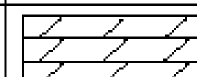
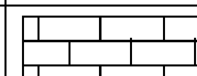
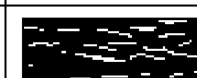


Scheme for Sedimentary Rock Identification

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	

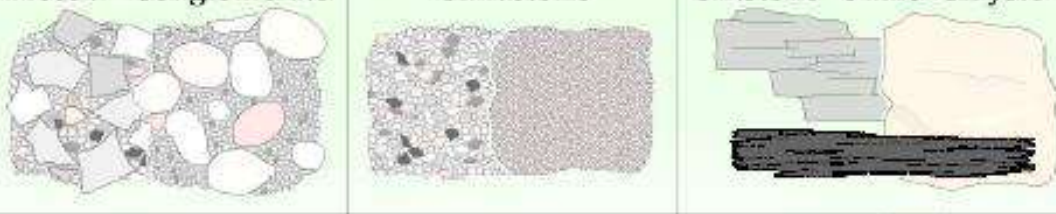
CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS

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	

Sedimentary Rocks

CLASTIC SEDIMENTARY ROCKS

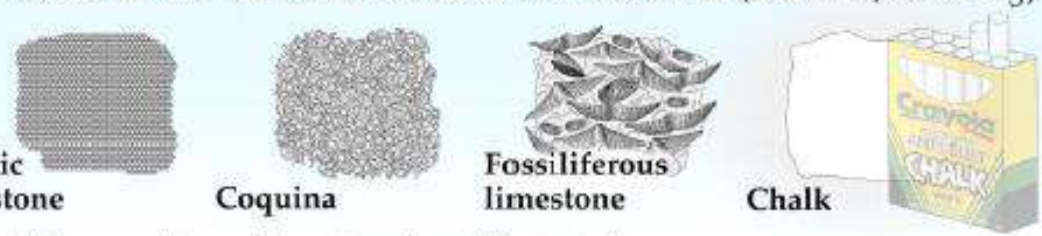
Breccia Conglomerate			Sandstone	Siltstone Shale Claystone	



Gravel			Sand	Mud (wet)	
Boulder	Cobble	Pebble	Sand	Silt	Clay

2 mm   1/16 mm

CLASTIC AND BIOCLASTIC LIMESTONE (Calcite, $CaCO_3$)



Oolitic limestone **Coquina** **Fossiliferous limestone** **Chalk**

Lime mudstone (limestone), not illustrated

CHEMICAL SEDIMENTARY ROCKS

Sedimentary rocks with crystalline and microcrystalline textures

Crystalline limestone	Calcite, $CaCO_3$
Chert	Quartz, SiO_2, microcrystalline
Rock salt	Halite, $NaCl$
Rock gypsum	Gypsum, $CaSO_4 \cdot 2H_2O$

ORGANIC SEDIMENTARY “ROCKS”

Peat, Coal

Examples of some Sedimentary Rocks

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

Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks

Breccia

Conglomerate

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

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

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 GYPSUM

Texture = crystalline (chemical)

crystals form from chemical precipitates and evaporites

Composition = gypsum $CASO_4 . 2H_2O$


© geology.com

fossilized limestone

Coquina : Bioclastic : from pieces of living things

fossiles in mud stone

Chert is a microcrystalline. Composed of silicon dioxide (SiO_2)

(Flint)

Oil Shale

rock that contains significant amounts of organic material. Up to 1/3 of the rock can be solid organic material. Liquid and gaseous hydrocarbons can be extracted from the oil shale but the rock must be heated and/or treated with solvents. This is usually much less efficient than drilling rocks that will yield oil or gas directly into a well. The processes used for hydrocarbon extraction also produce emissions and waste products that cause significant environmental concerns.

Engineering properties of some unweathered sedimentary rocks.

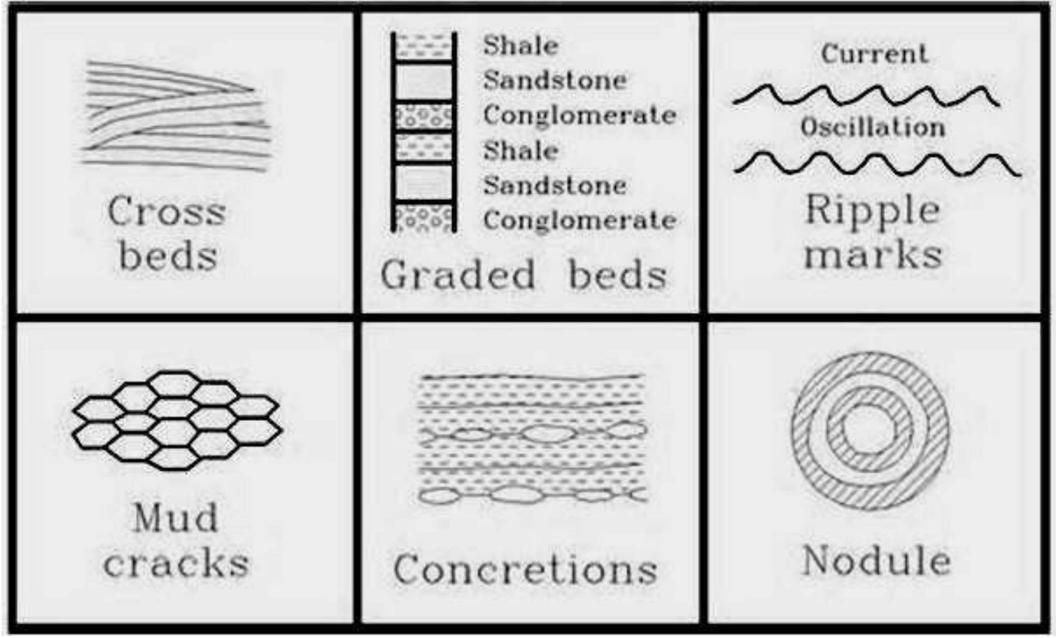
	Density (sp. gr.)	Porosity (%)	Water absorption (%)	Unconfined compressive ve strength (MN m^{-2})
conglomerate	2.5–2.8	1–20	—	—
sandstone	1.9–2.6	5–25	<14.0	20–179
siltstone	2.2–2.5	2–24	< 6.0	—
shale	2.0–2.4	10–35	<6.0	5–100
hard limestone	2.5–2.7	0–10	<2.0	60–200
soft limestone (e.g. chalk)	2.3–2.5	5–50	<4.0	20–50
dolomite	2.5–2.75	1–5	<1.5	30–200

Sedimentary rocks Structures

A) Structures formed during deposition

Bedding - Layering of sedimentary rocks. Each bed represents a homogeneous set of conditions of sedimentation. New beds indicate new conditions. Most layering is parallel, but occasionally it is inclined.

These inclined layers are **cross beds**. Examples of sedimentary environments in which cross beds form are dune fields and deltas.



http://geology.csupomona.edu/drjessey/class/Gsc101/Weathering.html

Graded beds occur when a mass of sediment is deposited rapidly. The bedding has the coarsest sediment at the bottom and finest at the top. Often found forming in submarine

Ripple Marks - Waves of sand often seen on a beach at low tide and in stream beds.

a) Current - asymmetrical - Rivers

b) Oscillation - symmetrical – Beaches

Mud Cracks - Polygonal-shaped cracks which develop in fine grained sediments as they dry out. Common in arid environments, such as a desert.

B) Structures formed after deposition

Nodule - Irregular, ovoid concentration of mineral matter that differs in composition from the surrounding sedimentary rock. Long axis of the nodule usually parallels the bedding plane and seems to prefer certain layers.

Concretion - Local concentration of cementing material. Generally round. Usually consist of calcite, iron oxide or silica. Can exceed 1 meter in diameter. Not understood how they form.

Chert nodules in chalk

The uses of dolomite are classified as follows:

- Direct applications of dolomite (Agriculture, Cement mortar, and treatment of cracks).
- Uses of selectively calcined dolomite (produce, Magnesium oxychloride cement, Magnesium oxysulphate cement, Inorganic magnesia foams, and silicate bricks)
- Chemicals from dolomite (Magnesium oxide, magnesium hydrooxide, magnesium carbonate).

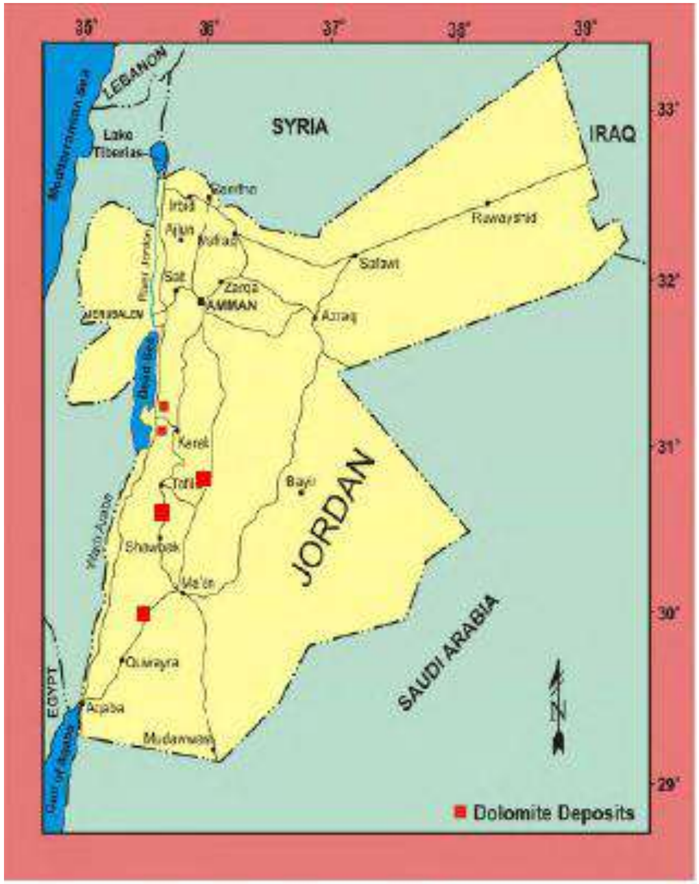


Figure (1): Location map of Dolomite deposits in Jordan.

Feldspar is the most important single group of rock forming silicate minerals. The mineral name feldspar is derived from the German words field + spar. The word (field) is field in German and (spar) is a term for light colored minerals that break with a smooth surface. feldspar minerals are usually white or very light in color, have a hardness of 6 on the Moh` Scale of Hardness and perfect to good cleavage (plane of breakage) in two directions.

There are four chemically district groups of feldspar; Potassium feldspar (KAlSi3O3), Sodium feldspar (NaAlSi3O8), calcium feldspar (CaAlSi3O8) and Barium feldspar (BaAl2Si3O8). About 90% of produced feldspar is used by the glass and ceramic industries. Soda feldspar is preferred in glass manufacture, but Potash feldspar is more popular for ceramic.

Engineering Geology

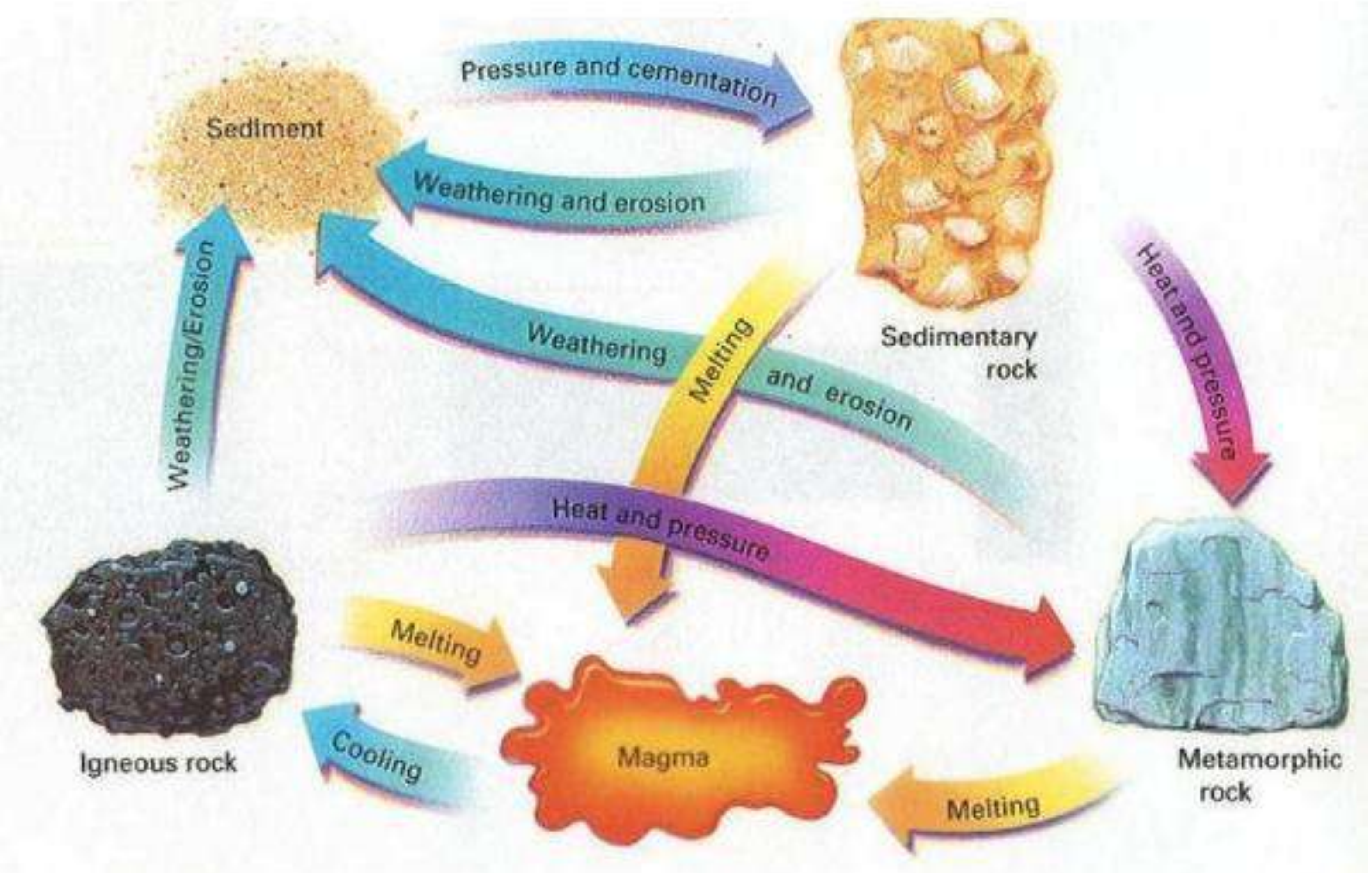
Engineering Geology is backbone of civil engineering

Rocks

6. Metamorphic Rocks

Eng. Iqbal Marie

Metamorphic rocks cycle

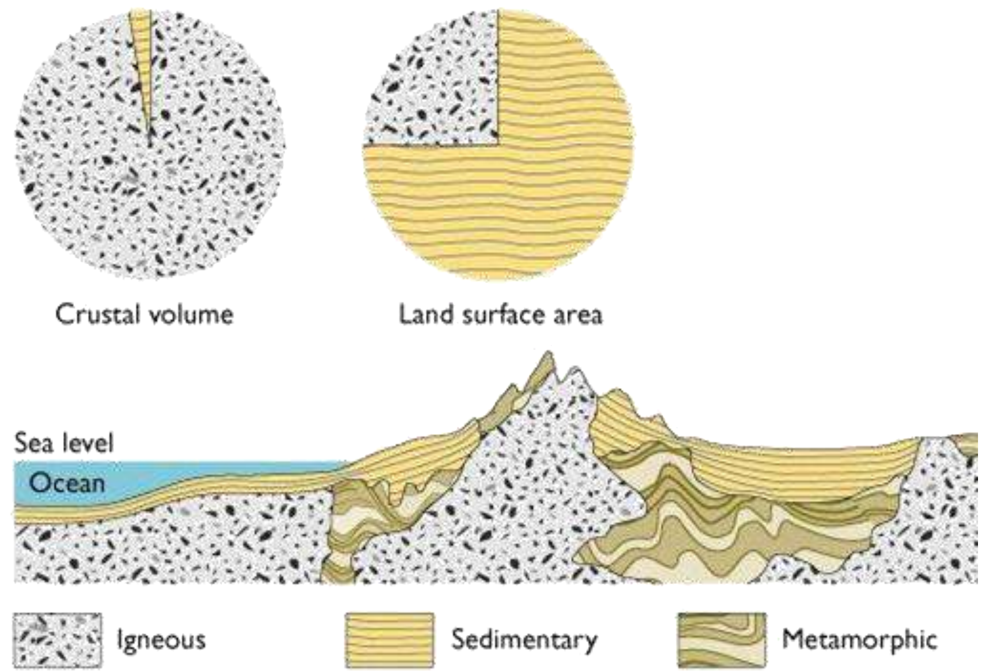


Metamorphism (meta = change; morph = form)

occurs when any previously existing rock, the *parent rock (protolith)* , is buried in the earth under layers of other rock, at high temperature and pressure to produce changes in texture and crystallization.

Metamorphic rock looks quite different from the original rock.

Metamorphic textures and minerals are most likely formed over 10 to 20 million years or longer



Metamorphic rocks are produced from

- **Igneous rocks**
- **Sedimentary rocks**
- **Other metamorphic rocks**

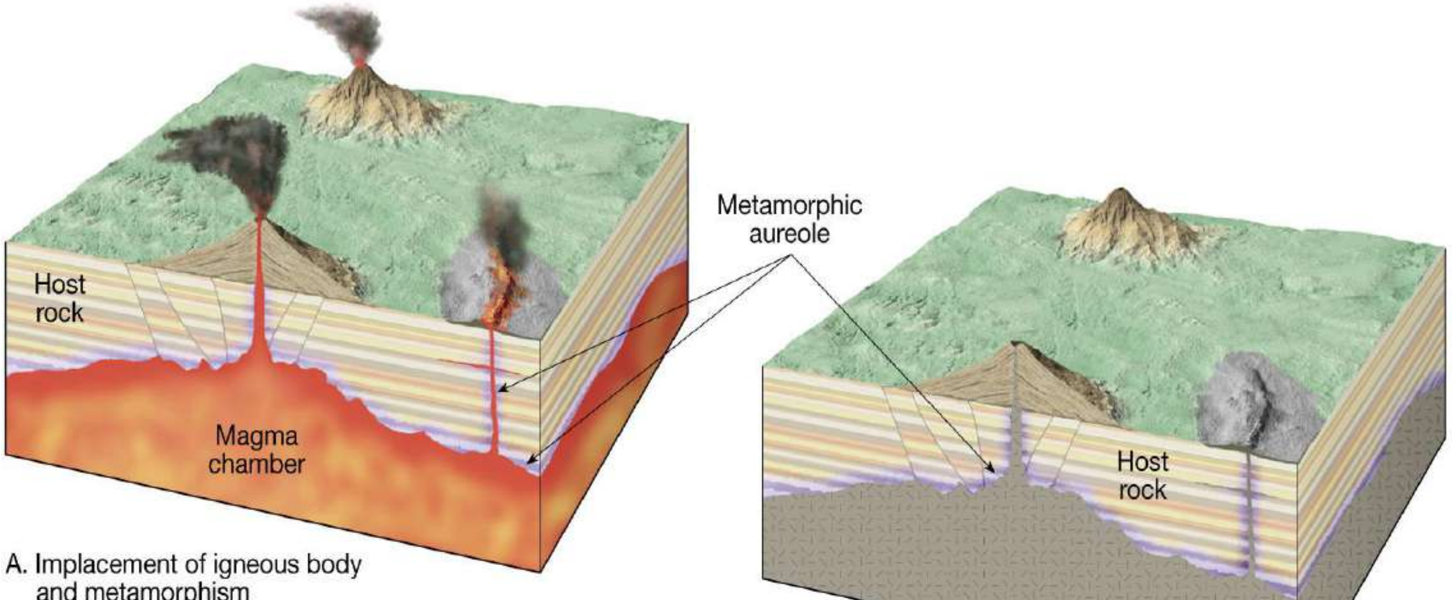
In most cases, the overall chemistry of the metamorphic rock is very similar to that of the parent rock

Metamorphic Environments

There are three types of metamorphism

- **Contact**
- **Regional**
- **Dynamic**

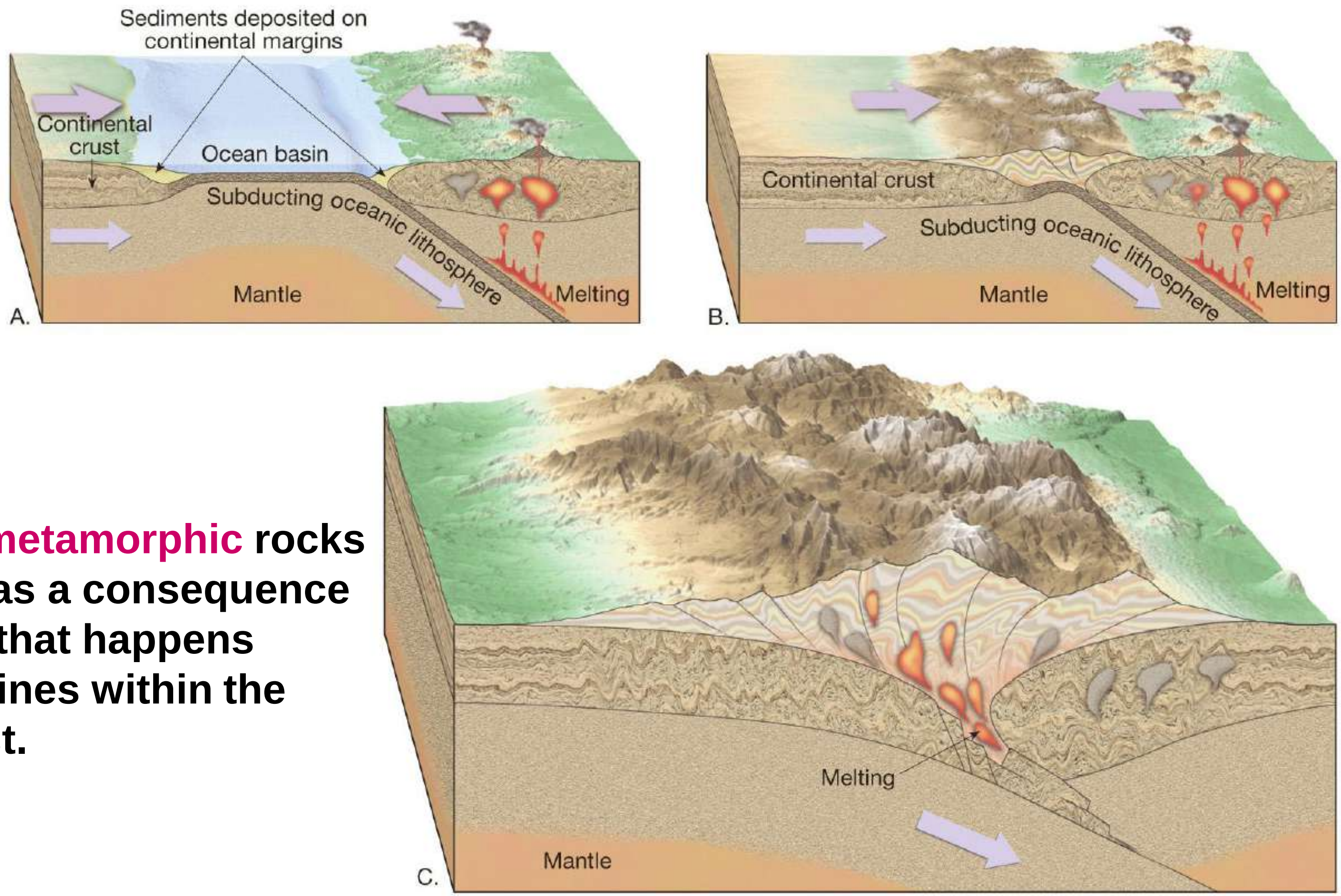
- **Contact or thermal metamorphism**
  - **Result from a rise in temperature when magma invades a host rock. Occurs at high temperature and (typically) low pressure. Normally affects a small area.**



A. Implacement of igneous body and metamorphism

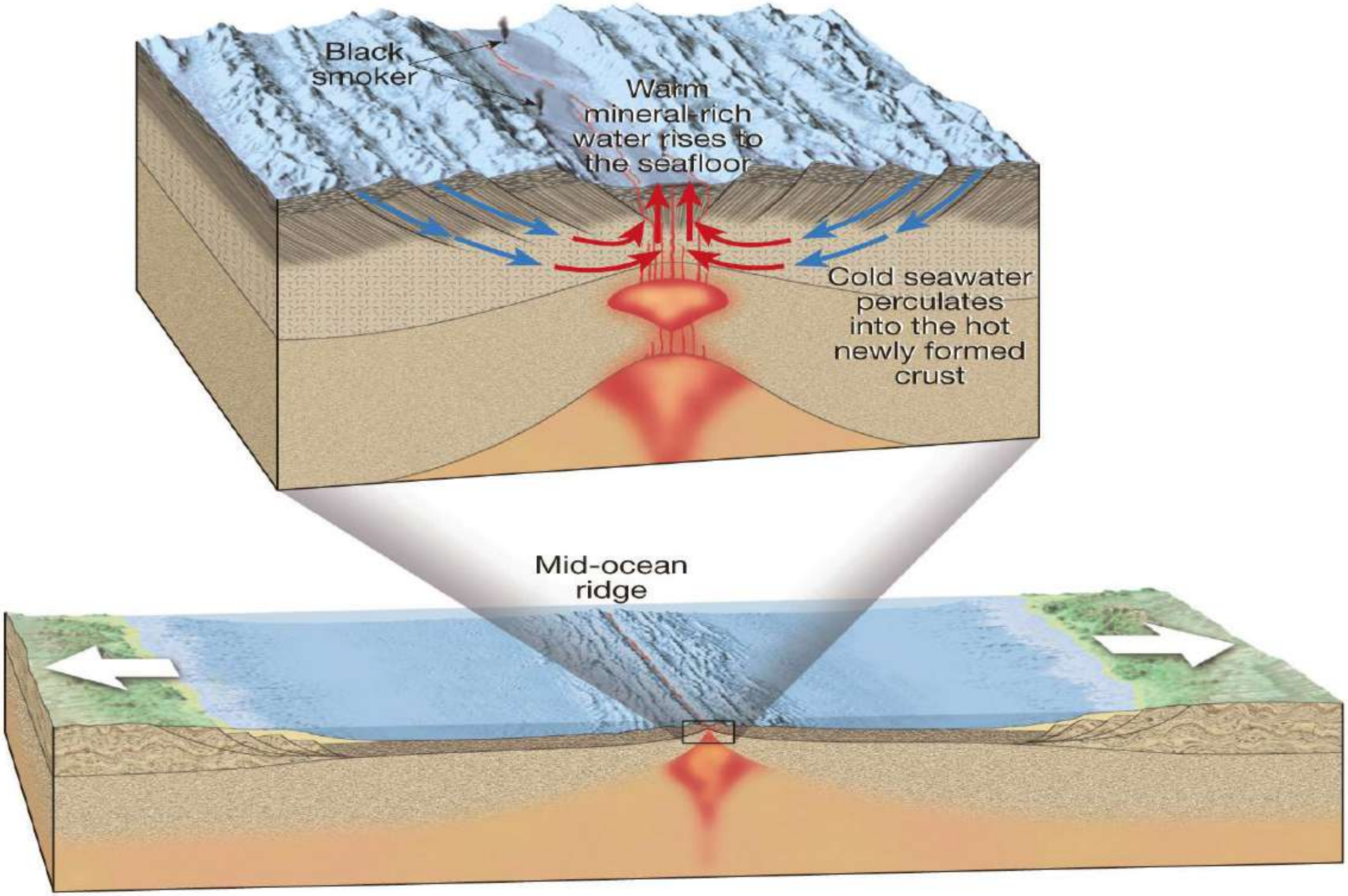
B. Crystallization of pluton

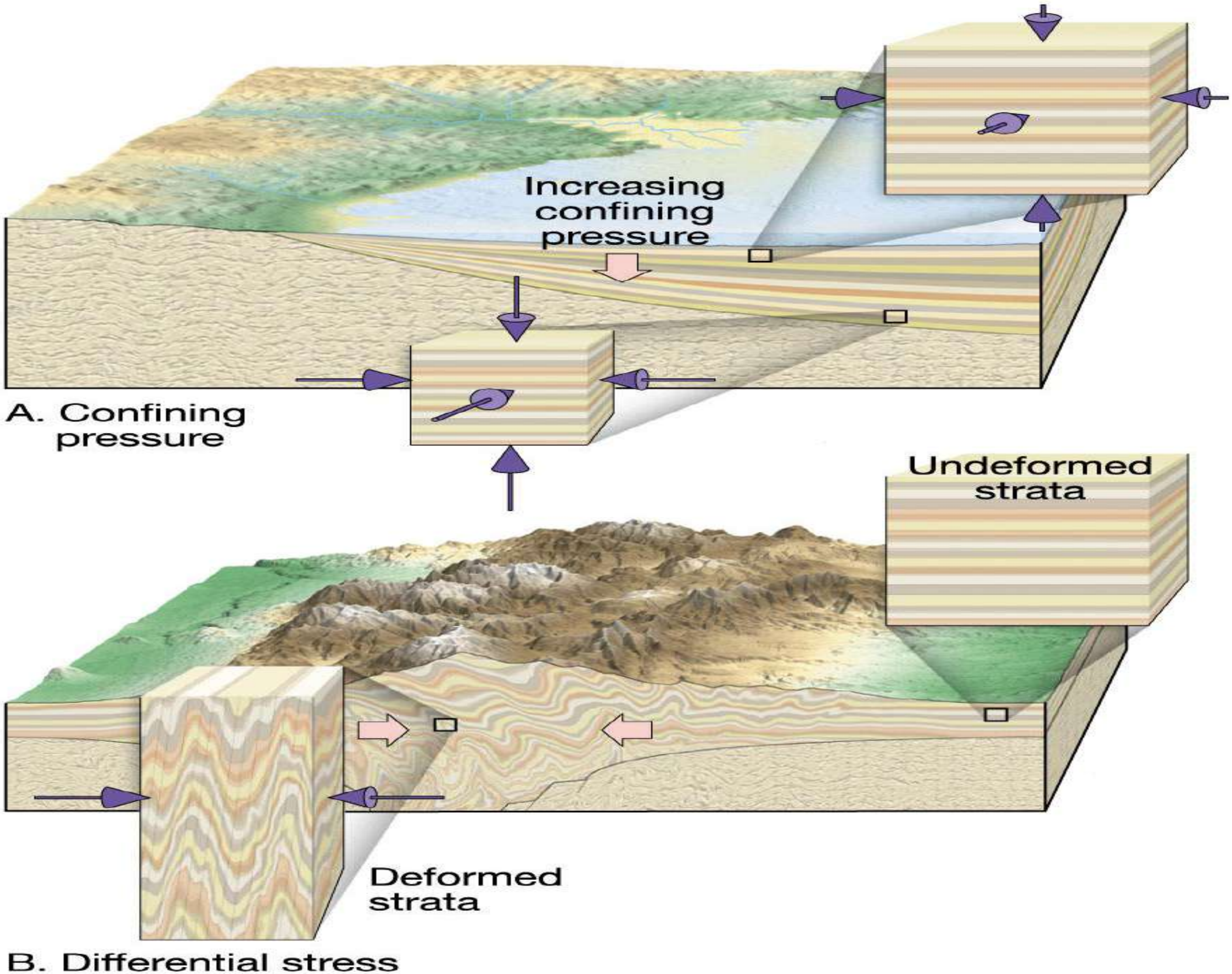
- # Regional metamorphism
  - **Affects a large area and produces the greatest quantity of metamorphic rock. Associated with mountain building**
  - **High temperature, high pressure and shear stress.**



Fault zone metamorphic rocks are formed as a consequence of changes that happens along fault lines within the Earth's crust.

- **Hydrothermal metamorphism**
  - **Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock**




Increasing
confining
pressure
A. Confining
pressure
Undeformed
strata
Deformed
strata
B. Differential stress

Factors Controlling Metamorphism

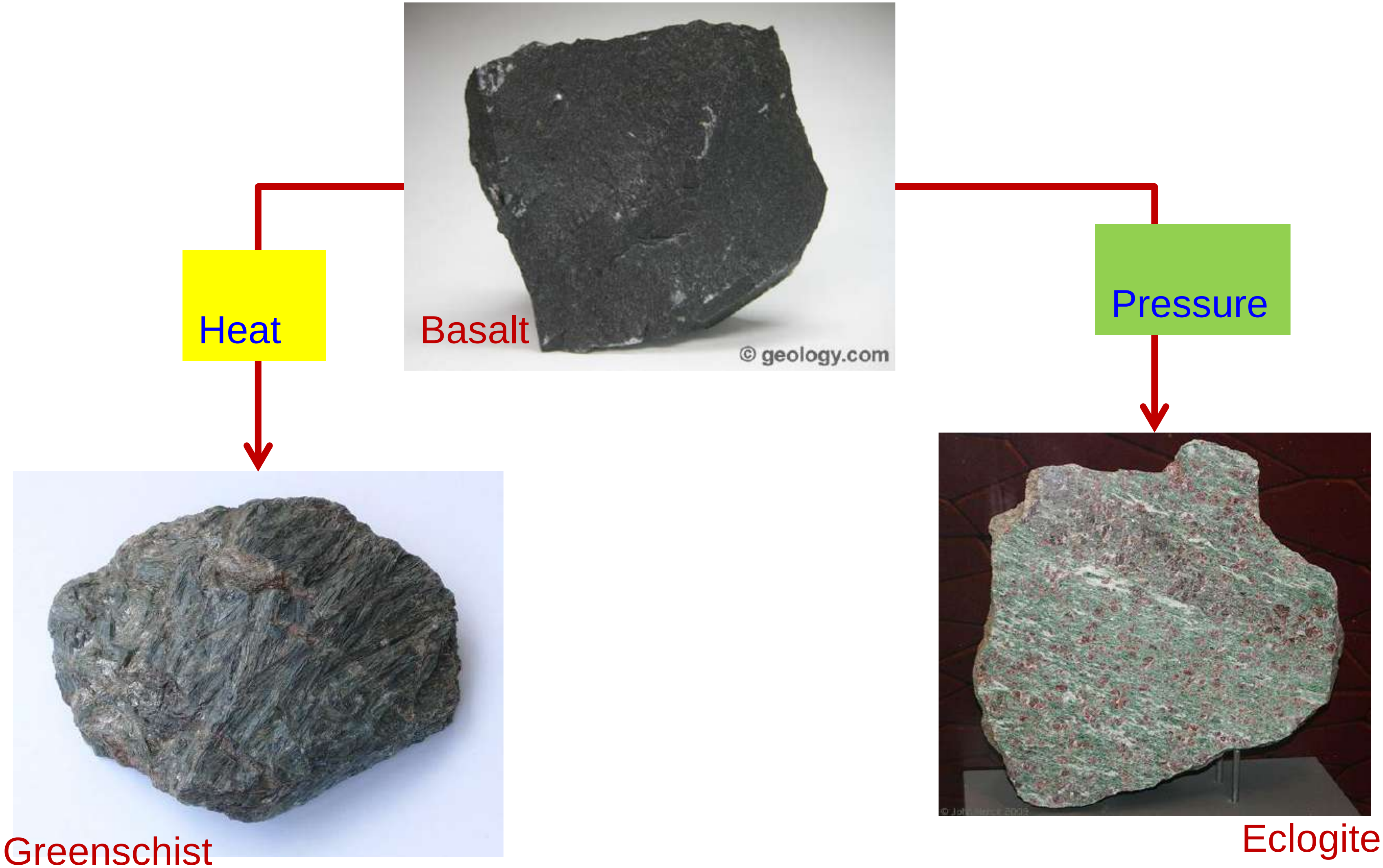
- **Heat**
  - **Most important agent**
  - **Two sources of heat**
    - **Contact metamorphism – heat from magma**
    - **An increase in temperature with depth due to the geothermal gradient**
      15-30^{o}C increase per km

- **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**

- **Chemically active fluids**
  - **Mainly water with other volatile components**
  - **Aids in re-crystallization of existing minerals**

- **Sources of fluids**
  - **Pore spaces of sedimentary rocks**
  - **Fractures in igneous rocks**
  - **Hydrated minerals such as clays and micas**

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

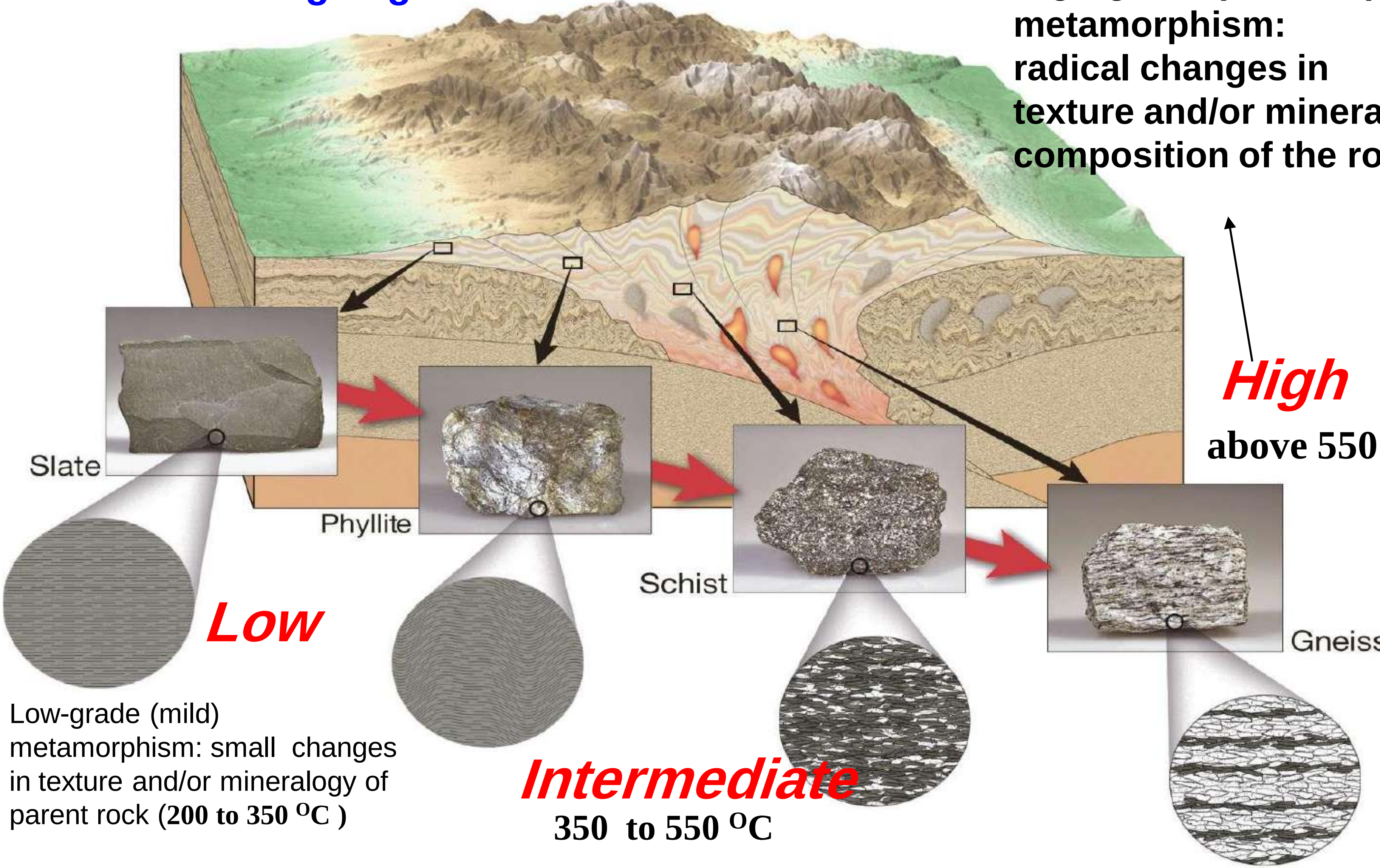


Metamorphic Grade: intensity of Metamorphism

Metamorphism ends when melting begins

Melting begins at ~700ºC

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



Low

Low-grade (mild) metamorphism: small changes in texture and/or mineralogy of parent rock (**200 to 350 ^{O}C**)

Intermediate

350 to 550 ^{O}C

High

above 550 ^{O}C

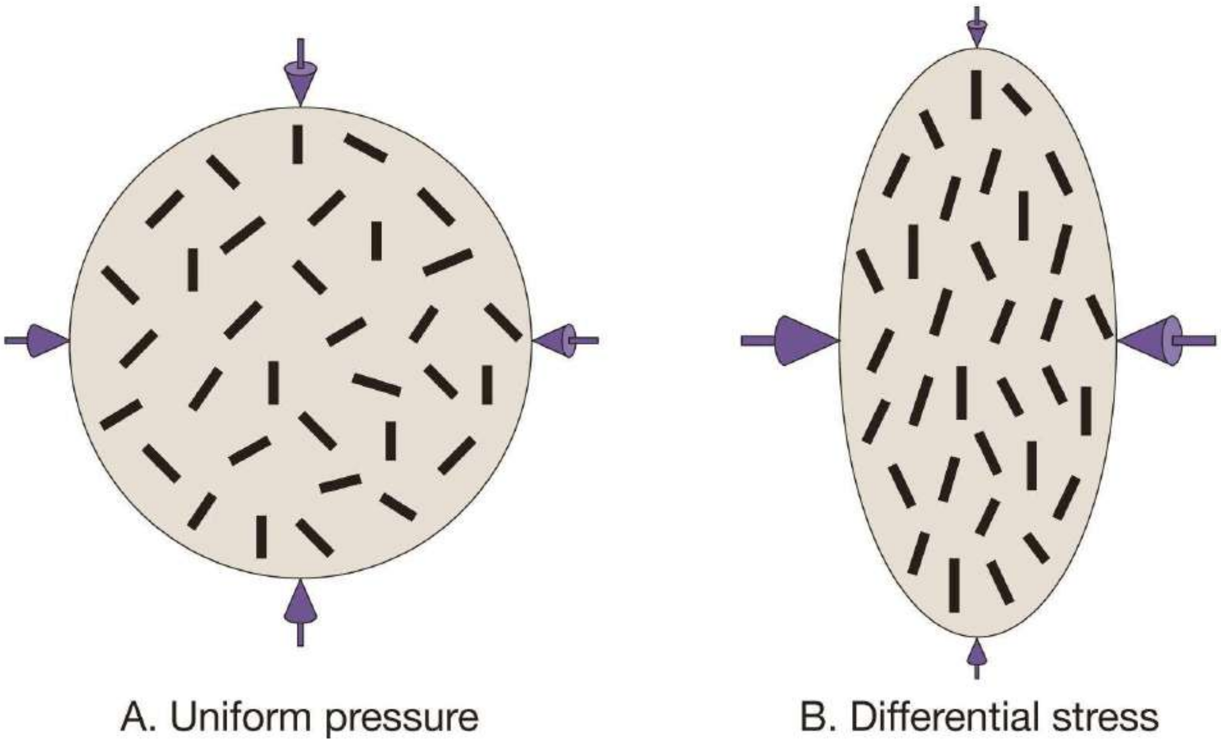
CHANGES DURING METAMORPHISM?

- *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 HIGHGRADE 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

Foliation. Due to compressive stress and differential stress and/or shearing forces the mineral grains in a metamorphic rock form parallel layers or bands. **New metamorphic minerals crystallize along this foliation**

Foliation usually formed planes of weakness in metamorphic rock because the rock can be easily break along the foliation planes.



Kinds of foliation

Slaty cleavage

(b) Schist

Schistosity

(c) Gneiss

Gneissic banding

Some main points about metamorphic rocks

-The rocks which do not have planar patterns of strain or stretching are termed as non-foliated metamorphic rocks. These rocks are most often deduced from single mineral sedimentary rocks.

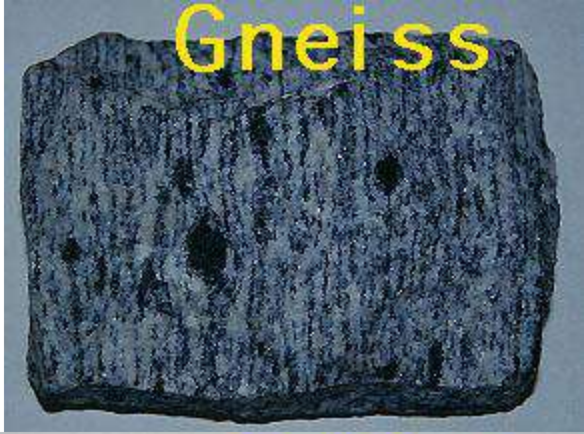
- High temperature and pressure erases out the fossils of the metamorphic rocks.

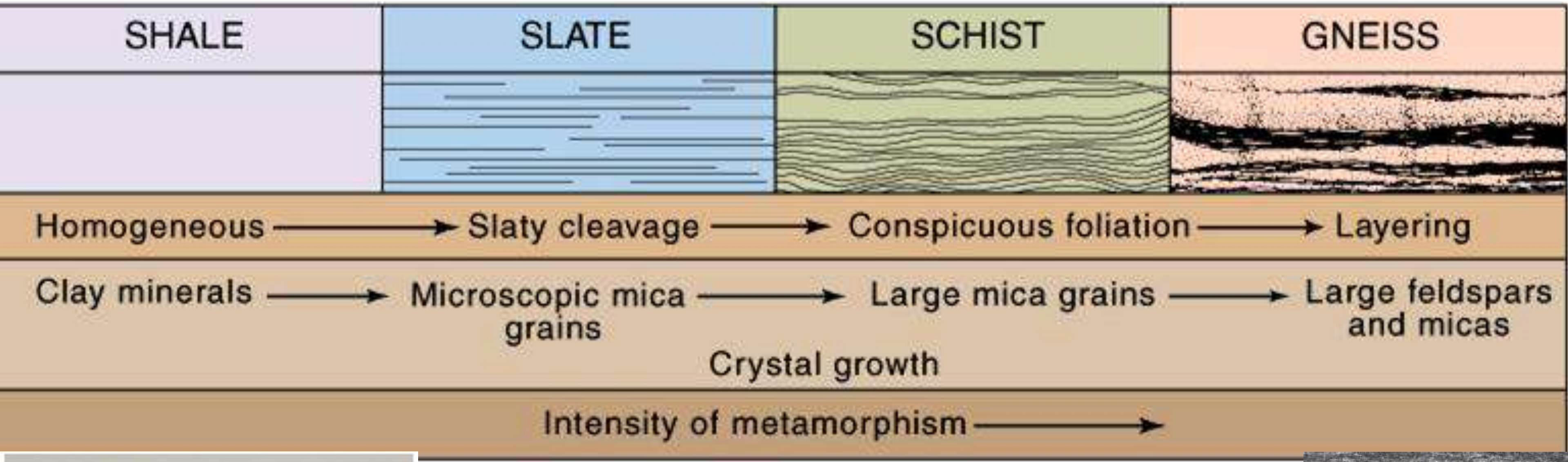
- Metamorphic rocks do not have pores or openings, and may be accompanied with visible layers of crystals.

Common metamorphic rocks

Foliated Metamorphic Rocks *(Regional Metamorphism)*

- Gneiss – highest grade of metamorphism, coarse grained; generally banded (segregation bands of light and dark-coloured minerals);
- Schist – medium grade of metamorphism; sand size, schistocity cleavage.
- Phyllite – low grade of metamorphism; fine grained (silt-sized);
- Slate – lowest grade of metamorphism; very fine-grained; mud-sized; smooth surface.



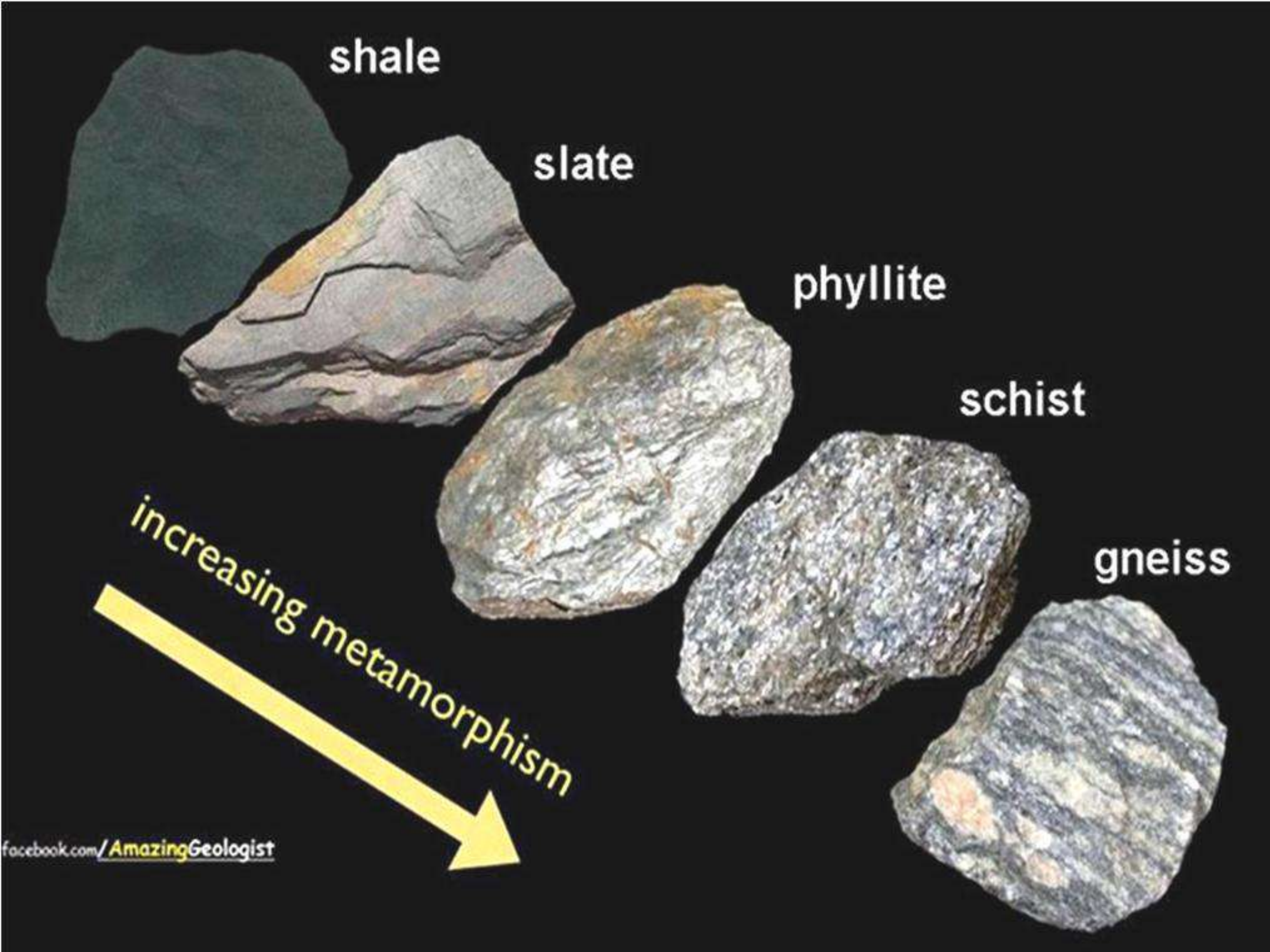


shale

slate

Schist

Gneiss


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

GNEISS

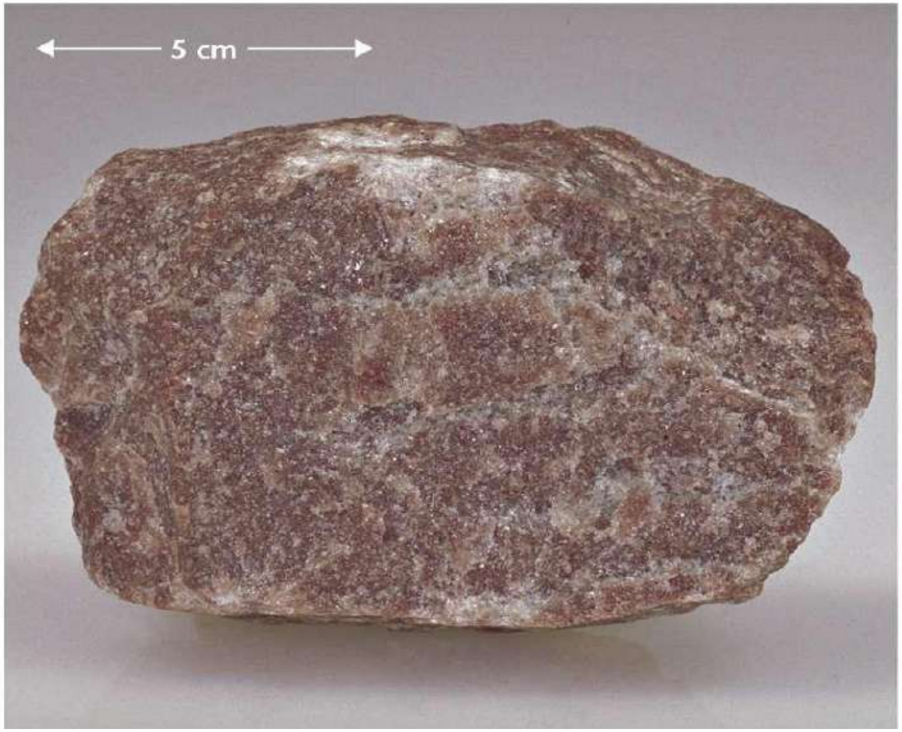
Medium- to coarse-grained
Often composed of white or light-colored feldspar-rich layers with bands of dark ferromagnesian minerals

Non-Foliated Metamorphic Rocks

(Contact/Thermal Metamorphism)

- **Granulite** ***(granite / acid igneous rocks origin)***
- **Amphibolite** ***(basic igneous rocks origin)-basalt (Amphipole)***
- **Quarzite** ***(sandstone origin)***
- **Marble** ***(limestone origin)***
- **Hornfels** ***(mudstone/shale origin)***

Recrystallization – minerals grow and develop an interlocking texture



Quartzite

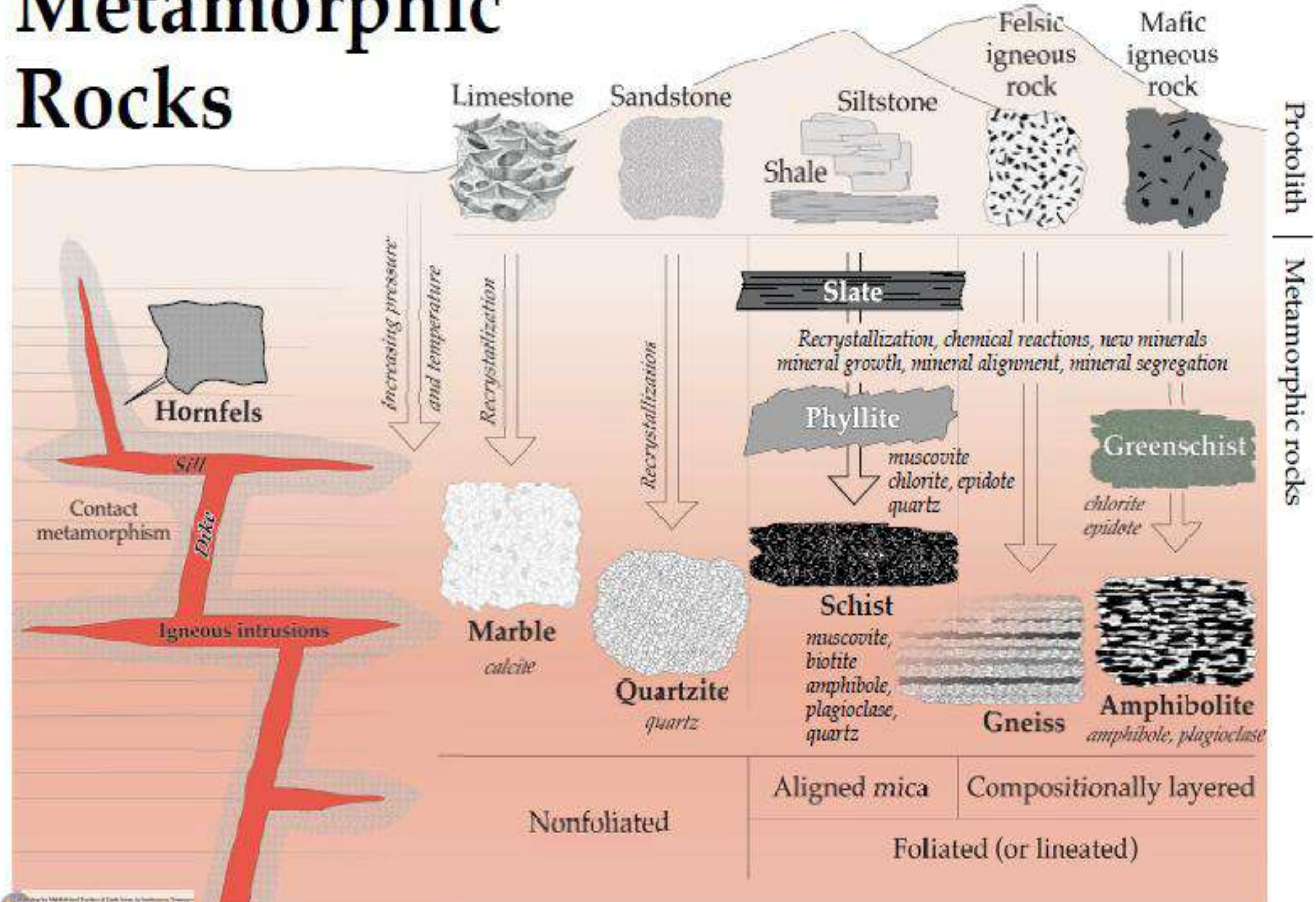
Formed from a parent rock of quartz-rich sandstone Quartz grains are fused together

Marble :Coarse, crystalline

- **Parent rock was limestone or dolostone**
- **Used as a decorative and monument stone**
- **Exhibits a variety of colors**

Texture	Grain Size	Comments	Parent Rock	Rock Name
Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone	Slate (Increasing Metamorphism ↓)
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

Metamorphic Rocks



Importance of Metamorphism
valuable mineral and rock resources

A. Building material:

– Marble which is used for ornamental building stone.
– Slate which is used for roofing, flooring, billiard/pool tables, and blackboards

B. Economic metamorphic minerals include:

– Graphite used in pencils and lubricants.
– Garnet and Corundum used as gemstones and abrasives.
– Asbestos formerly used as a heat insulator.
– Kyanite, Andalusite, Sillimanite (aluminum silicates) are used a raw material in the ceramics industry.

C. Ore Deposits - result from contact metamorphism where hydrothermal solutions precipitate ore minerals in surrounding rocks:

– Iron and Tin Oxides deposits (hematite, magnetite, and cassiterite)
– Precious metal deposits (gold)

Engineering properties of some common metamorphic rocks.

	Density (sp.gr.)	Porosity (%)	Water absorption (%)	Unconfined compressive strength (MN m^{-2})
slate	2.6–2.8	0.1–0.5	<0.5	70–200
schist	2.6–2.8	0.1–1.5	<1.5	50–150
gneiss	2.7–3.0	0.5–1.5	<1.0	50–200
quartzite	2.6–2.7	0.1–0.5	<0.5	150–300
marble	2.4–2.7	0.5–3.0	<1.0	70–150

Engineering Geology

Engineering Geology is backbone of civil engineering

7. Engineering Properties of Rocks

Eng. Iqbal Marie

Rock properties tend to vary widely, often over short distances

Engineering Properties of Rocks = **<u>Rock Mechanics</u>**,

It is a subdivision of "<u>Geomechanics</u>" which is concerned with the mechanical responses of all geological materials, including soils

rock will be used either as:

- **Building material: so the structure will be made of rock, or**
- **A structure will be *built on the rock*, or**
- **A structure will be *built in the rock***

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**

Rock Measurements: the physical characteristics of a rock mass are a fundamental geologic property and are extremely important to engineers.

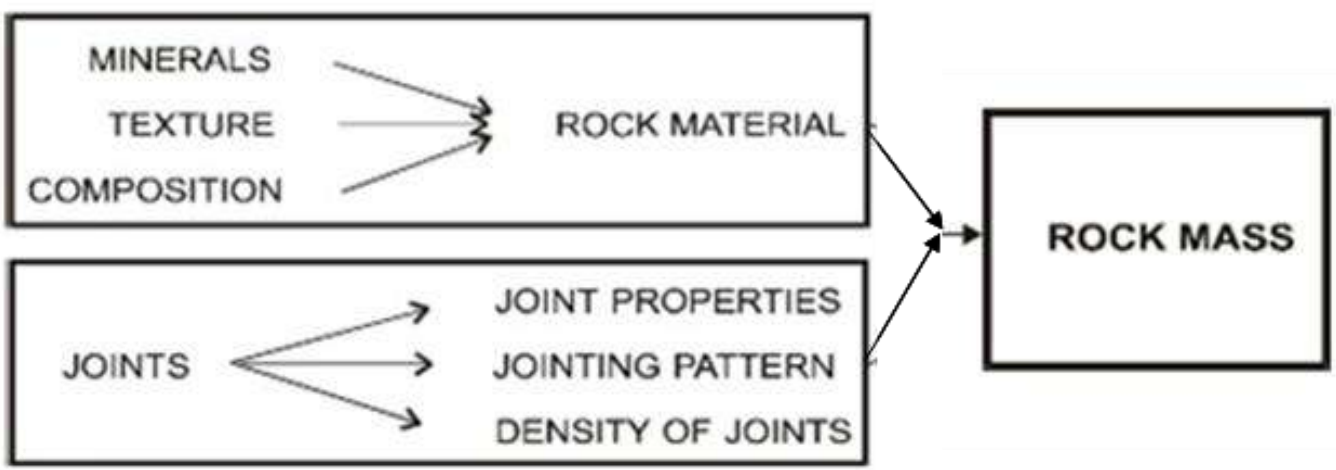
1. *laboratory measures*: are generally referred to as 'rock properties' and are acquired using small samples taken from the field site and analyzed in a laboratory setting.

2. *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 affecting Rock Properties:

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

Rock defects such as microfractures, grain boundaries, mineral cleavages, 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.

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).

Temperature and Pressure

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

Pore Solutions

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.

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.

- **Porosity: Proportion of void space given by- $n = \upsilon_p / \upsilon_t$, 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.

In general, the presence of microcavities in the fabric of a rock will influence its engineering properties. An increase in porosity is usually accompanied with an increase in deformability and permeability and a decrease in strength.

- **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.**

- **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. It Can be used to estimate the degree of fissuring of a rock specimen by plotting against porosity (%).**

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

Porosities for Different Rock Types (after Costa and Baker, 1981).

DEGREE OF FISSURING

The degree of intact rock fissuring can be characterized through direct observation using the microscope. It can also be characterized through simple tests such as measurement of sonic velocity or permeability

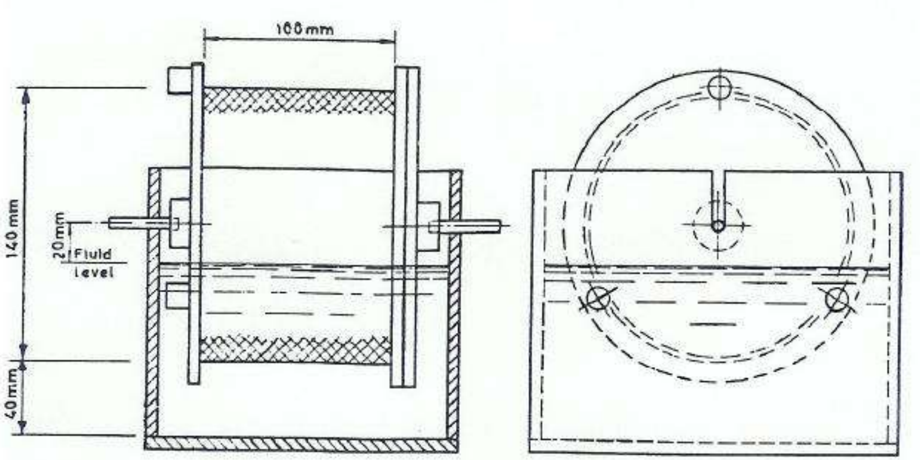
The sonic velocity method (or pulse method) consists of propagating waves in intact samples of rock. Transmitters and receivers transducers and an oscilloscope are used to measure the time that longitudinal and transverse elastic waves propagate through an intact rock sample ASTM D2845-90

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.

- **Permeability:** Dense rocks like granite, basalt, schist and crystalline limestone possess very low permeabilities as lab specimens, but field tests can show significant permeability due to open joints and fractures.
- **Durability:** Exfoliation, hydration, slaking, solution, oxidation & abrasion all lower rock quality.

Measured by Franklin and Chandra's (1972) :slake durability test.

Is a test intended to assess the resistance offered by a rock sample to weakening and disintegration when subject to one (or several) cycles of drying and wetting. It is a standardized measurement of the weight loss of rock lumps when repeatedly rotated through an air water interface. The procedure has been standardized ASTM (ASTM D4644-87).



Slake Durability Test Equipment (after Franklin, 1979).

Approximately 500 g of broken rock lumps (~ 50 g each) are placed inside a rotating drum (It consists of two drums 100 mm long and 140 mm in diameter) **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)**

After the 10 minutes rotation, the percentage of rock (dry weight basis) retained in the drum yields the "slake durability index (SDI)".

A six step ranking of the index is applied (very high- to very low) as shown in tables 1 and 2.

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

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,

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

Used to evaluate shales and weak rocks that may degrade in service environment.

From a practical point of view, slaking of clay-bearing rocks requires protection of all outcrops. Shotcrete or any other form of protective layers are usually adequate.

Table 1. Visual description of the rock samples retained in the test drum after the second cycle (after Franklin and Chandra. 1972).

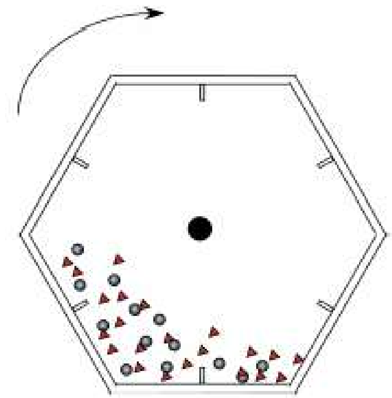
Type	Description
I	Pieces remain virtually unchanged
II	Consist of large and small pieces
III	Exclusively small fragments

Table 2. 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

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.

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 %.

The drum is rotated at 30-33 rpm for 500 revolutions.

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)

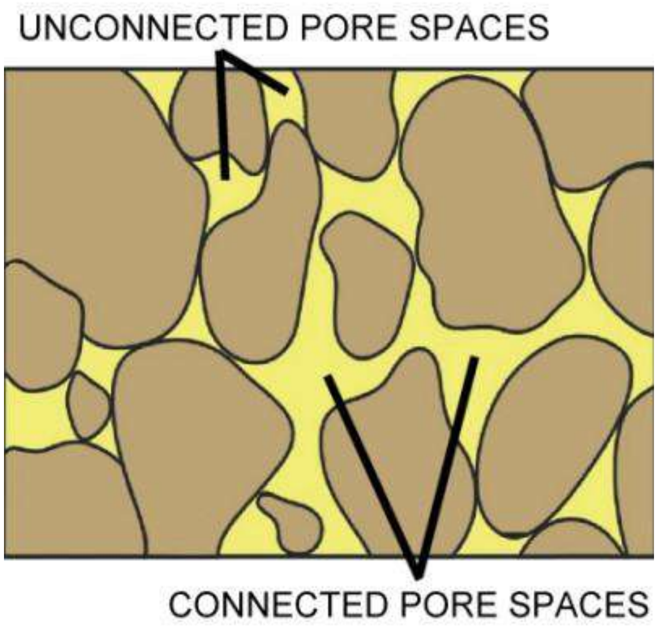
Tests and observations at the site

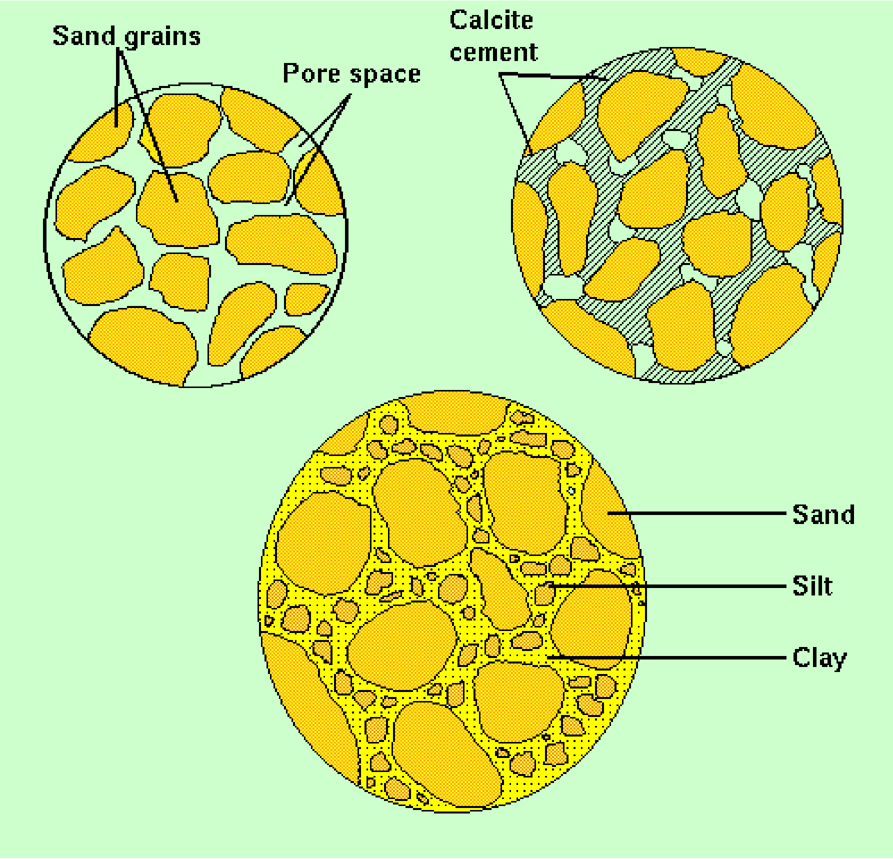
The following observations in the site are Important for the civil engineer

- **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**

Permeability related to the following

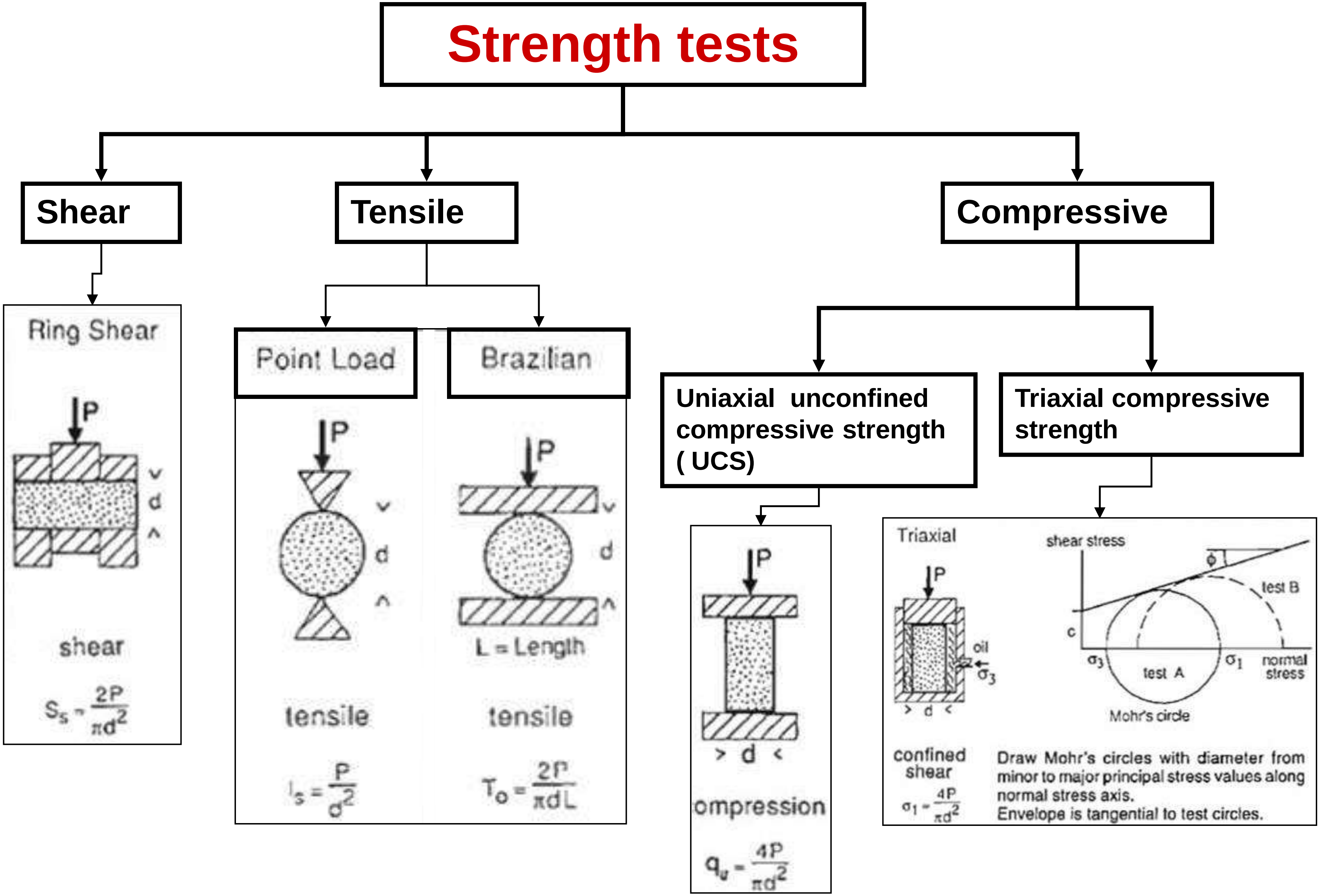
- volume of pores
- degree of openness or connection between pores and fractures
- Grain size
- Sorting of grains





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


Strength tests
Shear
Tensile
Compressive
Ring Shear
P
d
shear
$S_s = \frac{2P}{\pi d^2}$
Point Load
P
d
tensile
$I_s = \frac{P}{d^2}$
Brazilian
P
d
L = Length
tensile
$T_o = \frac{2P}{\pi d L}$
Uniaxial unconfined compressive strength (UCS)
P
d
ompression
$q_u = \frac{4P}{\pi d^2}$
Triaxial compressive strength
Triaxial
P
oil
σ_3
d
confined shear
$\sigma_1 = \frac{4P}{\pi d^2}$
shear stress
ϕ
test B
c
σ_3
σ_1
normal stress
test A
Mohr's circle
Draw Mohr's circles with diameter from minor to major principal stress values along normal stress axis.
Envelope is tangential to test circles.

Unconfined Compressive Test

Cube or cylinder of rock with flat, cut, parallel faces, loaded uniaxially between flat steel platens; sample diameter ≥ 54 mm.

Most common and easiest test of rock strength.

Brazilian Test

Cylinder of rock loaded across its diameter between two flat steel platens.

Easier than direct tensile test.

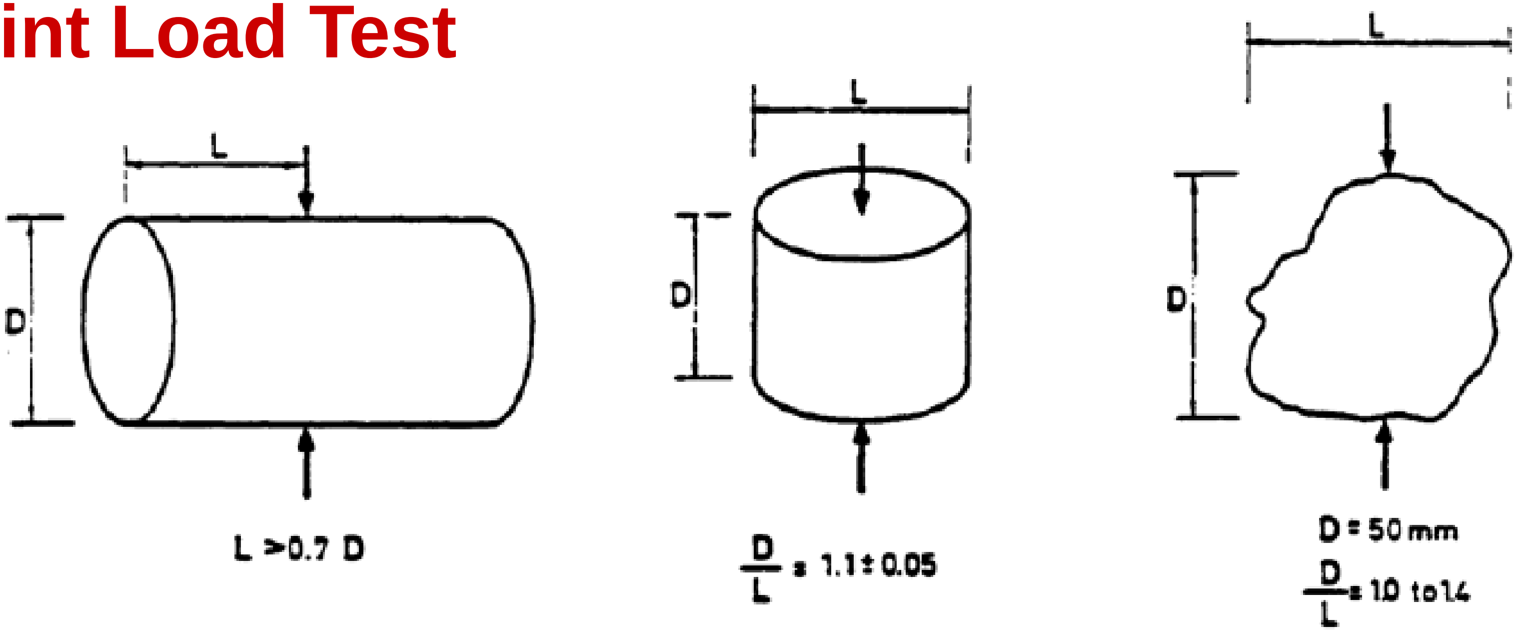
Schmidt Hammer

Hand held, spring loaded hammer measures rebound from rock surface; rebound values correlate with UCS and decline significantly in fractured rock.

Schmidt hardness	20	30	40	50	60
UCS (MPa)	12	25	50	100	200

Very rapid field test may identify weaker or weathered rock, or loose fracture blocks, in exposed rock face.

Point Load Test



Diametral **Axial** **Irregular Lump**

The procedure for measuring the unconfined rock strength is time consuming and expensive.
Indirect tests such as Point Load Index (Is(50)) are used to predict the UCS.
These tests are easier to carry out because they necessitate less or no sample preparation and the testing equipment is less sophisticated. Also, they can be used easily in the field.

Point Load Test as indication of Compressive Strength

Point Load Test of Broch and Franklin (1972).

Irregular rock or core samples are placed between hardened steel cones and loaded until failure by development of tensile cracks parallel to the axis of loading.

- **I_S = (point load strength) = P/D^2 , where P= load at rupture;**

  D= distance between the point loads.
- **The test is standardised on rock cores of 50mm due to the strength/size effect [*apply correction factor for other diameter]***
- **Relationship between point load index (I_s) and unconfined compression strength is given by: $\sigma_u = 24\, I_{s\,(50)}$ where σ_u is the unconfined compressive strength, and $I_s(50)$ is the point load strength for 50 mm diameter core.**

All of the above are measured on Lab specimens, not rock masses/ outcrops, which will differ due to discontinuities at different scales.

Correction for the load point index

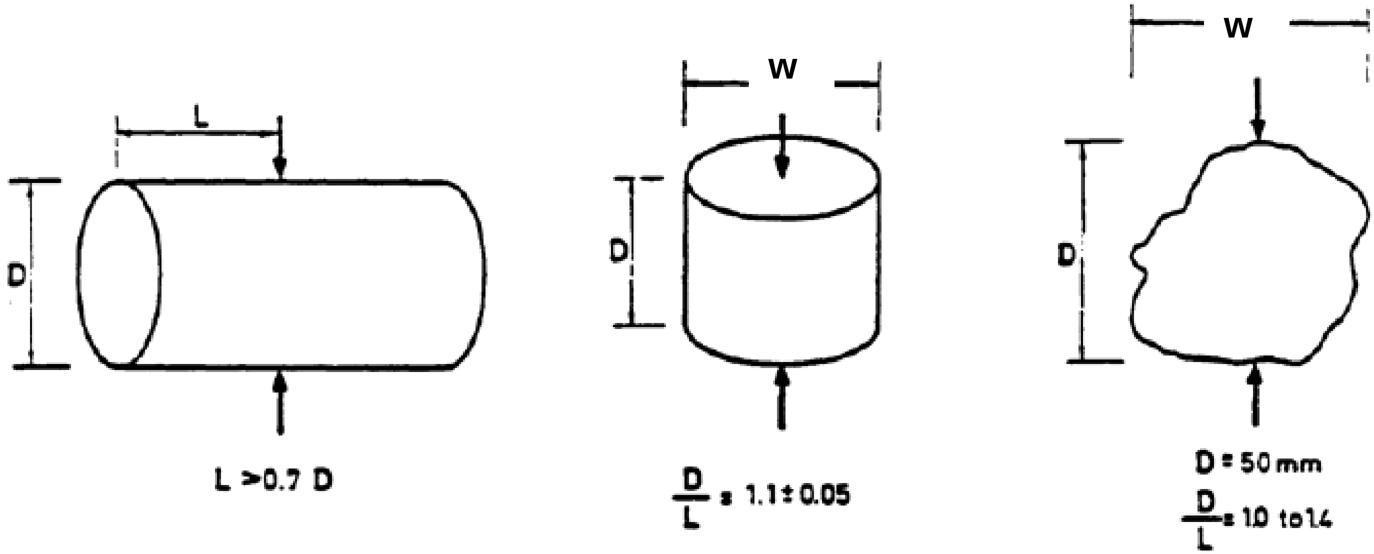


Fig. 2 (a) Diametral test

Fig. 2 (b) Axial test

Fig. 2 (c) Irregular lump test

I_S = Point load index (psi)
F = Failure load (lbs.)
D_e =Distance between platen tips (in.)
$D_e^2 = D^2$ = for diametrical test
$= 4A/\pi$ = for axial, block and lump test
A = W.D = minimum cross-sectional area of a plane through the platen contact points

$$I_S = \frac{F}{D_e^{\,2}}$$

Point load strength index classification (Broch and Franklin, 1972).

Is50 (MPa)	Strength classification
< 0.03	Extremely low
0.03 – 0.1	Very low
0.1 – 0.3	Low
0.3 – 1.0	Medium
1.0 – 3.0	High
3.0 – 10	Very high
> 10	Extremely high

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' INTACT ROCK STRENGTH FIELD ESTIMATES

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)

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.

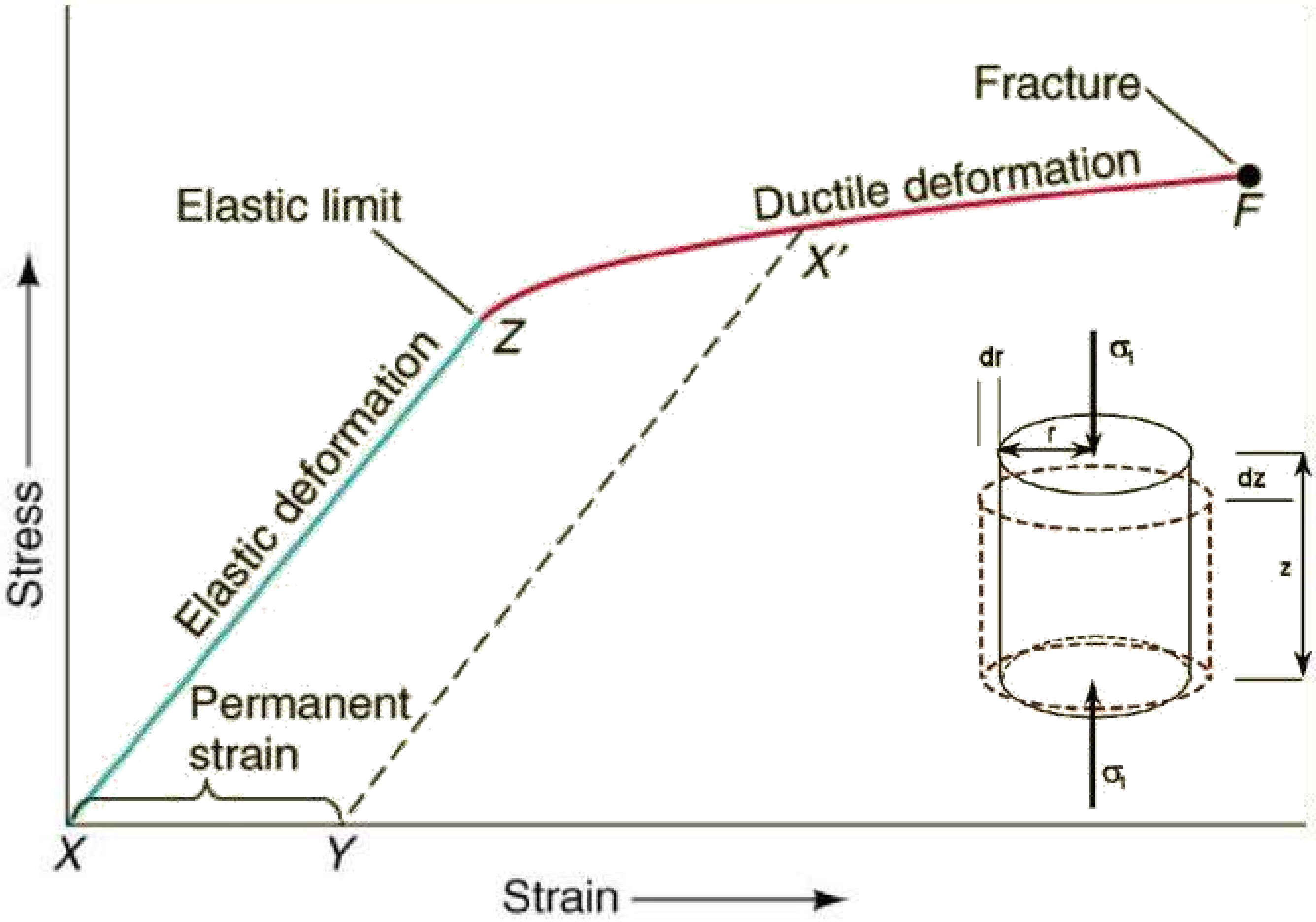
Uniaxial Compressive Strength-Unconfined

Young's modulus $E = \dfrac{\sigma_1}{\Delta z / z}$

Poisson's ratio $\nu = -\dfrac{\Delta r / r}{\Delta z / z}$

* كلما كان الصخر متماسك كانت قيمة E مرتفعة

* تزيد قيمة (((ν))) إذا كان الحمل في نفس اتجاه الشروخ



Intact rock is defined in engineering terms as rock containing no significant fractures. However, on the small scale it is composed of grains with the form of the microstructure being governed by the basic rock forming processes. Subsequent geological events may affect its mechanical properties and its susceptibility to water penetration and weathering effects.

- **Deformation and Failure of Rocks:**

Four stages of deformation recognized:

- **Elastic;**
- **Elastico-viscous;**
- **Plastic,** and
- **Rupture.**

All are dependent on the elasticity, viscosity and rigidity of the rock, as well as temperature, time, pore water, anisotropy and stress history.

- **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.**

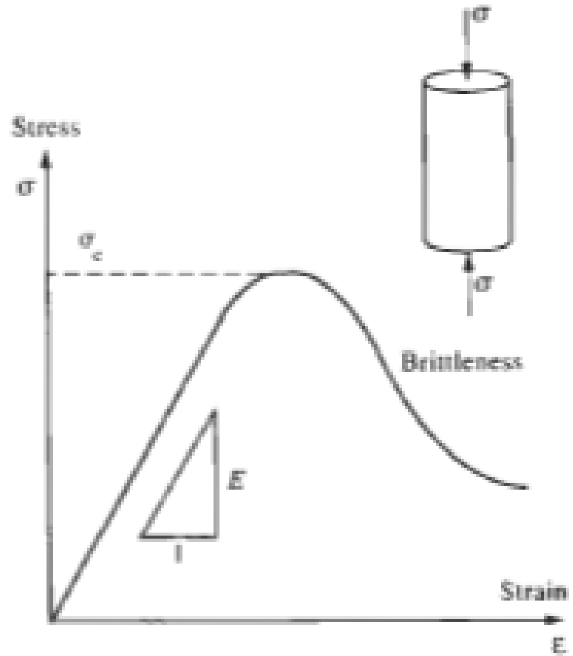


Figure 2.8 Complete stress–strain curve illustrating the stiffness (or modulus, E), the strength, σ_c, and brittleness.

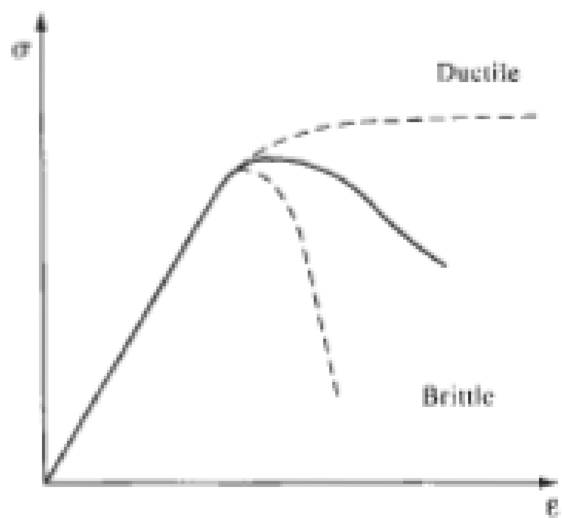
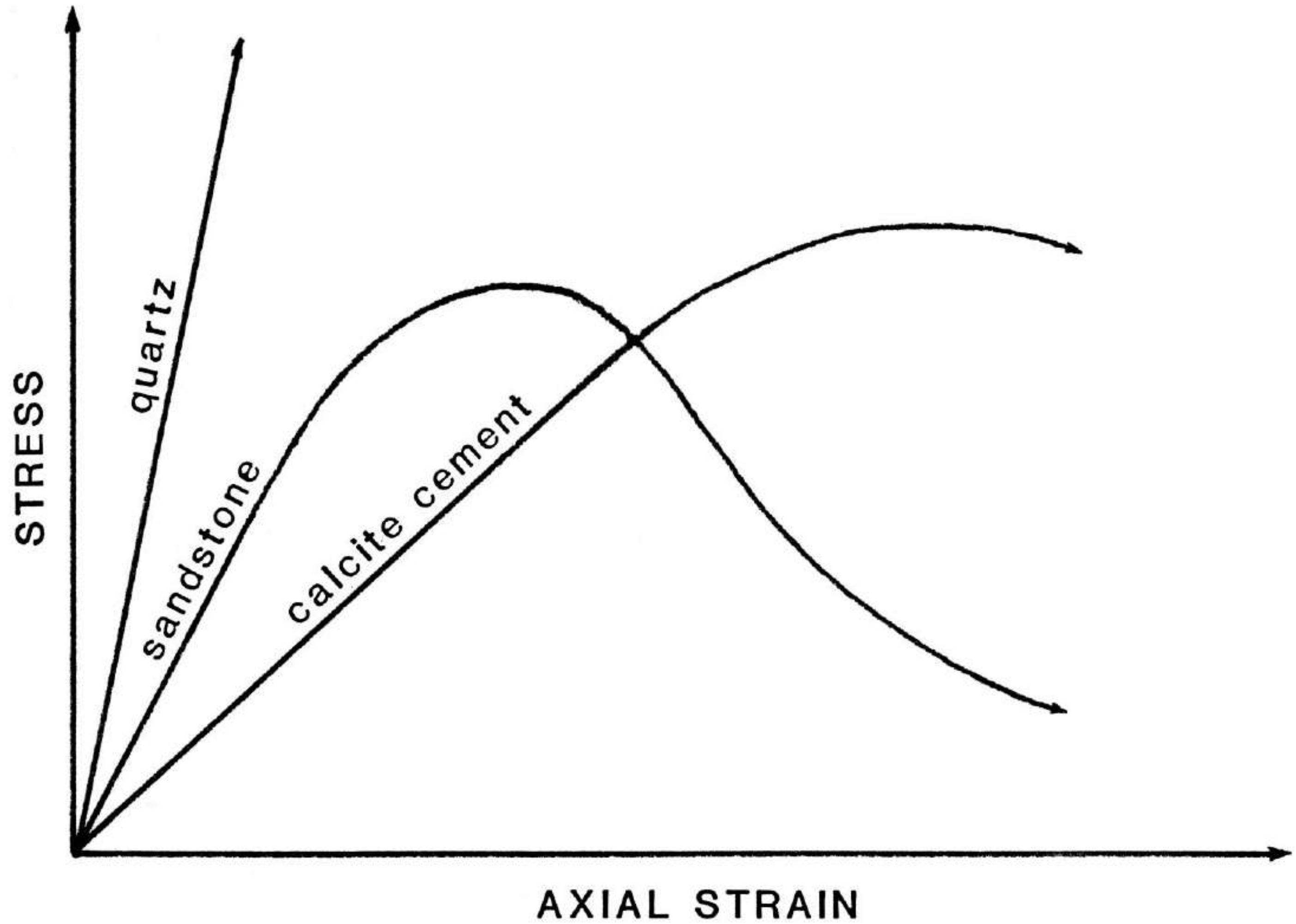
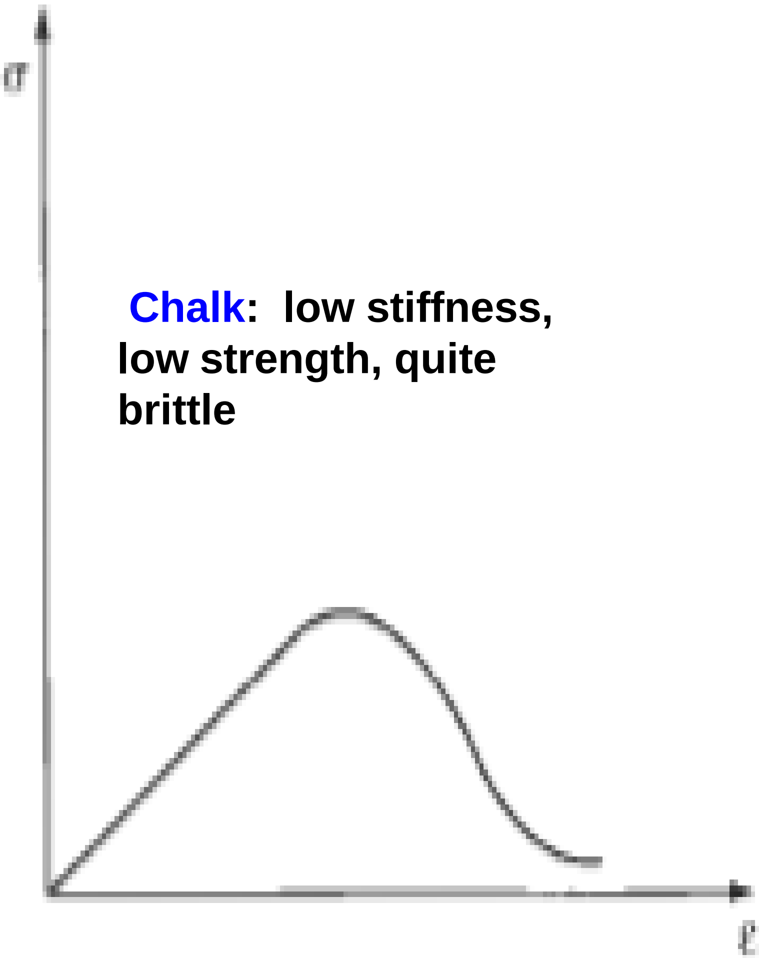
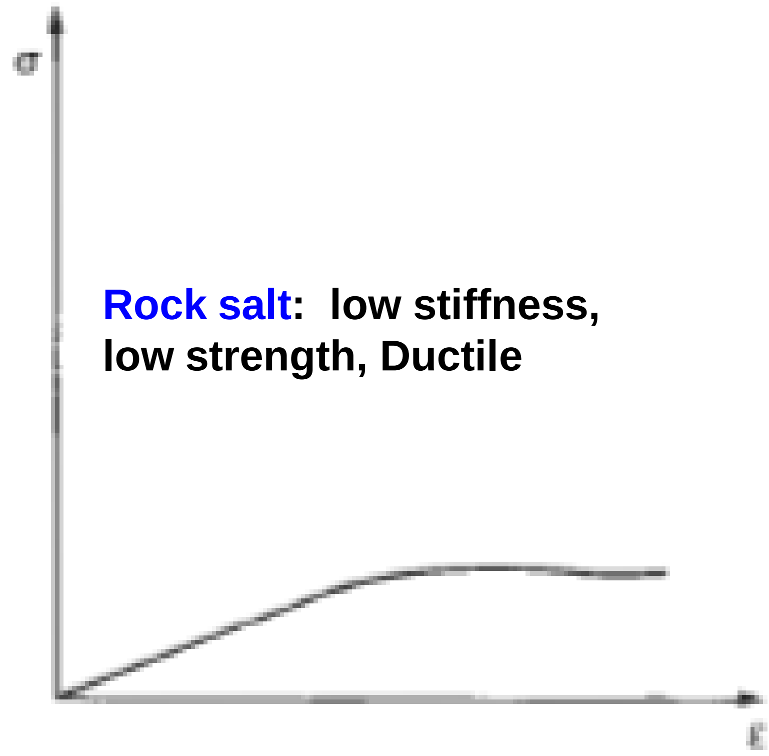


Figure 2.9 Illustration of the difference between a brittle material and a ductile material.



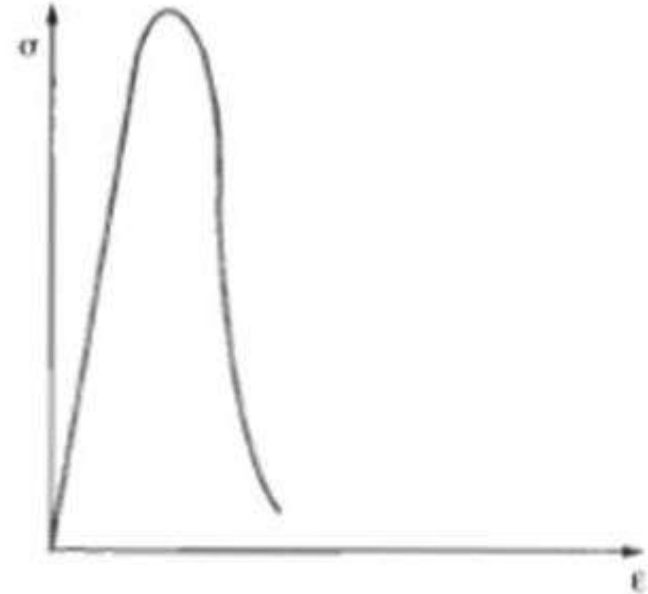
- **The stress strain behavior of a natural rock like sandstone is a combination of its mineralogical components, in this case: quartz and calcite**



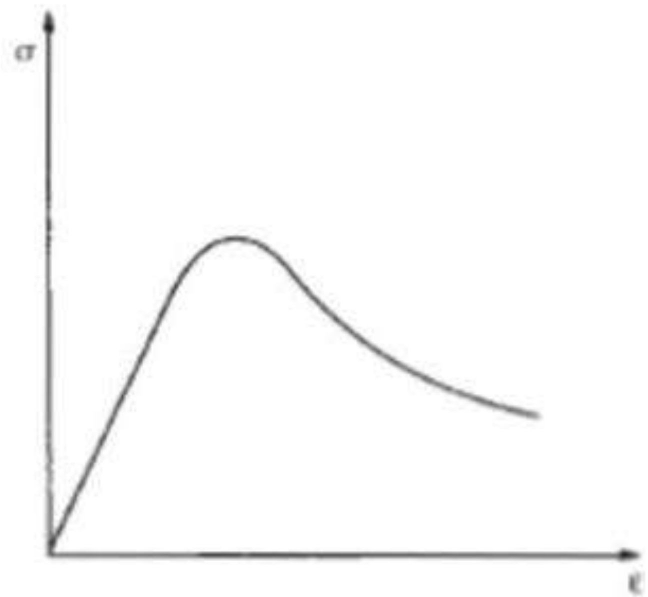


Stress- strain Diagrams

A **high grain strength, fine grain basalt has a high stiffness, high strength and is very brittle.**



limestone rock with a variation in the grain geometry has a medium stiffness, medium strength and a more gentle descending part of the curve caused by the gradual deterioration of the microstructure as it is progressively and increasingly damaged



Unconfined compressive strengths of the main rock types.

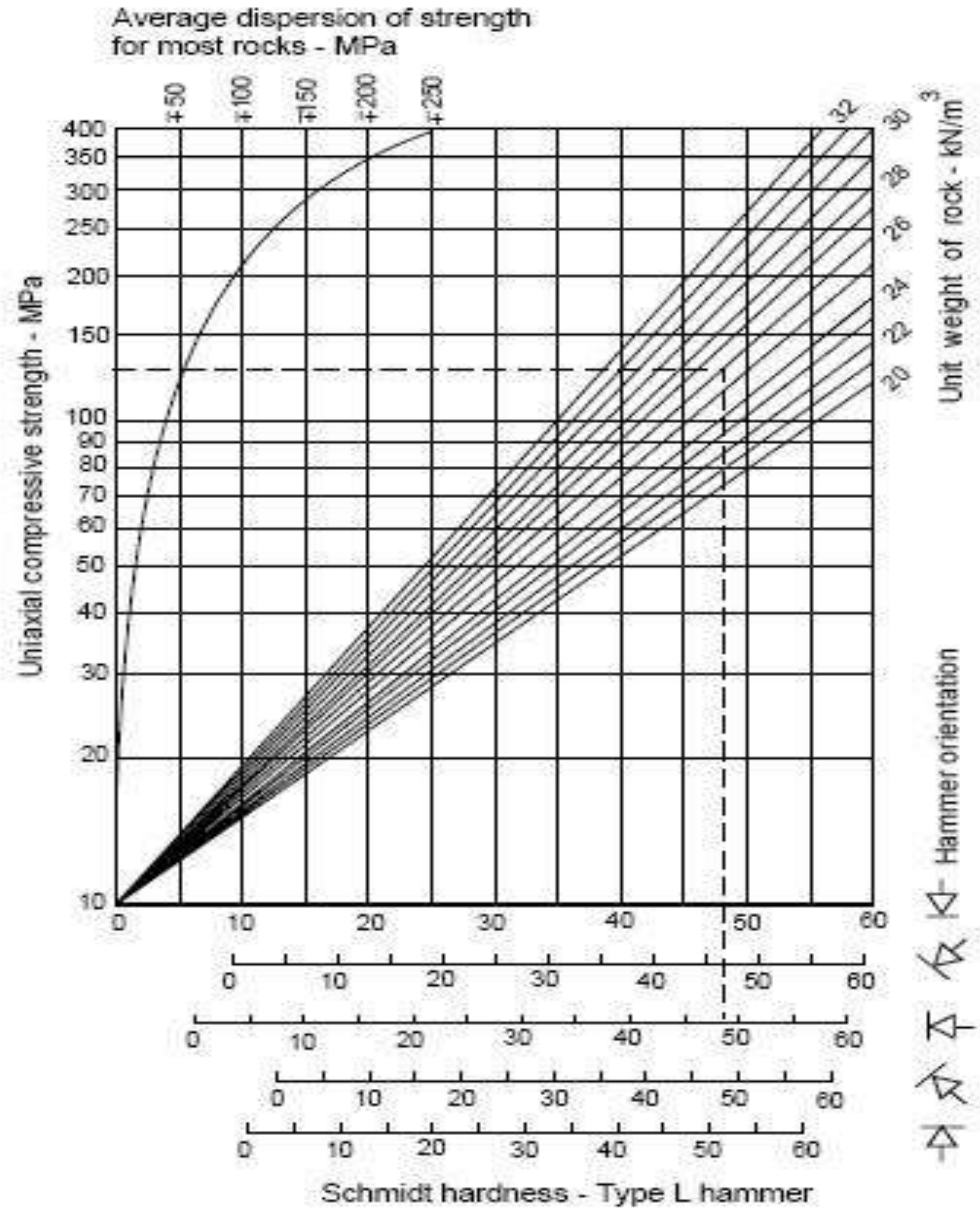
Descriptive term	Compressive strength ($MN\ m^{-2}$)	Indicative rock types
very weak	<1.25	some weakly compacted sedimentary rocks, some very highly weathered igneous or metamorphic rocks boulder clays
weak	1.25–5	
moderately weak	5–12.5	
moderately strong	12.5–50	some sedimentary rocks, some foliated 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 Schmidt Rebound Hammer, is used in rock mechanics (L-type) and is similar to that used to determine the strength of concrete (N-type).

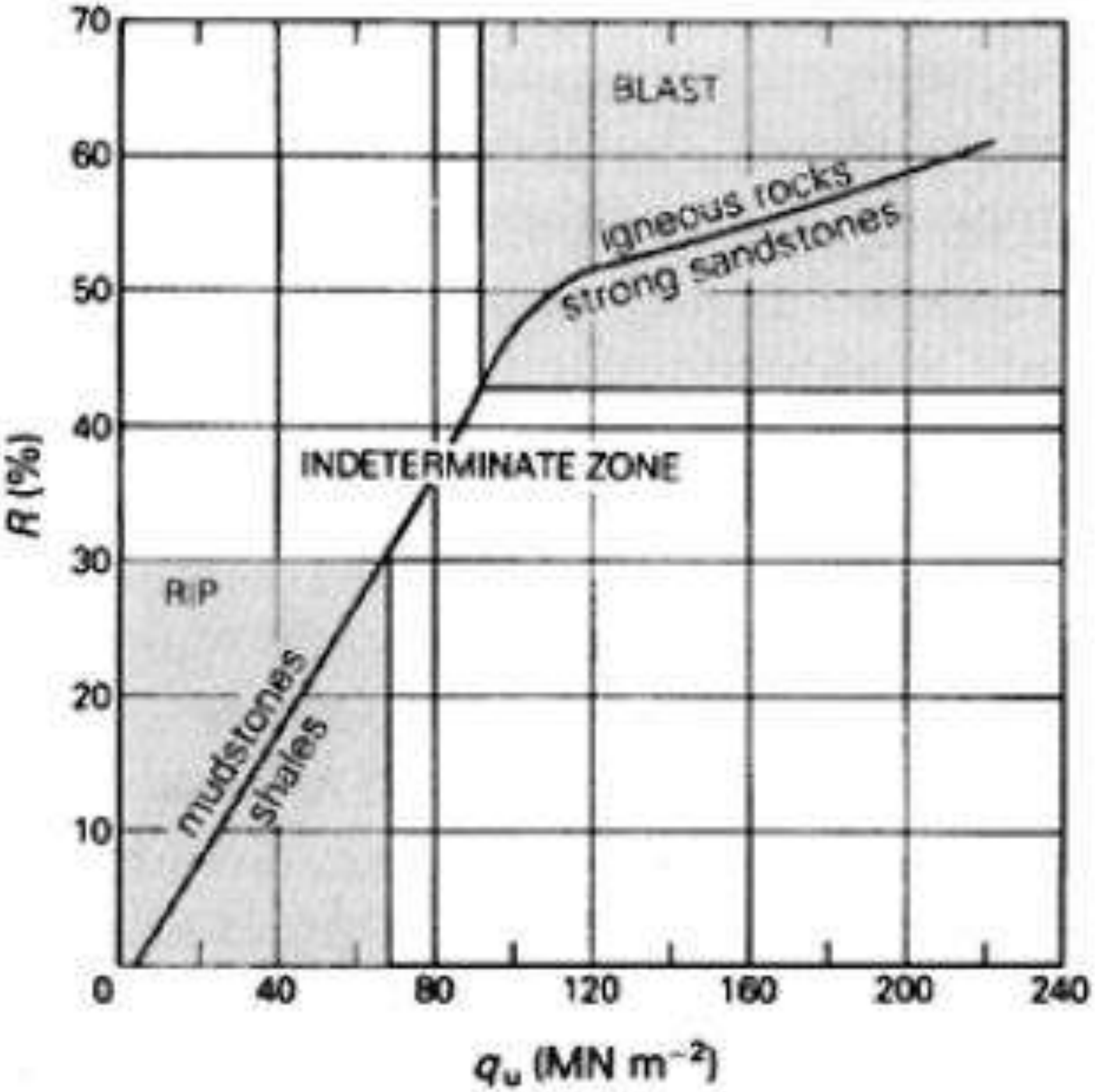
The rebound number, also known as the *Schmidt Rebound Index, R,*

The value of R is higher for harder and stronger rocks which absorb less of the impact energy. Tests can be conducted in the laboratory on rock specimens or in the field on rock surfaces away from major discontinuities. In all cases, measurements must be made at right angles to the surfaces. Empirical equations have been suggested to relate R to the unconfined compressive strength.

Relationship between R and unconfined compressive strength as a function of dry density (after Deere and Miller, 1966).



Average dispersion of strength
for most rocks - MPa
∓50
∓100
∓150
∓200
∓250
Uniaxial compressive strength - MPa
400
350
300
250
200
150
100
90
80
70
60
50
40
30
20
10
Unit weight of rock - kN/m³
32
30
28
26
24
22
20
0
10
20
30
40
50
60
Hammer orientation
Schmidt hardness - Type L hammer



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

ASTM D6032 - 08

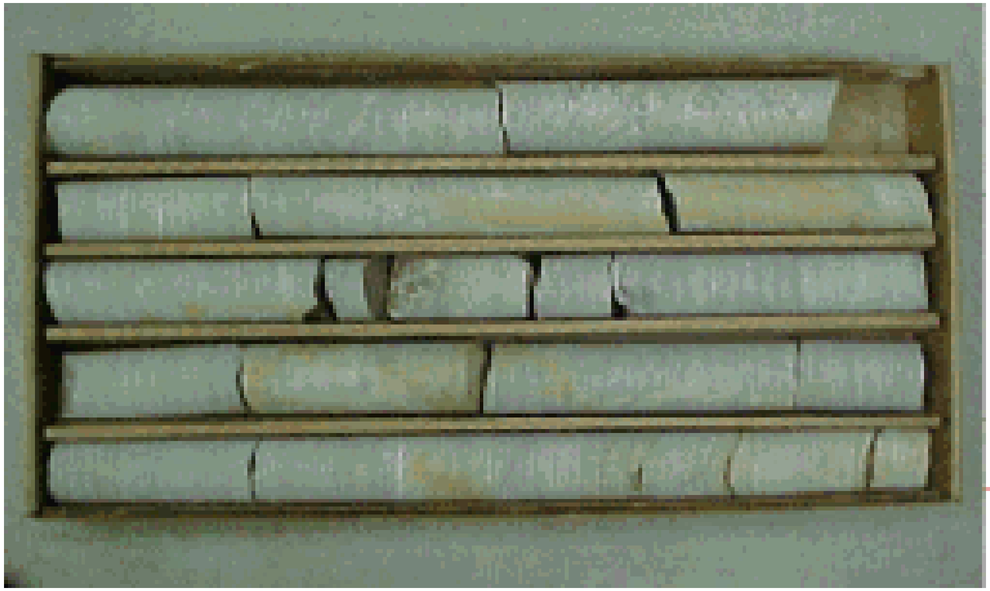
RQD

Rock Quality Designation (RQD) is a fracture quantification on borehole core > 50 mm diameter; lengths of core pieces are measured as they come from the drill barrel, and:

- RQD = Σ(core lengths >10 cm) × 100/borehole length

Values of RQD > 70 generally indicate sound rock.

NX core: standard diameter = 54 mm (2.15 inches)



Cores should be stored in either wooden boxes or corrugated cardboard box.

Box marked with boring number, depth of core run, type core, bit type, core recovery (CR), rock type, RQD, and other notes.

Core operations should be documented:

- Loss of fluid, rates, sudden drop in rods, poor recovery, loss of core

$$RQD = \frac{\text{Sum of core pieces} \geq 10\text{ cm}}{\text{Total drill run}} \times 100$$

RQD %	Description
0- 25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

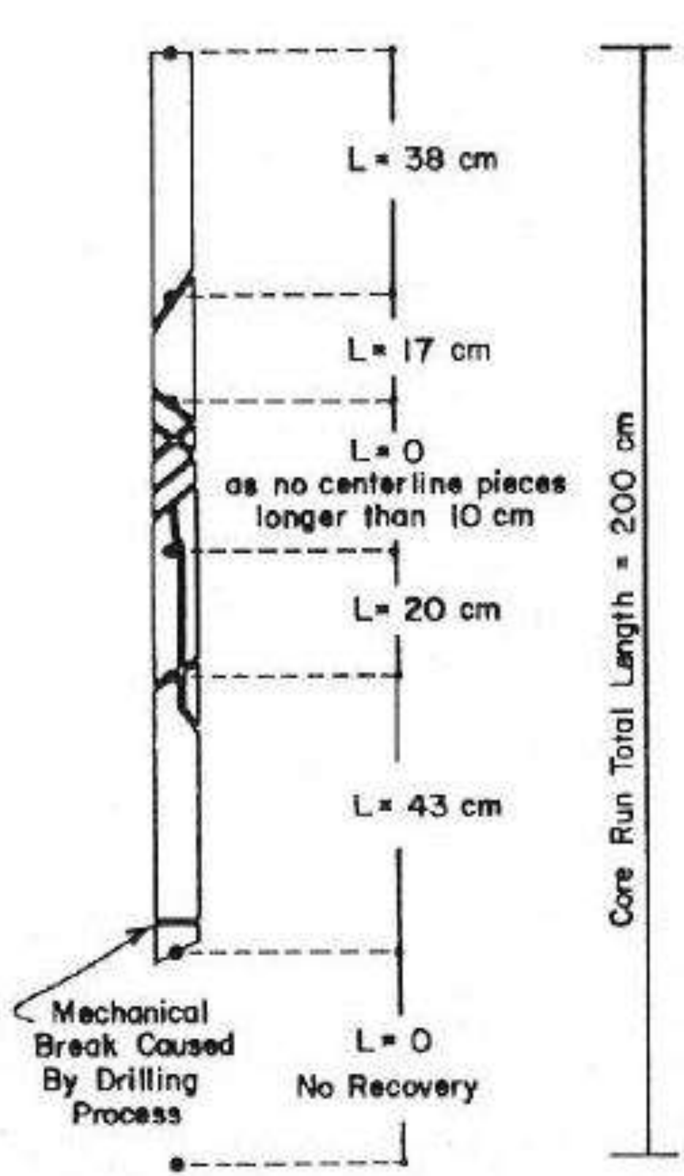
The RQD values provide a basis for making preliminary design decisions involving estimation of required depths of excavation for foundations of structures.

The RQD values also can serve to identify potential problems related to bearing capacity, settlement, erosion, or sliding in rock foundations.

The RQD can provide an indication of rock quality in quarries for concrete aggregate, rock fill .

The RQD must be used in combination with other geological and geotechnical input

Example:



$$RQD = \frac{\sum \text{Length of Core Pieces} > 10\ \text{cm (4 in.)}}{\text{Total Core Run Length}} \times 100\%$$

$$RQD = \frac{38 + 17 + 20 + 43}{200} \times 100\%$$

RQD = 59 % (FAIR)

RQD (Rock Quality Designation)	Description of Rock Quality
0 - 25 %	Very Poor
25 - 50 %	Poor
50 - 75 %	Fair
75 - 90 %	Good
90 - 100 %	Excellent

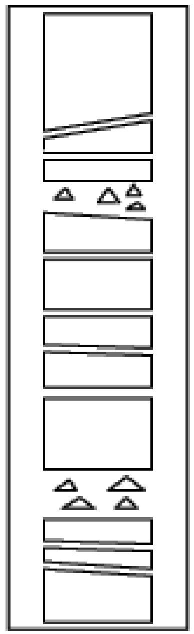
Core recovery versus Modified core recovery (RQD)

Core Recovery

10"
2"
2"
3"
4"
5"
3"
4"
6"
4"
2"
5"

50"

Core Rec.= 50/60=83%



Modified Core Recovery

10"
4"
5"
4"
6"
5"

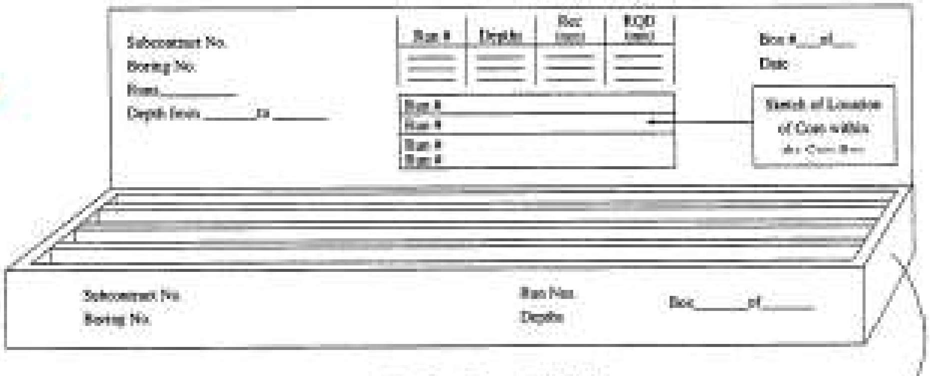
34"

RQD=34/60=57%

RQD Rock Quality Designation	Description of Rock Quality
0 -25	v. poor
25 -50	poor
50 -75	fair
75 -90	good
90 - 100	excellent

It has been found that the RQD is a more sensitive and consistent indicator of general rock quality than is the gross core recovery percentage.

Storage of rock core boxes



Core Box Front and Back Face

avoid exposure to shock and vibration during handling and transport.

Non-natural fractures may result from excessive movements, temperatures, and exposure to air.

Storage for future reference

- Deere and Miller (1966) **Classification of intact rock**:
  - **Any useful classification scheme should be relatively simple and based on readily measurable physical properties.**
  - **Deere and Miller based their classification on unconfined (uniaxial) compressive strength (σ_1) and Young's Modulus (E) or more specifically, the tangent modulus at 50% of the ultimate strength as ratio to the unconfined compressive strength (E/σ_1).**
  - **Rocks are subdivided into five strength categories on a geometric progression basis;**

    (A) very high – (B) high – (C) medium – (D) low – (E) very low.
  - **Three ratio intervals are employed for the modulus ratio;**

    high – medium – low.
  - **Rocks are therefore classed as BH (high strength- high ratio); CM (medium strength – medium ratio), etc.**
  - **This data should be included with lithology descriptions and RQD values.**

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	55-11	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

Using the ratio of Young's modulus to the compressive strength E/σ_u 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 E/σ_u

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

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

Strength of a rock largely depends on the density, nature and extent of the fracture within it.

Fracture Densities:

Rock fractures include:

- **Microstructures (spacing mostly 1mm – 1cm)**
- **Joints (1cm – 1m)**
- **Faults (> 1m)**

Also bedding, cleavage, schistosity.

Fractures allow inelastic deformation and reduce rock mass strength to 1/5 to 1/10 of the intact rock strength. This fraction known as rock mass factor.

Typical friction angles (ϕ):	clean rock	20–50°
	clay fill	10–20°
	breccia	25–40°

Cohesion across fractures varies 0–500 kPa.

Foundation on Rock

Safe Bearing Pressure – typical values		
Rock types	Unweathered and massive	Heavily fractured or thinly bedded
Strong igneous rock, gneisses	10 MPa	6 MPa
Strong limestones and sandstones	4 MPa	3 MPa
Schists and slates	3 MPa	2 MPa
Strong mudstones, soft sandstones	2 MPa	1 MPa
Shale, sound chalk, soft mudstone	750 kPa	400 kPa

Rock Mass Description Data Sheet

General information

Seq. No. [ ] Site [ ] Date (Day / Month / Year) [ ] Operator [ ] Method of location [ ] Co-ordinates or chainage (metres): Northings or chainage [ ] Eastings [ ] Elevation [ ]

Method of location:
1 By co-ordinates
2 Chainage
3 On attached map/drawing/photograph

Locality type [ ]
1 Natural exposure
2 Construction excavation
3 Trial pit
4 Trench
5 Adit
6 Tunnel

Size of locality [ ]
1 > 10 m^2
2 5–10 m^2
3 1–5 m^2
4 < 1 m^2
5 Line survey

No. of supplementary sheets of discontinuity data [ ]

Sketch [ ] Photograph [ ]
0 No
1 Yes

Field tests [ ]
Specify type

Remarks [ ]

Rock material information

Colour [ ]
1 Light 2 Dark

1	pinkish	1	pink
2	reddish	2	red
3	yellowish	3	yellow
4	brownish	4	brown
5	olive	5	olive
6	greenish	6	green
7	bluish	7	blue
8	greyish	8	white
		9	grey
		0	black

Grain size [ ]
1 Very coarse
2 Coarse (2–60 mm)
3 Medium (60 μm–2 mm)
4 Fine (2–60 μm)
5 Very fine (< 2 μm)

Compressive strength [ ]
1 Very strong (> 100 MPa)
2 Strong (50–100 MPa)
3 Mod. strong (12.5–50 MPa)
4 Mod. weak (5–12.5 MPa)
5 Weak (1.25–5 MPa)
6 V. weak/hard (600–1250 kPa)
7 Very stiff (300–600 kPa)
8 Stiff (150–300 kPa)
9 Firm (80–150 kPa)
0 Soft (40–60 kPa)

Method of determining compressive strength [ ]
1 Measured
2 Assessed

Rock type [ ]

Qualifying terms to describe rock ______________

Rock mass information

Fabric [ ]
1 Blocky
2 Tabular
3 Columnar

Block size [ ]
1 Very large (> 8 m^3)
2 Large (0.2–8 m^3)
3 Medium (0.008–0.2 m^3)
4 Small (0.0002–0.008 m^3)
5 Very small (< 0.0002 m^3)

State of weathering [ ]
1 Fresh
2 Slightly
3 Moderately
4 Highly
5 Completely
6 Residual soil

No. of major discontinuity sets [ ]

Line surveys to determine discontinuity spacings

	Plunge of line	Trend of line	Length of line (metres)	No. of fractures	Spacing	Remarks
Line 1						
Line 2						
Line 3						

Discontinuity spacing
1 Ext. wide (< 2 m)
2 Very wide (600 mm–2 m)
3 Wide (200–600 mm)
4 Mod. wide (60–200 mm)
5 Mod. narrow (20–60 mm)
6 Narrow (6–20 mm)
7 Very narrow (6 mm)

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).

(g) 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%.

Quarrying: Geological Materials Used in Construction

A number of factors determine whether a rock will be worked as a building stone. These include the volume of material that can be quarried; the ease with which it can be quarried; the wastage consequent upon quarrying; and the cost of transportation; as well as its appearance and physical properties (Yavuz et al., 2005). As far as volume is concerned, the life of the quarry should be at least 20 years. The amount of overburden that has to be removed also affects the economics of quarrying. Obviously, there comes a point when removal of overburden makes operations uneconomic.

fresh to weathered rock is another factor of economic importance. The ease with which a rock can be quarried depends to a large extent on geological structures, notably the geometry of joints and bedding planes, where present. Ideally, rock for building stone should be massive, certainly it must be free from closely spaced joints or other discontinuities as these control block size. The stone should be free of fractures and other flaws. In the case of sedimentary

rocks can also give rise to problems of slope stability when excavated. On the other hand, if beds of rock dip gently, it is advantageous to develop the quarry floor along the bedding planes. The massive nature of igneous rocks such as granite means that a quarry can be developed in any direction, within the constraints of planning permission.

The durability of a stone is a measure of its ability to resist weathering and so to retain its original size, shape, strength and appearance over an extensive period of time. It is one of the most important factors that determines whether or not a rock will be worked for building

According to Leary (1986), one of the tests that is frequently used in Britain to make an initial assessment of the durability of sandstone as a building material is the acid immersion test. This involves immersing specimens for 10 days in sulphuric acid of density 1.145 Mg m^{-3}. Stones that are unaffected by the test are regarded as being resistant to attack by acidic rain-water. Those stones that fail are not recommended for external use in polluted environments.

The crushing strength of rock used for aggregate generally ranges between 70 and 300 MPa. Aggregates that are physically unsound lead to the deterioration of concrete, inducing cracking, popping or spalling. Cement shrinks on drying. If the aggregate is strong, the amount of shrinkage is minimized and the cement–aggregate bond is good.

The shape of aggregate particles is an important property and is governed mainly by the fracture pattern within a rock mass. Rocks such as basalts, dolerites, andesites, granites, quartzites and limestones tend to produce angular fragments when crushed. However, argillaceous limestones, when crushed, produce an excessive amount of fines. The crushing characteristics of sandstone depend on the closeness of its texture, and the amount and type of cement. Angular fragments may produce a mix that is difficult to work, that is, it can be placed less easily and offers less resistance to segregation. Nevertheless, angular particles are said to produce a denser concrete. Rounded, smooth fragments produce workable mixes. The less workable the mix, the more sand, water and cement must be added to produce a satisfactory concrete.

Aggregate used as road metal must, in addition to having high strength, have high resistance to impact and abrasion, polishing and skidding, and frost action. It must also be impermeable, chemically inert and possess a low coefficient of expansion. The principal tests carried out in order to assess the value of a roadstone are the aggregate crushing test, the aggregate impact test, the aggregate abrasion test and the test for the assessment of the polished stone value. Other tests of consequence are those for water absorption, specific gravity and density, and the aggregate shape tests (Anon,

The properties of an aggregate are related to the texture and mineralogical composition of the rock from which it was derived. Most igneous and contact metamorphic rocks meet the requirements demanded of good roadstone. On the other hand, many rocks of regional metamorphic origin are either cleaved or schistose and are therefore unsuitable for roadstone. This is because they tend to produce flaky particles when crushed. Such particles do not achieve good interlock and, consequently, impair the development of dense mixtures for surface dressing. The amount and type of cement and/or matrix material that bind grains together in a sedimentary rock influence roadstone performance.

Engineering Geology

Engineering Geology is backbone of civil engineering

6. Site investigation

Eng. Iqbal Marie

Manual on Subsurface Investigations

by Paul W. Mayne, Barry R. Christopher, and Jason DeJong

July 2001

Site Investigation is the gathering of information about the proposed location of the highway or any engineering project

Ground investigation assesses ground conditions prior to starting a construction project

Ground investigation vary with the size and nature of the engineering works but includes one or more of the following:

- **Suitability of the site for the proposed project**
- **site conditions and ground properties**
- **ground difficulties and instabilities for construction work**
- **Ground data necessary for the design of the structures**
- **Are there any materials available on site, what quantity and quality?**

Some of the requirements for site exploration

1) The ideal *type* and the *depth* of the foundations for the structure.

2) The required *load-bearing capacity* of the foundations.

3) The admissible *settlements*

4) Where is the *ground water surface (GWT)*, and how much does it vary?

5) What *lateral loads* may be placed upon the structure? Is the ground slipping, and what is the *slope stability*?

6) What *constraints* are there for construction methods (for example, would a deep garage basement undermine the foundations of an older adjacent building?).

7) Does the structure require *long-term monitoring*?

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

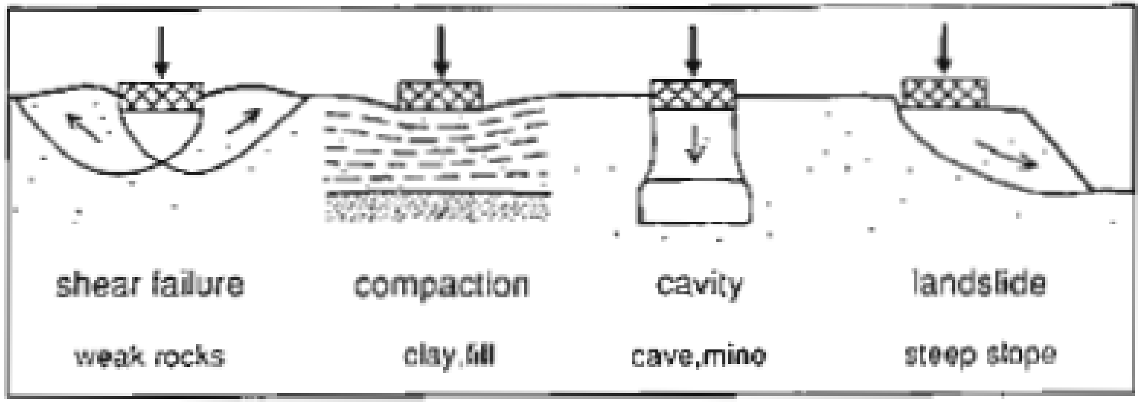
Project	% Total costs	% Foundations costs
Buildings	0·05–0·2	0·5–2
Roads	0·2–1·5	1–5
Dams	1–3	1–5

Examples for why site investigation?

FAILURE OF ROCK

Sound rock is capable of bearing most normal engineering loads; the same cannot be said for soils.
Normal variations in rock properties are covered by generous factors of safety in engineering design.
Major zones of significant weakness, including underground voids, can cause failures; should be avoided by adequate site investigation.
There are four possible modes of failures:

- Shear failure and upward displacement of the rock, due to imposed loading > rock strength.
- Compaction of porous rocks (causing extreme settlement), also due to loading > rock strength.
- Rock failure into underground cavity, where rock roof fails in shear or flexural tension.
- Landsliding and lateral displacement, where slope profiles are too steep.



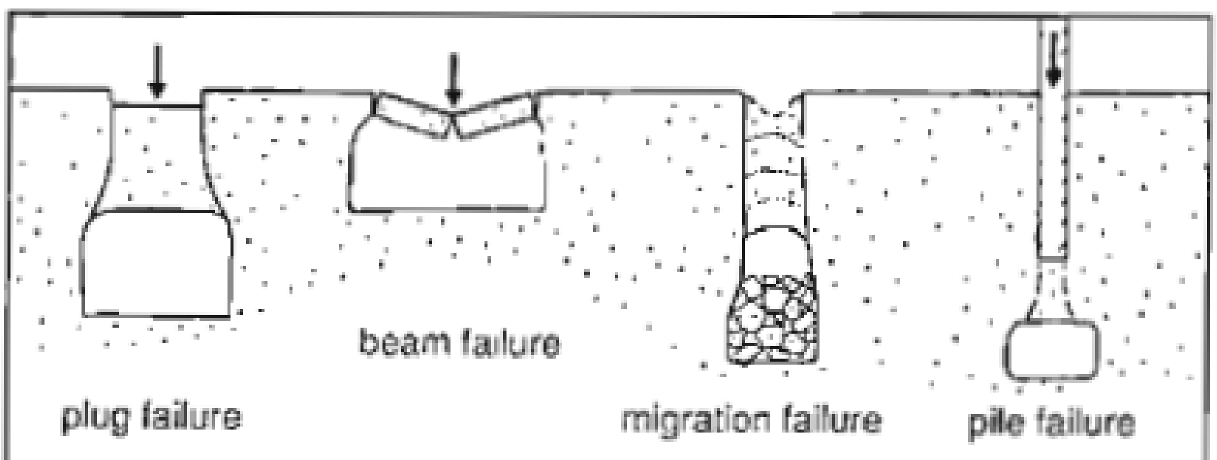
INFLUENCE OF BURIED VOIDS

Plug or beam failures of rock under structural loading over underground cavities depend on the rock strength and fracturing, the cavity size and depth, and the applied loads and stresses.

Natural and mined cavities can vary greatly in size, shape and stability, and each one requires individual assessment if it is relevant to engineering works.

Risk of ground failure increases if any one of the following guideline criteria is met:

- Cover thickness < cavity width;
- Cover thickness underneath end bearing piles < 5 times pile diameter;
- Loading to SBP above < 3 m of strong rock;
- Cover of weak rock or soil (with progressive failure and cavity migration) < 10 times cavity height.



GROUND IMPROVEMENT

Treatment of fresh rock is rarely necessary or economic for structural foundations.
Weathered and weak rock near surface is better removed or piled through.
Injection of cement grout to fill rock pores and increase strength is limited by low permeability of intact rock.

Grouting can double mass strength of fissured rocks.
Underground cavities can be filled with grout injected through 100 mm boreholes; may need 3–4 m grid of holes if cavities are partially blocked; use fluid mixture of 1:10 ratio of cement:*PFA or fines; need stiff grout with sand or gravel to form perimeter barrier to avoid high losses away from site.
Alternatives to cement grout are foamed concrete or uncemented rock paste if need is only to prevent progressive roof falls.

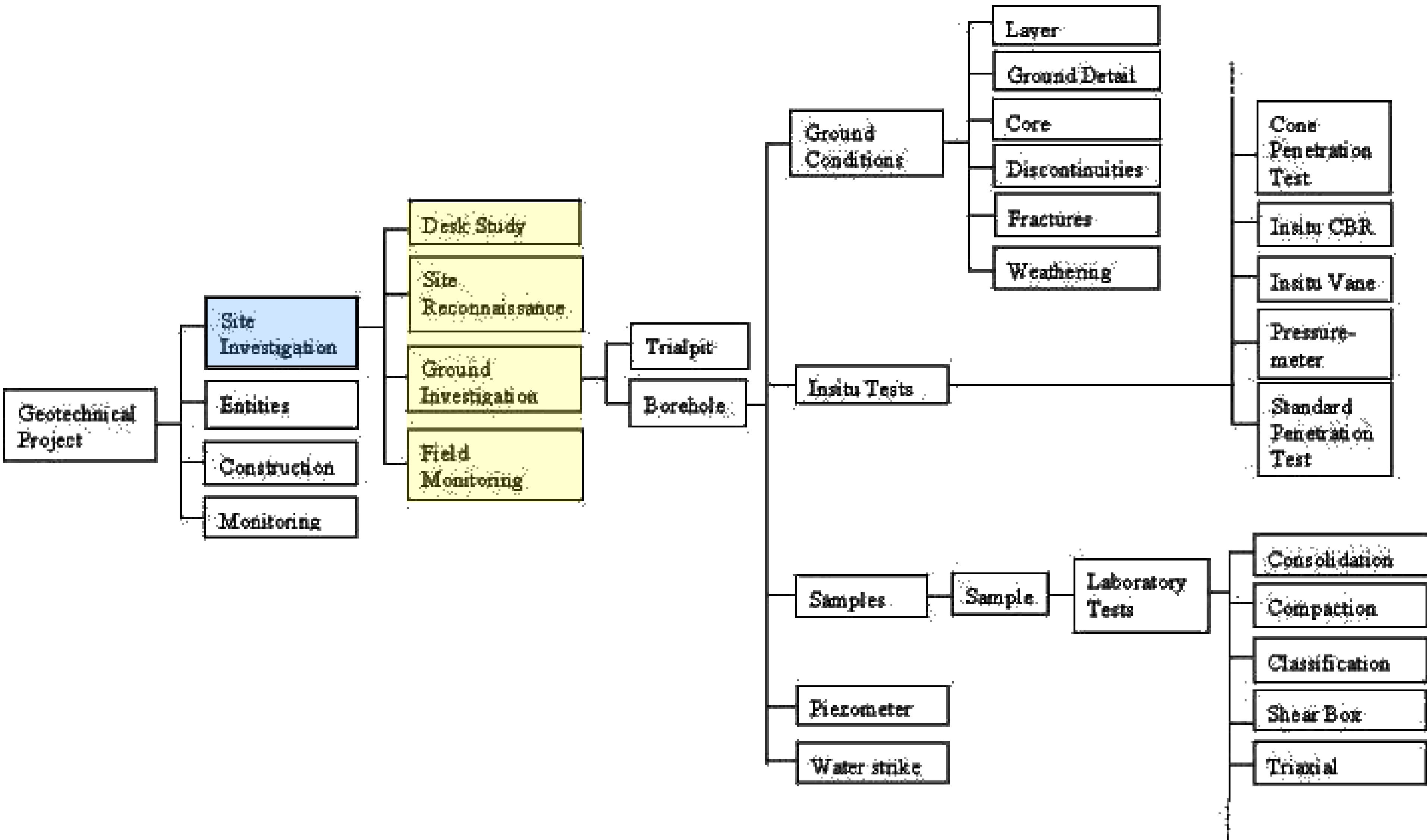
* **PFA:** ***Pulverised Fuel Ash***

Sequence of investigation stages

- Initial stage: Desk Study
  - Desk study of available data
  - Site visit and visual assessment
  - Preliminary report and fieldwork plan
- Main stage: Site Investigation
  - Fieldwork
    - Geological mapping if necessary
    - Trial pits, trenches and boreholes
    - Geophysical survey if appropriate
  - Lab testing, mainly of soils
  - Geophysical survey
  - Final Report
- Review stage
  - Monitoring during excavation and construction

It is essential to start the desk study: It is a basis for planning all further investigation.

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.

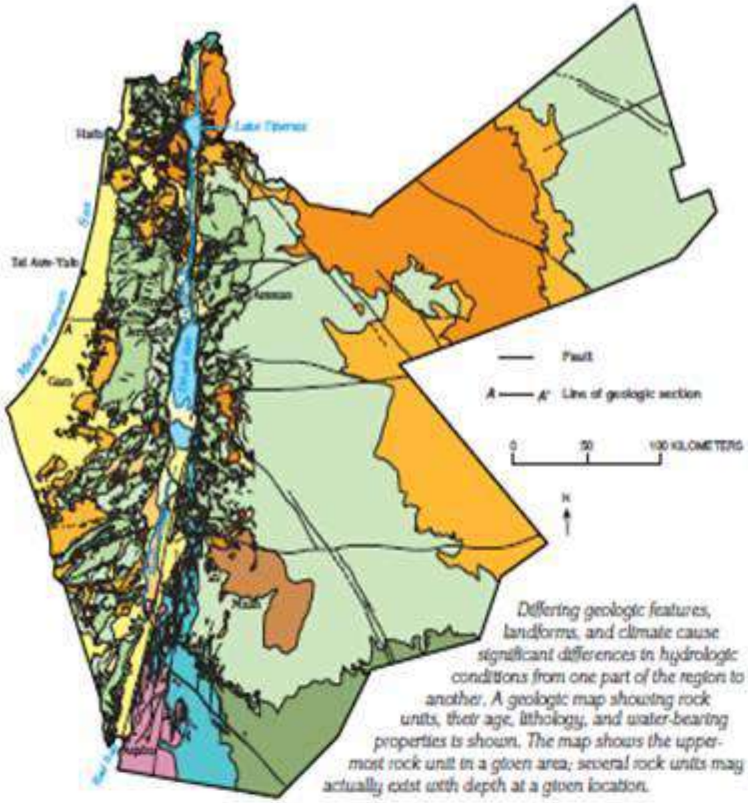
  (but in real practice the boundaries and especially the faults are interpolated, so accuracy cannot always be taken as granted)

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), ...



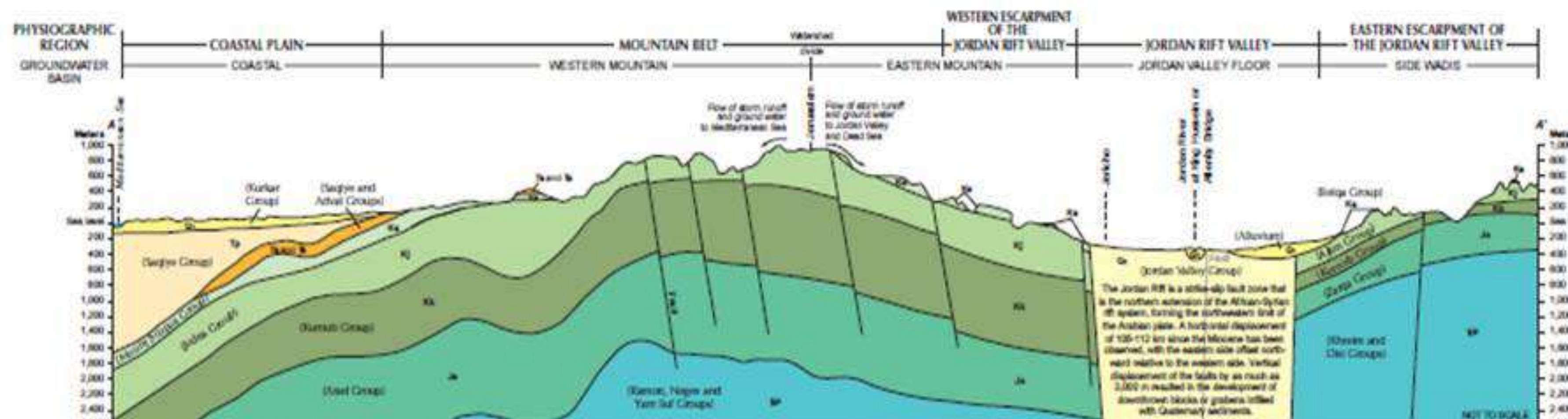
Differing geologic features, landforms, and climate cause significant differences in hydrologic conditions from one part of the region to another. A geologic map showing rock units, their age, lithology, and water-bearing properties is shown. The map shows the uppermost rock unit in a given area; several rock units may actually exist with depth at a given location.

Generalized geologic units and water-bearing properties

System/Series		Stage	West of Jordan River and Wadi Araba: Group	West of Jordan River and Wadi Araba: Unit	East of Jordan River and Wadi Araba: Group	East of Jordan River and Wadi Araba: Unit	This report	SEDIMENTARY ROCKS Unit description
Quaternary	Holocene, Pleistocene		Kurkar	Qs, Qd, Qk	Jordan Valley	Alluvium and Lisan Sediments	Qs	Soil, sand, gravel, sandstone, and conglomerate. Comprise prolific aquifer in Coastal Plain Basin. In Jordan Valley Floor Basin, alluvial fan deposits along flanks form aquifers that contain most of the freshwater of the basin.
Tertiary	Pliocene		Saqiye	Ql, Qs	Jordan Valley	Absent	Qp	In Jordan Valley Floor Basin, upper part includes marl, clay, and evaporites that inhibit groundwater flow. Lower part consists of water-bearing conglomerate, sand, and gravel.
Tertiary	Pliocene		Saqiye	Tp	Jordan Valley	Absent	Tp	In Coastal Plain Basin, consists mainly of clay and marl, that inhibit groundwater flow.
Tertiary	Miocene, Oligocene		Saqiye	Ts	Jordan Valley	Absent	Ts	Marl, limestone, sandstone, conglomerate. Generally an aquitard; limestone and sandstone layers are water bearing.
Tertiary	Eocene		Avdat	Te	Belqa	B5	Te	Chalk, limestone, chert, marl. Generally aquitard; limestone layers are water bearing.
Tertiary / Cretaceous	Paleocene, Upper	Senonian	Mount Scopus	Ks	Belqa	B4, B3 B2/A7	Ks	Chalk, chert, limestone, marl. Limestone and chert layers are prolific aquifers in much of Jordan. Well yields are highly variable and are controlled largely by cavernous zones in the limestone that are affected by geologic structure. Flowing wells common in areas of low elevation. Salinity increases in an eastward direction in Jordan.
Cretaceous	Upper	Turonian, Cenomanian	Judea	Kj, Kc	Ajlun	A1/A6	Kj	Limestone, dolomite, marl, shale. Limestone and dolomite layers are prolific aquifers in Eastern and Western Mountain Basins.
Cretaceous	Lower	Albian, Aptian	Kurnub	Kk	Kurnub	K	Kk	Sandstone, dolomite, marl, sand, shale, clay, sandy limestone. Upper part mostly consists of shale and carbonates forming aquitude; lower part mostly consists of water-bearing sandstone. High salinity in vicinity of Jordan Rift Valley.
Jurassic			Arad	Ja	Zarqa	Z	Ja	Limestone, dolomite, sandstone, marl, shale. Limestone, dolomite and sandstone layers water bearing. Important source of water in Negev, north and south Wadi Araba, and south Jordan Desert Basins. High salinity in parts of region. Groundwater development is limited by drilling depths, high pumping lifts, and mineralization of groundwater.
Triassic			Ramon	Tr, Pn	Zarqa	Absent	TrP	Limestone, sandstone, shale, clay, dolomite, gypsum. Limestone, dolomite and sandstone layers water bearing. Important source of water in Negev, north and south Wadi Araba, and south Jordan Desert Basins. High salinity in parts of region. Upper part largely aquitude. Groundwater development is limited by drilling depths, high pumping lifts, and mineralization of groundwater.
Paleozoic			Negev and Yam Suf	Pz	Khreim and Disi	R	TrP	

System/Series		Stage	West of Jordan River and Wadi Araba Unit	East of Jordan River and Wadi Araba Unit	This report	IGNEOUS AND METAMORPHIC ROCKS Unit description
Quaternary	Holocene, Pleistocene		B4	BA	Ba	Basalt, tuff, and alkaline magmatic rocks. Major source of water in northern and northeastern part of region. Basalt is hydraulically connected with conglomerate, sandstone, marl, and chalk. Basalt and coarse grained clastics form aquifers that are separated by layers of marl and chalk. Water is generally of very good quality and high well yields are common.
Tertiary	Pliocene, Miocene		B4	BA	Ba	
Cretaceous	Upper	Senonian, Turonian, Cenomanian	B3	Absent	Ba	
Cretaceous	Lower	Albian, Aptian	B2	Absent	Ba	
Jurassic			B1	Absent	Ba	
Triassic			B1	Absent	Ba	
Precambrian			p€3	Absent	p€	Metamorphic rocks, volcanic intrusives. Water occurs in fractures in crystalline bedrock. Generally not utilized as water source.
Precambrian			p€2	G	p€	
Precambrian			p€1	Absent	p€	

Volcanic plug rising through eroded sandstone of geologic unit Kk, near Wadi Hasa



A schematic cross section shows the arrangement of rock units along a vertical slice through the earth's surface from the Mediterranean Sea to east of the Jordan River and illustrates the relative vertical positions of the rock units. In general, rock units thicken west of the Jordan River and continue to thicken toward the Mediterranean Sea. Rock units have been faulted and folded. Volcanic deposits occur as surficial flows and as volcanic necks in subsurface areas. (Local names are in parentheses.)

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

Ground Investigation: other than the information available from the walk over survey that will be governed by:

- **trial pits**
- **boreholes.**

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.

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

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.

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

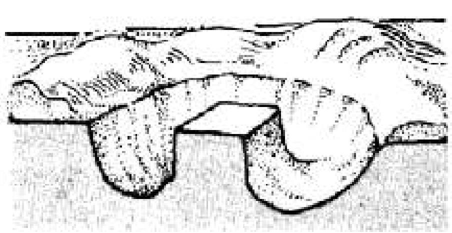
- **Timbering**
- **Steel frames with hydraulic jacks**
- **Battered or tapered sides**

- An important safety point to note is that *ALL pits below a depth of 1.2m must be supported.*

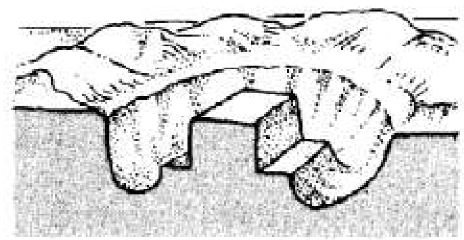
Block sampling

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.

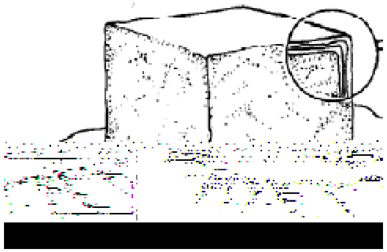
Undisturbed block sampling is limited to cohesive soils and rocks. The procedures used for obtaining undisturbed samples vary from cutting large blocks of soil using a combination of shovels, hand tools and wire saws, to using small knives and spatulas to obtain small blocks

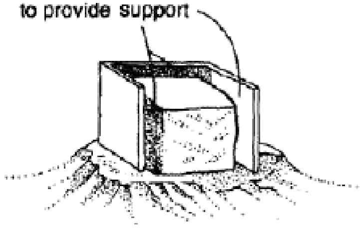


(a) Level ground surface, mark outline of sample and carefully excavate trench

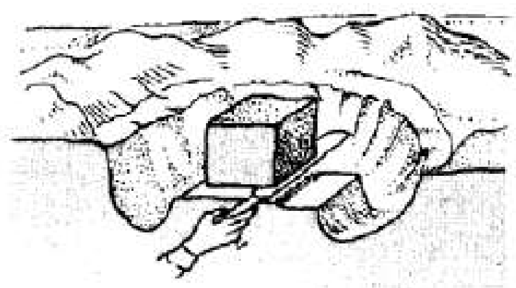


(b) Deepen excavation below base of sample, and trim to size with a knife





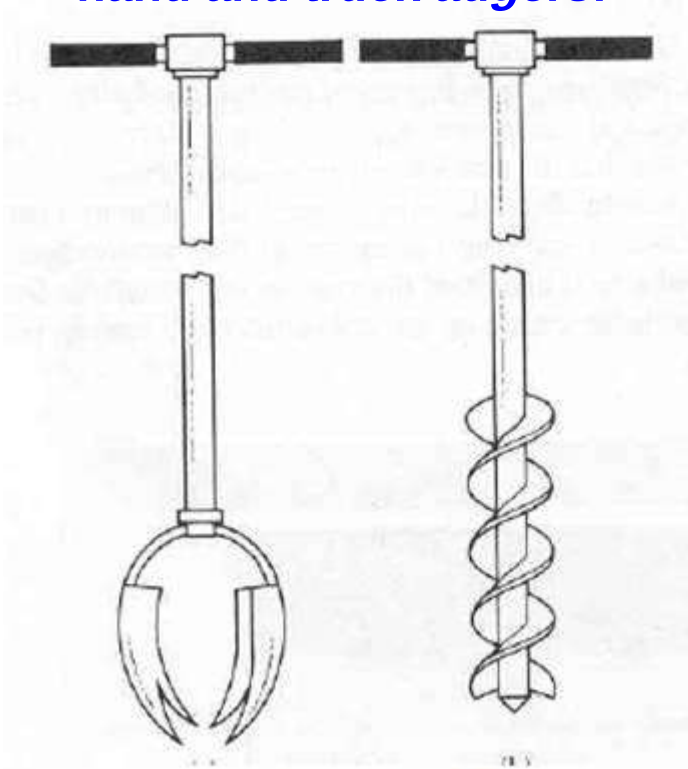
(d) Encase sample in a wooden box, packed with foam or damp woodshavings, if soil is easily disturbed



(e) Cut sample from bottom of pit, and seal base as in (c). Place wooden lid, if box is used

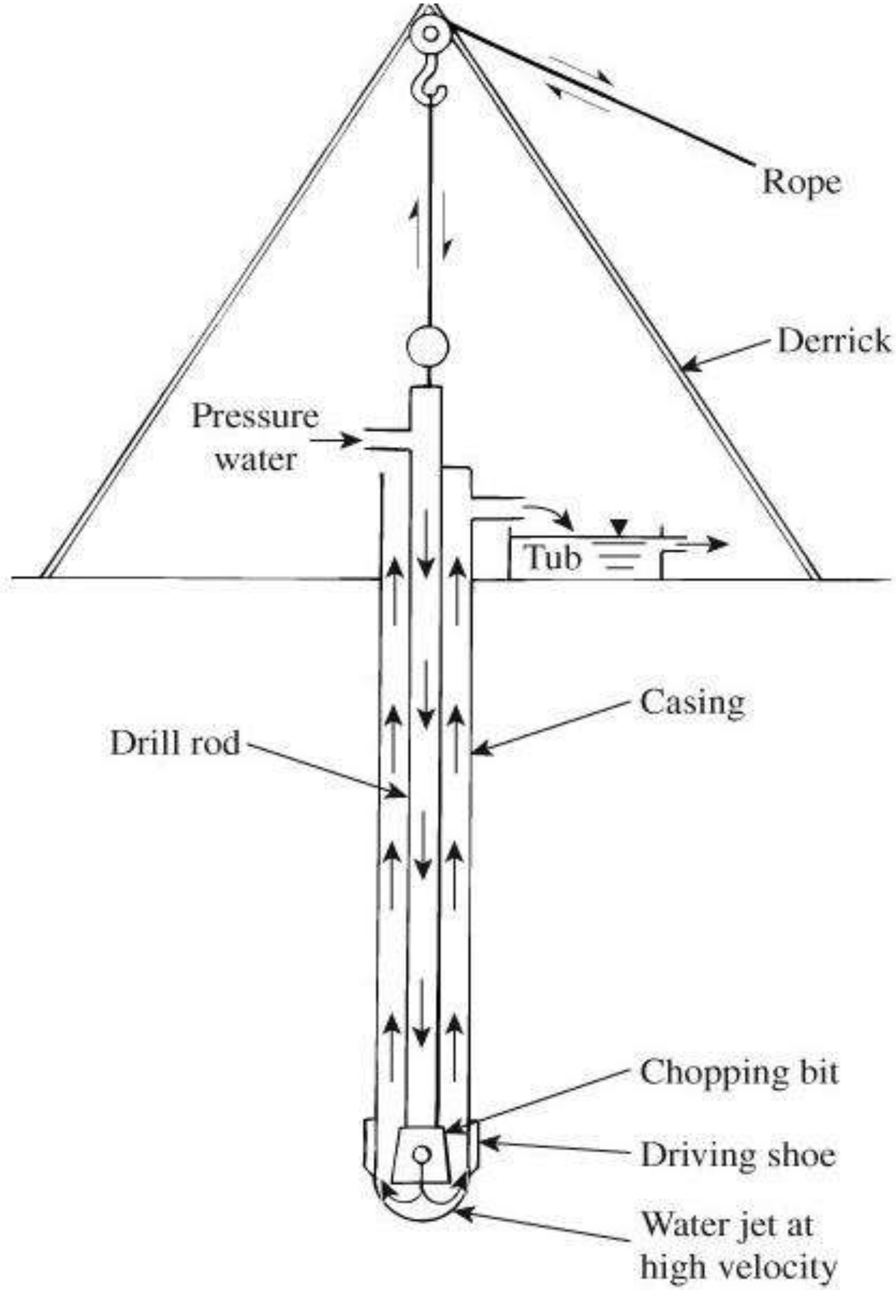
Boreholes: used to determine the nature of the ground (usually below 6m depth) in a qualitative manner and then recover undisturbed samples for quantitative examination.

hand and truck augers:



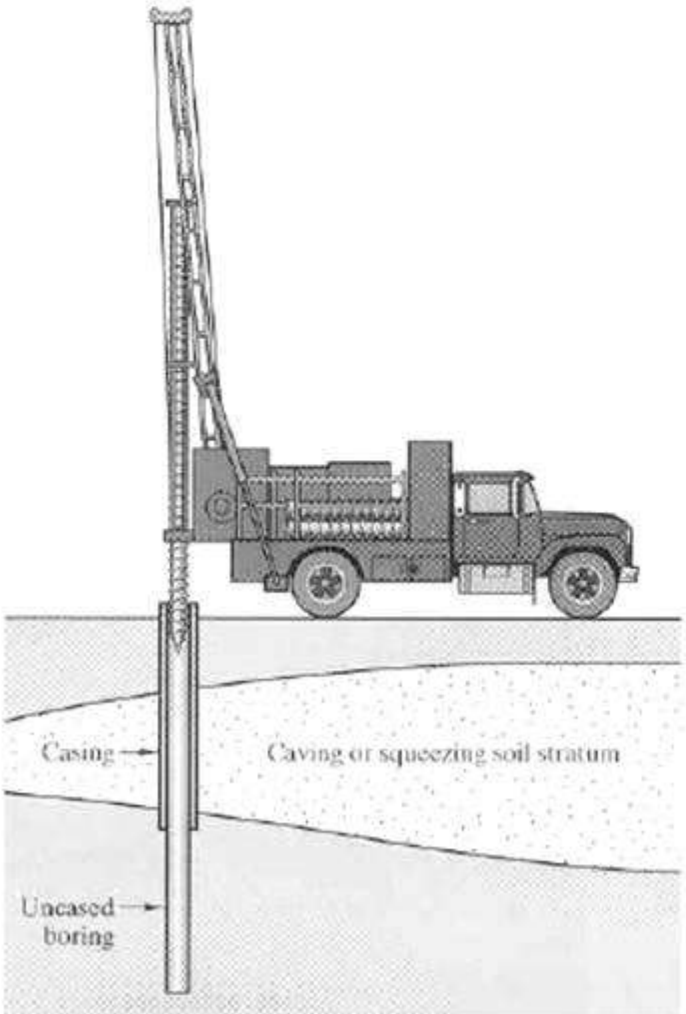
An Iwan auger (left) and a Slip auger.

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.**

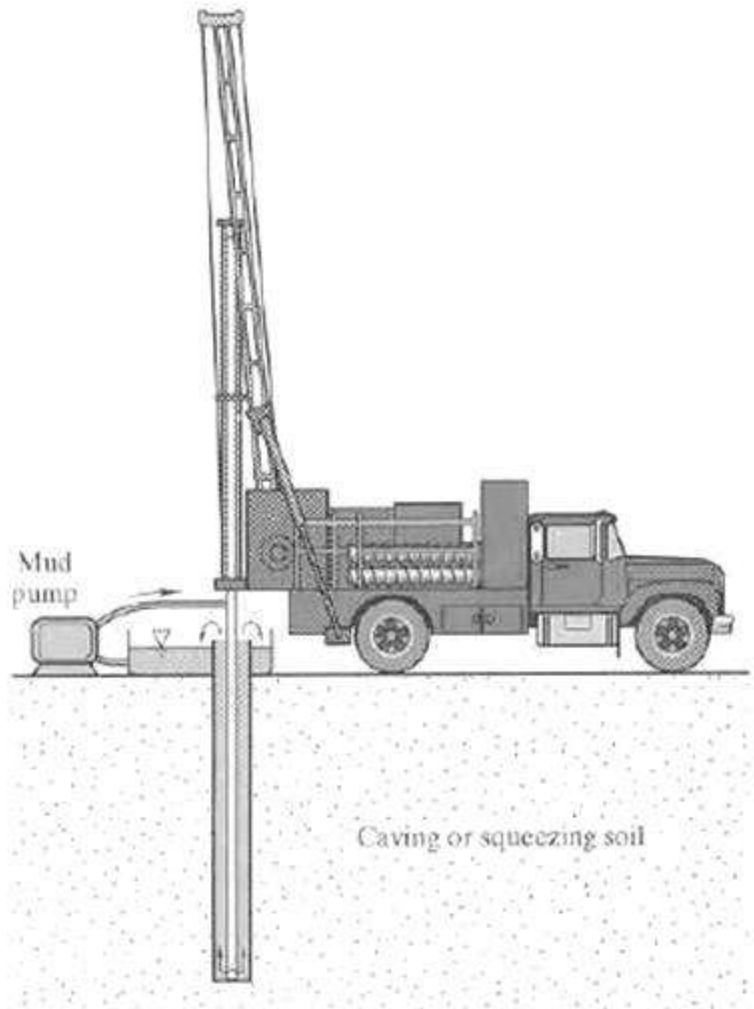


Wash boring

Truck Mounted Sampling Drills.



Casing a collapsible soil stratum.



Casing a caving (eg., loose sand) soil stratum.

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

Drilling Mud called quick-Gel

Each boring is carefully recorded to help in the preparation of the final report.

4-wing (solid head) drag bit

Straight chopping bit

Tri-cone rock bit.

Diamond casing bit

Drill bits for rock penetration

11/04/2013

تعاملت كوادر الدفاع المدني في مديرية دفاع مدني غرب عمان ظهر يوم الخميس مع حادث محاصرة (3) أشخاص يحملون الجنسية المصرية اثر انهيار أتربة عليهم داخل حفرية لمشروع سكني قيد الإنشاء أثناء قيامهم بعملية الحفر على عمق يقدر بـ (10)م في منطقة مرج الحمام.

من جهته ذكر العقيد فريد الشرع مدير إدارة الاعلام والتثقيف الوقائي الناطق الإعلامي في المديرية العامة للدفاع المدني أن كوادر الدفاع المدني عملت على إزاحة الردم وإخراج الأشخاص المحاصرين وتقديم الإسعافات الأولية لهم ونقلهم الى مستشفى البشير الحكومي وعند الوصول أفاد الطبيب المناوب وفاة شخصين وإصابة الثالث بجروح وكسور في مختلف أنحاء الجسم وحالة المصاب العامة متوسطة.

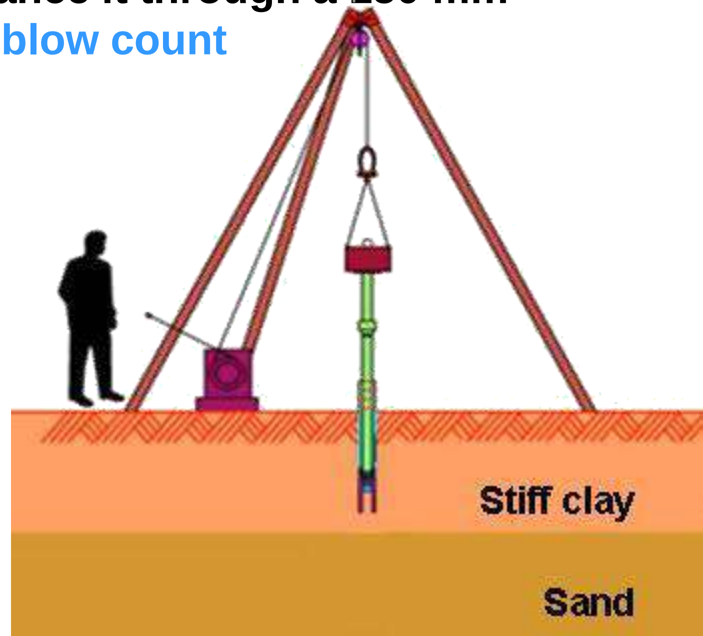
Standard Penetration Test SPT → N Value

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

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.



BOREHOLE, SAMPLER, AND ROD CORRECTION FACTORS

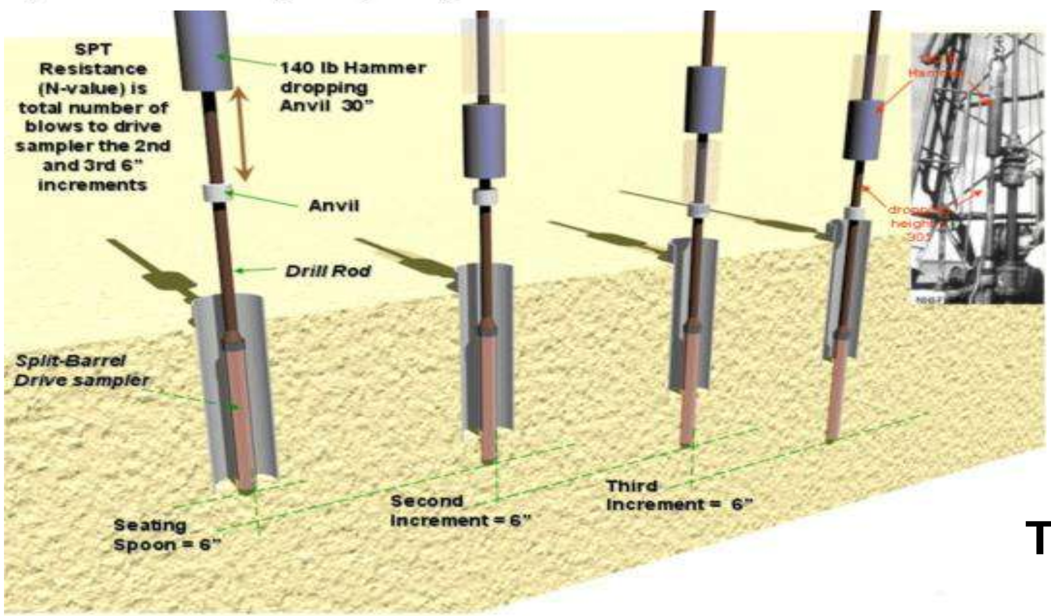
Factor	Equipment Variables	Value
Borehole diameter factor, C_B	2.5 - 4.5 in (65 - 115 mm)	1.00
	6 in (150 mm)	1.05
	8 in (200 mm)	1.15
Sampling method factor, C_S	Standard sampler	1.00
	Sampler without liner	1.20
Rod length factor, C_R	10 - 13 ft (3 - 4 m)	0.75
	13 - 20 ft (4 - 6 m)	0.85
	20 - 30 ft (6 - 10 m)	0.95
	> 30 ft (> 10 m)	1.00

Adapted from Skempton (1986).

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

N: measured SPT N- value

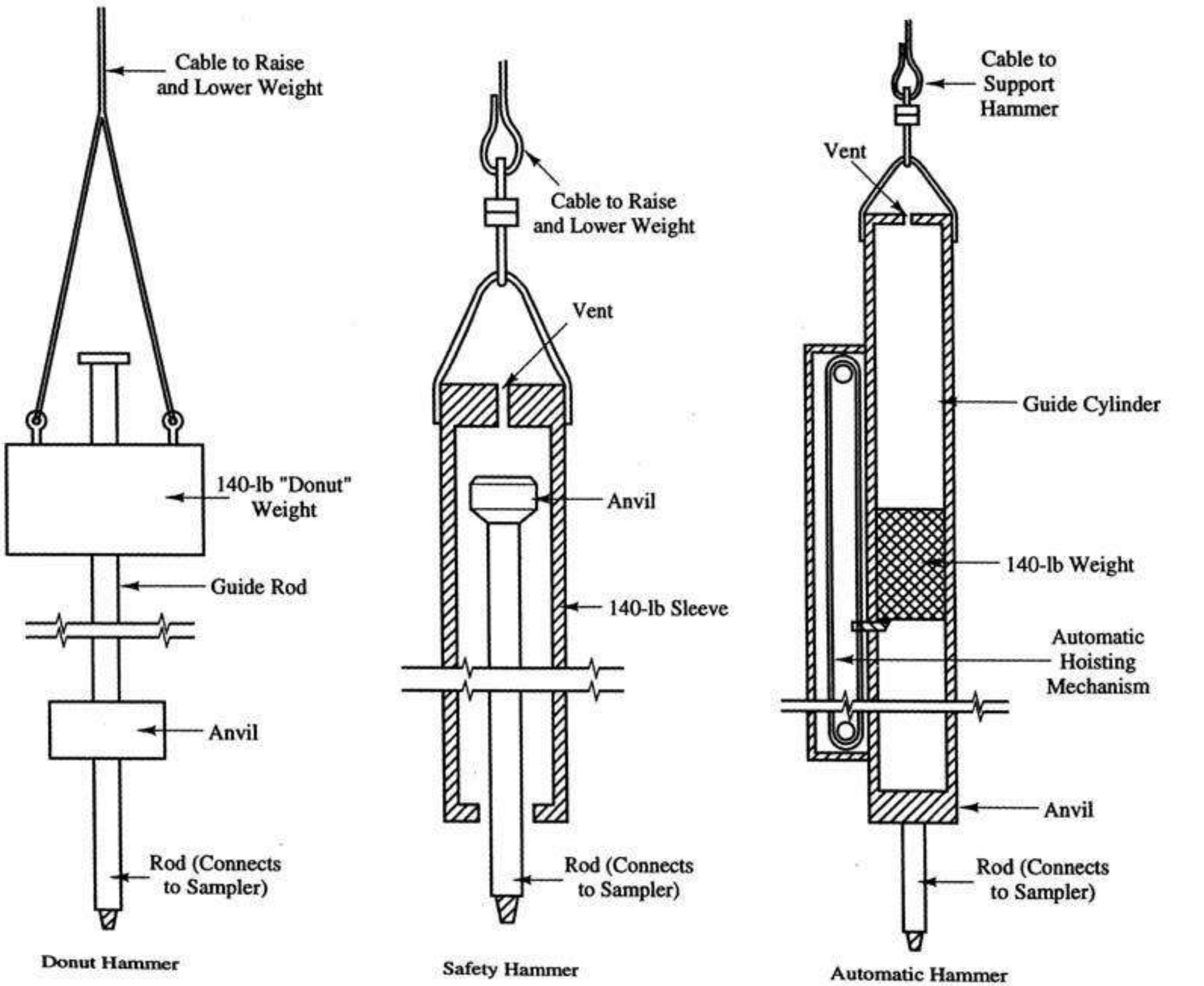
E_m: Hammer efficiency =0.6 for safety hammer and = 0.45 for doughnut hammer



*** Uncorrected "N" values can vary by a factor of 3.**

Test SPT

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



SPT Hammer Types

The following soil properties can be estimated.

- Unit Weight (γ)
- Relative Density (Dr)
- Angle of internal friction (ϕ)
- undrained Compressive Strength (qu)
- Bearing Capacity of Foundation
- Stress Strain Modulus (Es)

. 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

The results obtained from the standard penetration test provide an evaluation of the degree of compaction of sands, and the *N* values may be related to the values of the angle of internal friction, ϕ, and the allowable bearing capacity.

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.

Permeability is the ease with which the water flows through a soil medium

Coefficient of permeability in different soils

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

Guidelines for location of boreholes

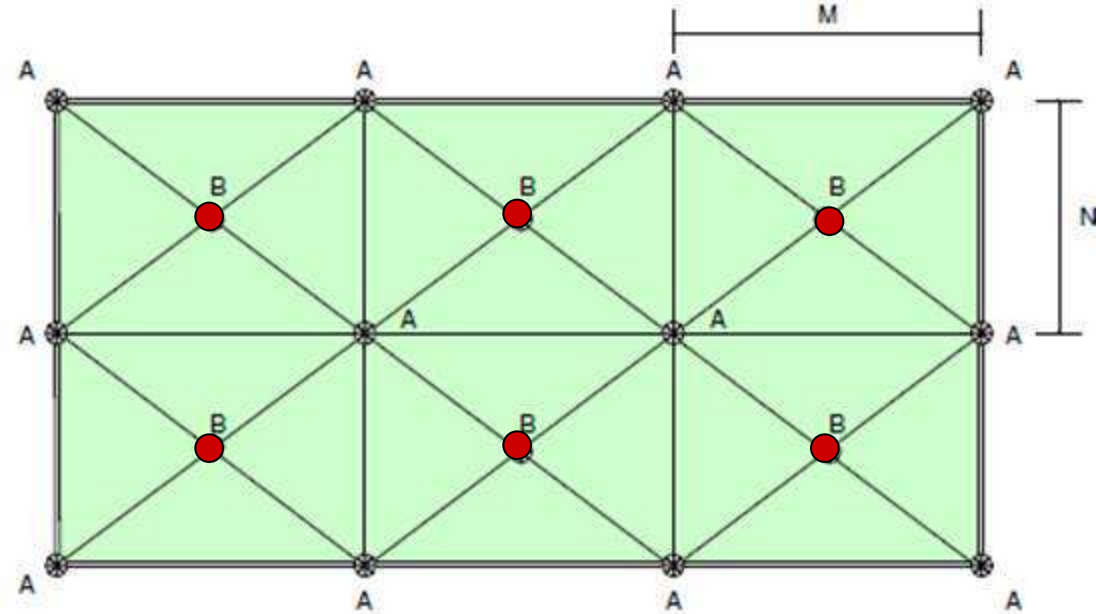
may be located at every strategic importance where are heavy concentrated loads occurred

Dames → Along the centerline of the axis

Buildings (irregular areas) → Load sensitive points based on experience

- Beneath Heavy columns
- Areas near to load bearing walls
- One borehole beneath water tank if present

Selection of Borings

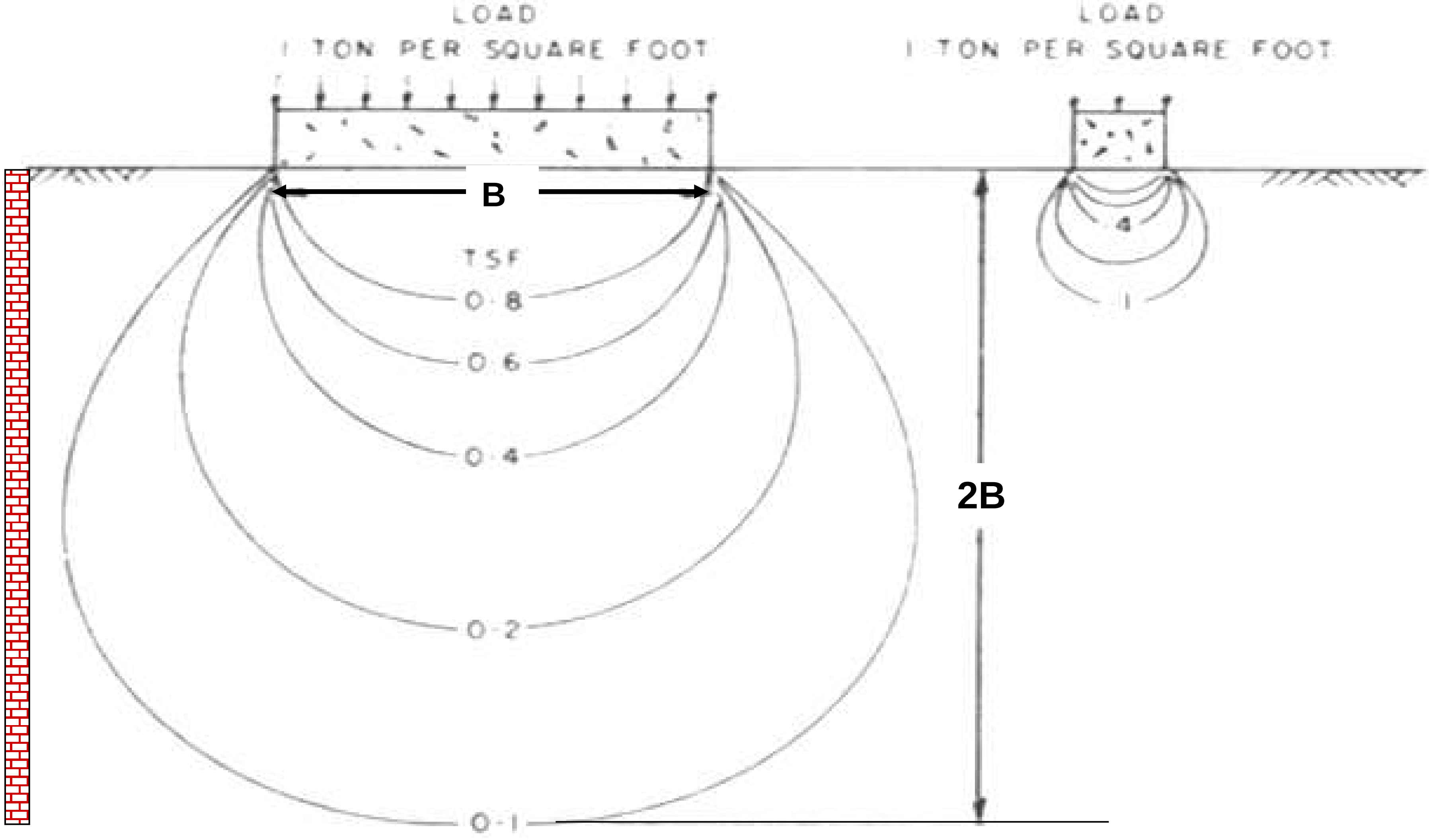


A preliminary guideline for choosing the number of borings and their depth.

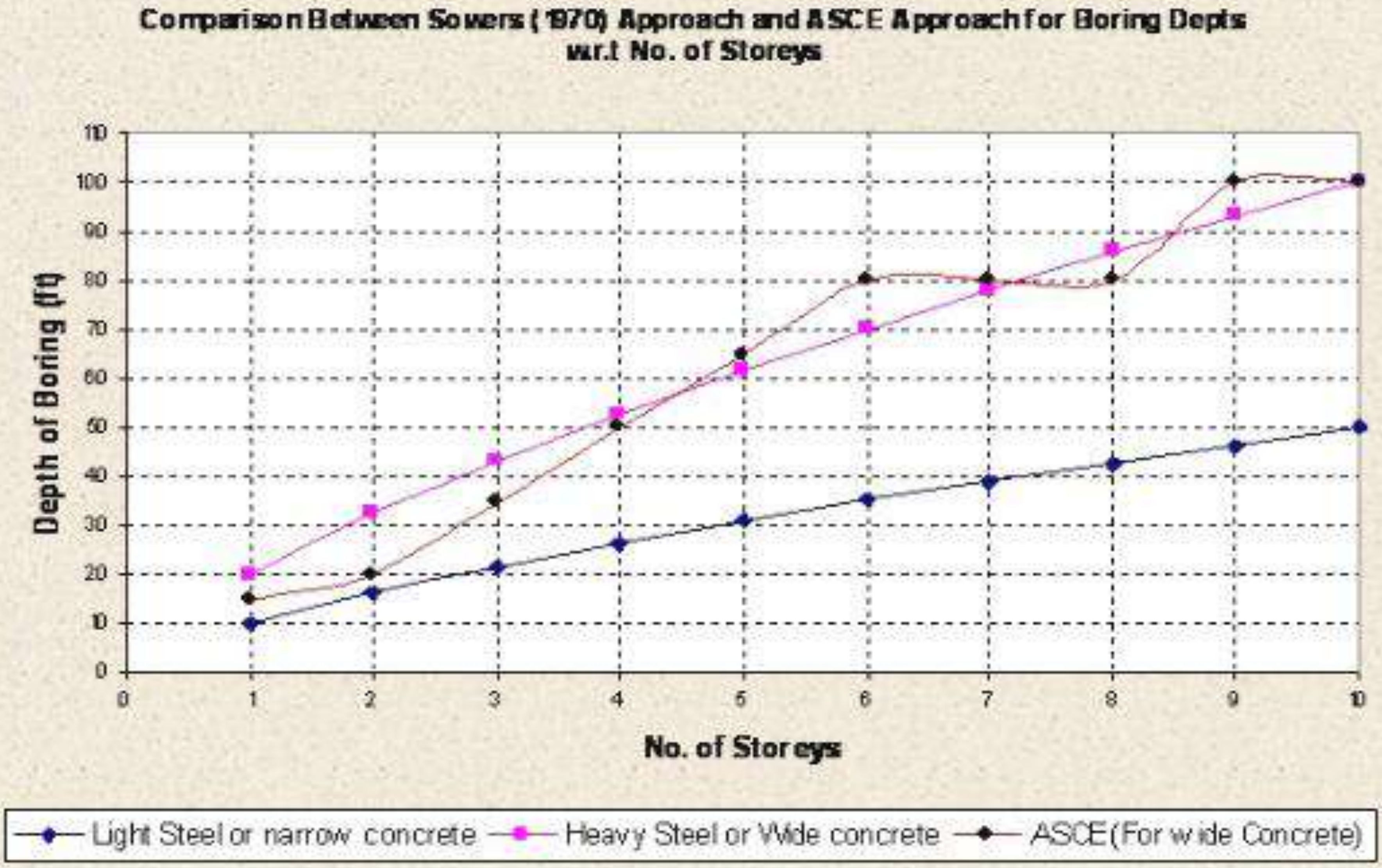
each site is unique and requires careful selection based on local conditions.

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

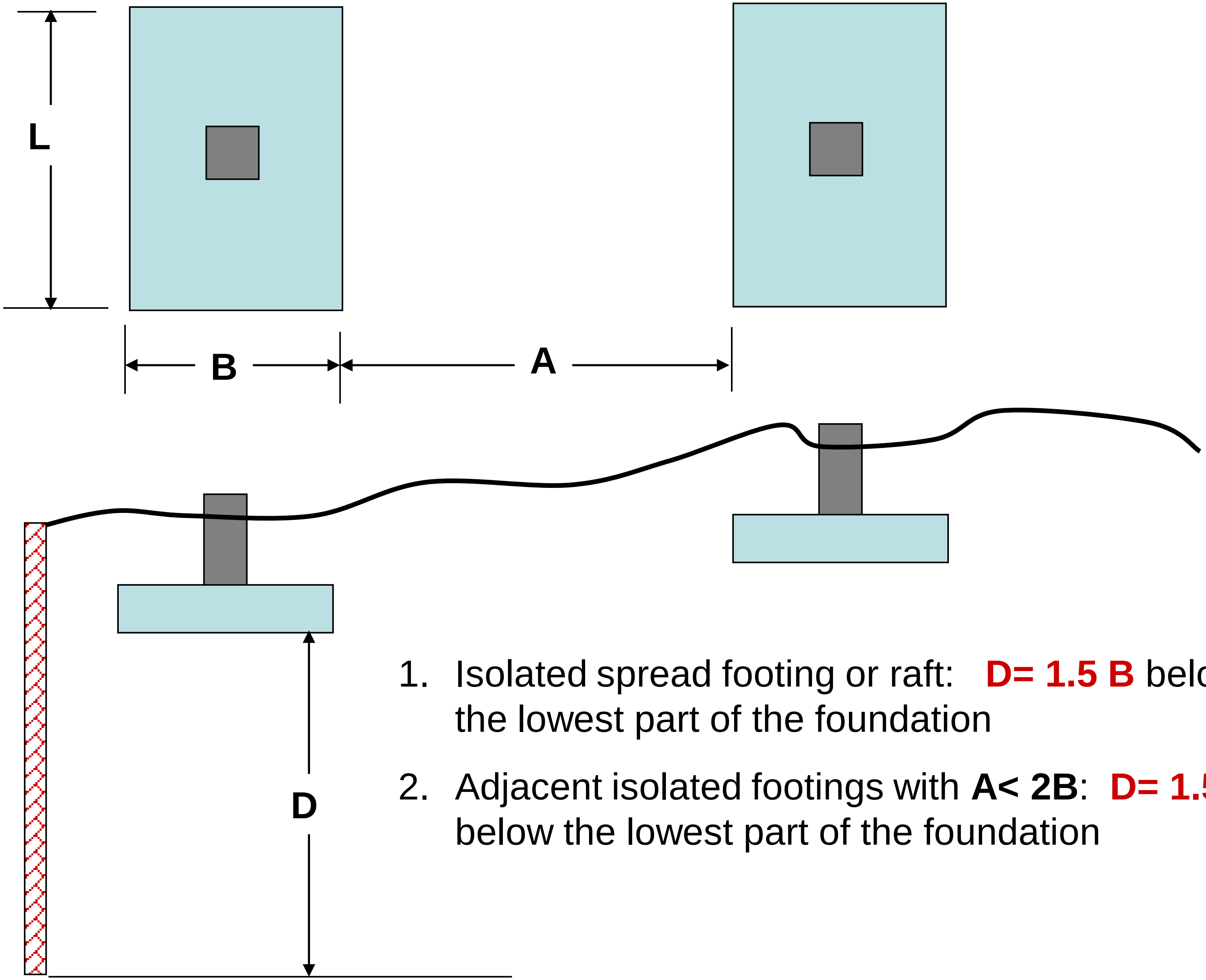
Depth of Borehole/Depth to Investigate



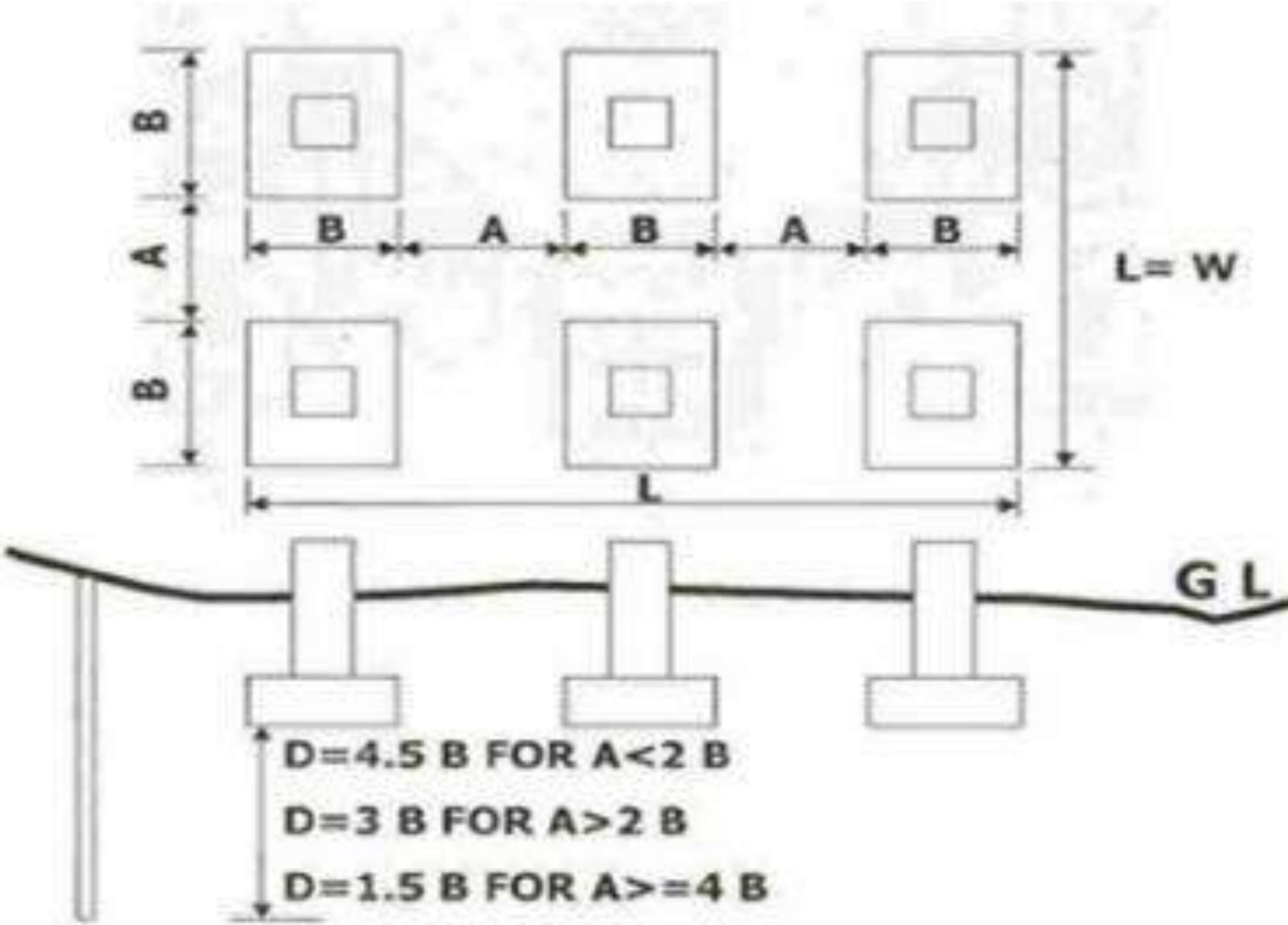
Guidelines for Depth



Depth of borehole for isolated footing

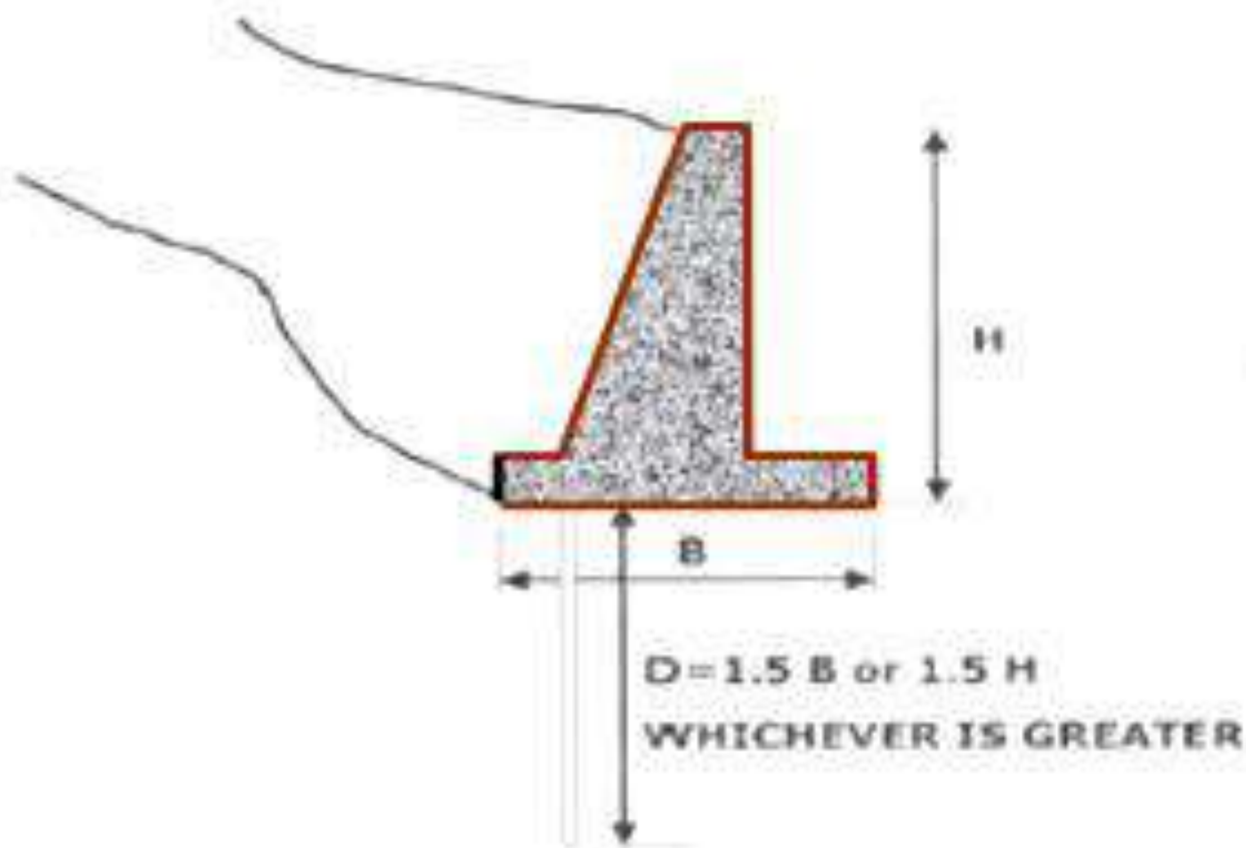


1. Isolated spread footing or raft: **D= 1.5 B** below the lowest part of the foundation
2. Adjacent isolated footings with **A< 2B**: **D= 1.5L** below the lowest part of the foundation



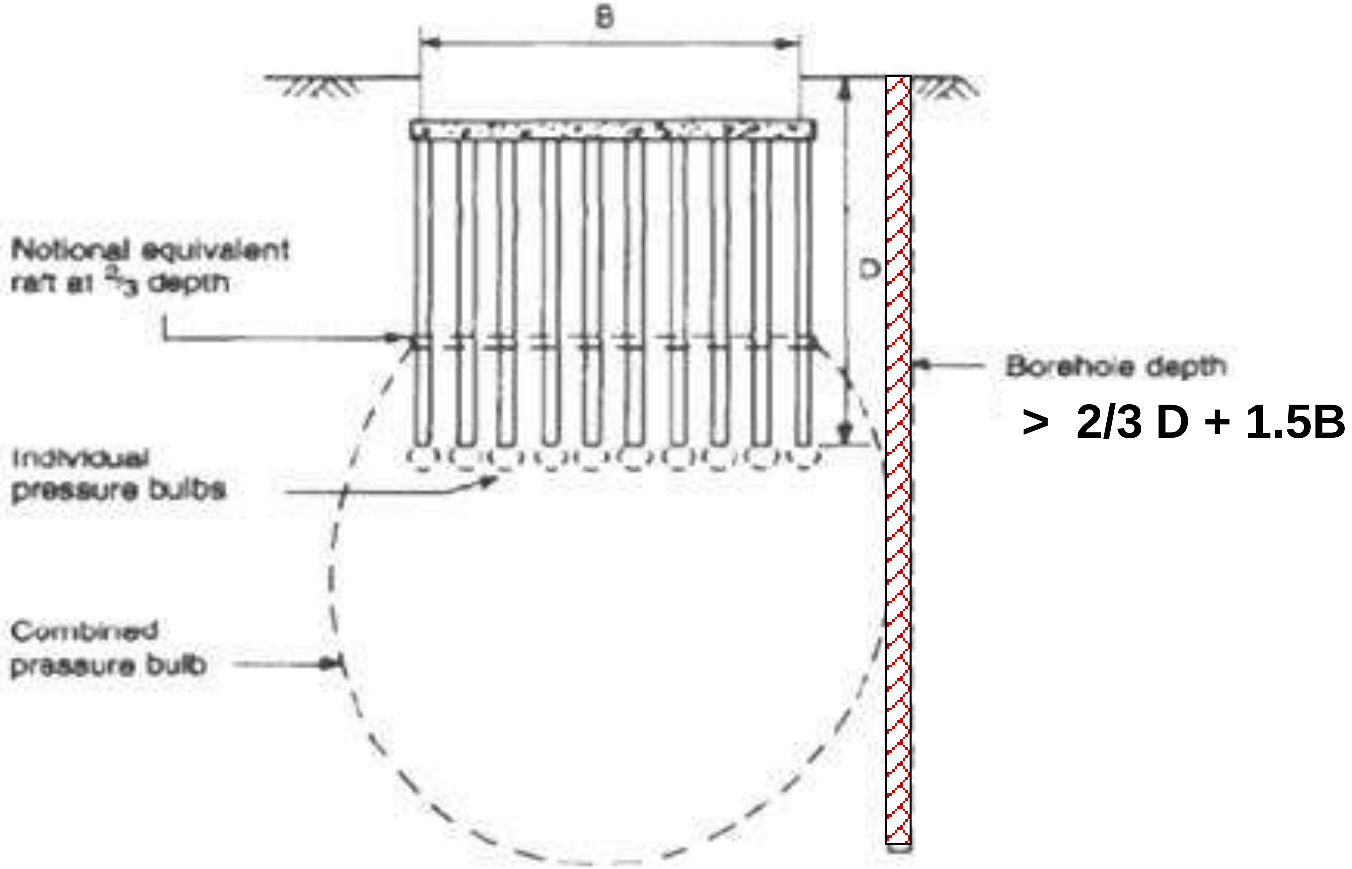
ADJACENT ROWS OF FOOTING

- For retaining walls:
  1.5 times the width or height of retaining wall, whichever is more



RETAINING WALL

Depth to investigate for Large Structure on piles



(c) Large structure on friction piles

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.

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 is 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.

NB: There are many other criteria being used by some engineers. For example, (1) spaced at 2x the least side of the building; (2) a minimum of 10 m spacing, (3) use a minimum of 3 borings, and an average of 5 borings for a typical small building, and increase fo uneven sites. Depths are also determined to where the increase in the stress from the new structure has decreased to less than 10%.

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

Boring Log

Name of the Project Two-story apartment building

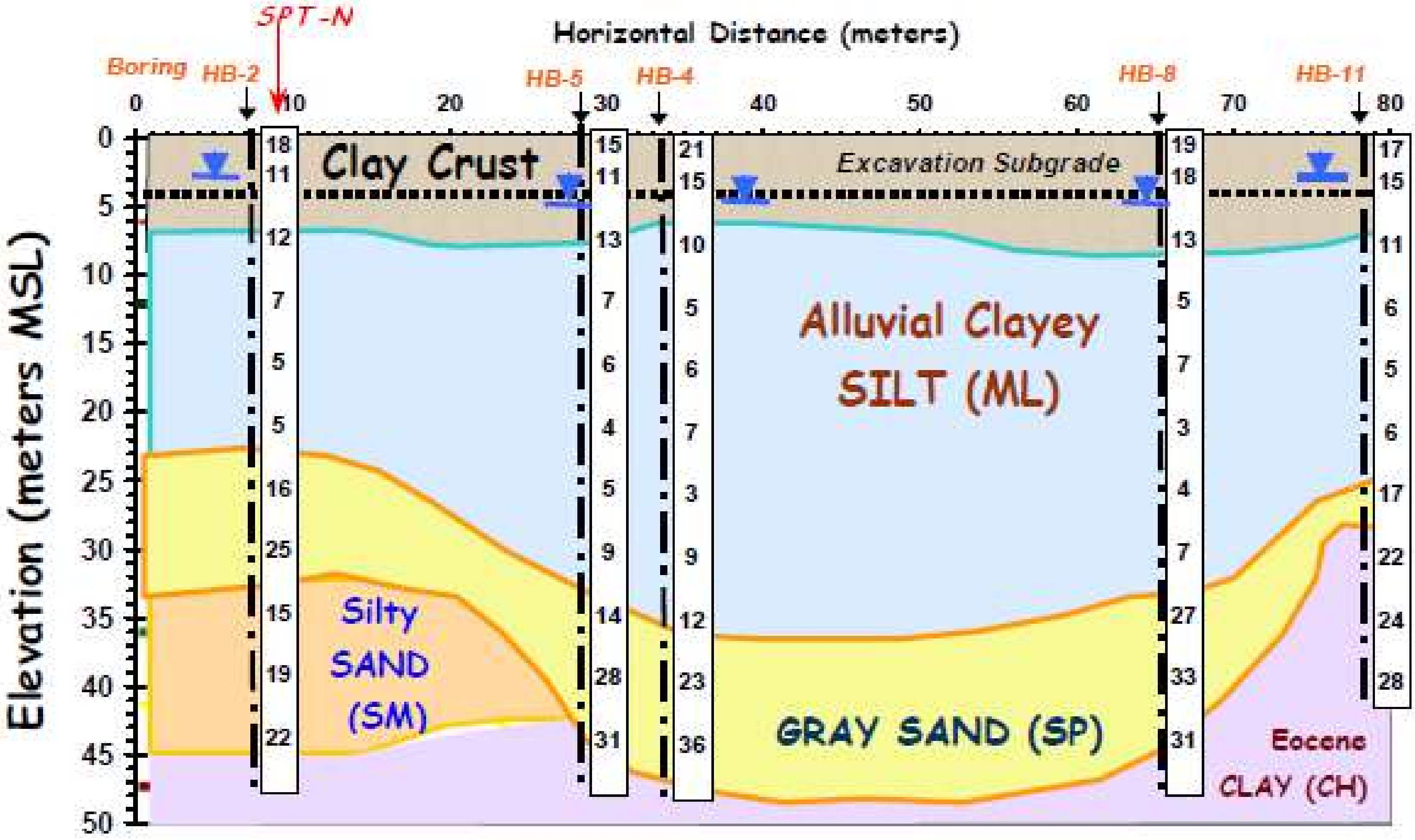
Location Johnson & Olive St. Date of Boring March 2, 1982

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

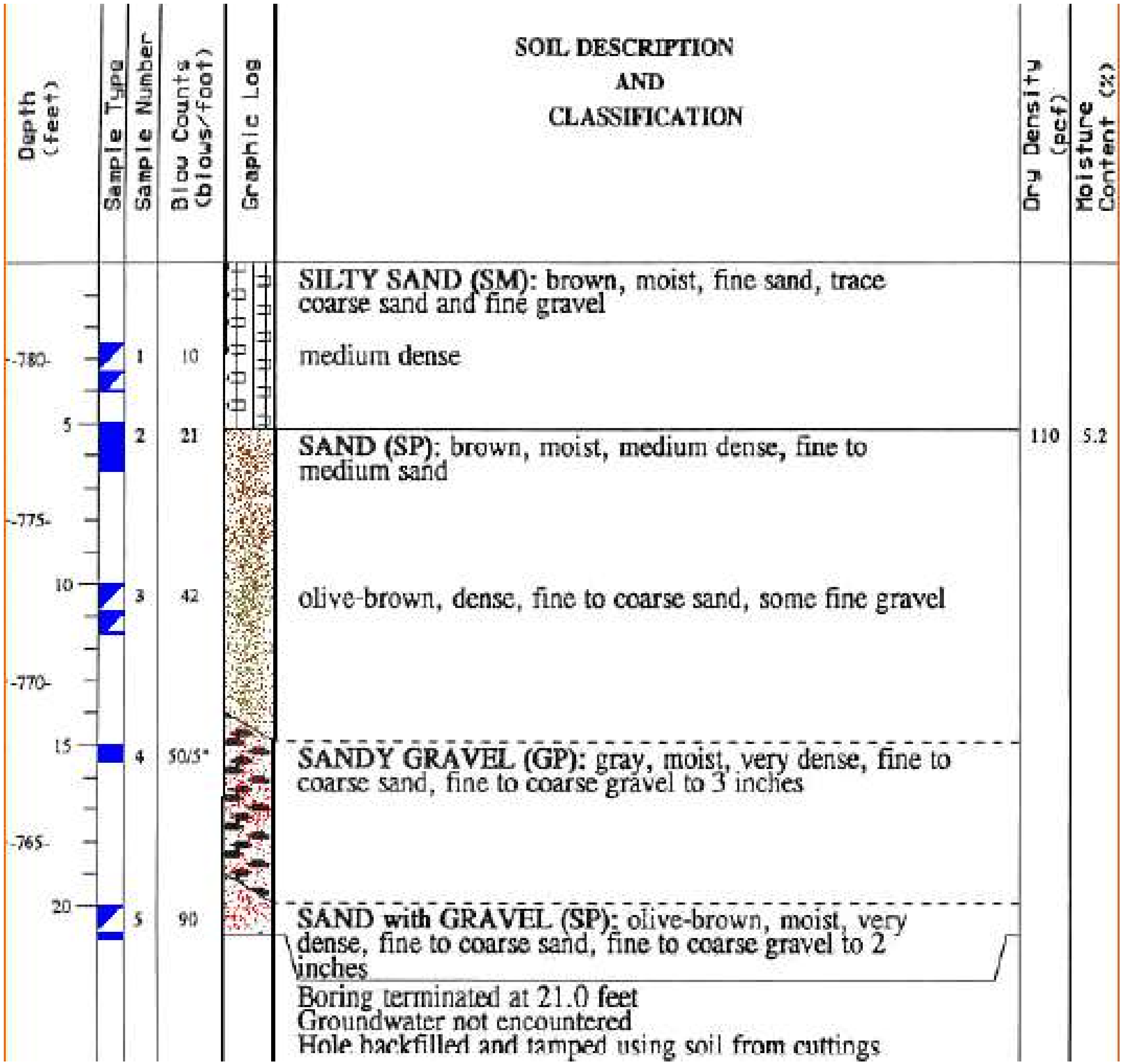
N = standard penetration number (below/304.8 mm)
w_n = natural moisture content
LL = liquid limit; PI = plasticity index
q_u = unconfined compression strength
SS = split-spoon sample; ST = Shelby tube sample

*Ground water table observed after one week of drilling



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.

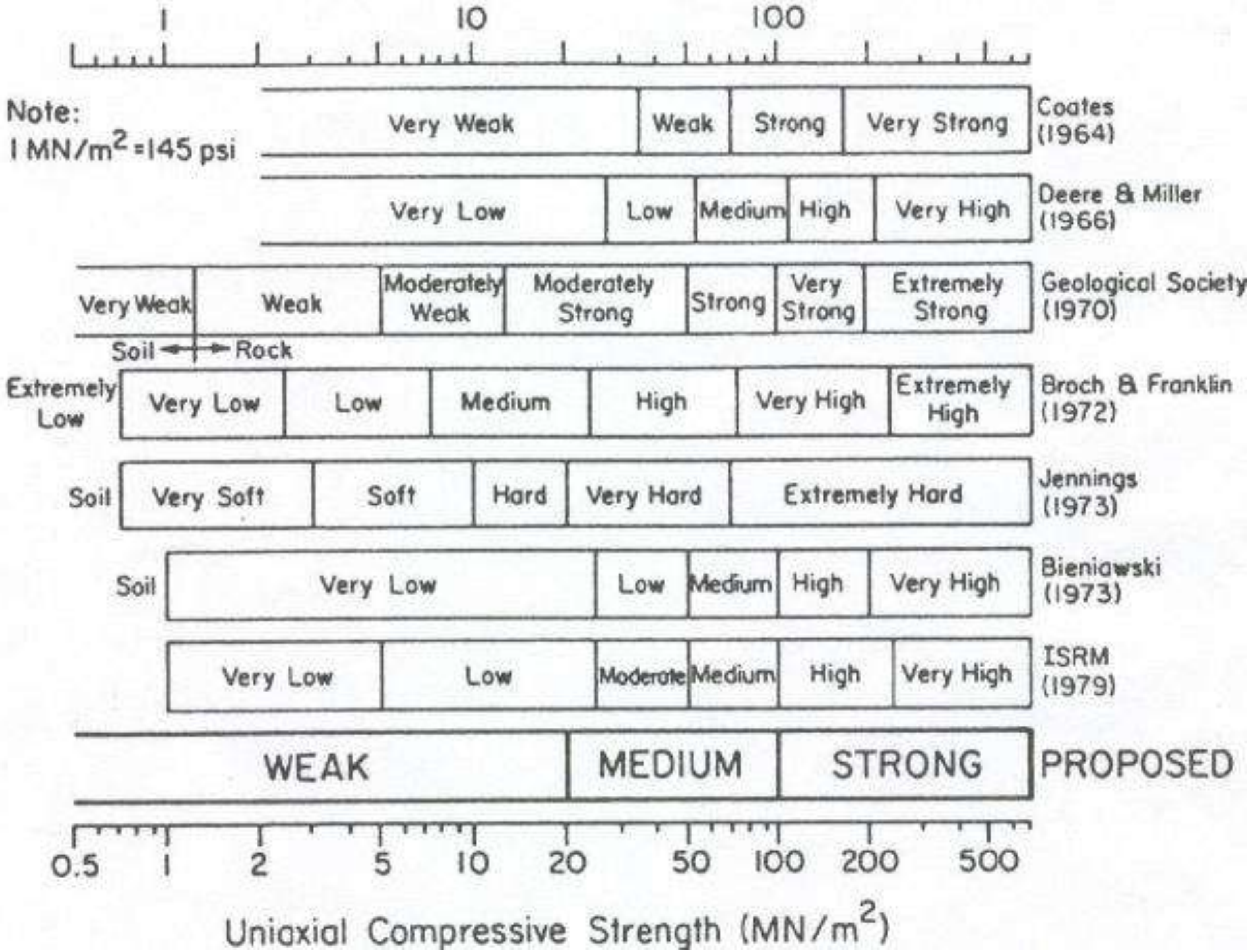


Solution:

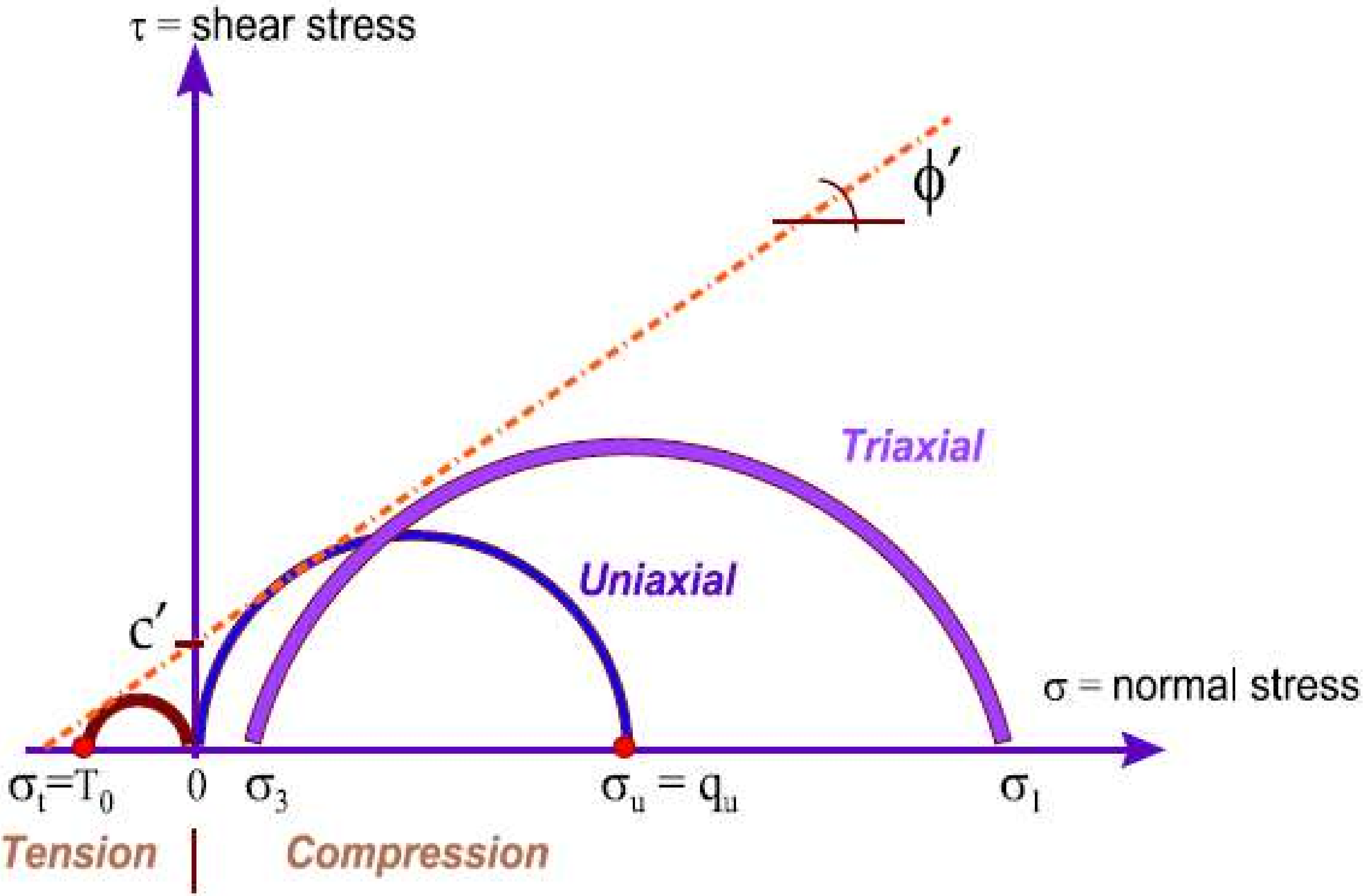
(1) The phreatic surface (the water table) was *not* encountered in this boring and is noted at the bottom of the report;
(2) The boring was terminated at 21 feet in depth; and
(3) Five samples were taken. Only one sample (#2) was used for laboratory tests (dry density and moisture content). Samples #1 and #3 were complete split-spoon samples. Samples #4 and #5 were incomplete split-spoon samples because of the high blow counts.

Primary Rock Types Classified by Geologic Origin

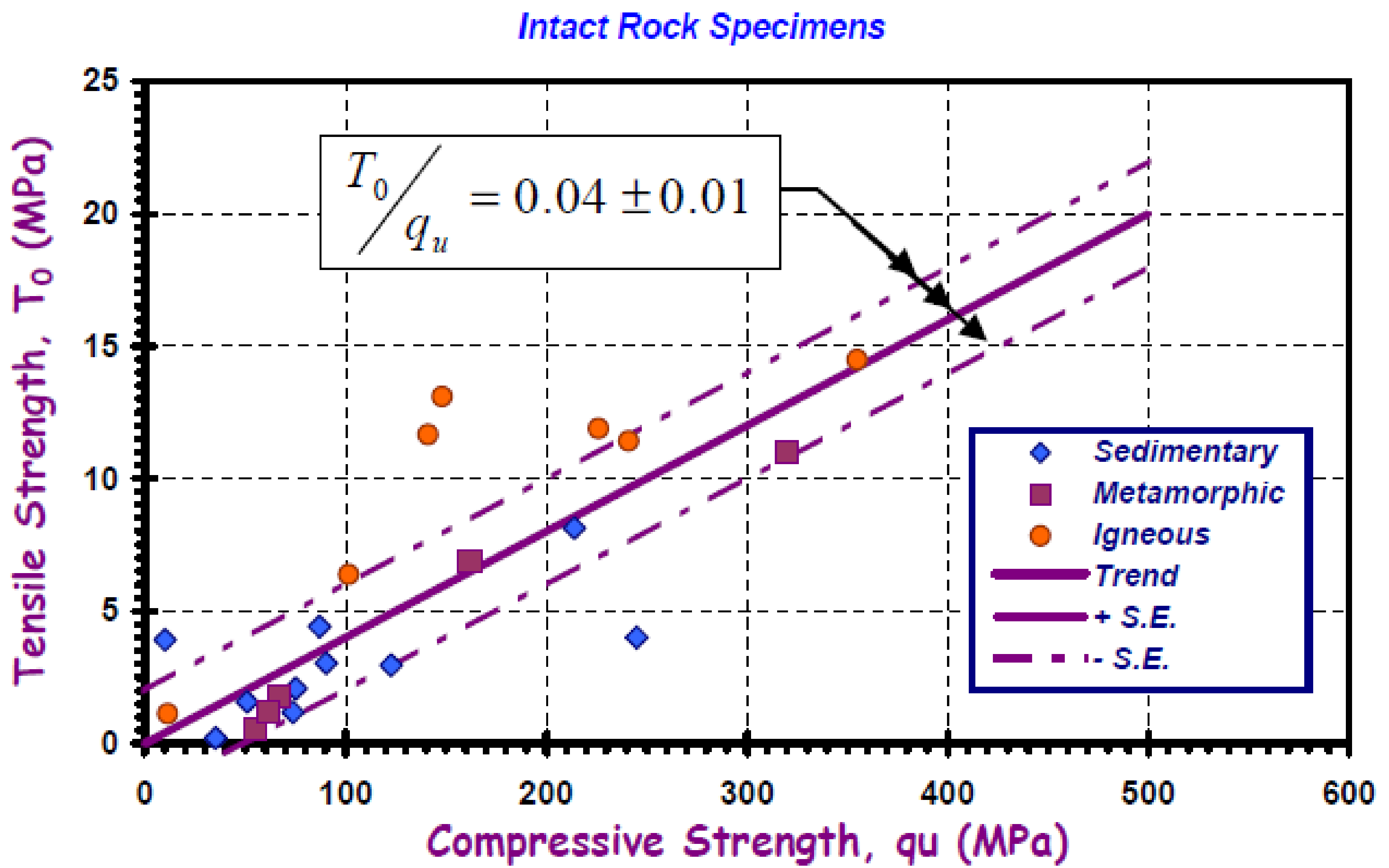
Grains Aspects	Sedimentary Types		Metamorphic Types		Igneous Types	
	Clastic	**Carbonate**	**Foliated**	**Massive**	**Intrusive**	**Extrusive**
Coarse	*Conglomerate Breccia*	*Limestone Conglomerate*	*Gneiss*	*Marble*	*Pegmatiite Granite*	*Volc;anic Breccia*
Medium	*Sandstone Siltstone*	*Limestone Chalk*	*Schist Phyllite*	*Quartzite*	*Diorite Diabase*	*Tuff*
Fine	*Shale Mudstone*	*Calcareous Mudstone*	*Slate*	*Amphibolite*	*Rhyolite*	*Basalt Obsidian*



Classifications for Unweathered Intact Rock Material Strength (Kulhawy, Trautmann, and O'Rourke, 1991 - a comparison of several classification schemes.



Interrelationship Between Uniaxial Compression, Triaxial, and Tensile Strength of Intact Rock in Mohr-Coulomb Diagram.



Comparison of Tensile vs. Compressive Strengths for Intact Rock Specimens.

Operational Shear Strength

The shear strength of rock usually controls in the geotechnical evaluation of slopes, tunnels, excavations, and foundations. As such, the shear strength (τ) of inplace rock often needs to be defined at three distinct levels:

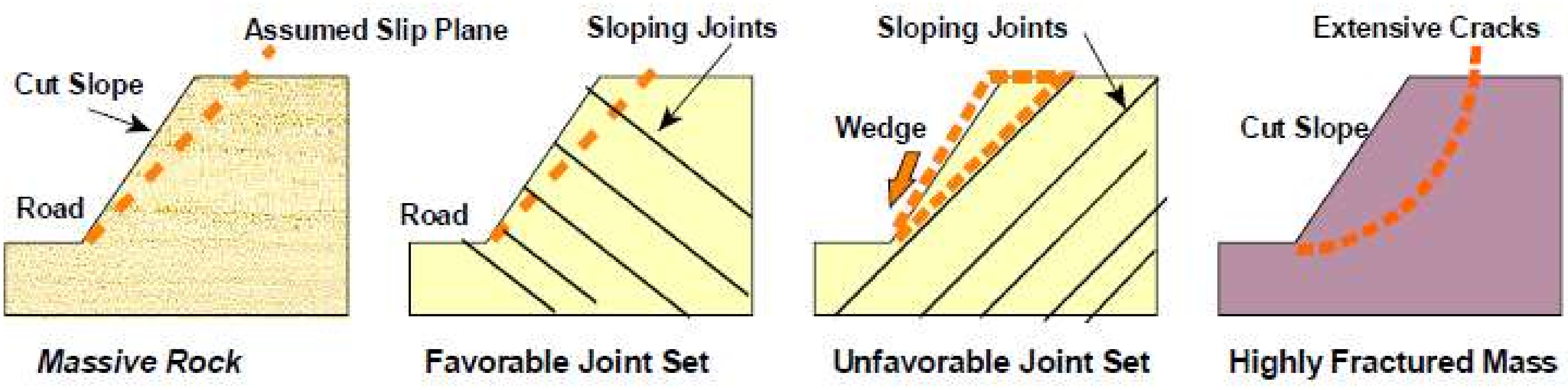
(a) intact rock,

(b) along a rock joint or discontinuity plane, and

(c) representative of an entire fractured rock mass.

In all cases, the shear strength is most commonly determined in terms of the Mohr- Coulomb criterion

$$\tau = c' + \sigma' \tan \phi'$$



Soil and Rock Sampling

- **Number of samples taken depends on the size of the site**
- **Usually sample every 1.5m in depth or at every change in formation**

A selected number of samples are sent to the lab Usually one per soil boring

Soil samples obtained for engineering testing and analysis, in general, are of two main categories:

Disturbed (but representative): are those obtained using equipment that destroy the macro structure of the soil but do not alter its mineralogical composition

Undisturbed: are obtained with specialized equipment designed to minimize the disturbance to the in-situ structure and moisture content of the soils. Specimens obtained by undisturbed sampling methods are used to determine the strength, stratification, permeability, density

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

Split Barrel Sampler

The split-barrel (or split spoon) sampler is used to obtain disturbed samples in all types of soils. The split spoon sampler is typically used in conjunction with the *Standard Penetration Test* (SPT), as specified in AASHTO T206 and ASTM D1586, in which the sampler is driven with a 63.5-kg (140-lb) hammer dropping from a height of 760 mm (30 in).

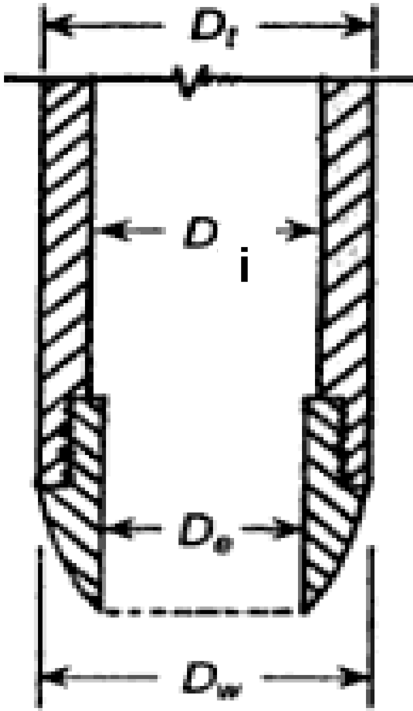
(a) (b)

Split Barrel Sampler: (a) Open sampler with soil sample and cutting shoe; (b) Sample jar, split-spoon, shelby tube, and storage box for transport of jar samples.

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.

$$\textbf{Recovery ratio } L_r = \frac{\text{Recovered length of sample}}{\text{Penetration length of sample}}$$

If :

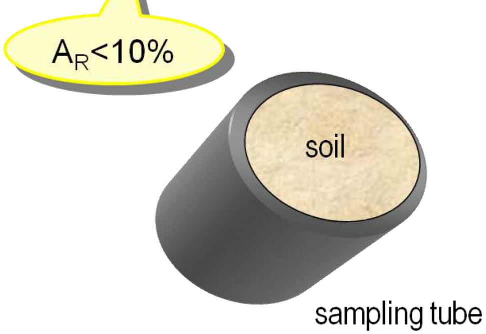
L_r =1 good recovery

$L_r < 1$ soil is compressed

$L_r > 1$ soil has swelled

Disturbed vs Undisturbed

- Good quality samples necessary.

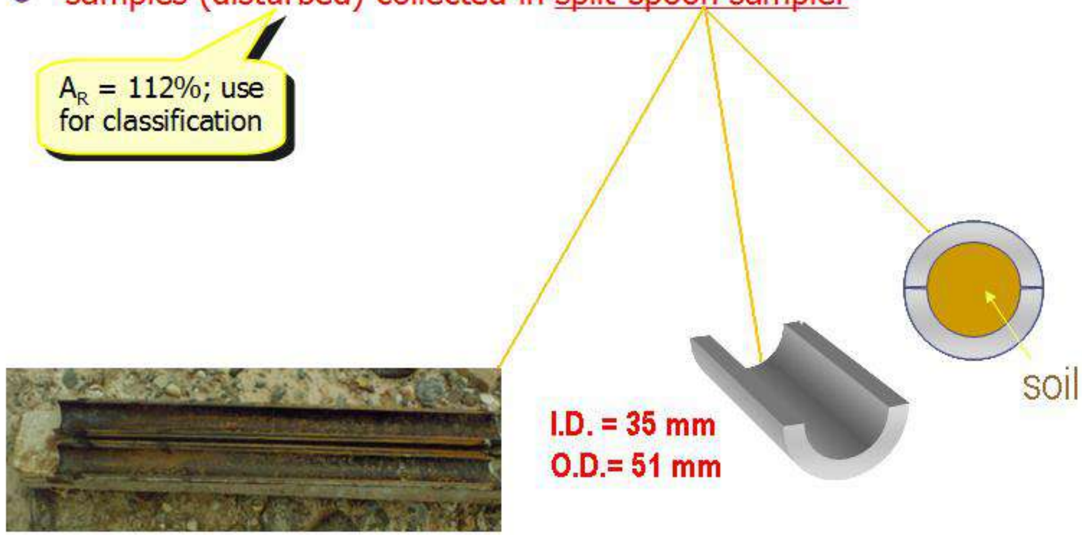


$$A_R = \frac{O.D.^2 - I.D.^2}{I.D.^2} \times 100(\%)$$

area ratio

- Thicker the wall, greater the disturbance.

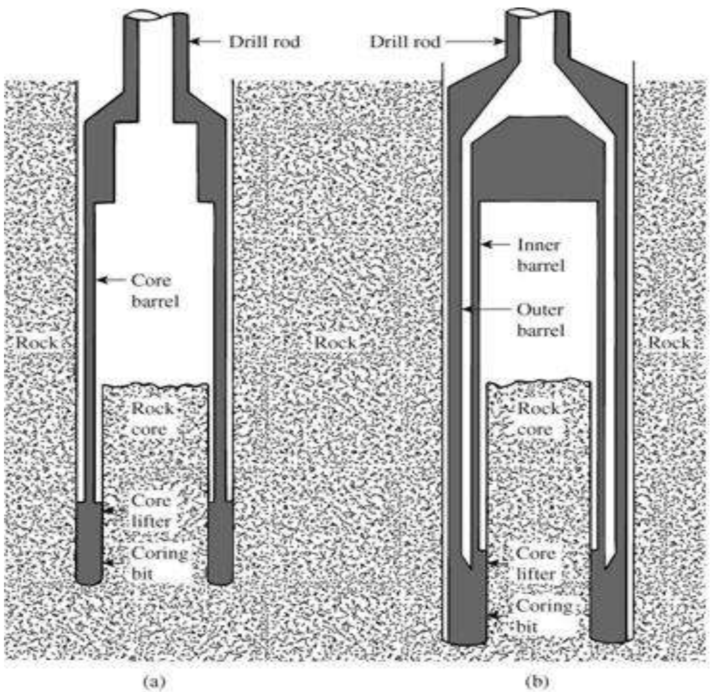
- samples (disturbed) collected in split-spoon sampler



Rock coring

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

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

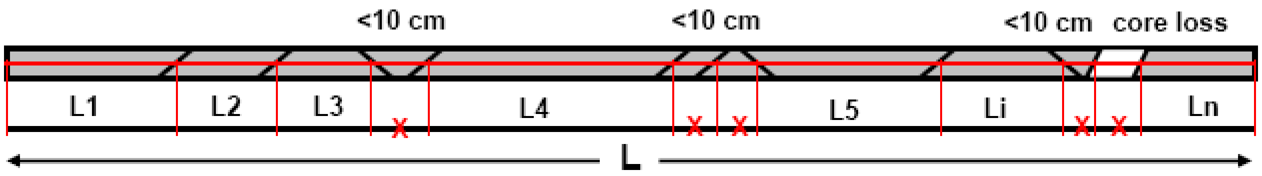


Rock coring: (a) single-tube core barrel; (b) double-tube core barrel

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.

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



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

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

Example 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 %

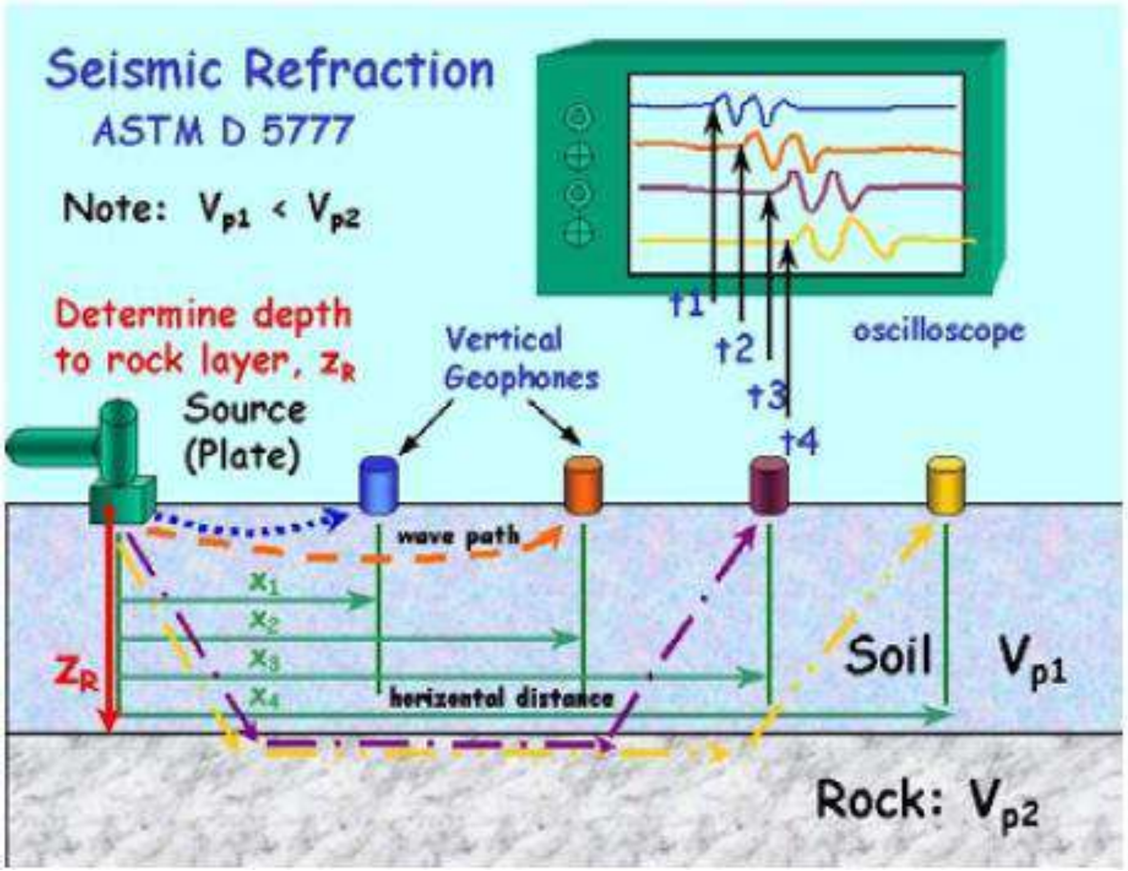
Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	0
7.5	0
10	10
12.5	12.5
7.5	0
10	10
15	15
10	10
5	0
12.5	12.5
125	95

Geophysical Methods: Indirect Site Exploration

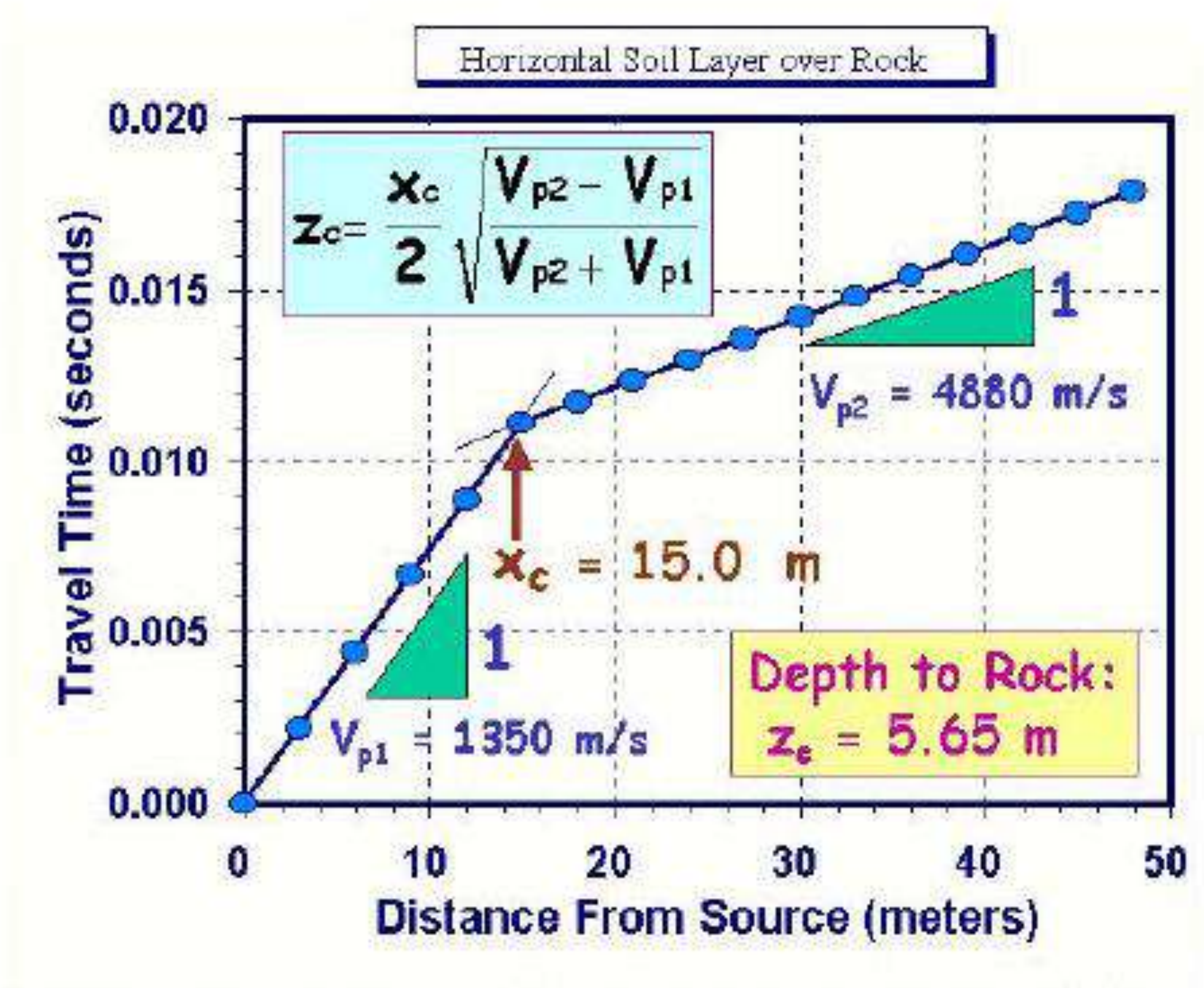
A geophysical exploration may be included in a site investigation for an important engineering project in order to provide subsurface information over a large area at reasonable cost.

used for determining the depth to very hard layers, such as bedrock. The seismic refraction method is performed according to ASTM D 5777 procedures and involves a mapping of V_p arrivals using a linear array of geophones across the site

Seismic Refraction (SR)



Field Setup & Procedures for Seismic Refraction Method



Data Reduction of SR Measurements to Determine Depth to Hard Layer.

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.

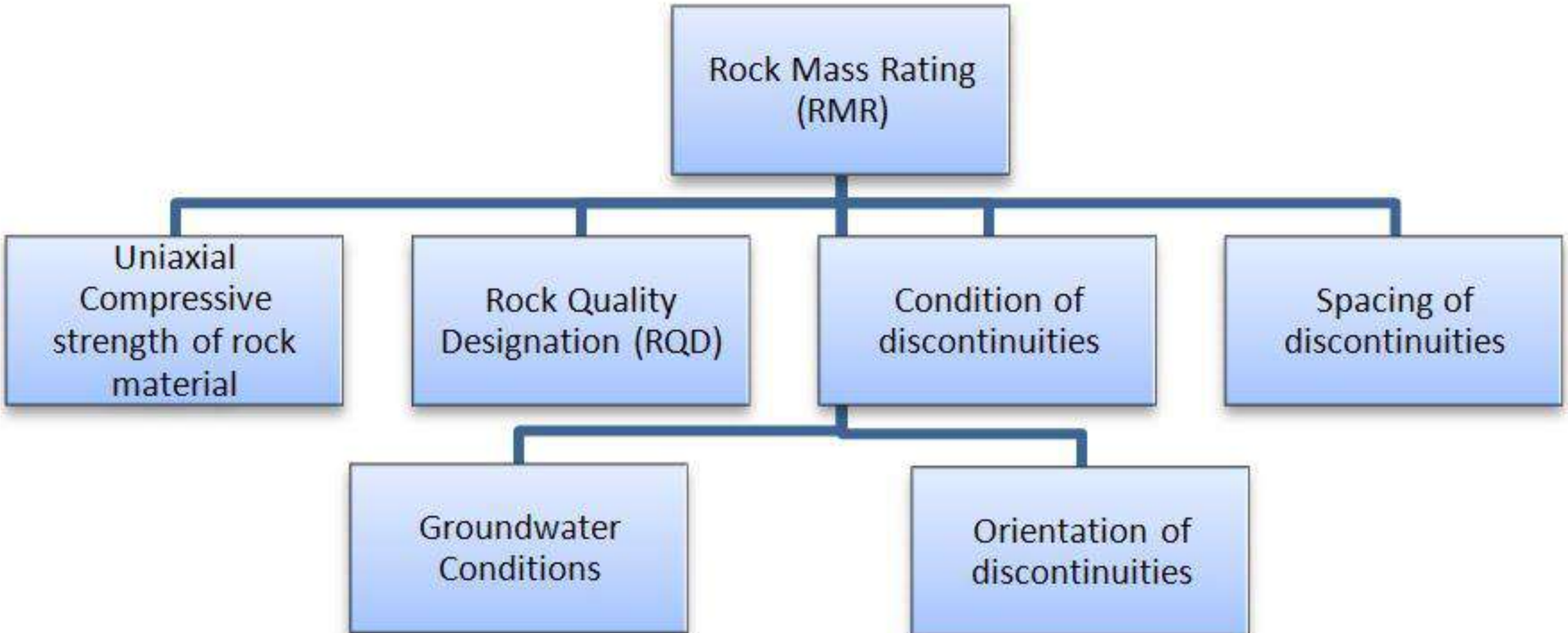
The six parameters used to determine the RMR value are:

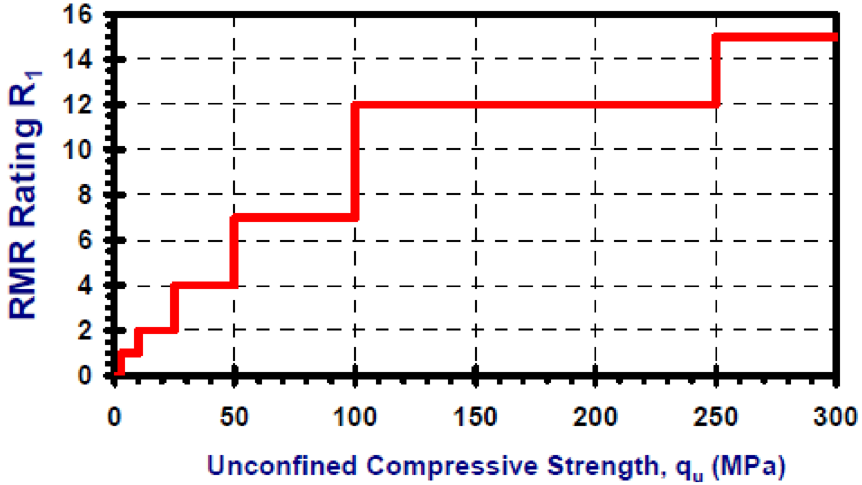
- **Uniaxial compressive strength (σu)*.**
- **Rock Quality Designation (RQD)**
- **Spacing of discontinuities**
- **Condition of discontinuities**
- **Groundwater conditions**
- **Orientation of discontinuities**

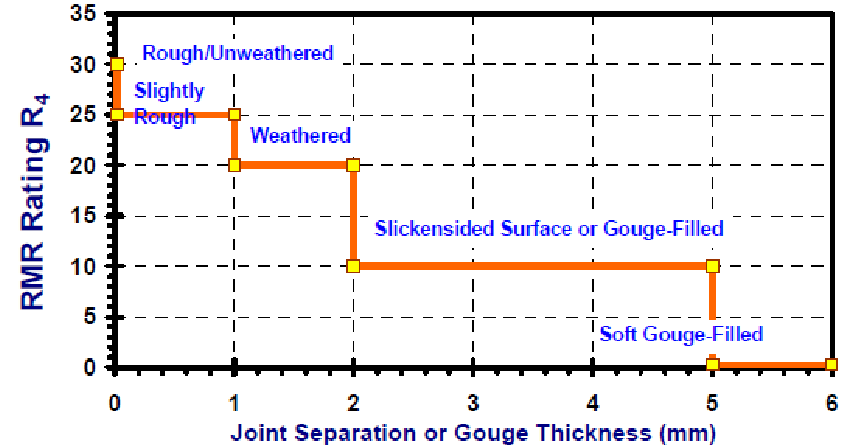
***Note: Value may be estimated from point load index (Is).**

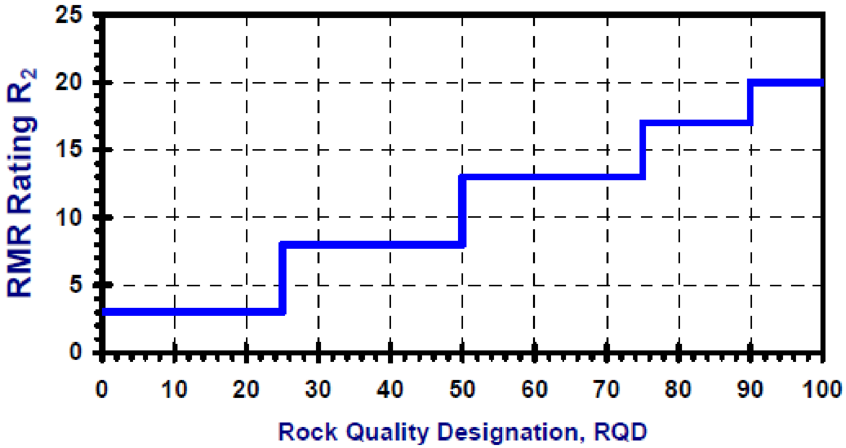
The rating is obtained by summing the values assigned for the first five components

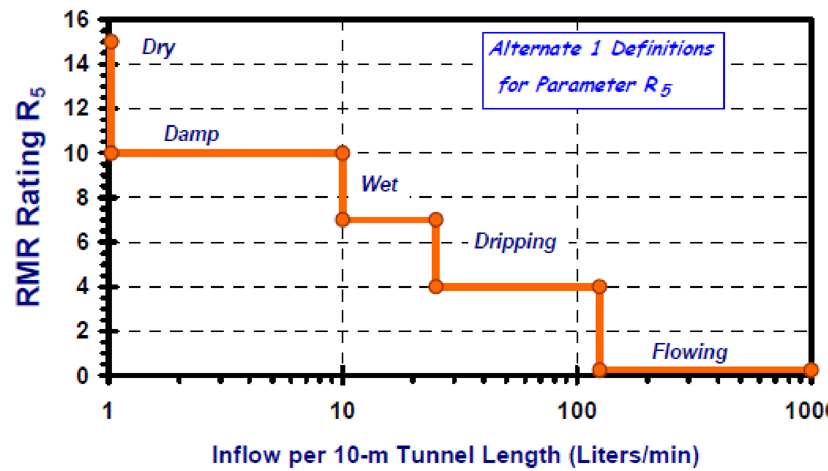
$$RMR = \sum_{i=1}^{5} (R_i)$$

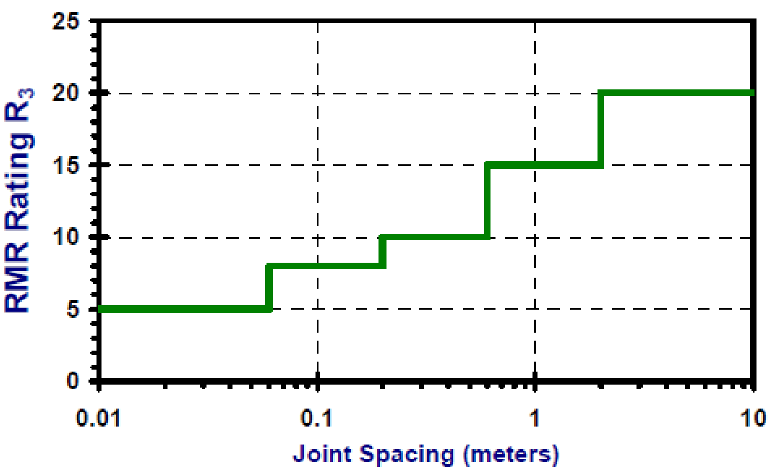

Rock Mass Rating (RMR)
Uniaxial Compressive strength of rock material
Rock Quality Designation (RQD)
Condition of discontinuities
Spacing of discontinuities
Groundwater Conditions
Orientation of discontinuities

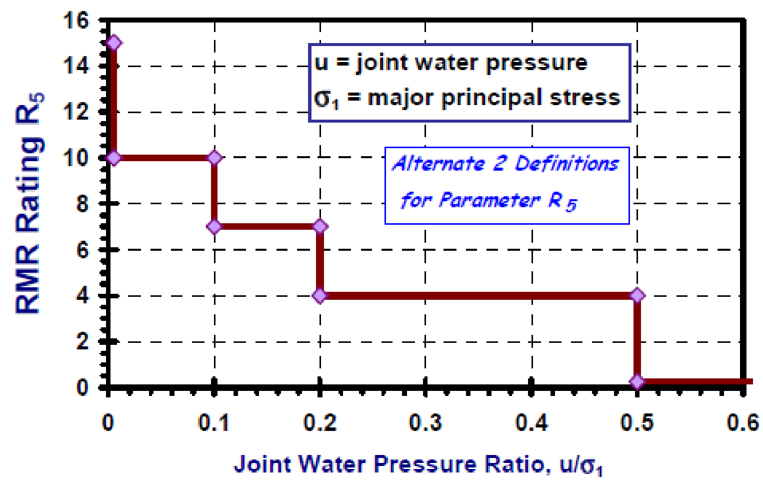

RMR Rating R_1
Unconfined Compressive Strength, q_u (MPa)


RMR Rating R_4
Rough/Unweathered
Slightly Rough
Weathered
Slickensided Surface or Gouge-Filled
Soft Gouge-Filled
Joint Separation or Gouge Thickness (mm)


RMR Rating R_2
Rock Quality Designation, RQD


RMR Rating R_5
Dry
Damp
Wet
Dripping
Flowing
Alternate 1 Definitions for Parameter R_5
Inflow per 10-m Tunnel Length (Liters/min)


RMR Rating R_3
Joint Spacing (meters)


RMR Rating R_5
u = joint water pressure
σ_1 = major principal stress
Alternate 2 Definitions for Parameter R_5
Joint Water Pressure Ratio, u/σ_1

The Geomechanics Classification System for Rock Mass Rating (RMR)

Geomechanics System - (Bieniawski, 1984, 1989)

Geomechanics Classification for Rock Masses				
CLASS	DESCRIPTION	RANGE of RMR		
I	Very Good Rock	81	to	100
II	Good Rock	61	to	80
III	Fair Rock	41	to	60
IV	Poor Rock	21	to	40
V	Very Poor Rock	0	to	20

Laboratory Testing and Reports.

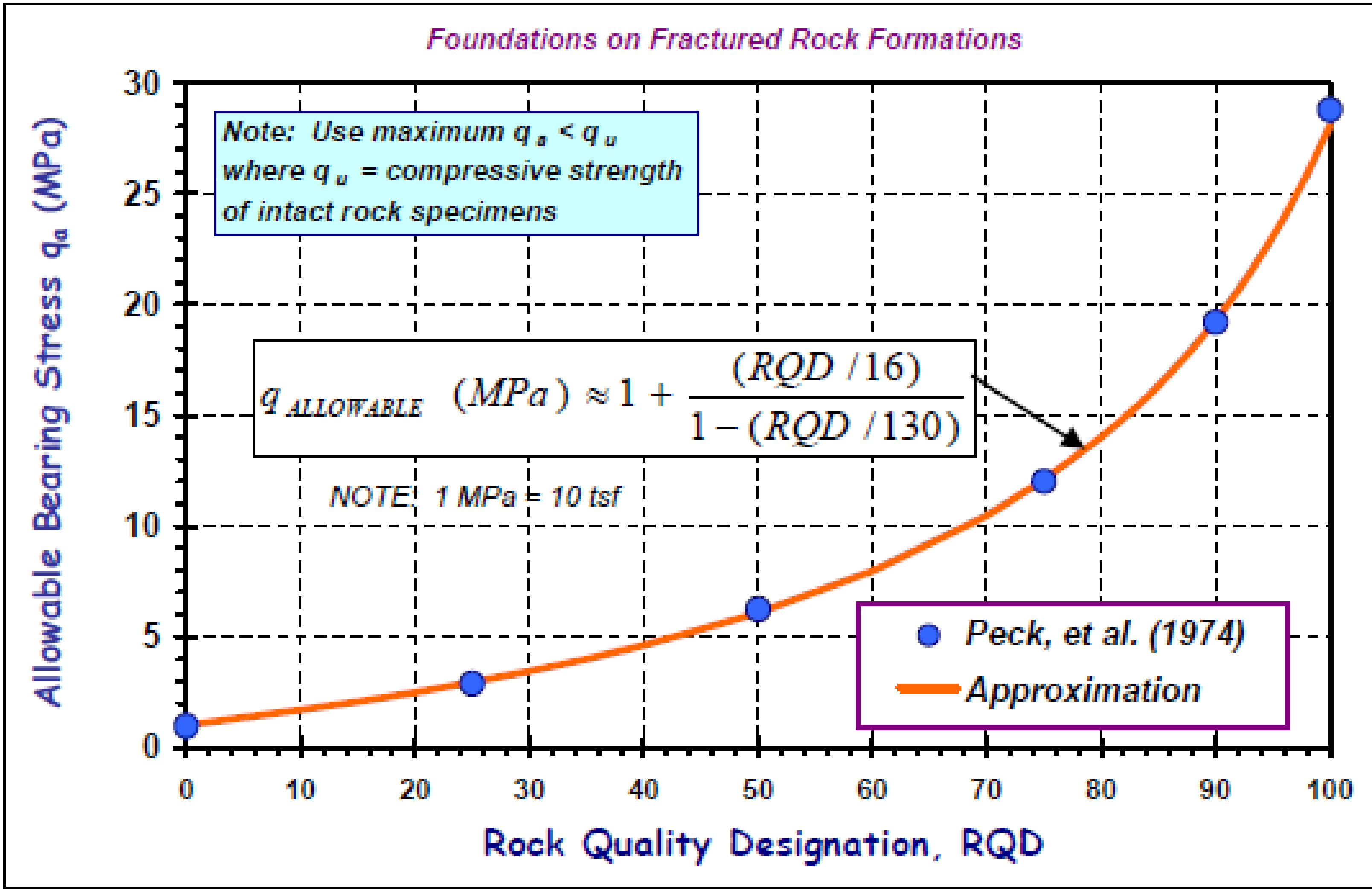
The samples are taken to the laboratory to calculate:

bearing capacities,
settlements.

Material	Assumed Bearing Capacity
Hard, sound rock	100 tons/sq ft
Soft rock, hard pan	12 tons/sq ft
Very compact sandy gravel	10 tons/sq ft
Compact sandy gravel; very compact clay, sand and gravel; very compact coarse or medium sand	6 tons/sq ft
Firm sandy gravel; compact coarse or medium sand	5 tons/sq ft
Loose sand gravel; firm coarse or medium sand	4 tons/sq ft
Loose coarse or medium sand; compact fine sand; stiff clay	3 tons/sq ft
Firm fine sand; firm sand-clay soils	2 tons/sq ft
Loose fine sand; firm inorganic silt	1.5 tons/sq ft
Loose sand clay; inorganic silt; soft clay	1 ton/sq ft

The effect of fracture intensity on bearing capacity can be estimated from the RQD of drill core as follows (Peck *et al.,* 1974):

RQD **>90%**	**no reduction**
50%, < *RQD* < 90%	**reduce bearing pressure by factor of about 0.25–0.7**
RQD **< 50%**	**reduce bearing pressure by a factor of about 0.25–0.1**
reduce bearing pressure further if extensive clay seams present.	



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

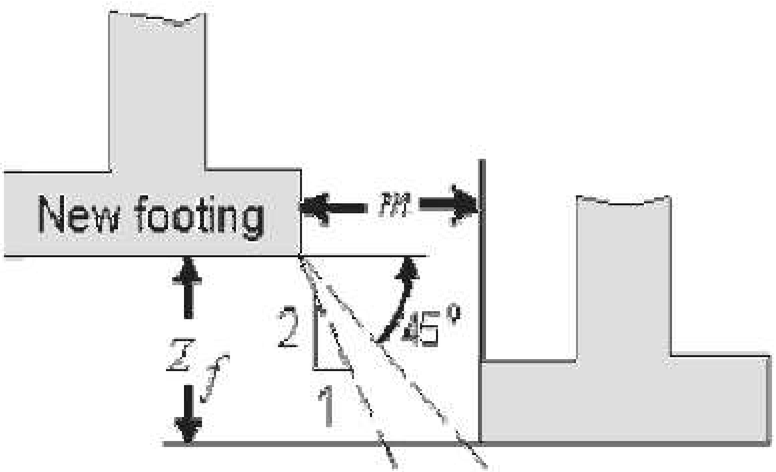
Reporting

Upon completion of the field investigation and laboratory testing program, the geotechnical engineer will compile, evaluate, and interpret the data and perform engineering analyses for the design of foundations, cuts, embankments, and other required facilities

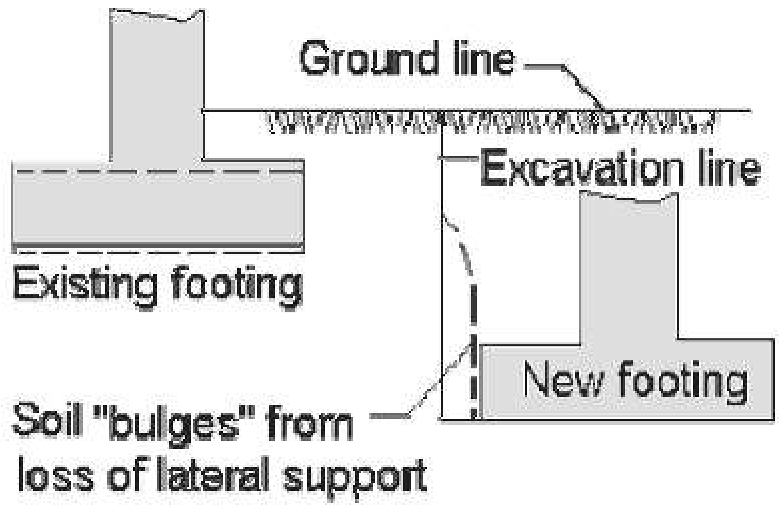
The Geotechnical Report should include the following:

- Scope and Purpose
- Proposed Development
- Field Exploration
- Groundwater Monitoring
- Laboratory Testing
- Analysis of Subsurface Conditions
- Design Recommendations
  - Grading
  - Foundations
  - Retaining walls
  - Pavements
- Closure
- Appendix A - Boring Logs
- Appendix B - Laboratory Test Results
- Appendix C - Recommended Construction Specifications

Spacing: The Report must include future conflicts with adjacent structures.



a) New footing is higher than existing footing.



b) New footing is lower than existing footing.

Ground Improvement Methods

Grouting

Grouting involves injection of an aqueous suspension of solids (commonly cement-based) in the form of slurry or a uniform chemical mixture under pressure into the ground through drill holes or pipes to seal all weak zones in the formations. The injected grout hardens with time.

Grouting is under taken to :

1. Improve the strength and bearing capacity of the formation
2. Block seepage by reducing the permeability of rock and soil formations
3. Completely fill underground openings such as solution cavities
4. Fill shear zones with crushed material making the entire material as a single solid entity effectively tied with the surrounding solid rock.
5. Raise and re-level structures and foundation elements that have settled uniformly or otherwise
6. Augment pile capacity and pile repair

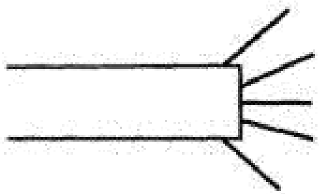


Fig. 6.20 Grouting in tunnel advance.

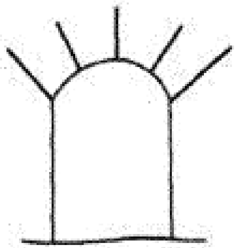


Fig. 6.21 Grouting on tunnel linings.

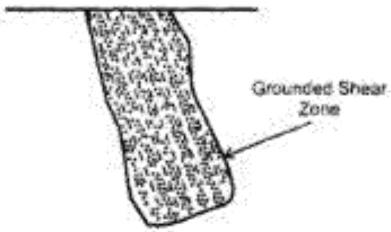


Fig. 6.22 Grout-fill in excavated shear zones.

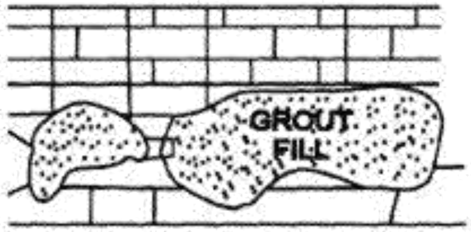


Fig. 6.23 Grout filling in solution cavities in limestone.

Soil stabilization

This is commonly adopted in the case of expansive soils to improve strength as also to reduce swelling and shrinkage. In some instances, it is also resorted for stabilizing loose alluvial soils. The process involves mixing admixtures into the soil and compacting the soil at optimum moisture conditions. If the additive is only to improve the density of the soil and does not react with the soil, the process is known as mechanical stabilization.

If the admixtures chemically interact with the soil ingredients (the granular and colloidal fractions), the process is designated as chemical stabilization. The main intention in this case is to achieve artificial cementation in the soil mass, thus improving the strength and reducing swelling, shrinkage and permeability of the soil. The mixing has to be effective and the process of hardening is time-sensitive. During ageing period, pozollanic reactions in the soil-additive system result in the formation of strength-imparting reaction products. Additives commonly added include portland cement, flyash, lime, blast furnace slag and rice-husk ash. Lime, being of low-cost and reactive, is the most common additive. Lime raises the pH of the soil-additive system. Under the enhanced pH of the system, the soil minerals decompose resulting in the dissolution of silica. In the hydrated soil-lime system, the Ca of lime reacts with the silica and alumina to form calcium silicate hydrate and calcium aluminate hydrate phases as products on ageing with time. Just as in the case of cement on hydration, in the lime-stabilized soil the calcium silicate hydrate that forms with long-term ageing is the main strength-imparting pozzolanic product. In the hydrated cement it is tobermorite (a particular calcium silicate hydrate phase). However, compared to the reaction in the hydrated cement, the rate of reaction in soil-lime system is relatively very slow and the quantity of the product is also less.

Engineering Geology

Engineering Geology is backbone of civil engineering

8. Mass movements

Eng. Iqbal Marie

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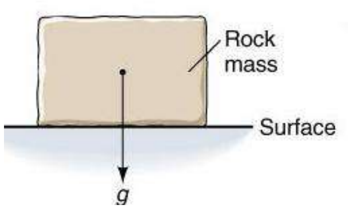
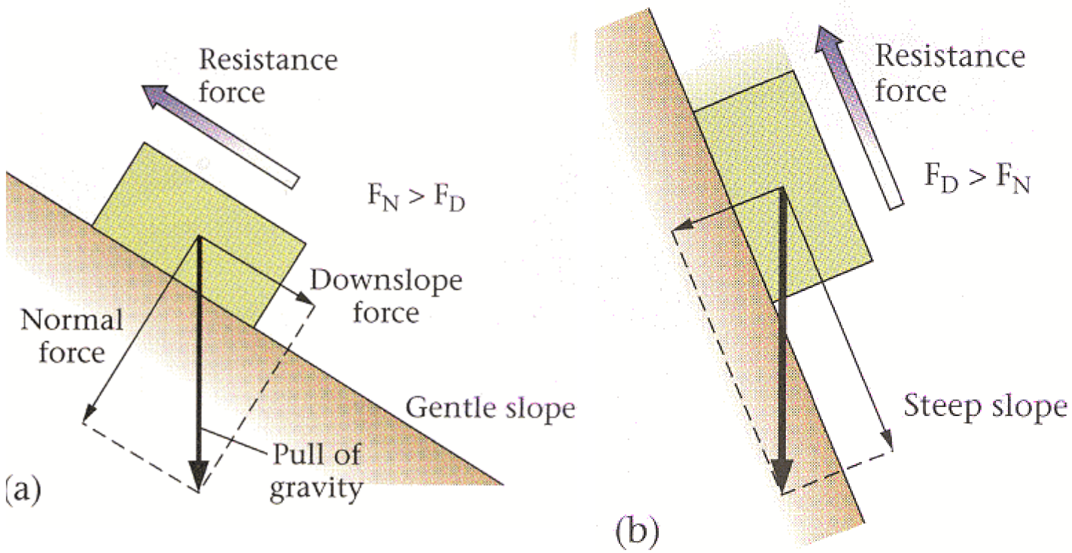
Mass-Wasting is the down slope movement of rock and regolith near the Earth's surface mainly due to the force of gravity. It is an important part of the erosional process, as it moves material from higher elevations to lower elevations where transporting agents like streams and glaciers can then pick up the material and move it to even lower elevations.

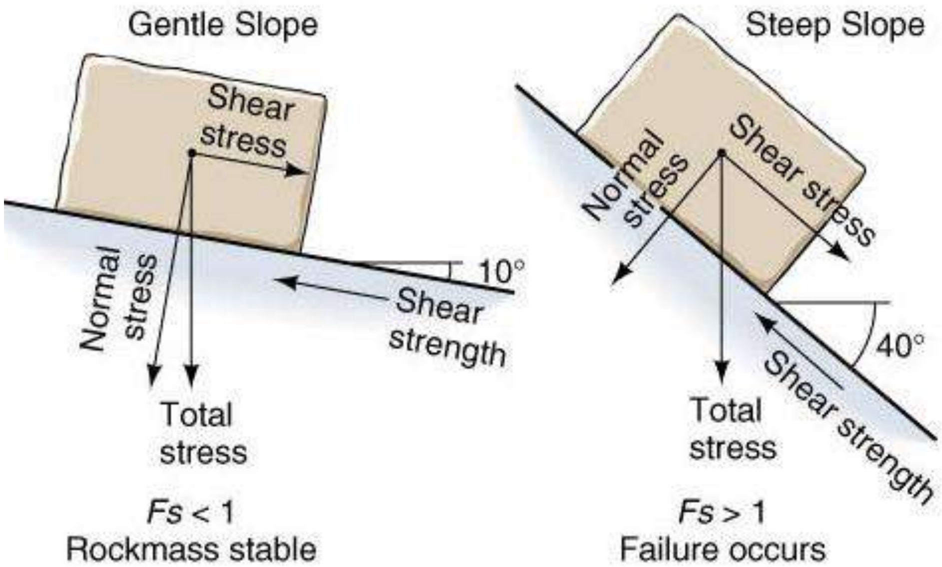
Mass-wasting processes are occurring continuously on all slopes; some act very slowly, others occur very suddenly, often with disastrous results.





Mass movement Agents

- Gravity
- Running water
- Glacial ice
- Wind
- Wave action (shorelines)
- Strong ground shaking (earthquakes, tsunamis)



Safety Factor

$$S.F. = \frac{\Sigma \text{ resisting forces}}{\Sigma \text{ Driving Forces}}$$

If S.F.<1 then failure occurs

S.F.>1 then Stable

- **Resisting Forces**
  - Friction and Cohesion of Soil or Rock
  - $F_f = \mu (W \cos \theta)$

    μ: coefficient of static friction

- **Driving Forces**

  i.e., Shear Force

  - $F_s = W \sin \theta$

    F_s: Shear force

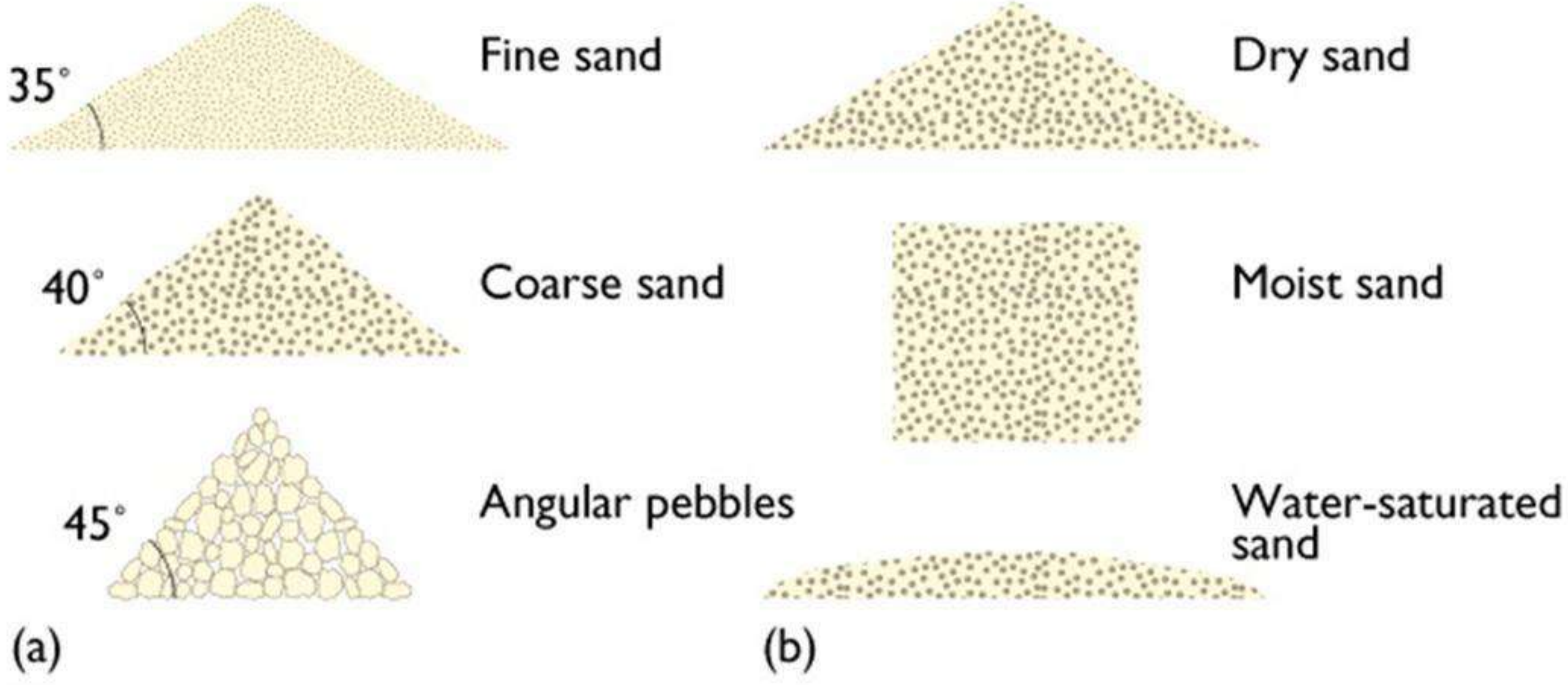
    W: Weight

    θ : Dip of slope

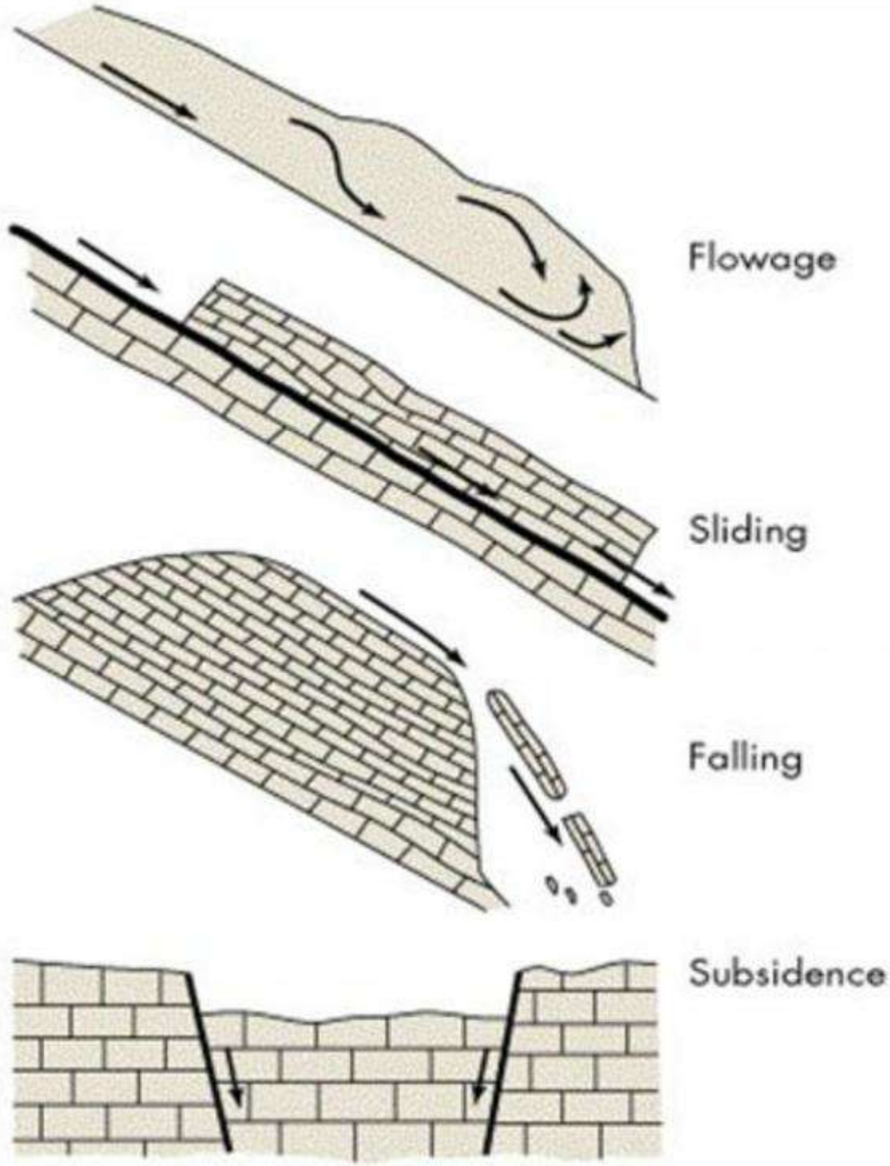
Angle of Repose

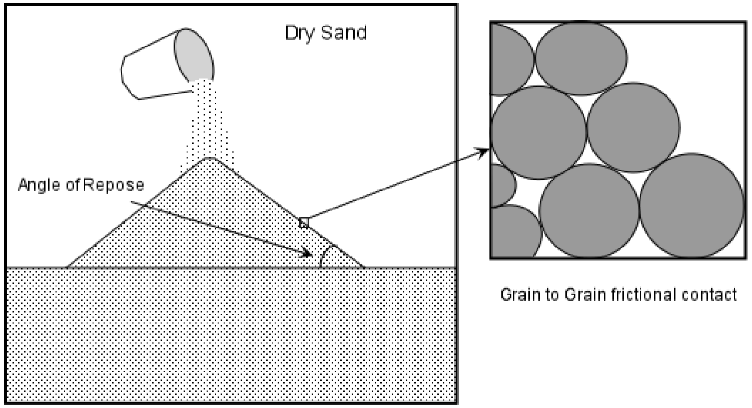
Function of

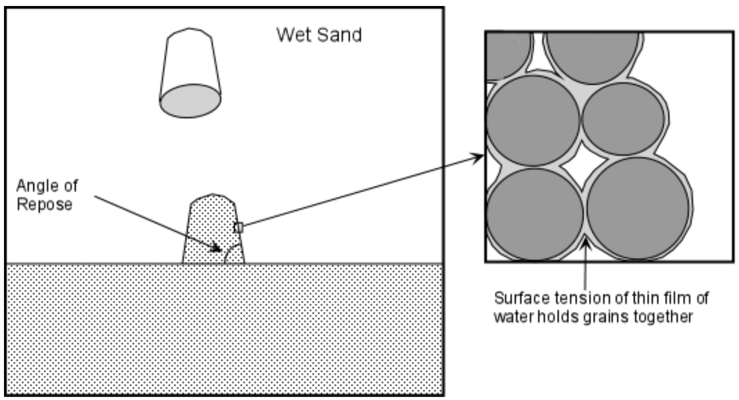
- Particle size
- Particle shape
- Moisture Content

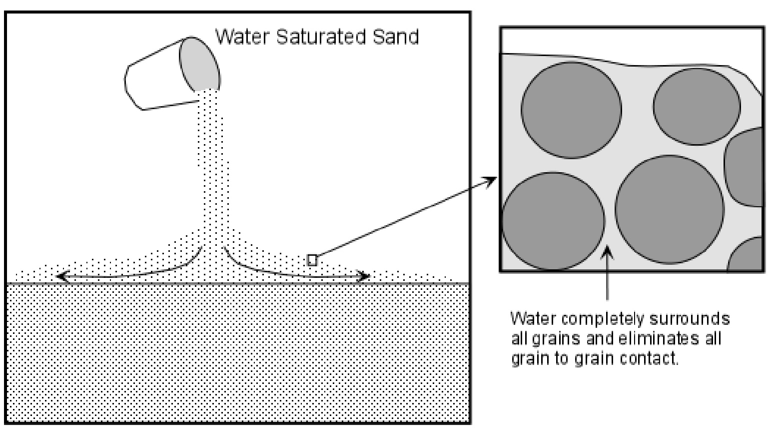


Types of Mass Movement









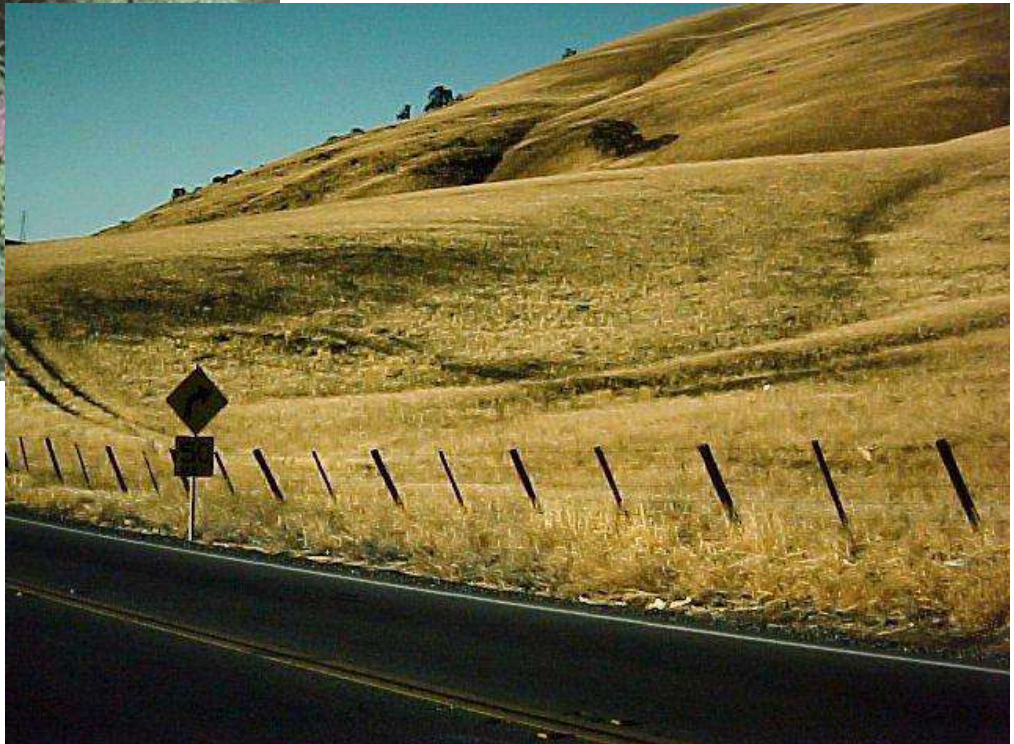
- Important factors include:
  - The role of water
    - Diminishes particle cohesion (friction)
    - Water adds weight
  - Oversteepening of slopes—slope angle
    - Stable slope angle (**angle of repose**) is different for various materials
    - Oversteepened slopes are unstable

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**

- **Slope failure** is the collapse of rock or sediment mass.
- Three major types of slope failure:
  - Slumps.
  - Falls.
  - Slides.

Flow- Soil Creep



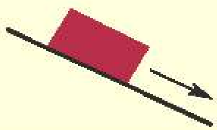
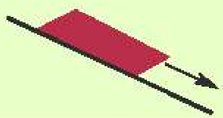
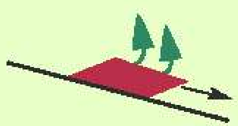
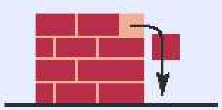
Rockfalls,

21/06/2013

السوسنة ـ توفى شاب يبلغ من العمر (22) عاماً أثناء قيامة بالحفر تحت صخرة يبلغ وزنها (طن ونصف) الأمر الذي أدى الى سقوطها عليه في منطقة بدر وادي الذهب .

وتحركت فرق الإنقاذ والإسعاف في مديرية دفاع مدني غرب عمان وقامت بسحب الوفاة وإخلائه الى مستشفى البشير الحكومي

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

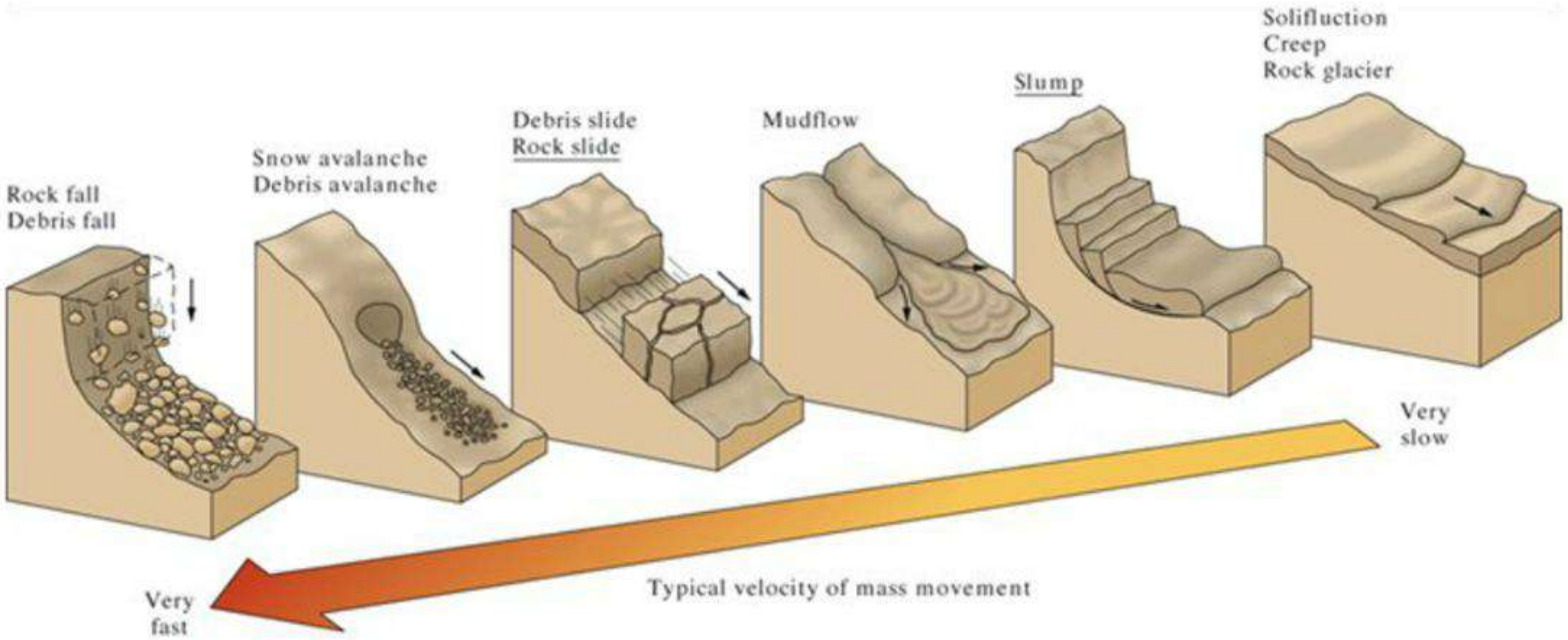
MECHANISM		MATERIAL: Rock	MATERIAL: Fine-grained Soil	MATERIAL: Coarse-grained Soil	VELOCITY
SLIDE		Slump	Earth slump	Debris slump	Slow
		Block glide	Earth slide	Debris slide	Rapid
FLOW		Rock avalanche	Mudflow, avalanche	Debris flow, avalanche	Very Rapid
		Creep	Creep	Creep	Extremely slow
FALL		Rockfall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

– The down slope flow of mixtures of solid material, water, and air are distinguished on the basis of :

- **Velocity.**
- **The concentration of particles in the flowing mixture.**

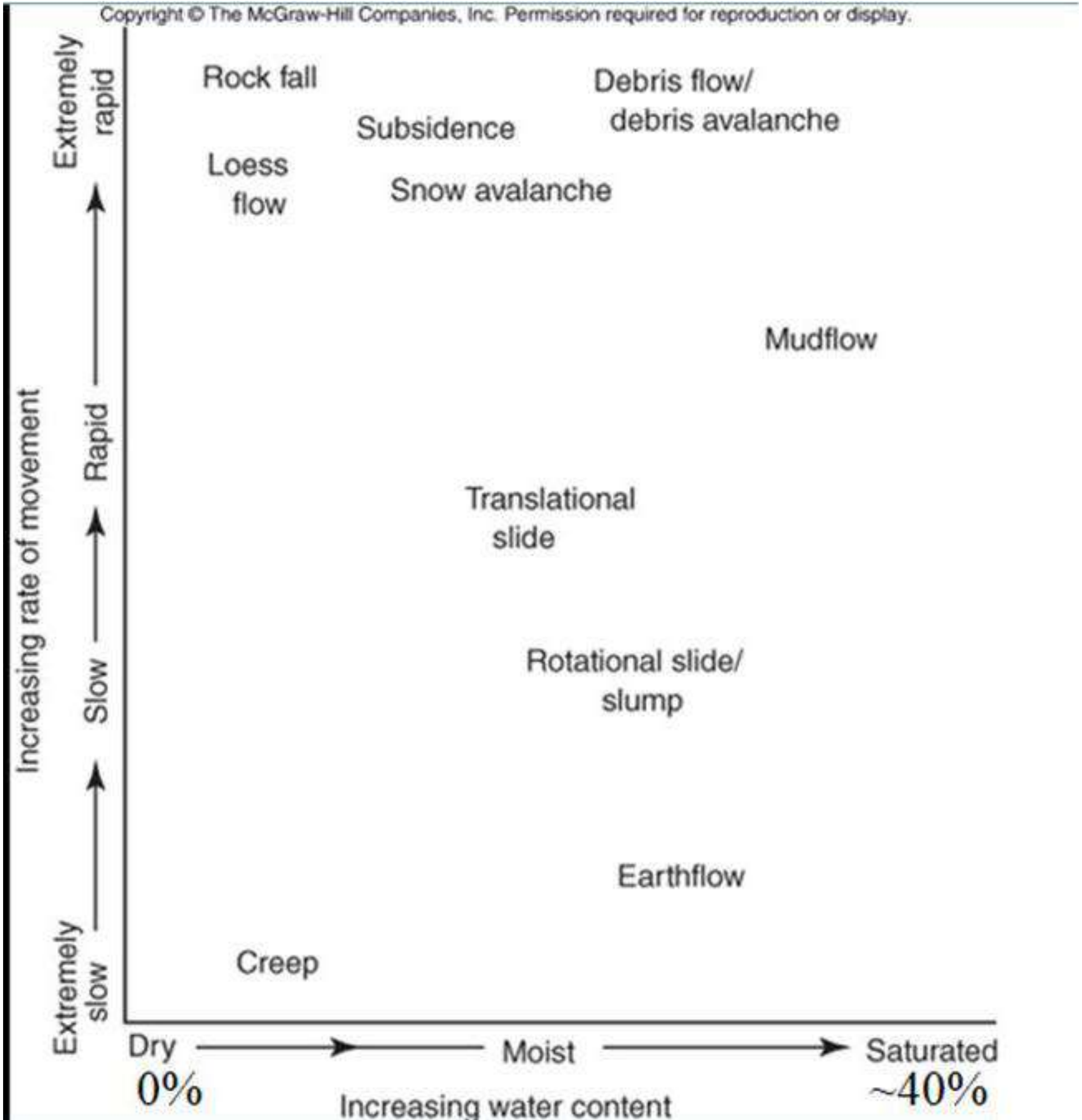
Rate of movement?

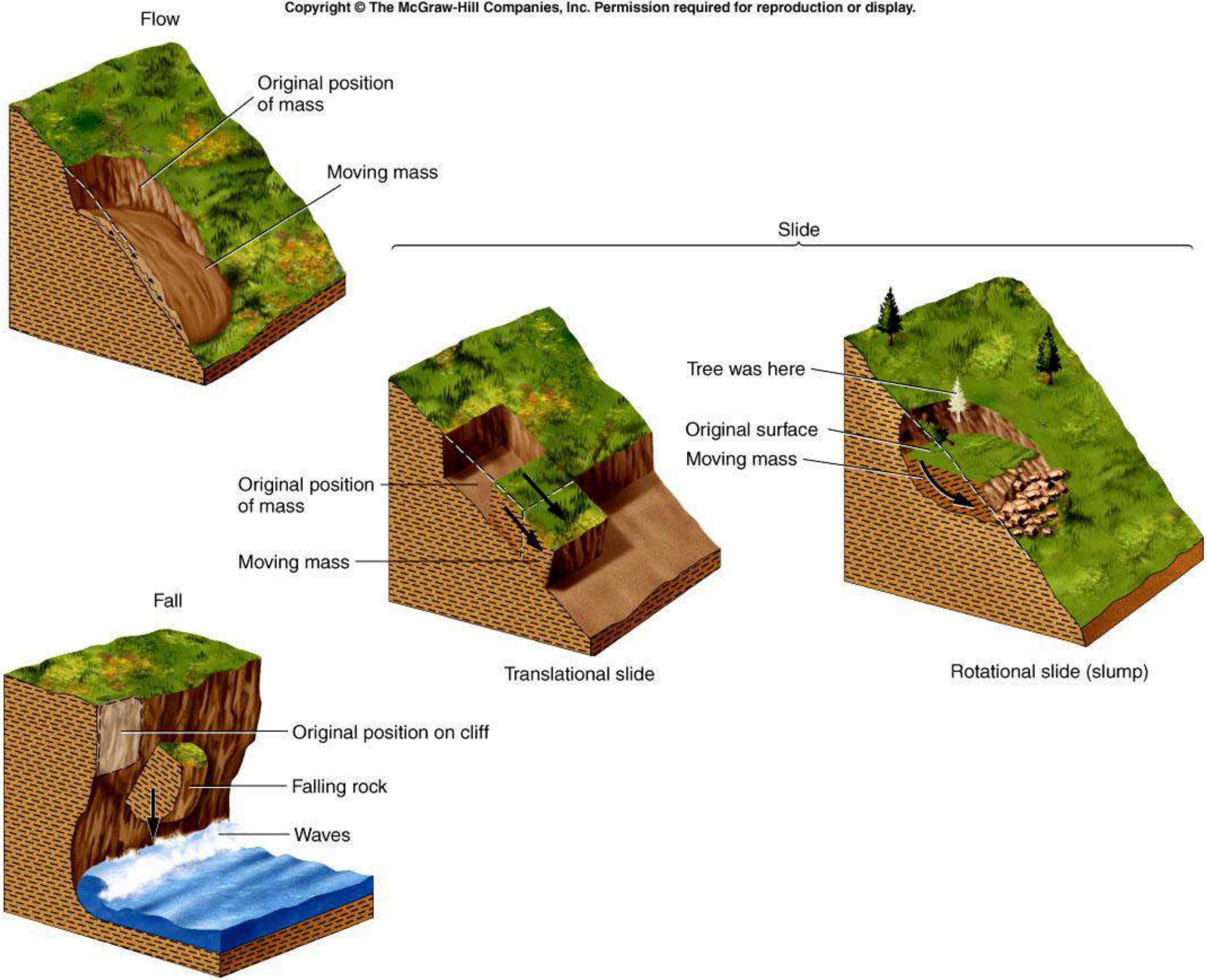
mm/yr or km/hr


Rock fall
Debris fall
Snow avalanche
Debris avalanche
Debris slide
Rock slide
Mudflow
Slump
Solifluction
Creep
Rock glacier
Very slow
Very fast
Typical velocity of mass movement

> 100 km/year

< 1 cm/year




Flow
Original position of mass
Moving mass
Slide
Tree was here
Original surface
Moving mass
Original position of mass
Moving mass
Translational slide
Rotational slide (slump)
Fall
Original position on cliff
Falling rock
Waves

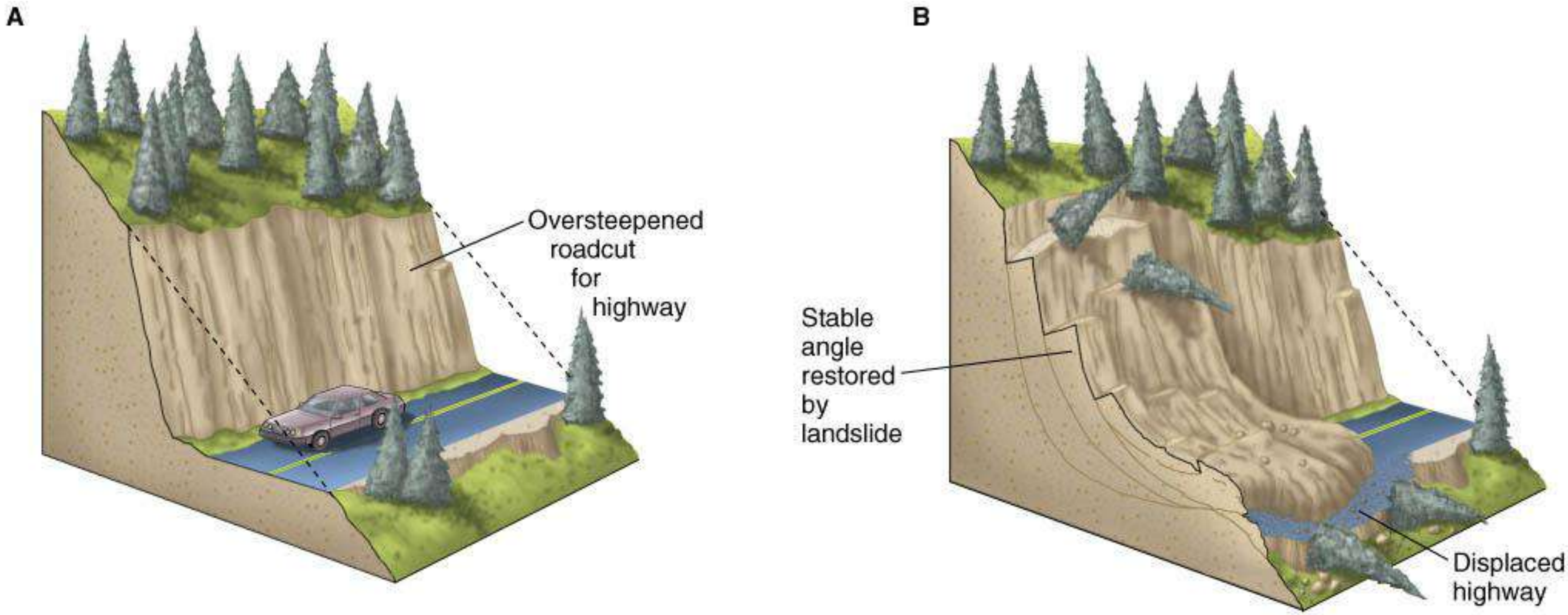
Slides : **Downslope movement of a large unit of rock or soil down a distinct surface of failure or slide plane.**

Slides are generally caused by :

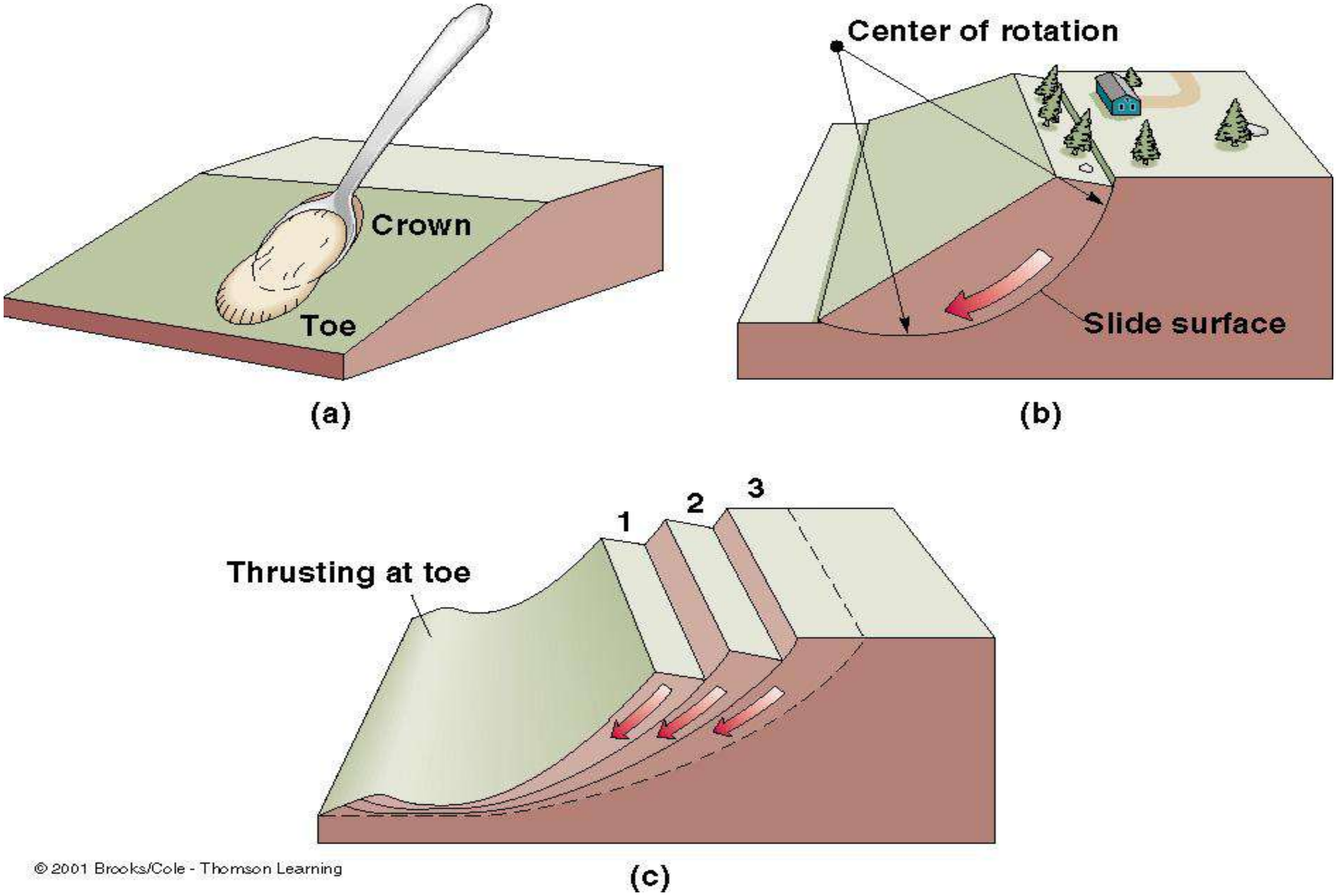
- **water saturation or weathering which weakens a slope**
- **increased steepness of a slope caused by undercutting at the base**
- **increased weight added at the top of a slope**
- **shaking (by earthquakes, explosions) that triggers movement on a vulnerable slope**

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

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

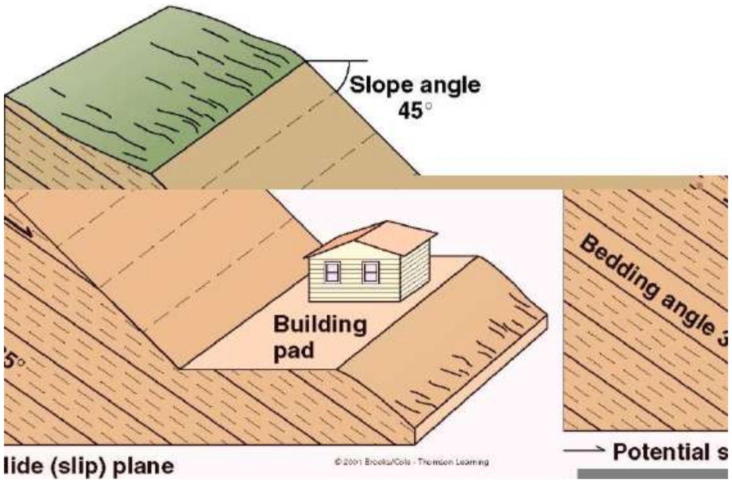


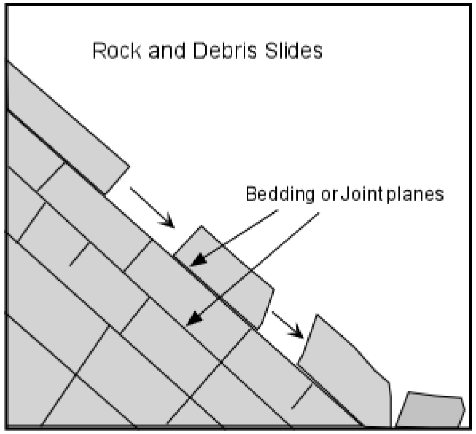
A **Translational Slide** (block glide) occurs on a relatively **flat sloping surface of failure.**

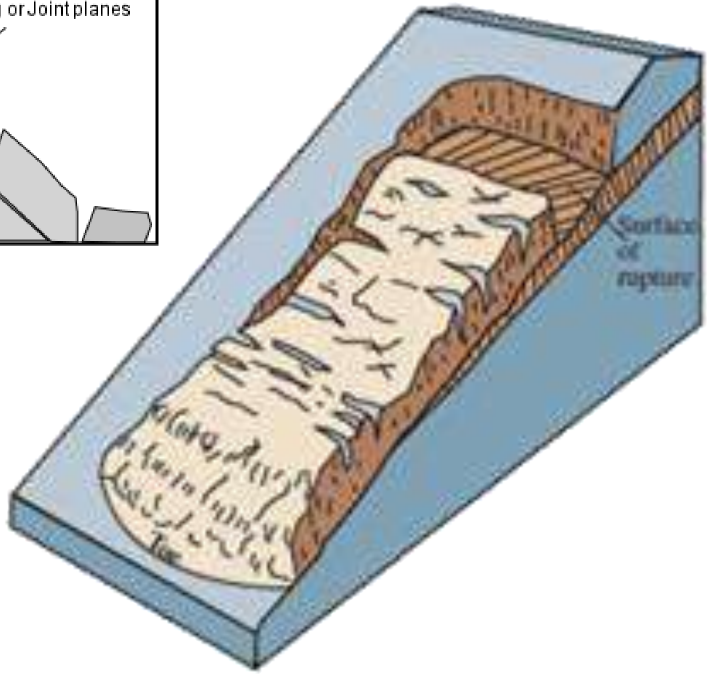
One very common cause of translational slides is dipping planes of weakness in the rock. These planes might be:

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

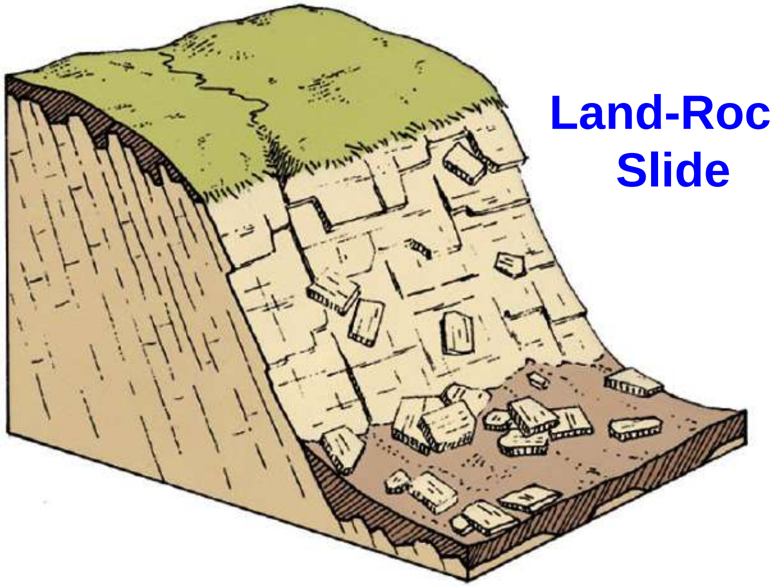
A translational slide is likely to occur *if the slope dips at an angle that is greater than the dip of the planes of weakness in the rock.*





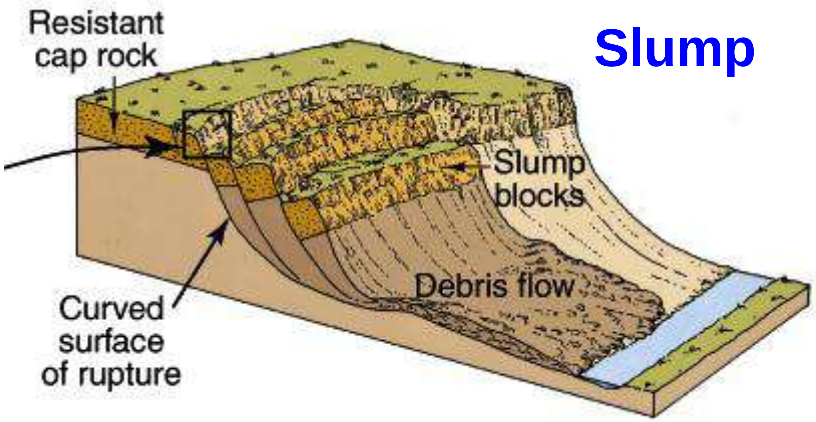


For example, the slope shown has been cut at an angle 45° > the dip angle of the planes of weakness in the sedimentary layers. With nothing to hold the layers back, they may slide onto the house.



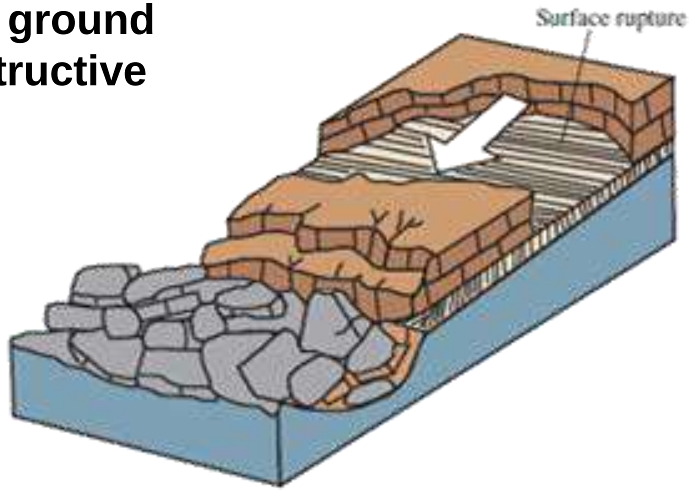
Land-Rock Slide

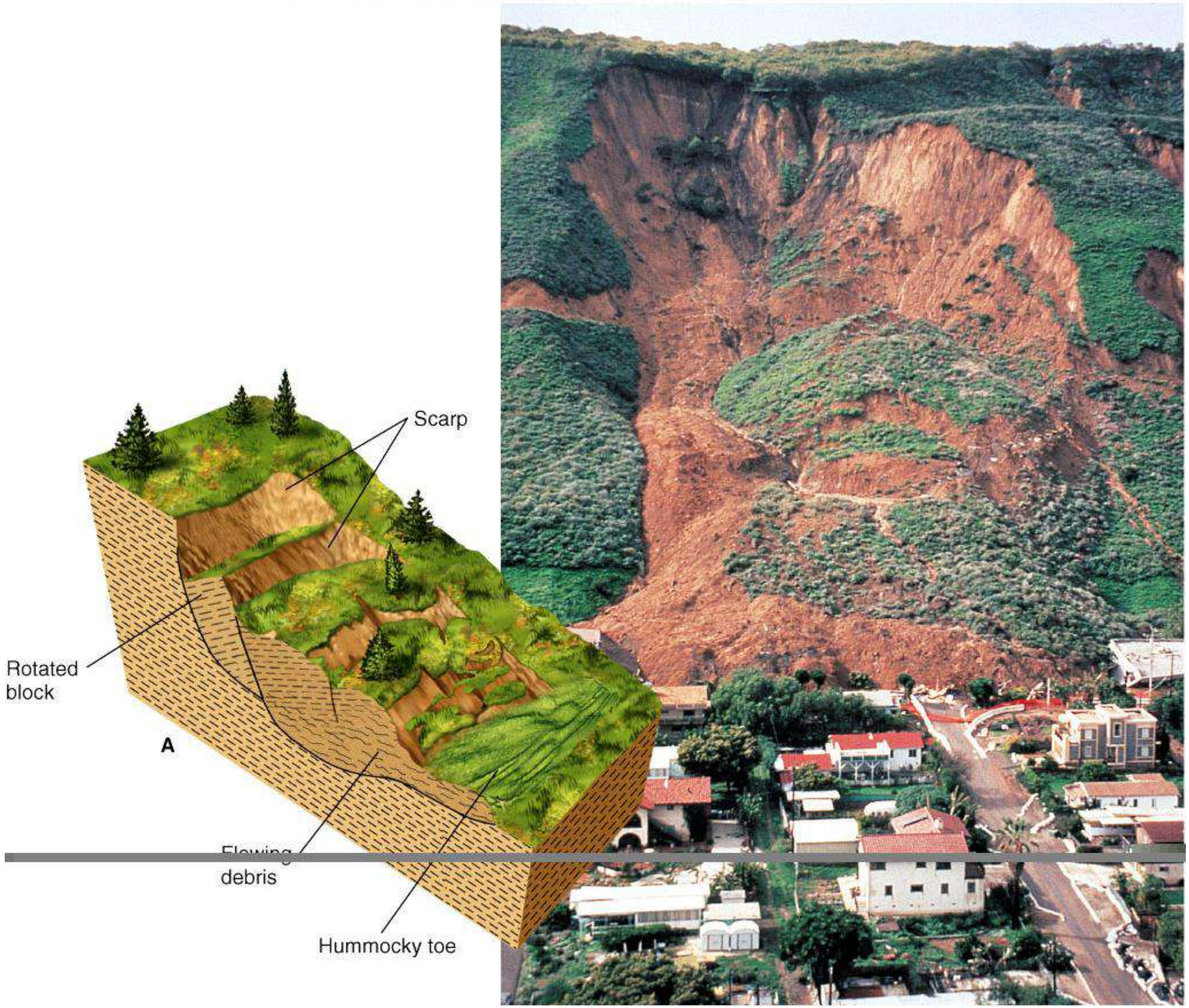
- Movement of material along a defined slippage plane, Sudden and rapid movement
- Large blocks of rock detach along bedding planes, joints, fractures, etc.
- Occur on steep slopes
- Can be triggered by rain falls or ground vibration, Fastest and most destructive type of mass wasting



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




Scarp
Rotated block
A
debris
Hummocky toe

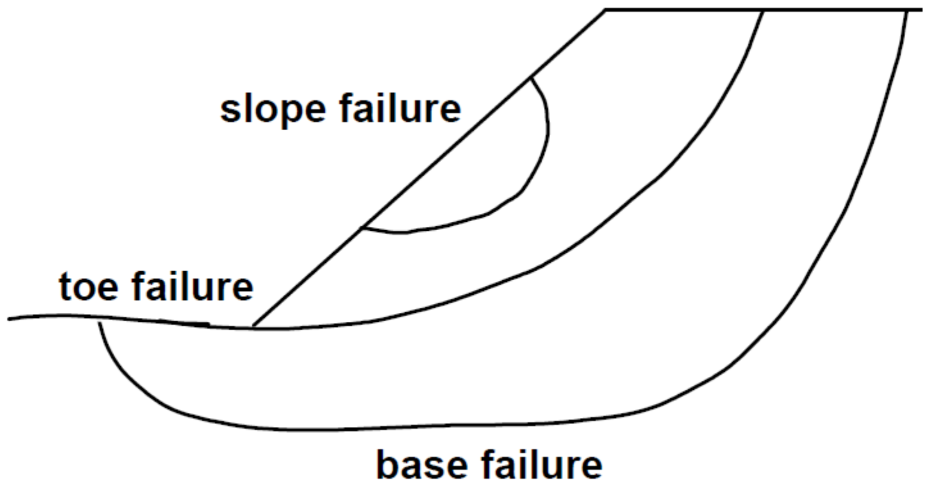
The slope failure (slump)

Circular surface of failure is common for considering essentially homogeneous materials (soils, loose or weak materials);

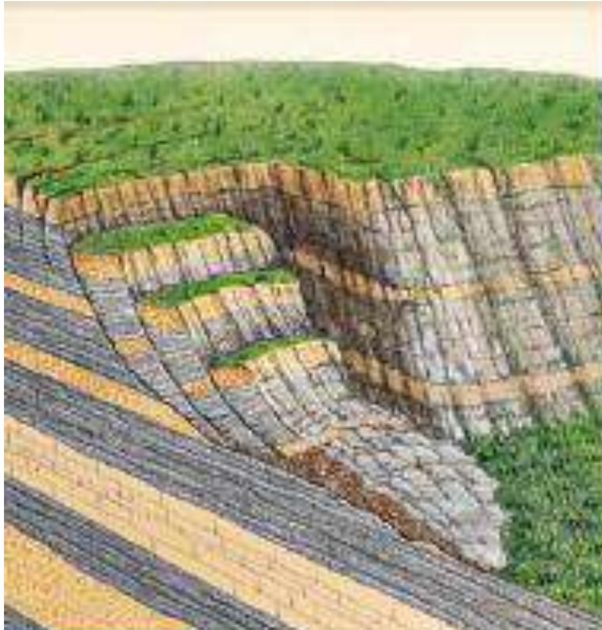
Slumps usually occur in humid areas, groundwater plays an important role in slump failure. In springtime, after the thawing, after heavy rainfall, slump failures are very common in all natural slopes, road cuts, out slopes, and embankments.

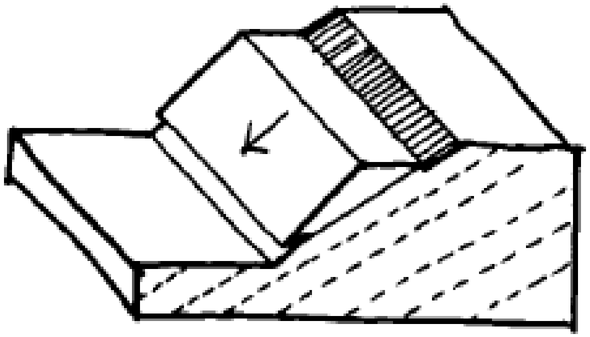
Three types of slump failure

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

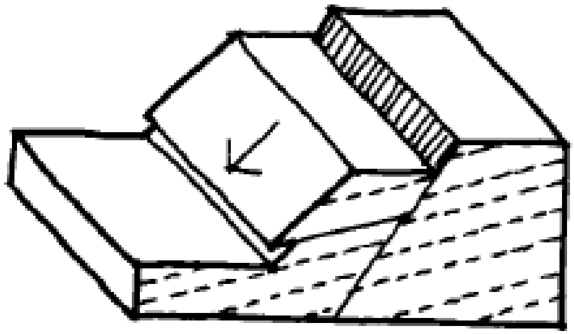


Slump

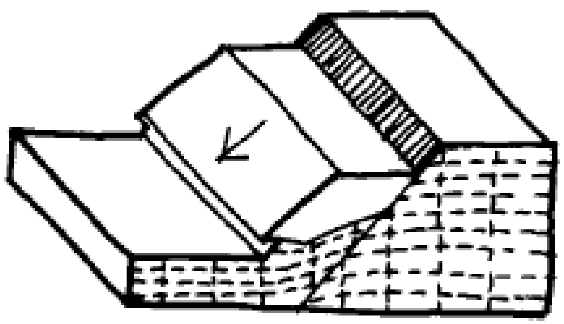




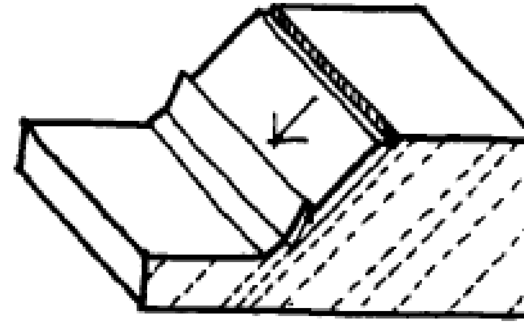
i Planar Failure



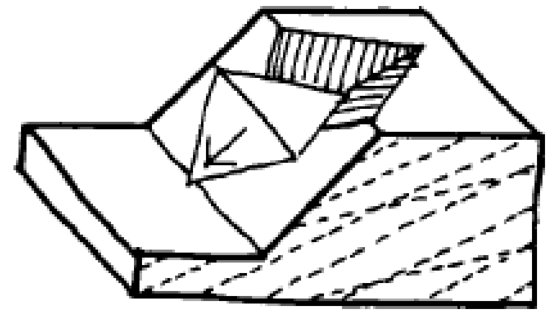
ii Biplanar Failure



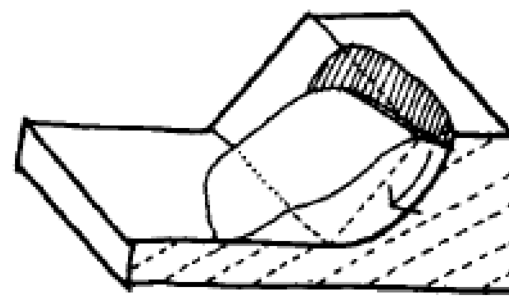
iii Multiplanar Failure



iv Slab Failure



v Wedge Failure



vi Circular or Rotational Failure

General modes of slope failure

- Whenever the resultant weight of a block, W, projects beyond the downslope 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** -flowage 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.*

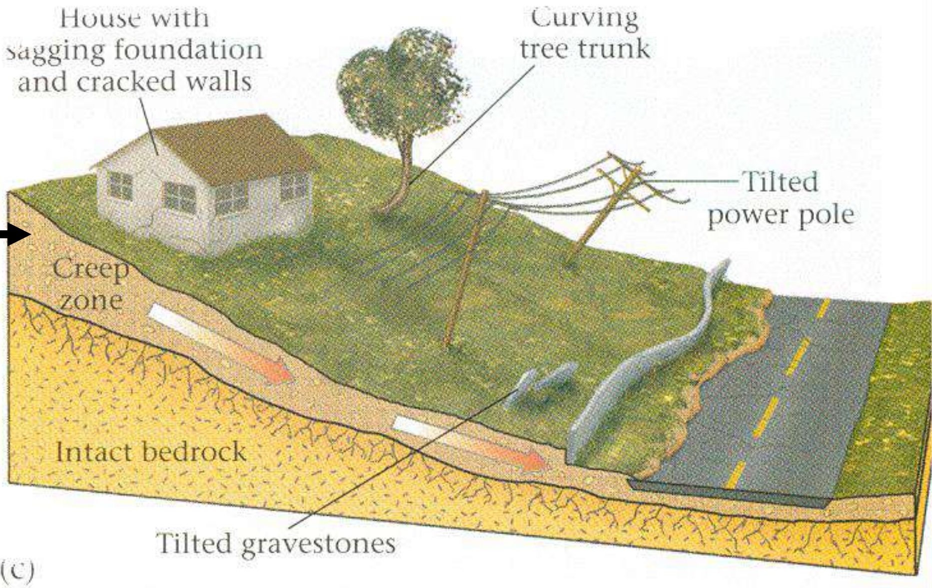
***Debris Flows** - often result from heavy rains causing saturation of the soil and regolith with water. A debris flow is a moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. To be considered a debris flow the moving material must be loose 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*

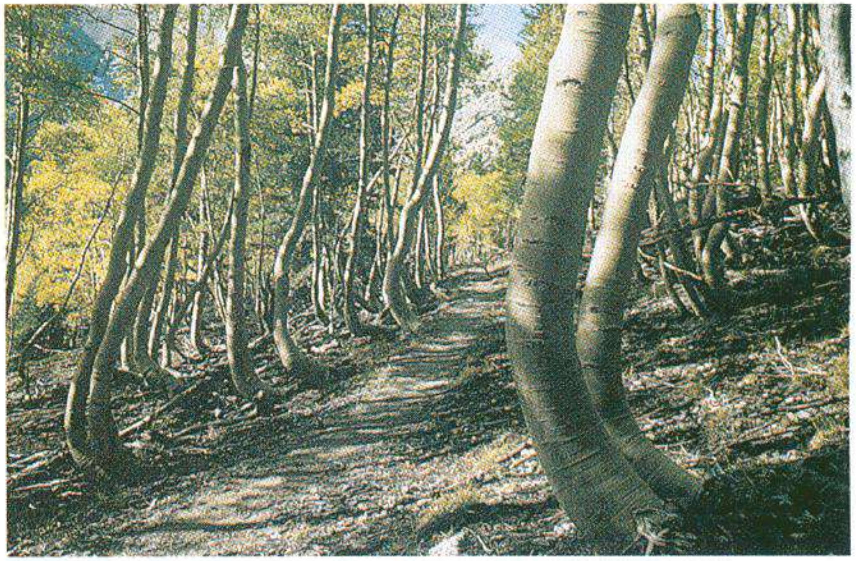
Granular Flows

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**

Earthflows - **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.**



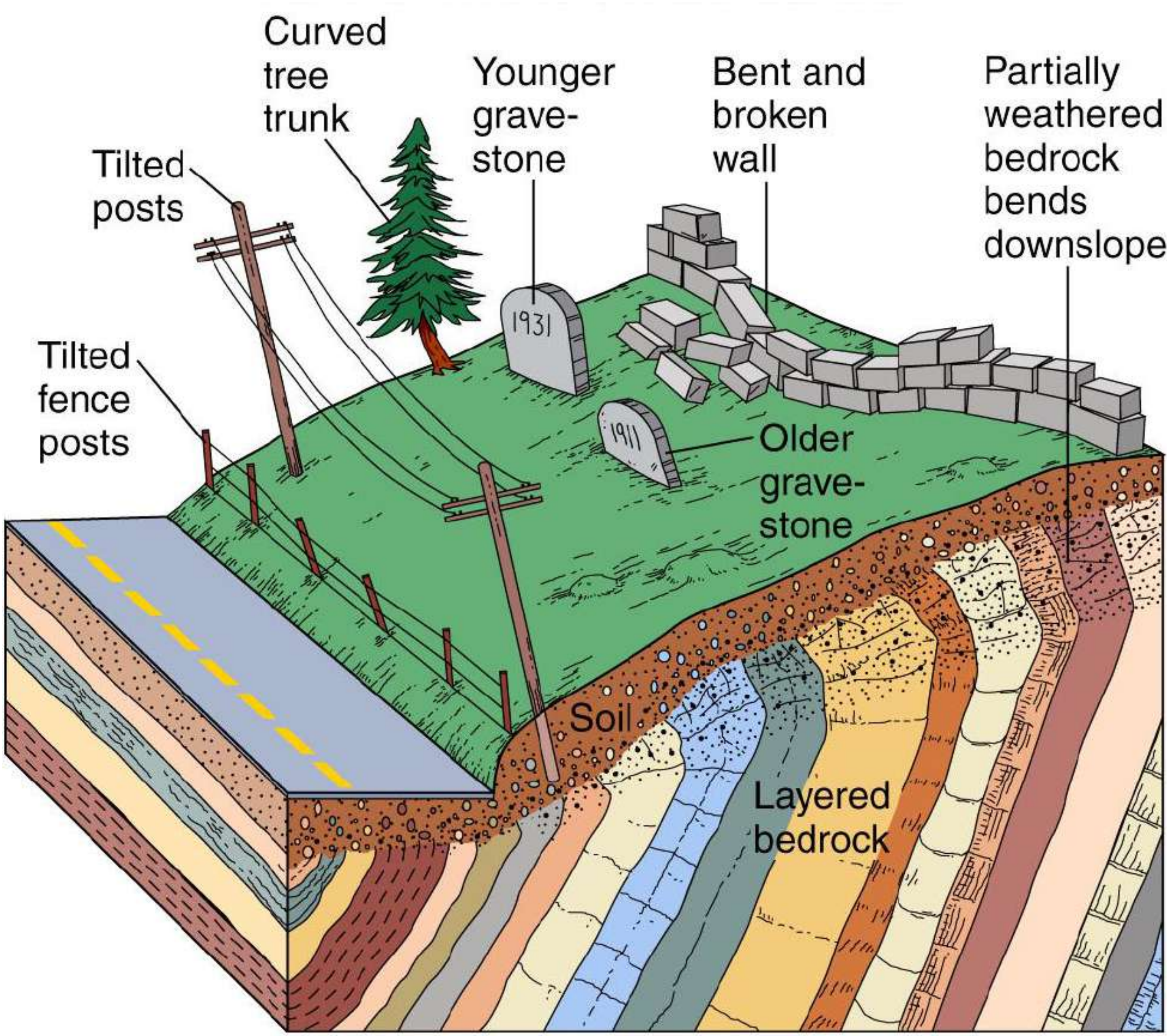
(c)


(d)

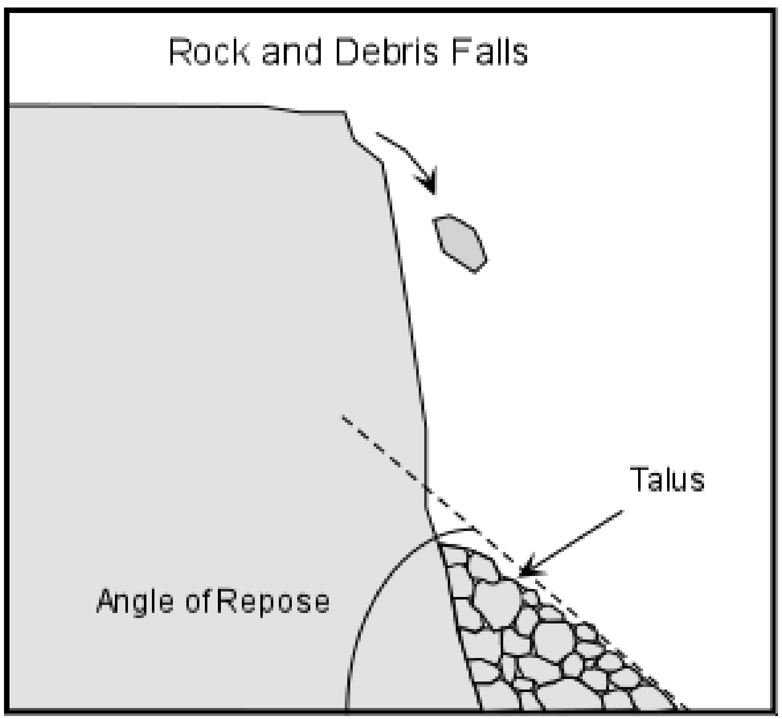
Earthflow

Creep

- Downslope 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

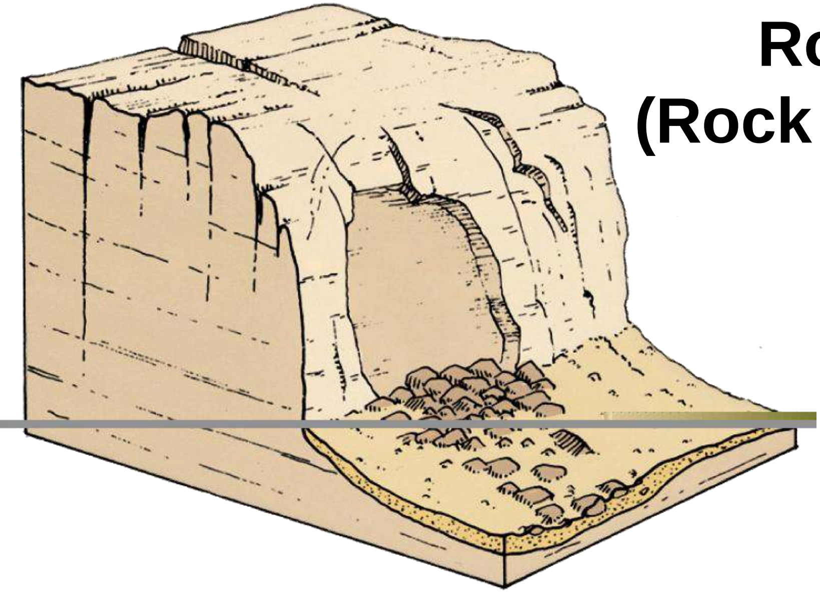


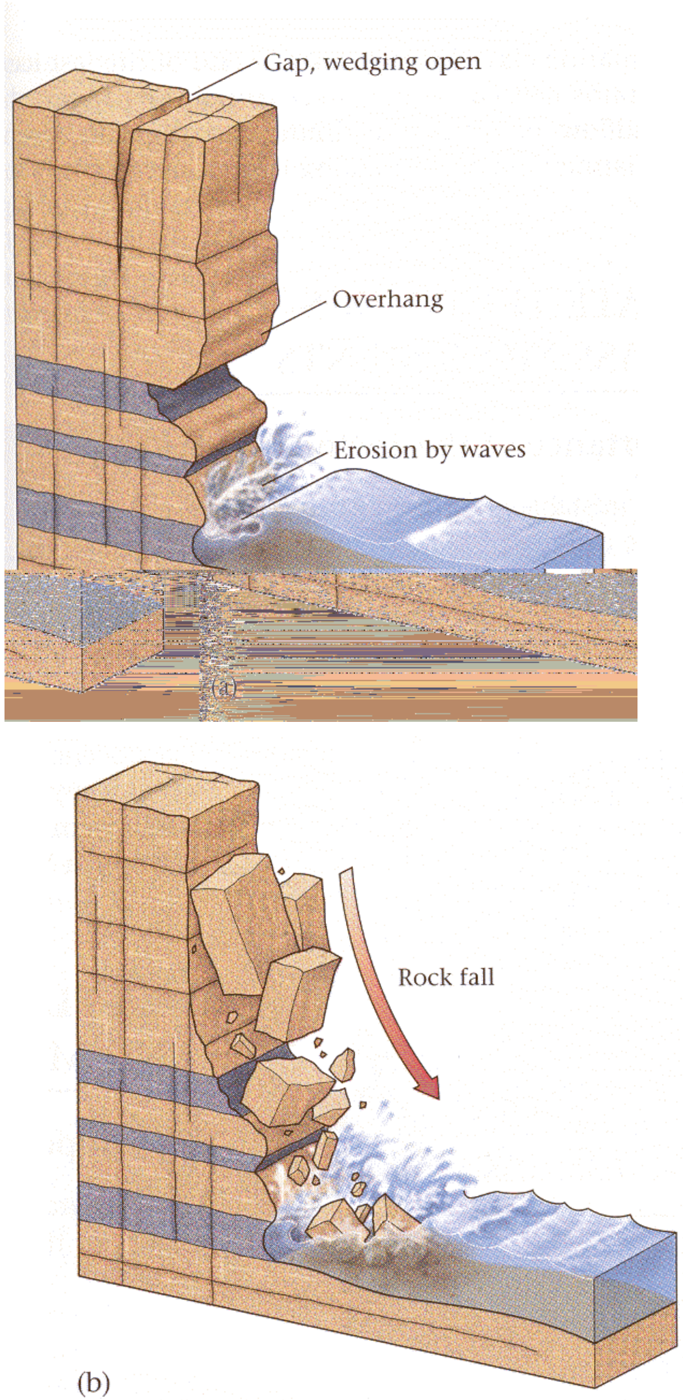
Falls - **Abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly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



http://geology.com/usgs/landslides/

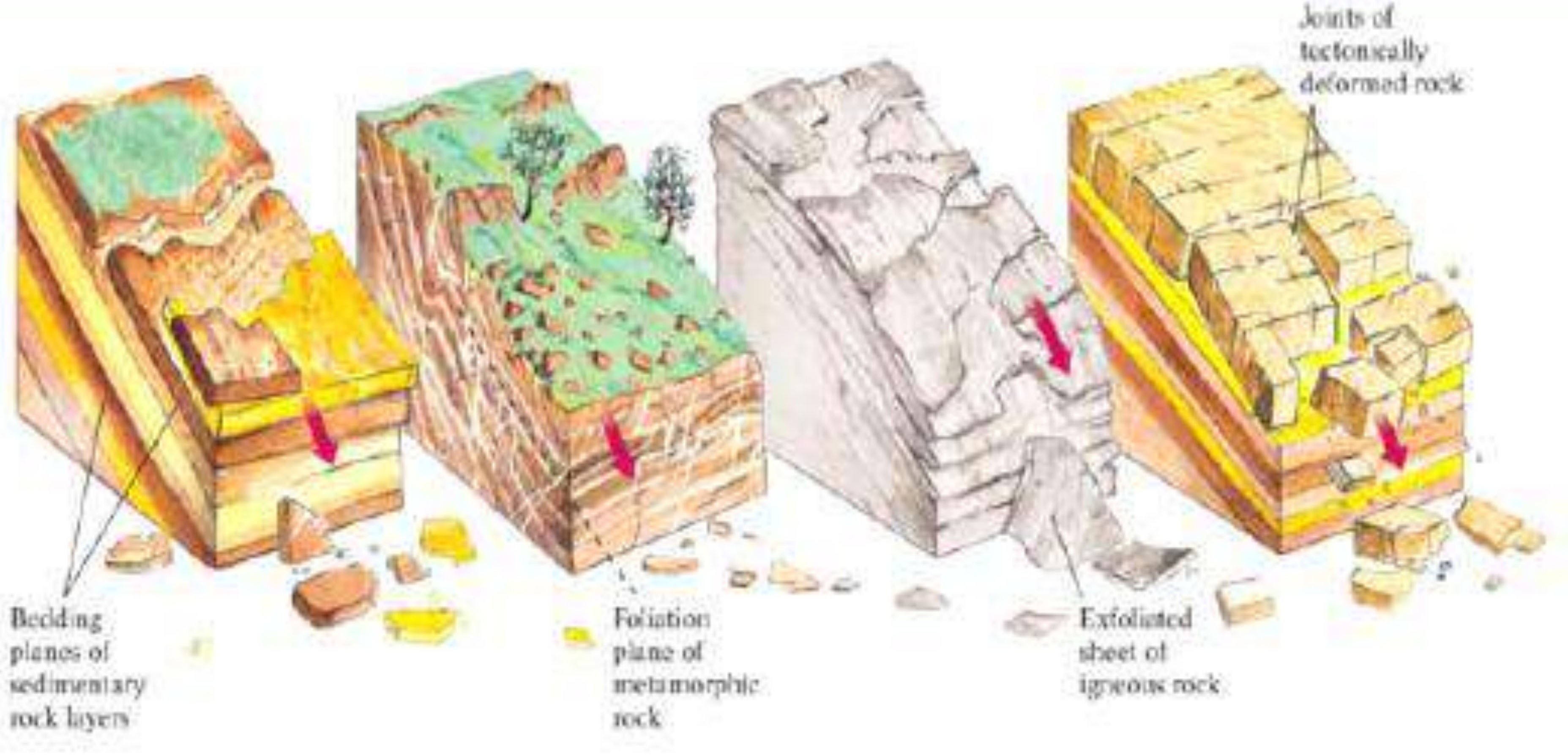
Rock Fall
(Rock Avalanche)



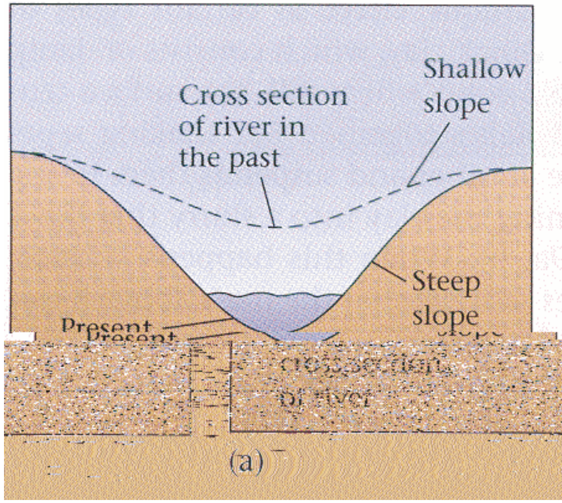


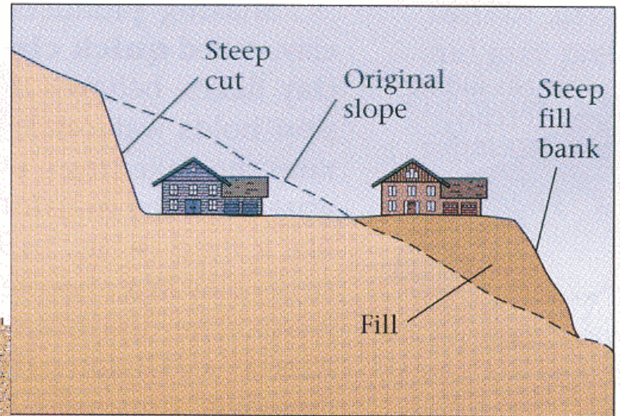
- Sudden and rapid free fall movement of rock
- Occur on steep slopes
- Forms talus piles
- Can grade into a rockslide if material greater a slope greater than the angle of repose

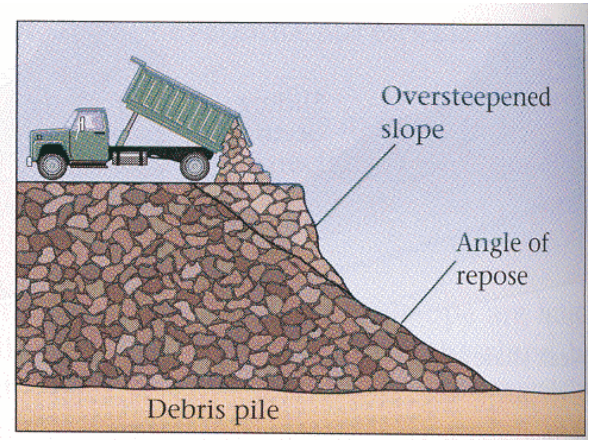
Slopes susceptible to mass movement



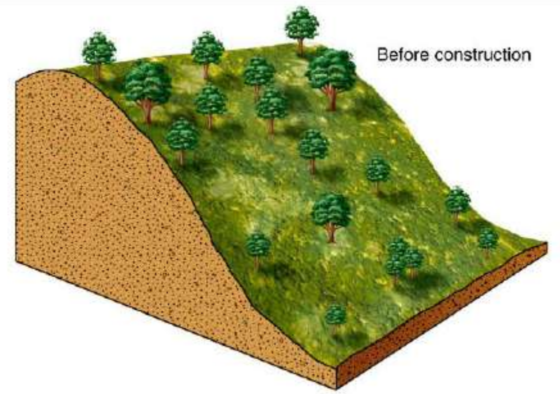
Over-steepening of the Slope

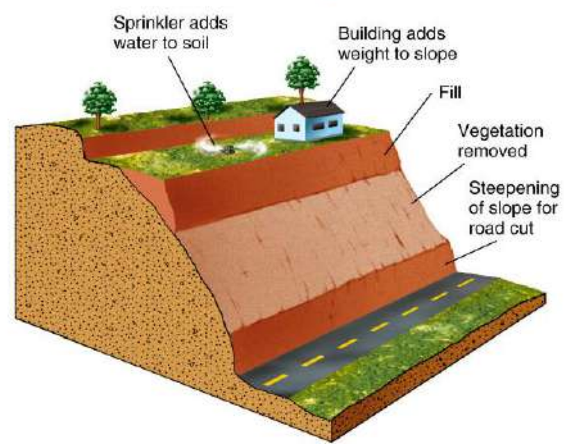


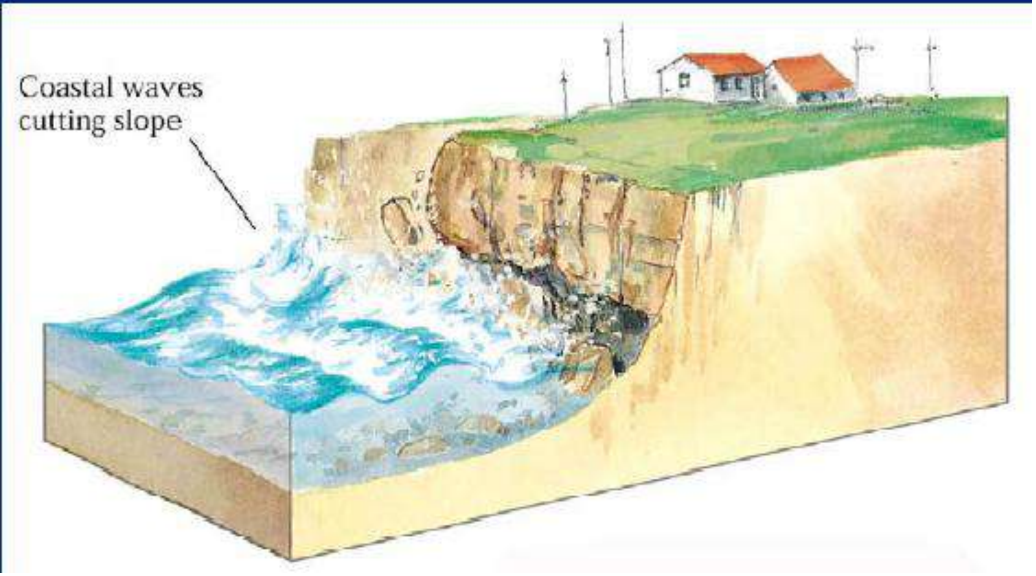




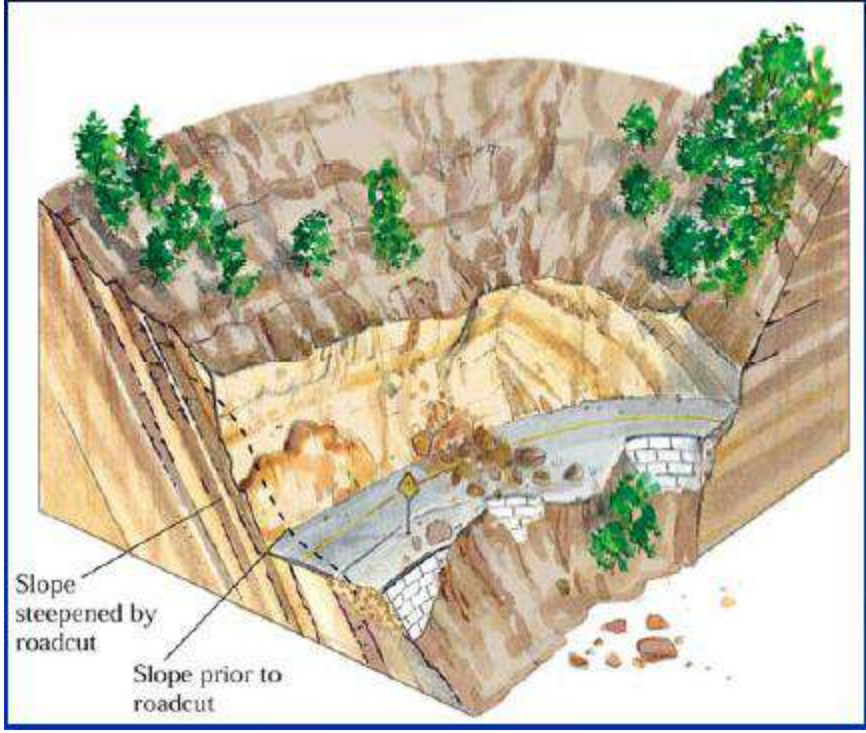
- human-induced or by natural processes – increases the downslope force.
- Stream undercutting a valley wall
- Waves cutting cliffs on a shoreline.
- Construction of roads, buildings, homes etc.



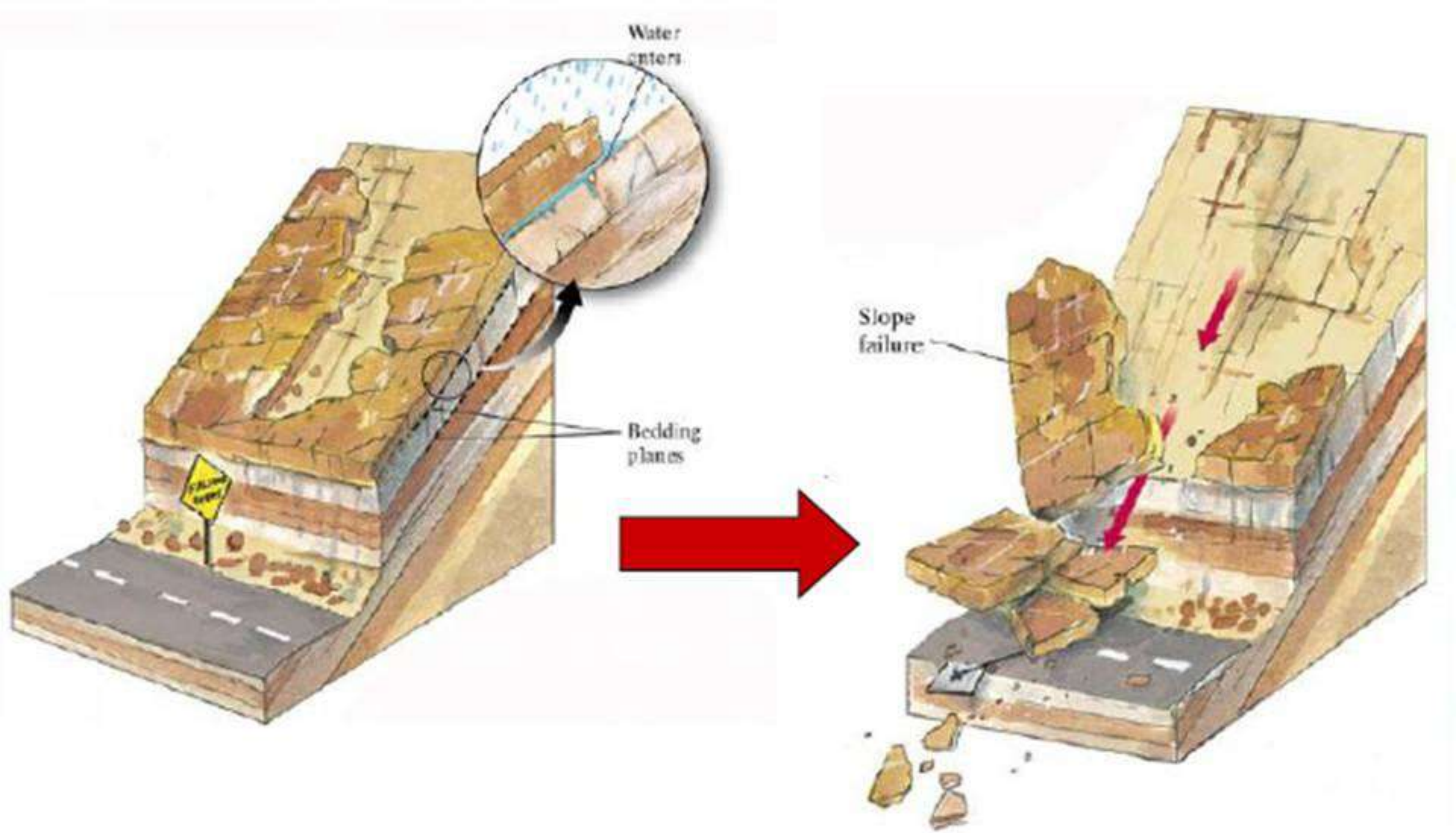




Waves Over steepening slopes



Water cause failure in slopes of bed rock



الطفيلة: انهيارات طينية تعيق الطرق وتهدد سلامة السائقين - صور

PM 02:19 24-11-2012

زاد الاردن الاخباري - أدى التساقط الغزير للأمطار على مختلف مناطق الطفيلة، إلى حدوث انهيارات طينية على طريق عين البيضاء - النمتة، ما تسببت بإغلاقه جزئيا، وانحراف 'قلاب' محمل بالرمل عن سيره، الأمر الذي كاد أن يؤدي إلى تدهوره.

وكانت 'الغد' رصدت في تقرير سابق لها، خطورة الوضع على الطريق، وأشارت إلى الخشية من احتمالية حدوث انهيارات طينية عليه، في حال عدم إيجاد حلول كفيلة بتفادي الانهيارات الطينية اللزجة على الطرق، ما يشكل خطرا يهدد الحركة المرورية ويشكل خطورة على السائقين.

Mitigation of mass wasting problems is accomplished by:

- **Sinking foundations down into solid rock** below weaker surface zones.
- **Hazard zone mapping** to identify areas where movements have occurred in the past.
- **Building codes** that limit the steepness of slopes and the types of fill used in construction.
- **Drainage systems** that drain water from the surface and/or the subsurface.
- **Buttress fills and retaining devices** to hold slopes in place. Examples include retaining walls, “shotcrete”, and rock bolts.

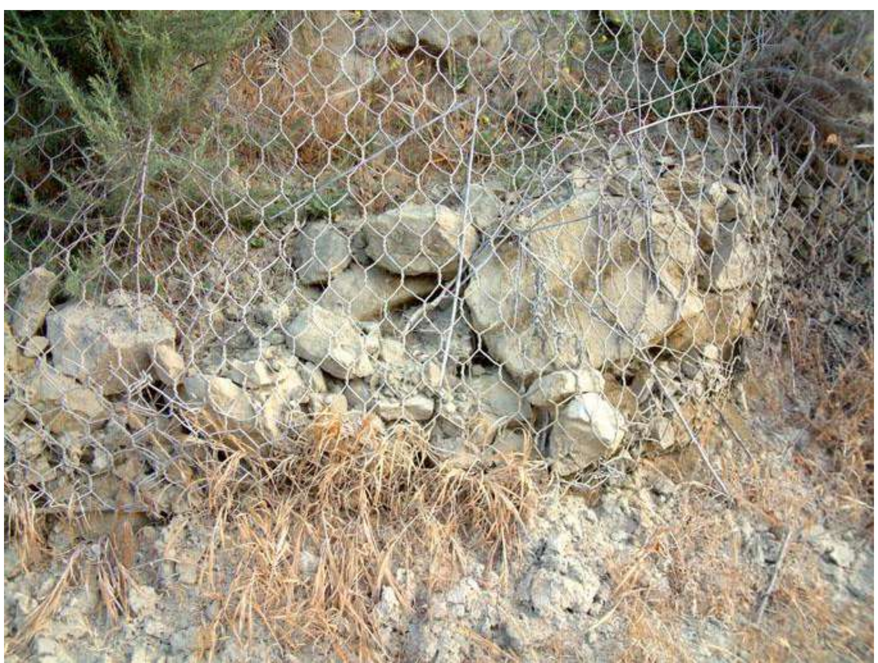
Preventing slope failure

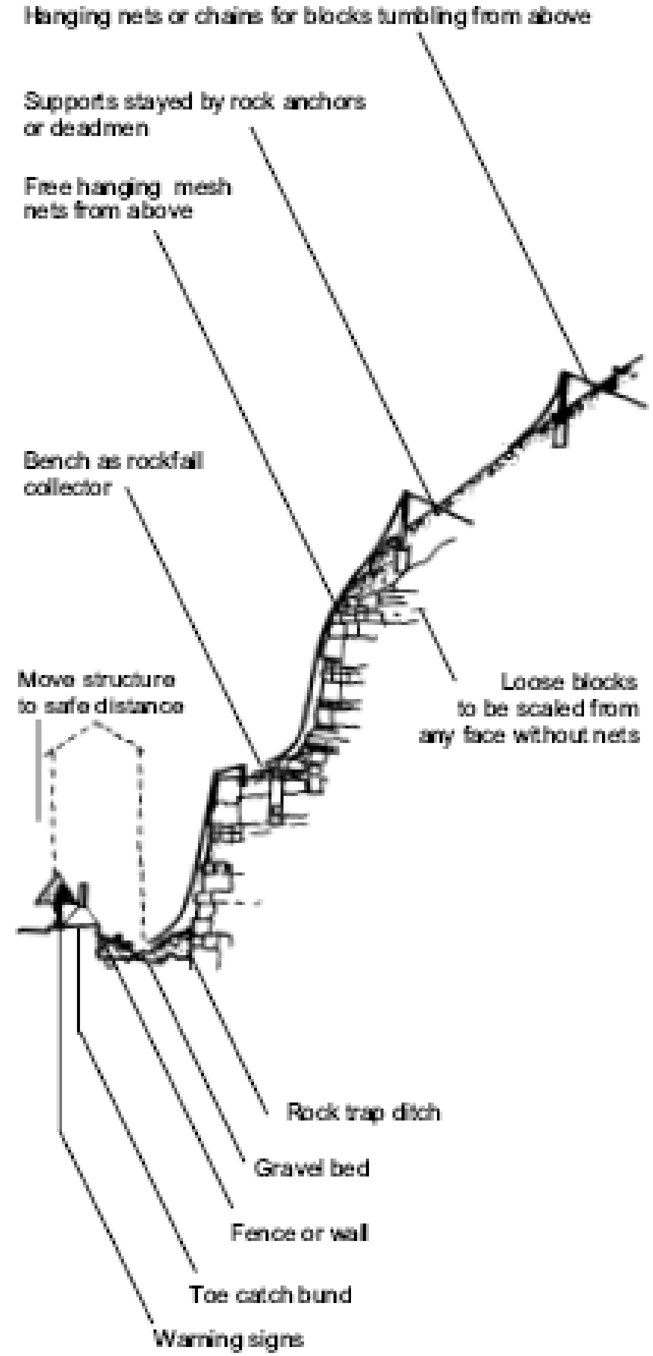
Engineering solutions

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

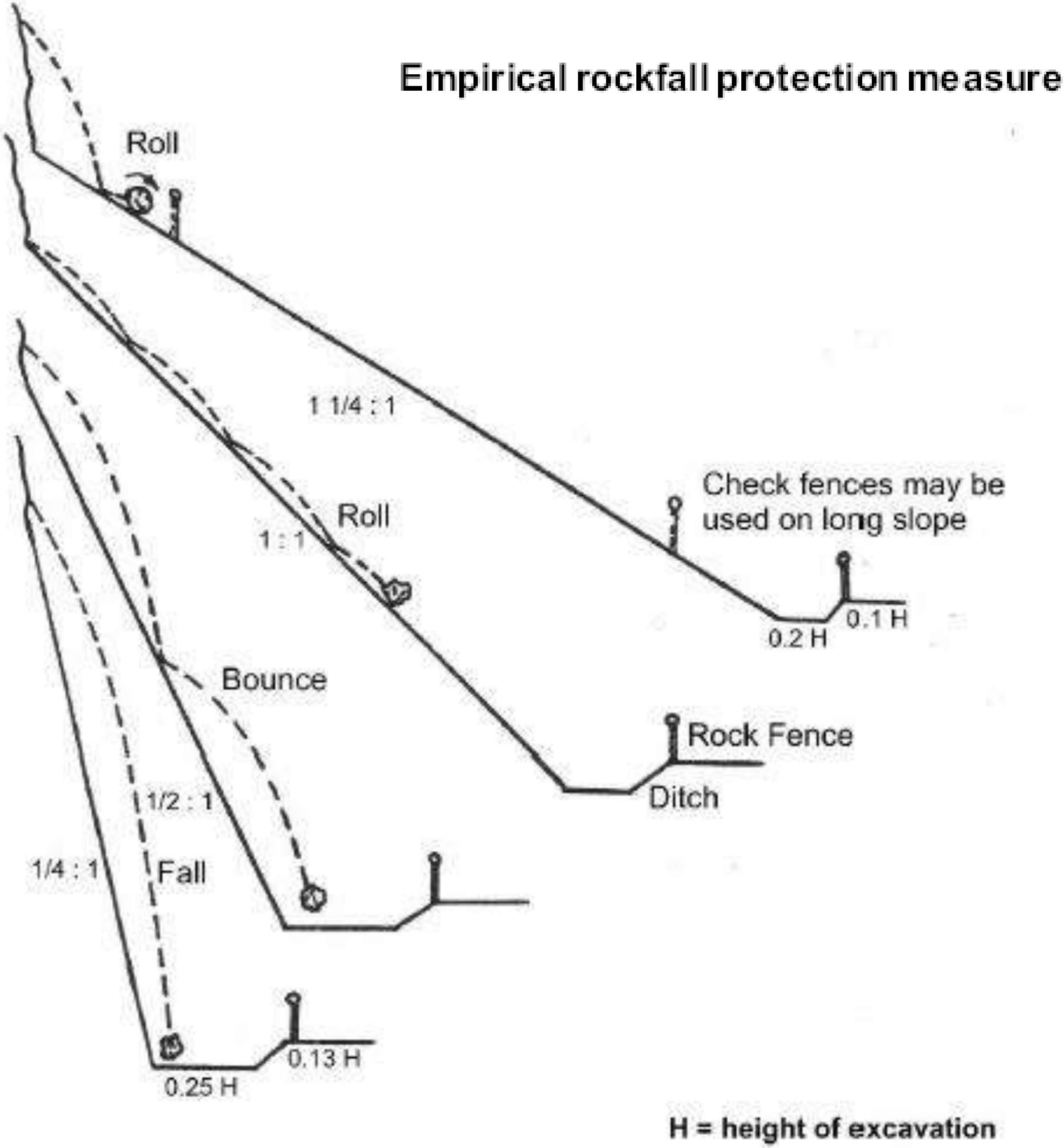
- **drainage and dewatering –**
- **grading and benching**
- **retaining walls**
- **bolting, netting, spray crete**

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.

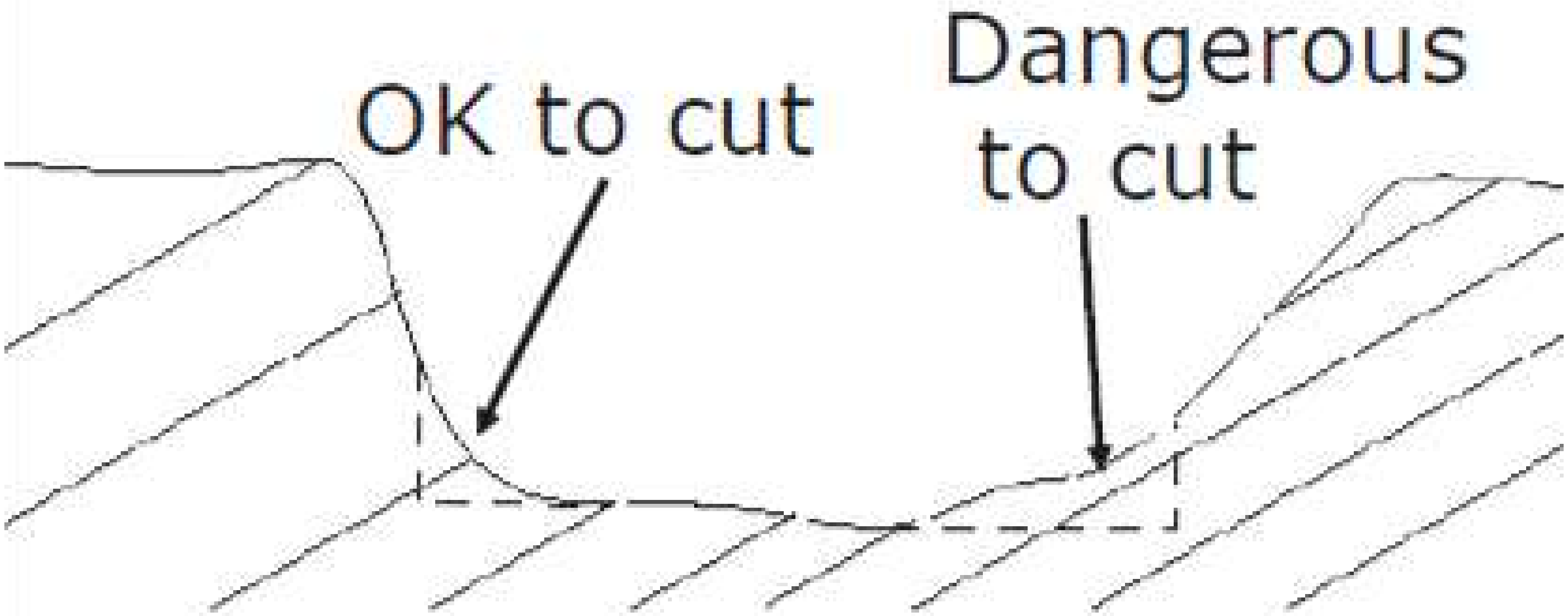




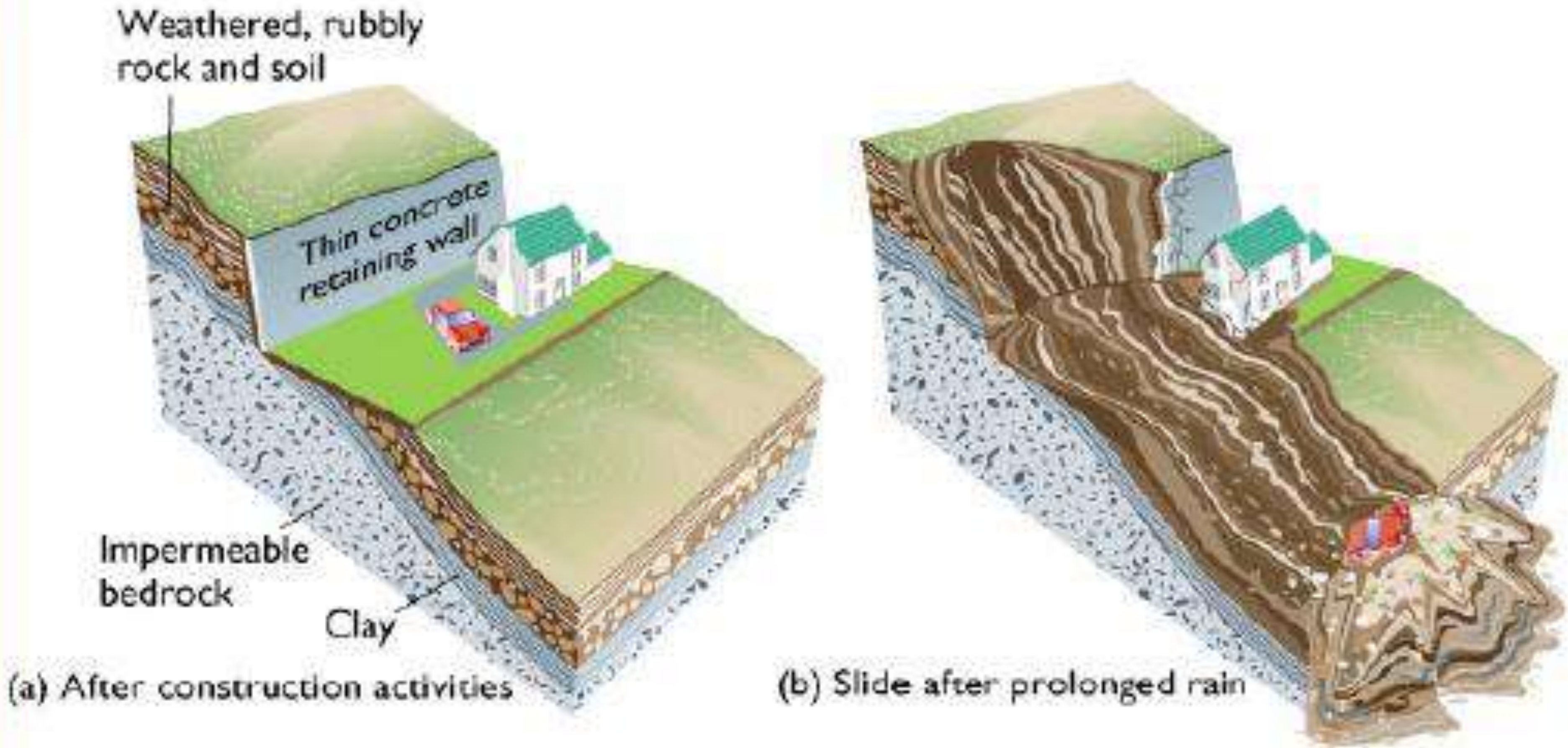
screen mesh is a relatively cheap and effective method to protect the roadway. The screen mesh is also referred to as "slope revetment" (covers the face of the slope) or as "rock-fall barrier

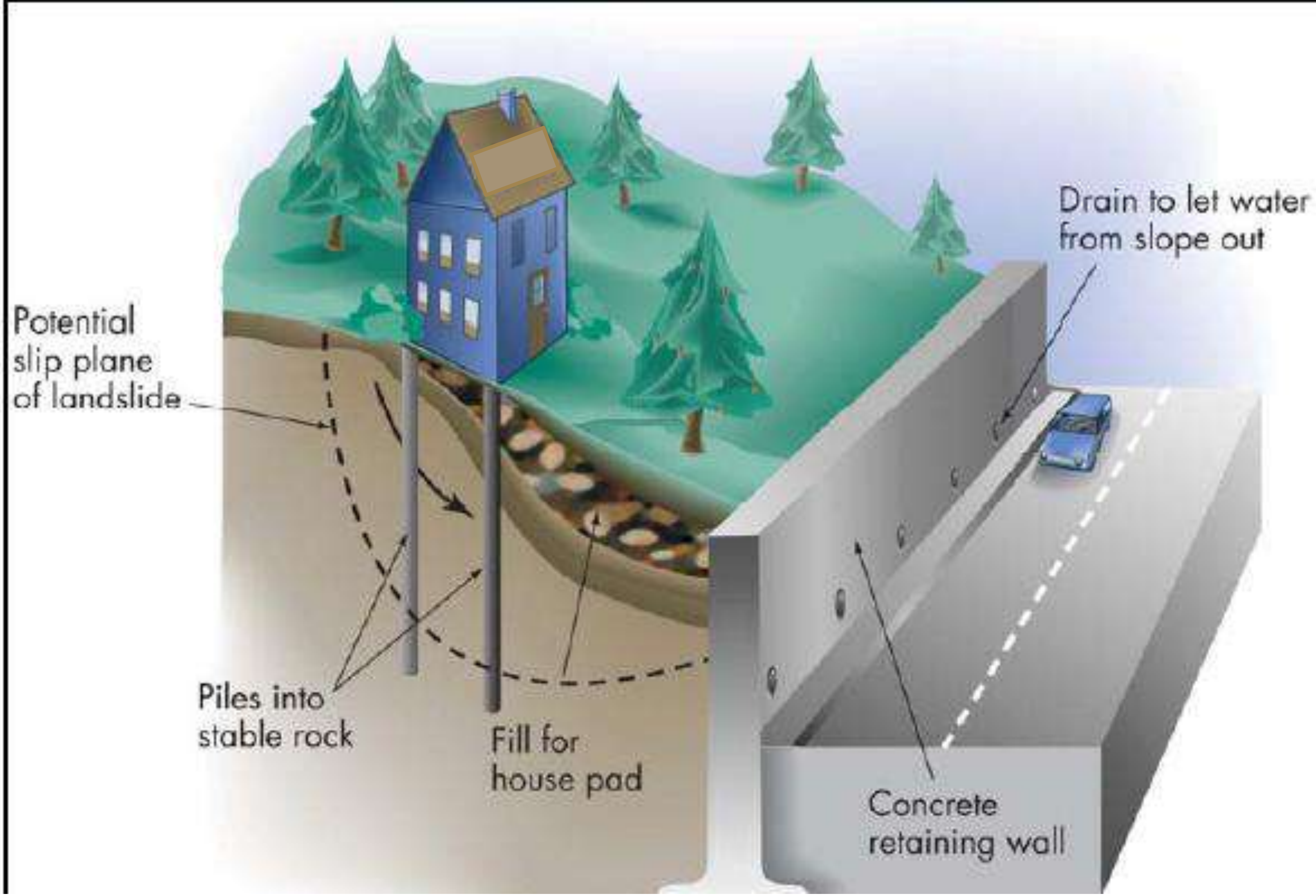


http://www.gwalton.co.uk/mistslopes/slopes_chapter_5.pdf



Cutting a slope during construction can cause a landslide


Weathered, rubbly rock and soil
Thin concrete retaining wall
Impermeable bedrock
Clay
(a) After construction activities
(b) Slide after prolonged rain

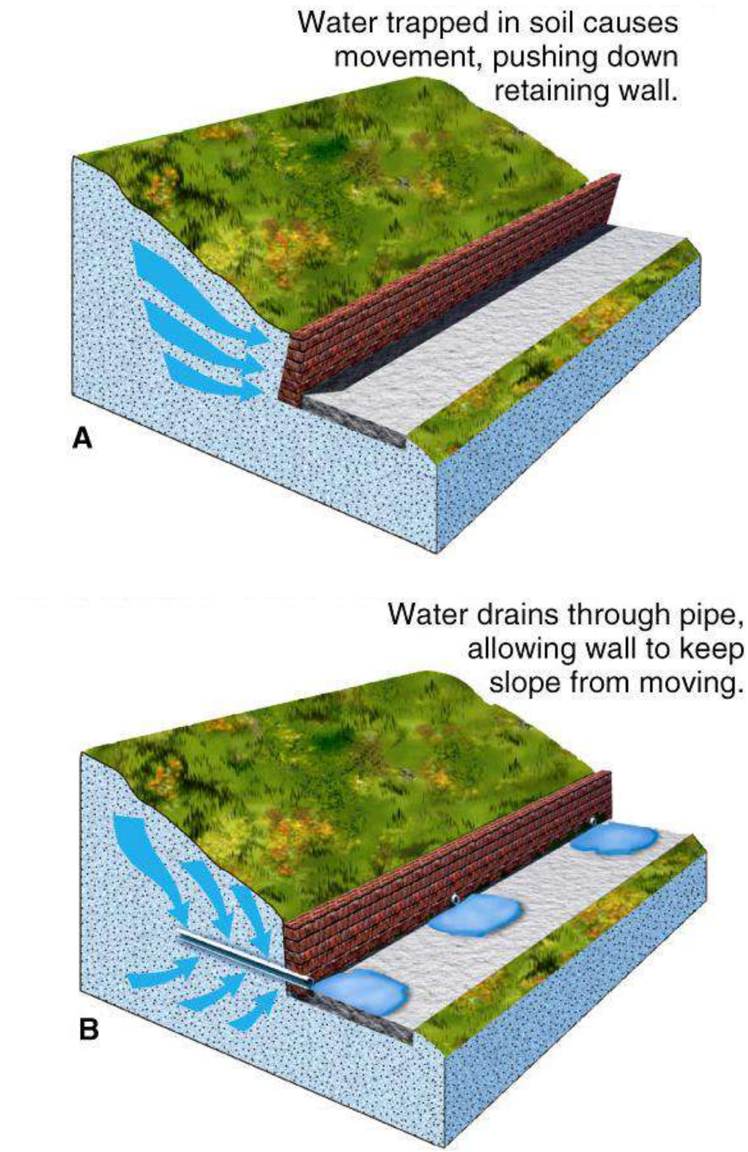


Potential slip plane of landslide
Drain to let water from slope out
Piles into stable rock
Fill for house pad
Concrete retaining wall

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



Prevention of Landslides

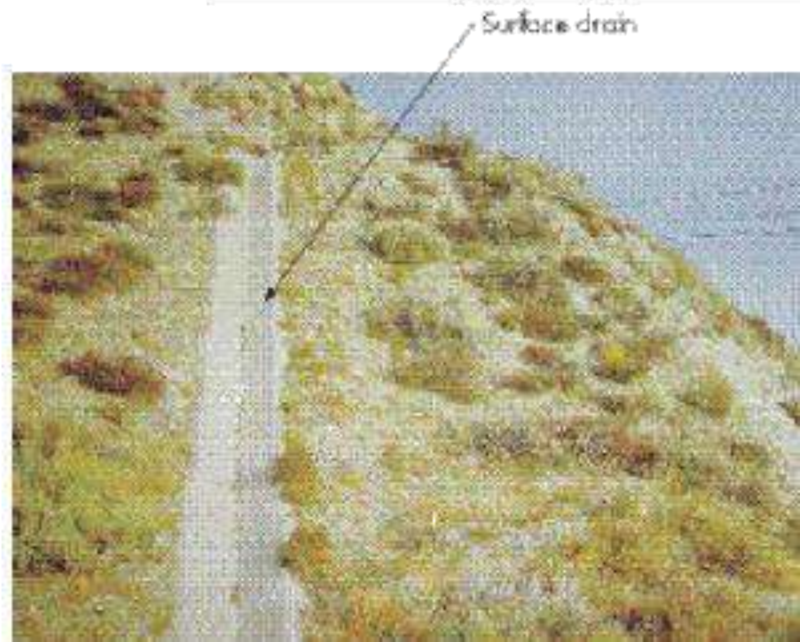
Prevention of large, natural landslides is difficult, but common sense and good engineering practices can help to minimize the hazard.

For example, loading the top of slopes, cutting into sensitive slopes, placing fill material on slopes, or changing water conditions on slopes should be avoided or done with caution.

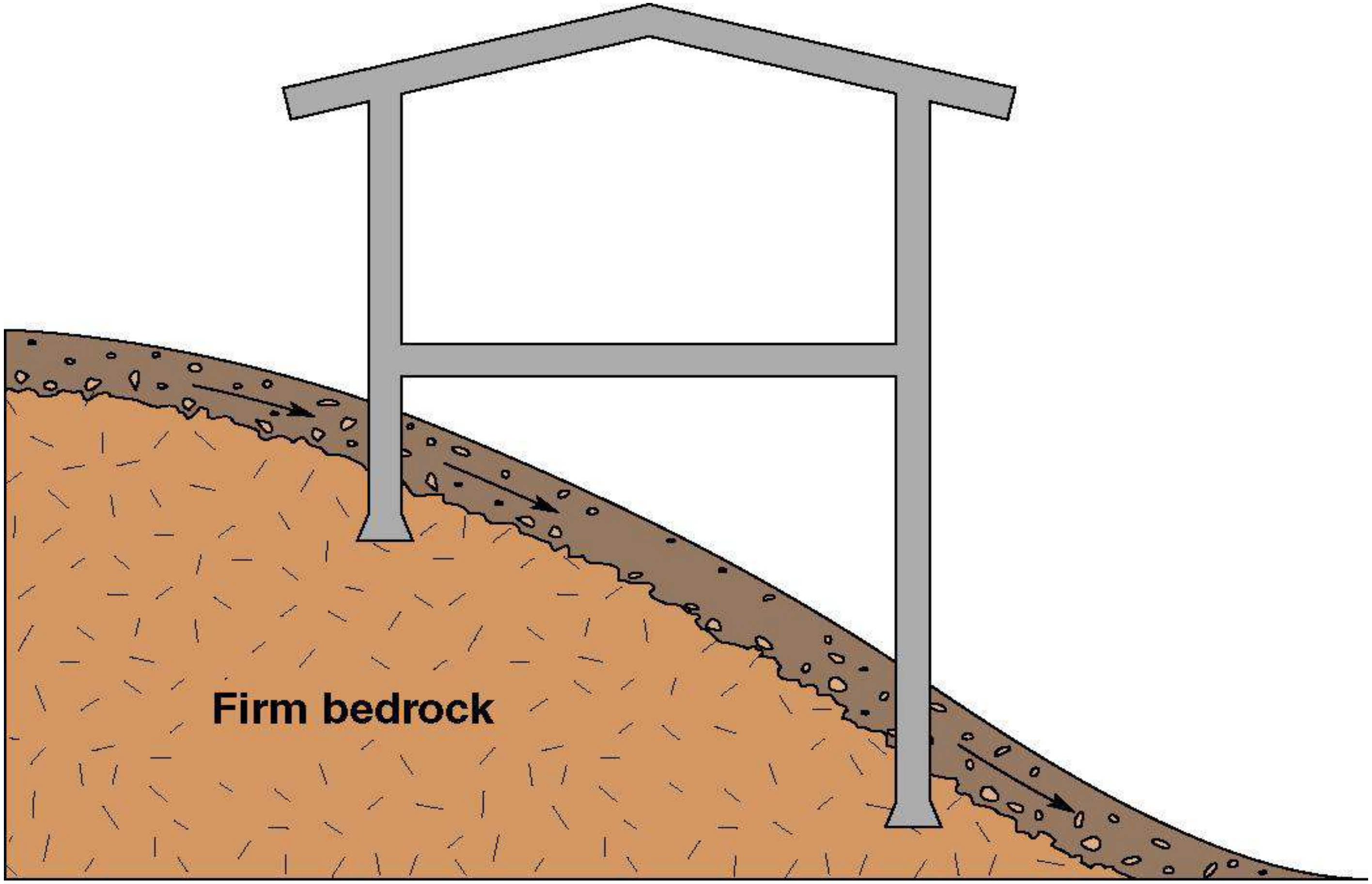
Common engineering techniques for landslide prevention include:

- **surface and subsurface drainage,**
- **removal of unstable slope materials,**
- **construction of retaining walls or other supporting structures,**
- **or some combination of these techniques.**

1. Drainage Control : Surface and subsurface drainage control are usually effective in stabilizing a slope. The objective is to divert water to keep it from running across or infiltrating into the slope. Surface runoff may be diverted around the slope by a series of surface drains



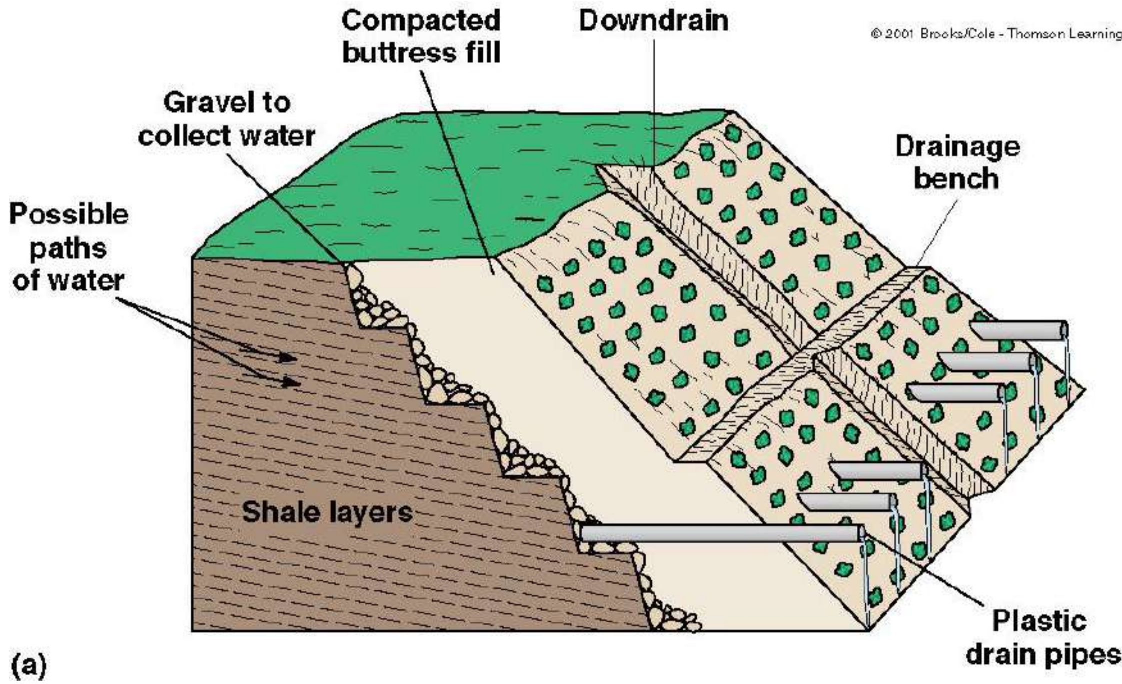
A simple mitigation method for **creep**. Structures will shift and slide if they are built on the creeping surface layer. By sinking foundations down through the creeping surface zone and anchoring the footings of the structure in solid bedrock, the structure will remain in place even if the surface creeps.



Since ***WATER*** is a major factor in most mass wasting problems, control of water on the surface and below ground figures prominently in most mitigation methods.

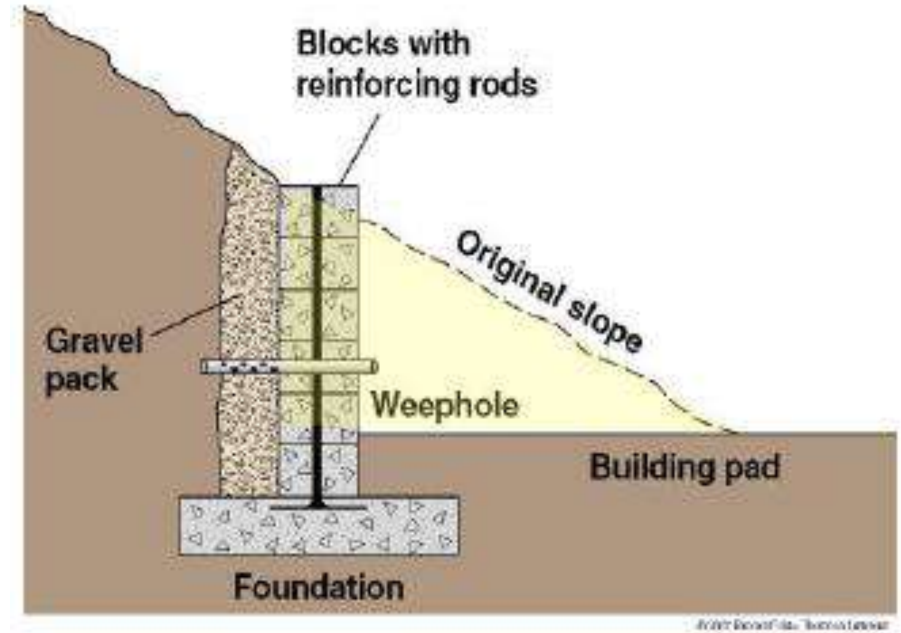
Water within the ground can be controlled by **hydrauger holes**: horizontal holes drilled into the ground and lined with perforated pipe. Excess water leaks into the pipes and flows into other pipes that take it away from the slide-prone area.

Buttress fills: compacted earth that is laid onto a slope to hold it in place : commonly used to stabilize slopes.
A buttress fill used together with internal and external drainage systems, such as shown in the diagram below, makes for a very stable slope.

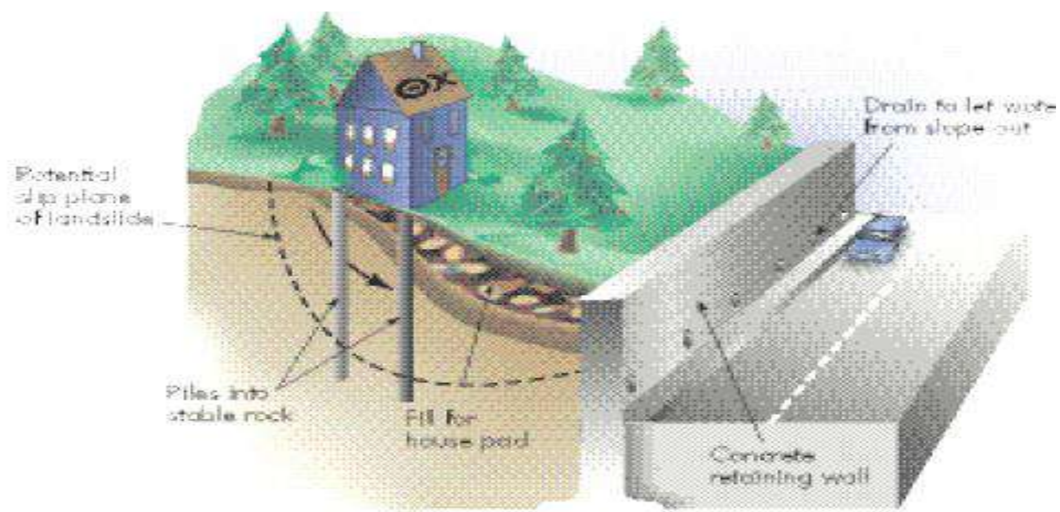


Retaining devices are also commonly used to stabilize slopes, typically in places where the base of the slope has been cut away to create more flat building area.

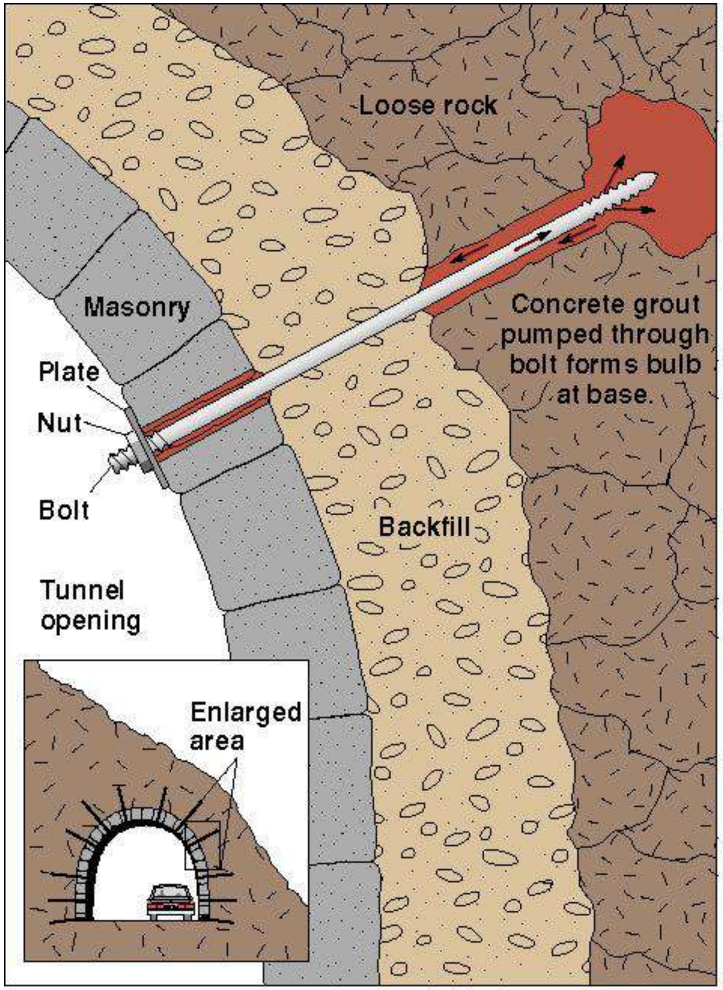
Retaining walls must be strong enough to replace the resisting force supplied by the original slope. It must also be equipped with a water drainage system, The layer of gravel in back of the wall allows water behind the wall to drain into perforated pipes, called **weepholes**.



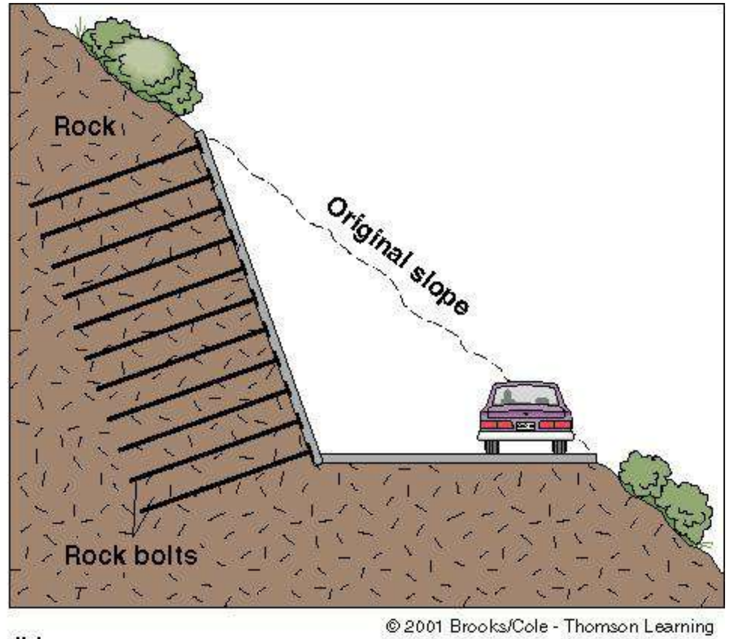
These walls can be constructed of concrete or brick, stone-filled wire baskets called *gabions*, or a series of piles of long concrete, steel, or wooden beams driven into the ground



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.



(a)



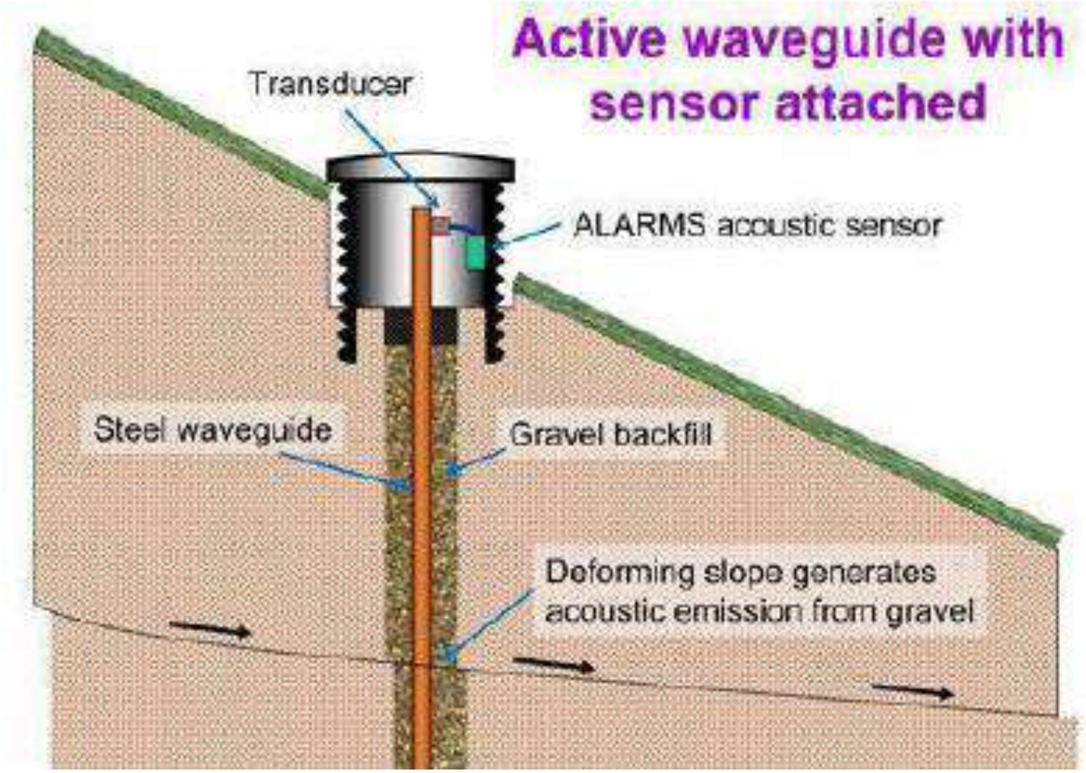
(b)

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.

Landslide Warning Systems: **They** **do not prevent landslides, but they can provide time to evacuate people and stop trains or reroute traffic.**

Hazardous areas can be visually inspected for apparent changes, and small rockfalls on roads and other areas can be noted for quick removal. Human monitoring has the advantages of reliability and flexibility, but becomes difficult during adverse weather and in hazardous locations.

Other warning methods include electrical systems, tilt meters, and geophones that pick up vibrations from moving rocks.

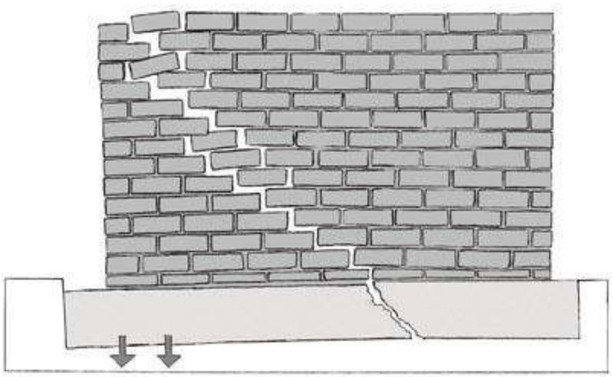


A diagram of the acoustic monitoring system. (Credit: Image courtesy of Engineering and Physical Sciences Research Council)

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.**



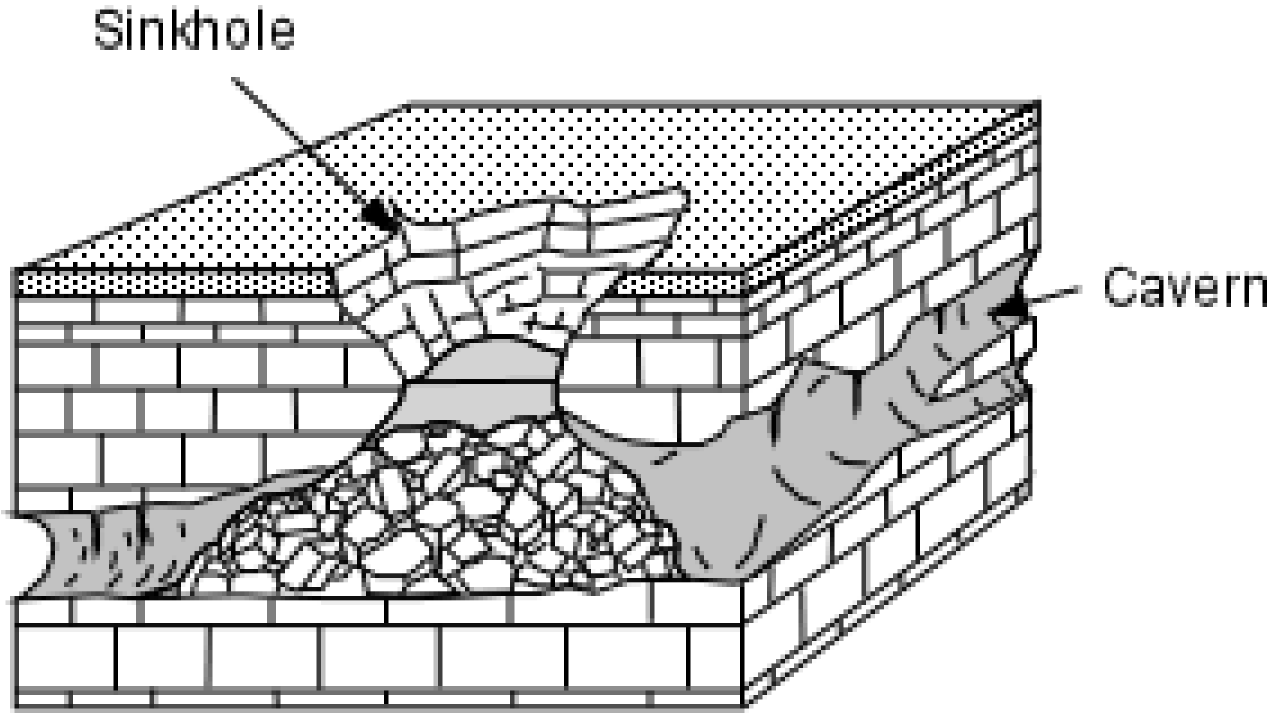
Mitigation of subsidence is accomplished by:

- **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.

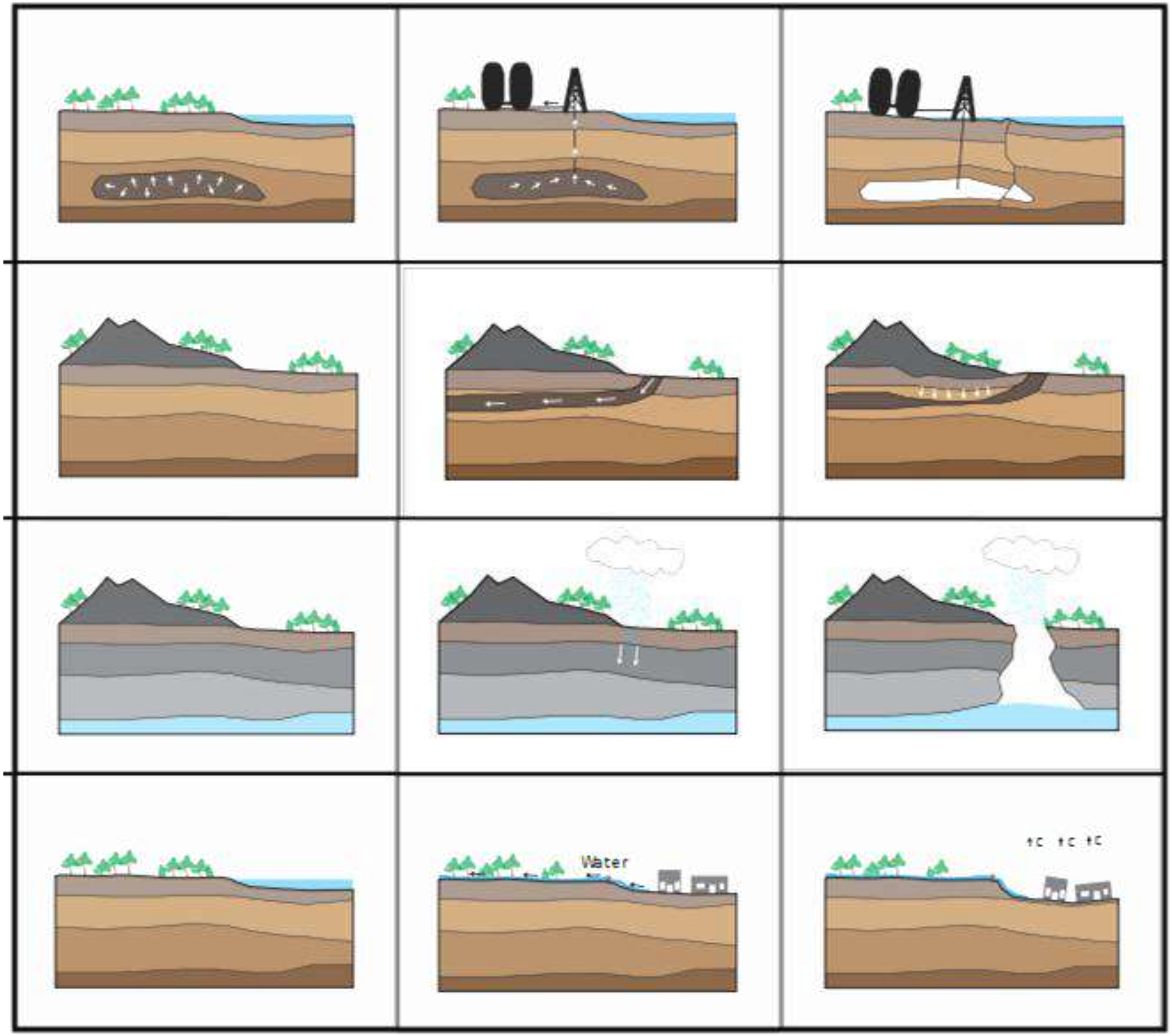
The mechanisms of subsidence include:

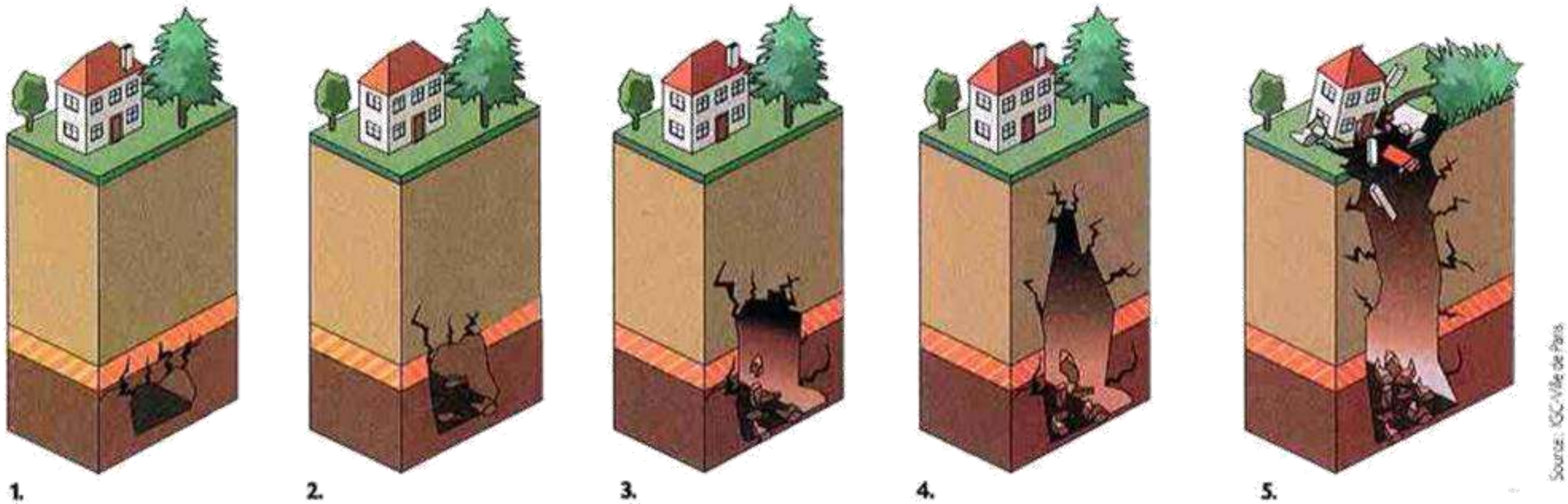
- compaction;
- consolidation;
- plastic outflow of weak layers (organic, silty layer near surface, etc.);
- collapse of subsurface openings.

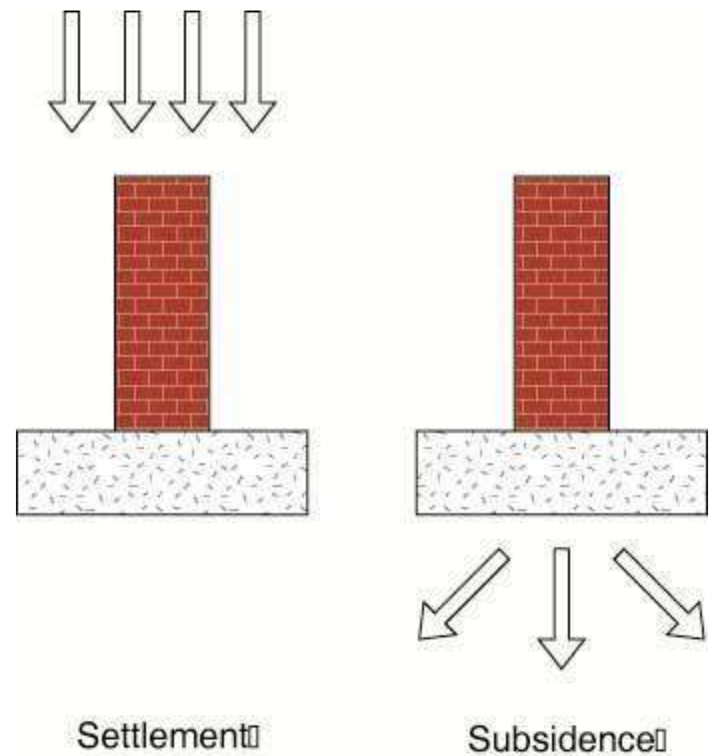


sinkholes can form in any area where highly water soluble rocks occur close to the surface. Such rocks include rock salt made of the mineral halite, and gypsum deposits, both of which easily dissolve in groundwater.

Causes of Subsidence





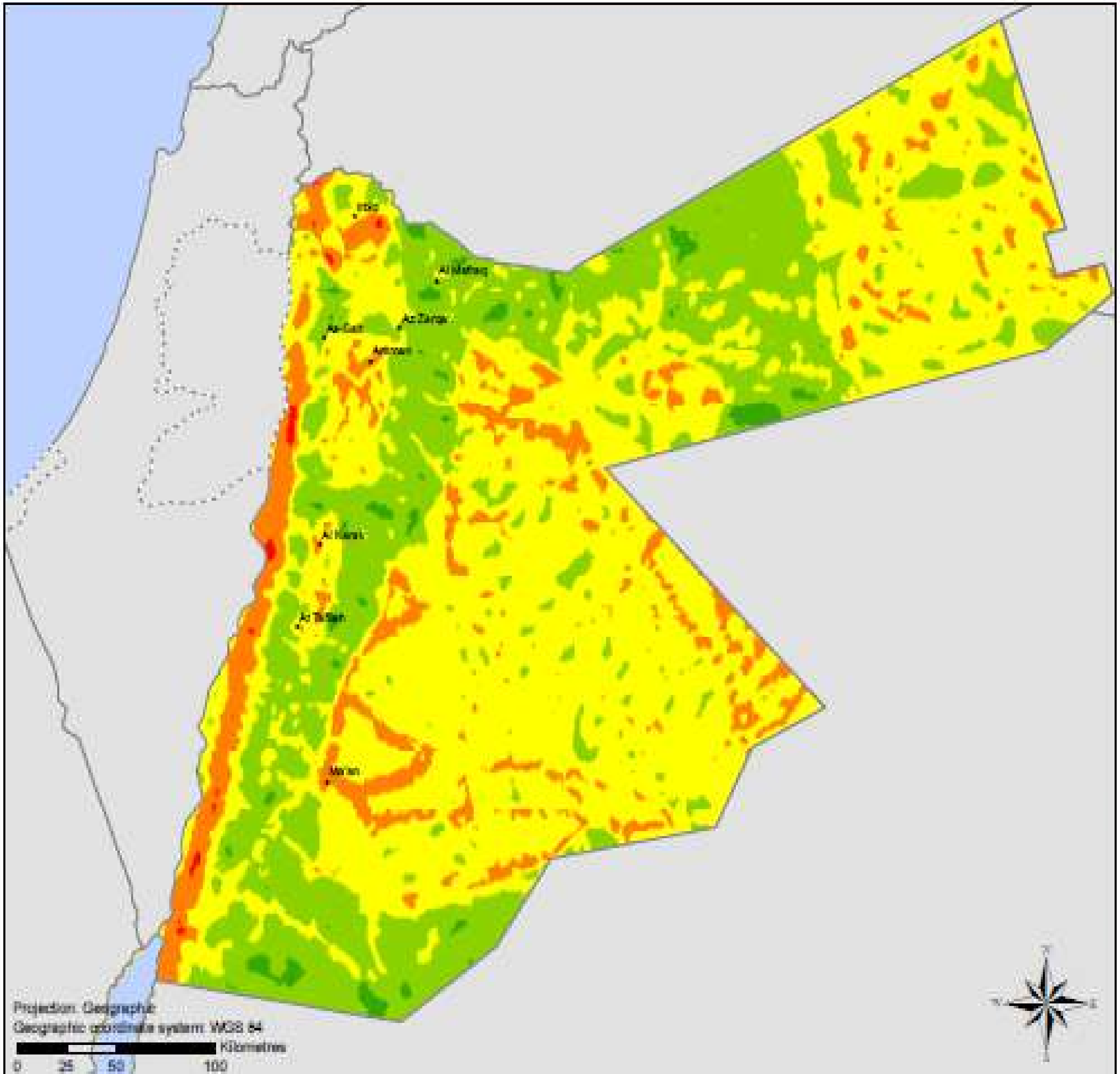


Settlement occurs due to downward pressure.

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.

Jordan: Landslide Hazard Distribution Map

World Health Organization
Regional Office for the Eastern Mediterranean



Legend

Intensity level *(WHO,2007)*

- Very low
- Low
- Medium
- High
- Very high
- No data

International boundaries *(UN, 2007)*

Major cities *(DCW, 1993)*

Disclaimer

The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

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Contacts

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Engineering Geology

Engineering Geology is backbone of civil engineering

10. Deformation of rocks (Geological Structures)

Eng. Iqbal Marie

Behavior of materials (rocks) depend on several factors:

Temperature – high temperature : ductile behavior
low Temperature : brittle behavior

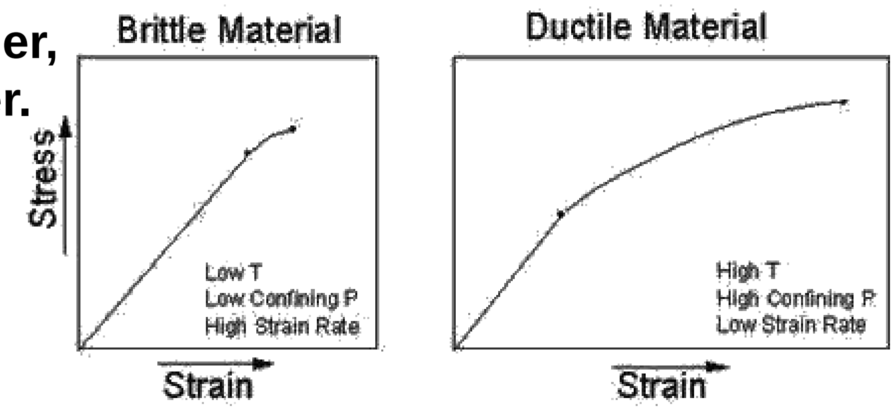
Confining Pressure –
At high confining pressure : materials are less likely to fracture.
At low confining stress, material will be brittle and tend to fracture.

Strain rate:
At high strain rates material tends to fracture.
At low strain rates more time is available for individual atoms to move, therefore ductile behavior

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.

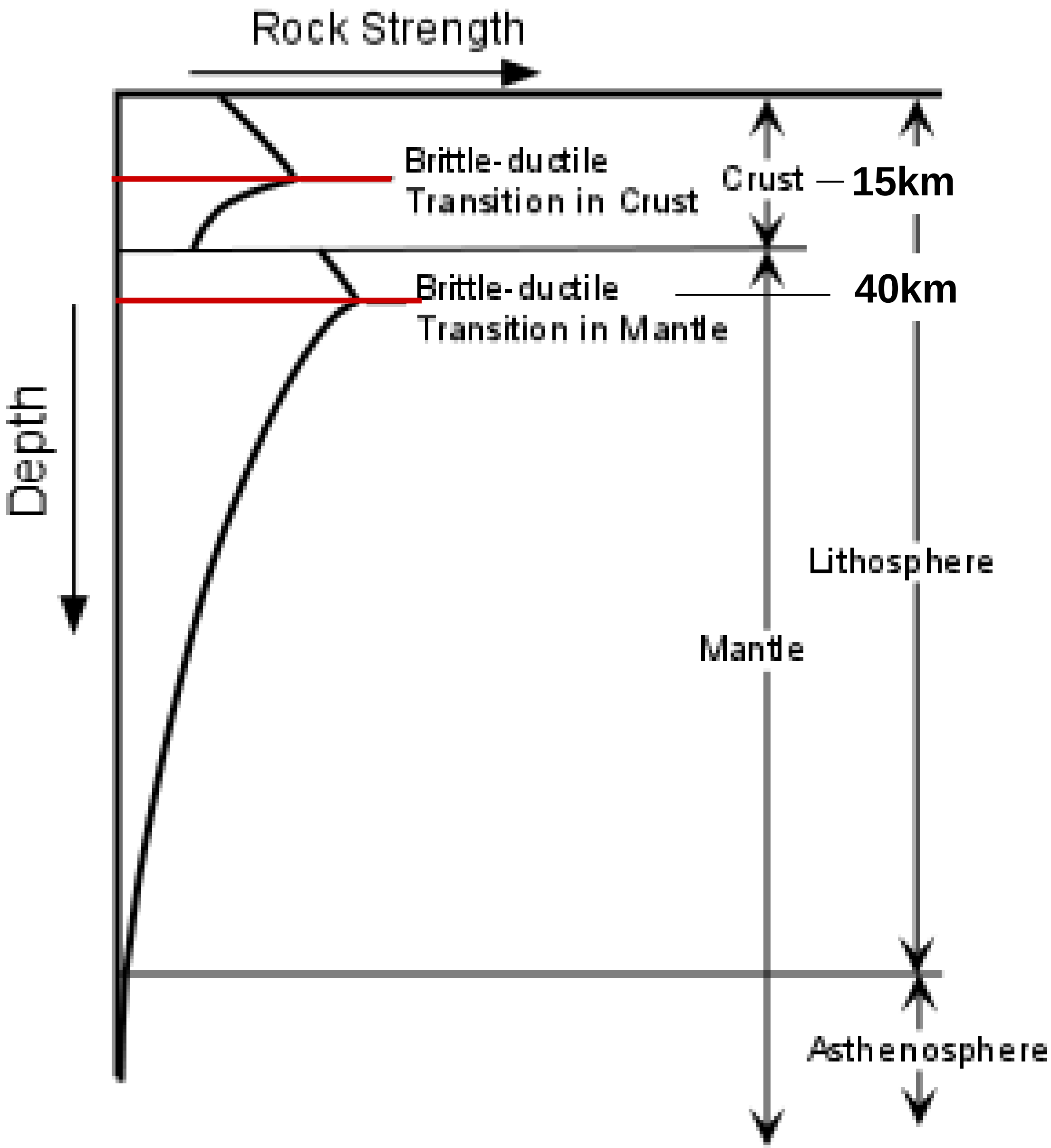
wet rock tends to behave in ductile manner,
dry rocks tend to behave in brittle manner.



Brittle-Ductile Properties of the Lithosphere

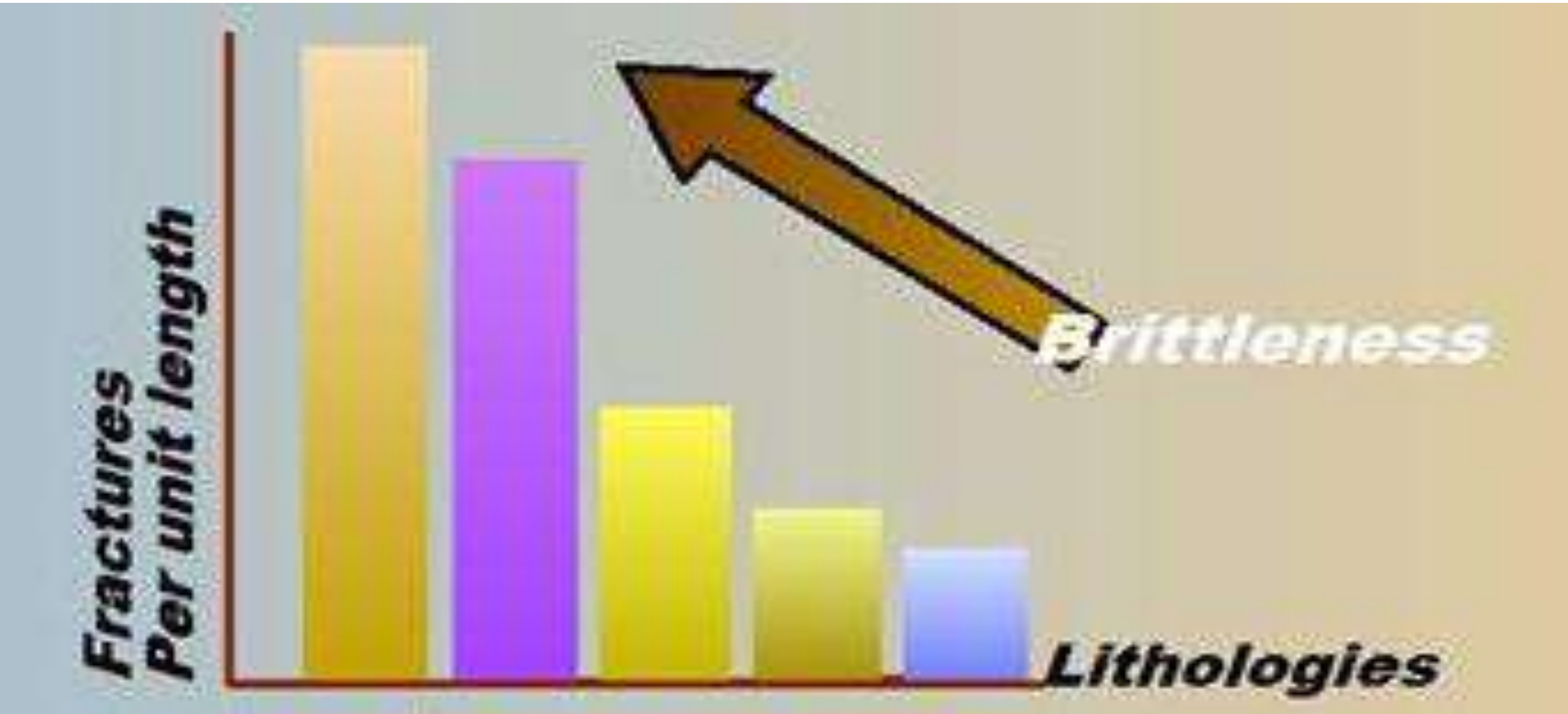
rocks near the surface of the Earth behave in a brittle manner. Crustal rocks are composed of minerals like quartz and feldspar which have high strength, particularly at low pressure and temperature.

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 transition in crust and mantle

Fractures and Rock types



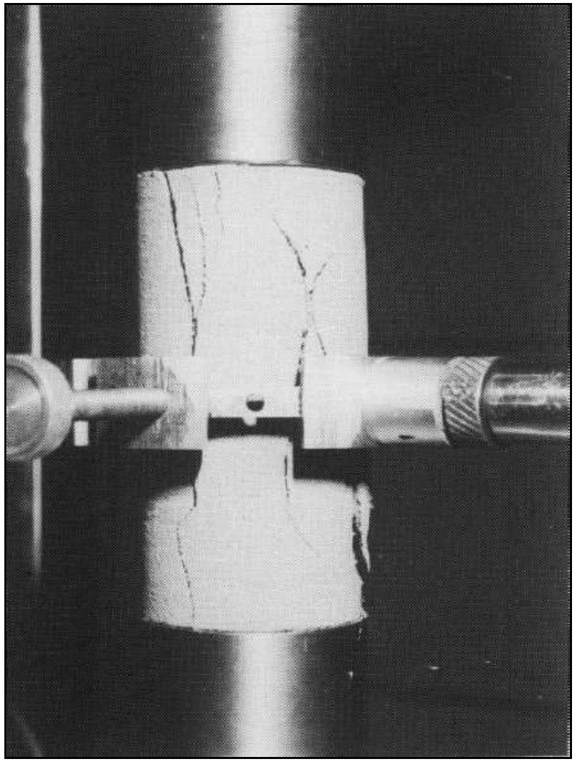
Quartizite

Dolomite

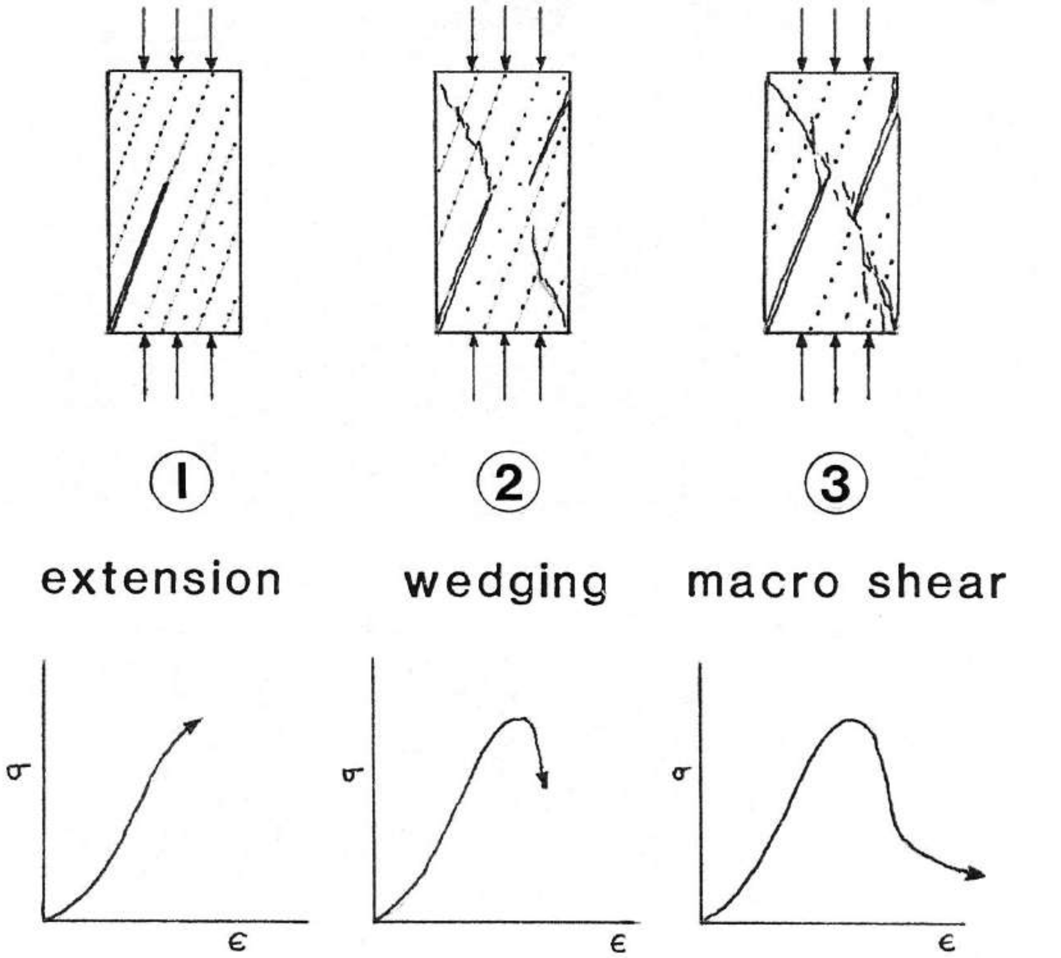
Silica cemented Sst

Calcite cemented Sst

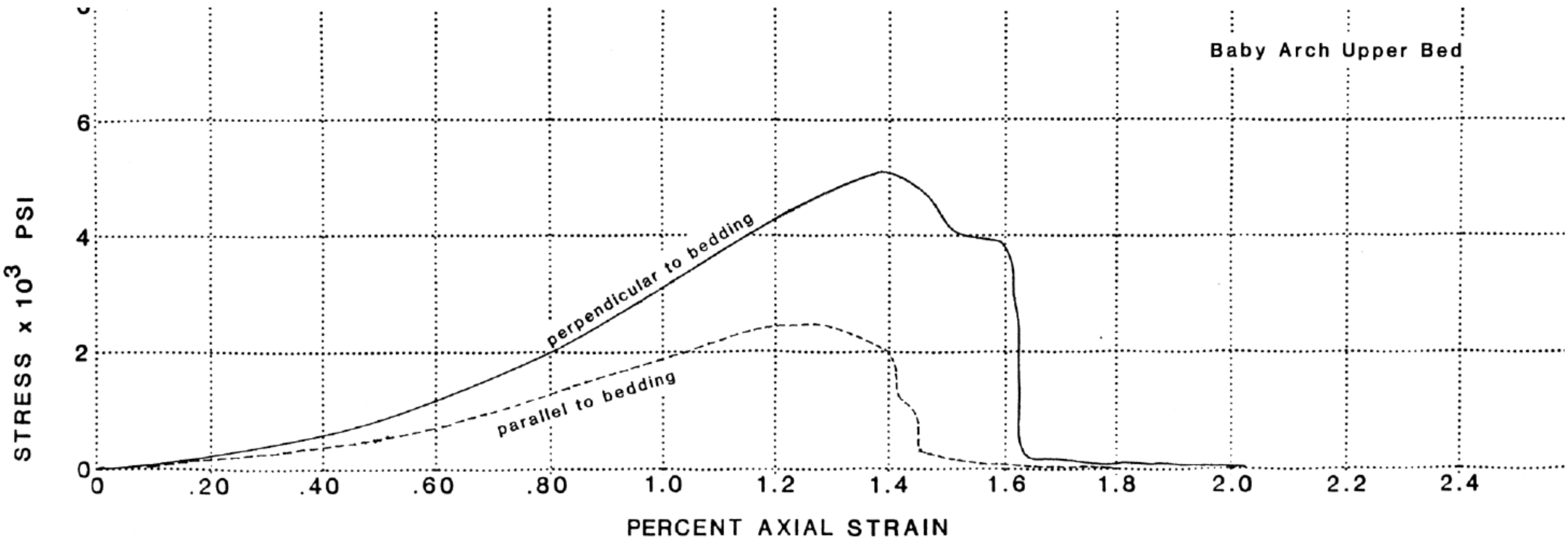
Limestone



- Most rocks are brittle, and break under induced tension when compressed
- Even modest lateral confinement can exert significant increase in observed strength.
- This is why tensile reinforcement provided by rock bolts can be so effective

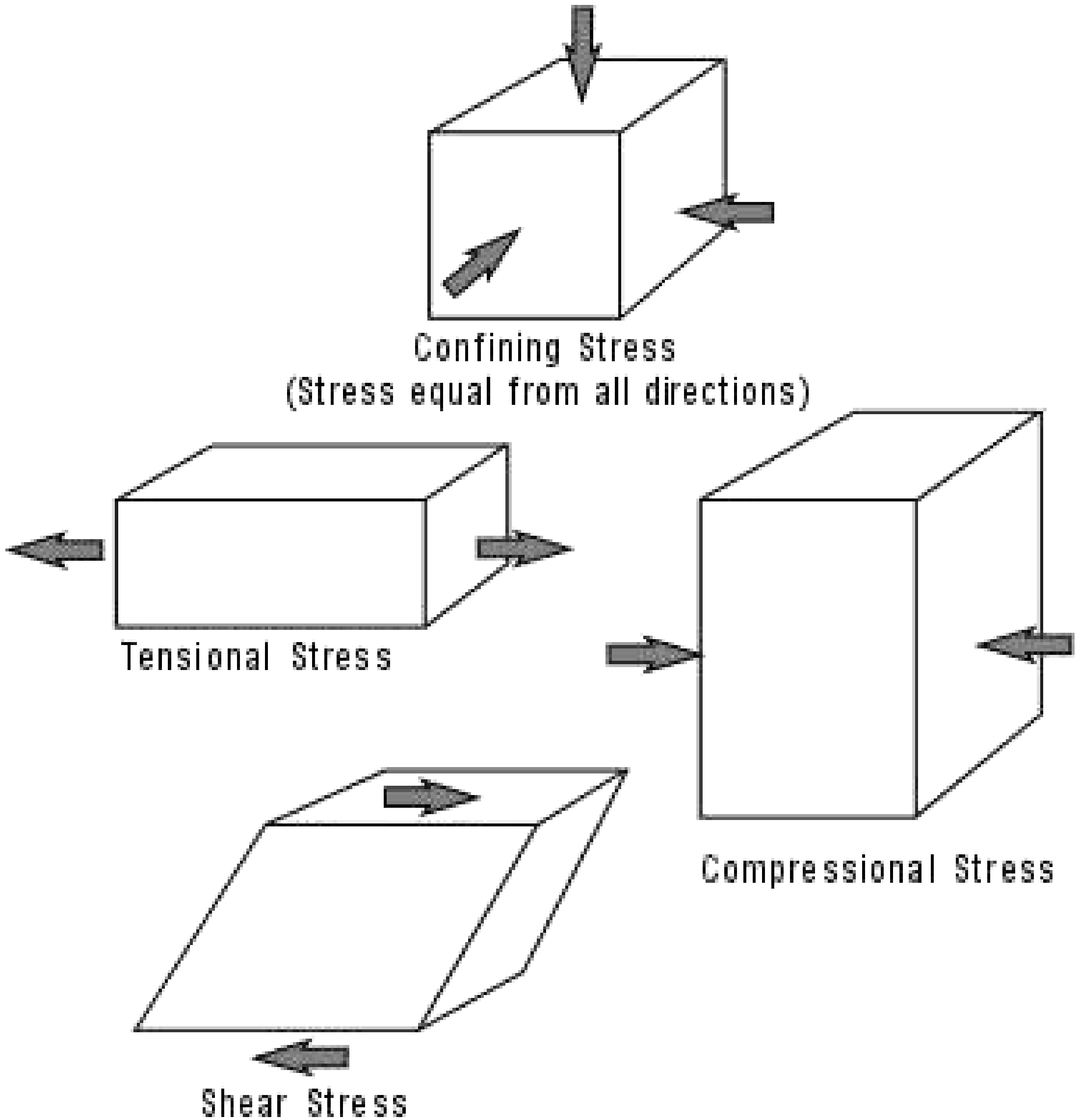


Physical behavior of rock cylinders with bedding oriented from vertical

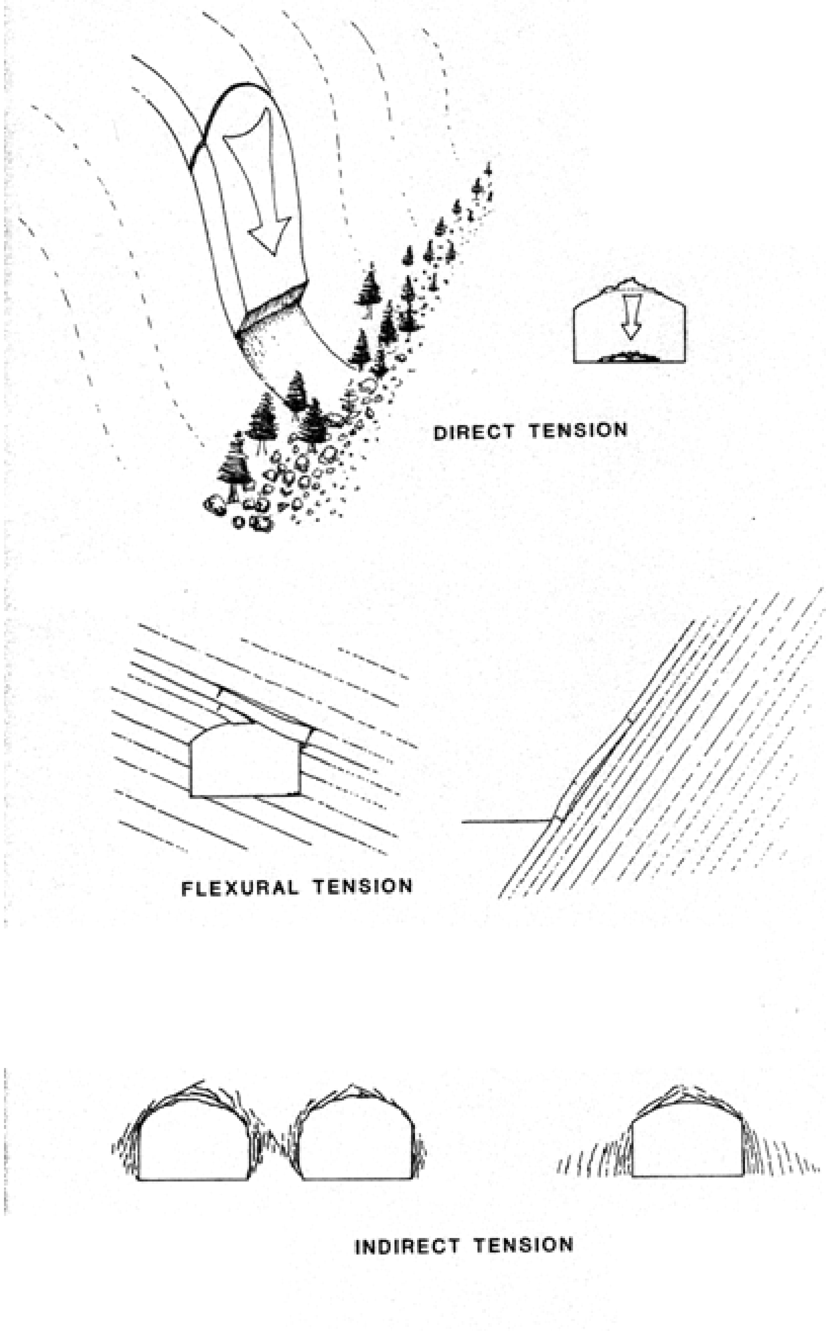


Stress-strain plots for the same samples of Sandstone, tested parallel and perpendicular to the bedding. anisotropy

Rocks are continually being subjected to forces that tend to bend them, twist them, or fracture them. So they deform (change shape or size).



Tensile Failure Modes



TENSILE FAILURE MODES

- **Rock is much weaker in tension than in compression.**
- **Most rock failures involve tensile fractures**
- **Three types: direct tension; flexural tension; and indirect tension**

In rock, the tensile strength can vary between 1/12th and 1/70th of the compressive strength, depending on porosity and weathering.

Crust Deformation

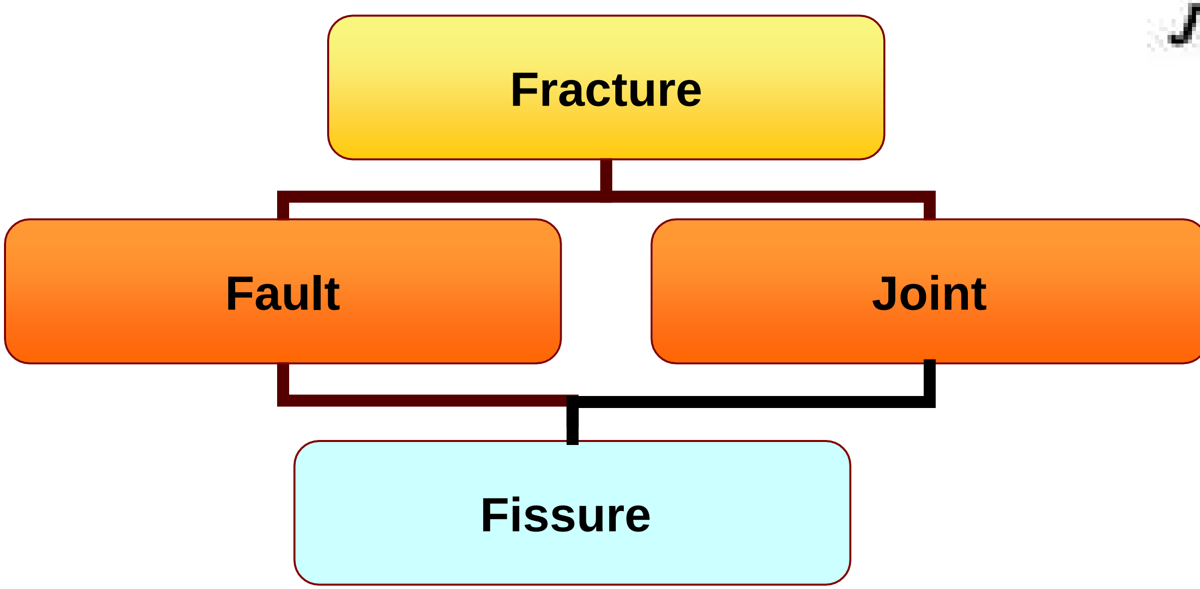
Brittle Deformation of the Crust

Brittle deformation results in fracturing of the rocks. There are two principal kinds of fractures:

- **Joints involve fracturing without movement**
- **Faults are fractures where rocks on one side of the fracture move relative to the other side.**

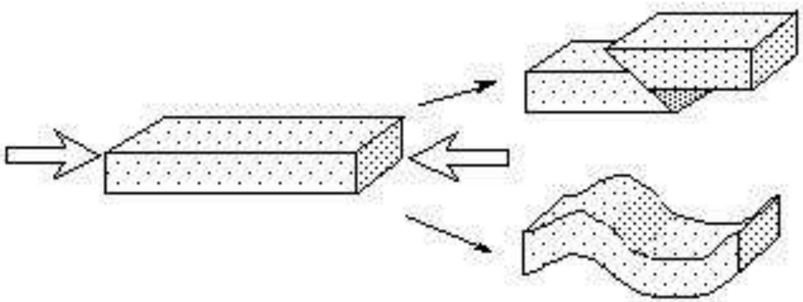
Faults	الفوالق
Folds	الطيات
Joints	الفواصل و الشروخ

Ductile Deformation of the Crust: **Folds**

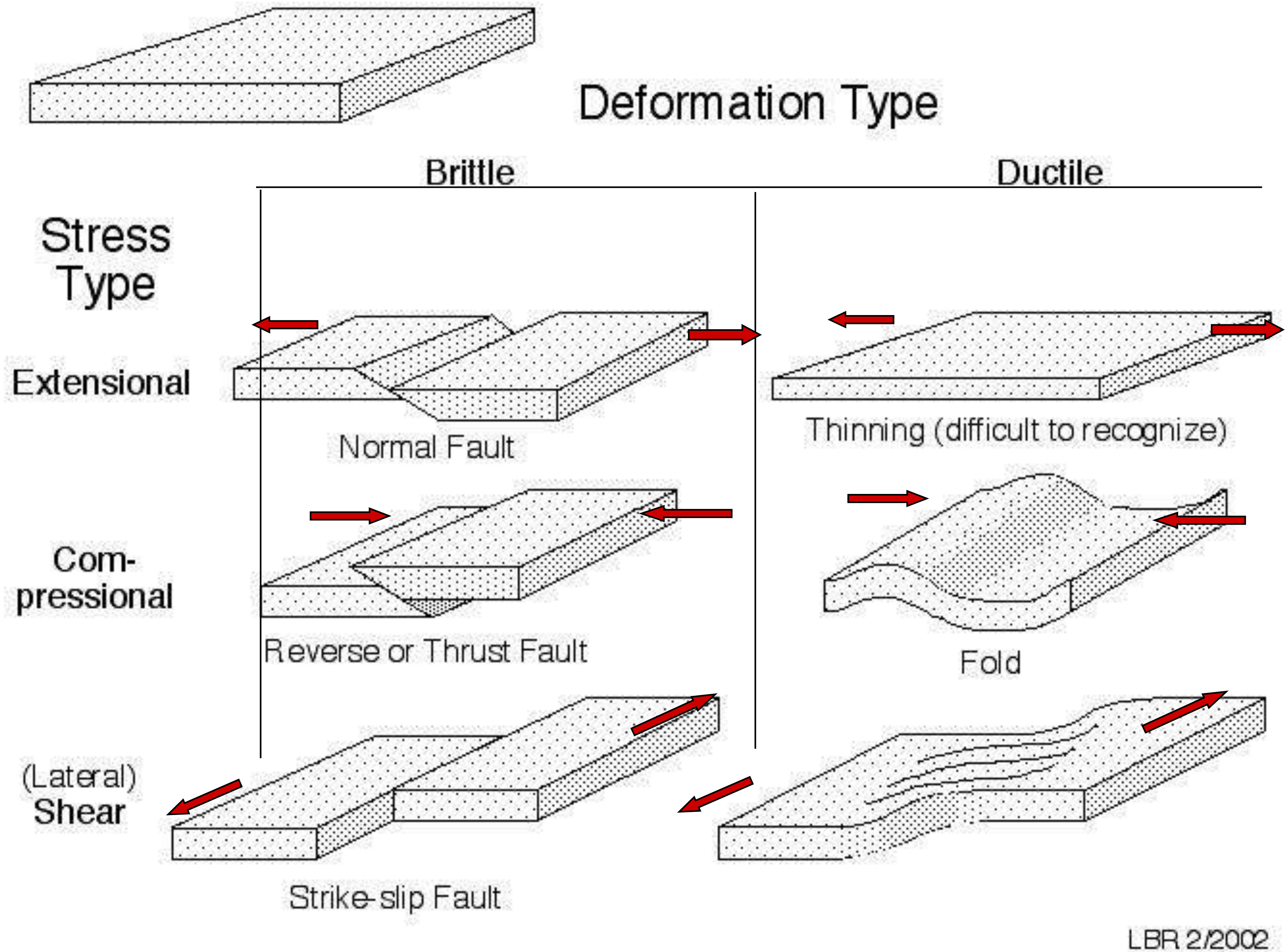


Types of Rock Deformation

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



LBR 2/2002
rev. 6/2002


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

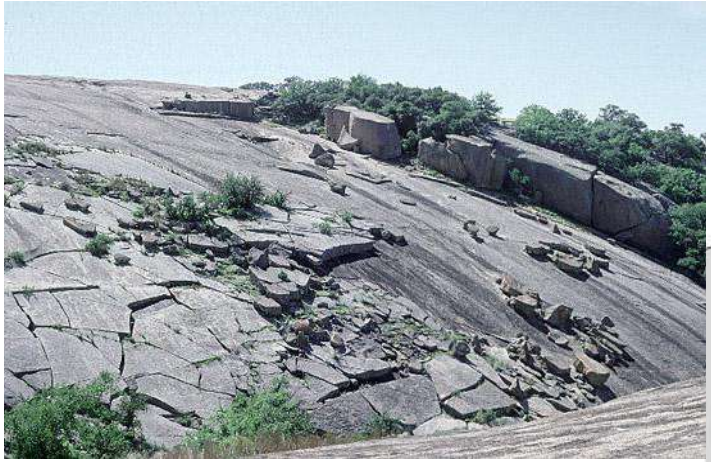
Joints

Types of Joints:

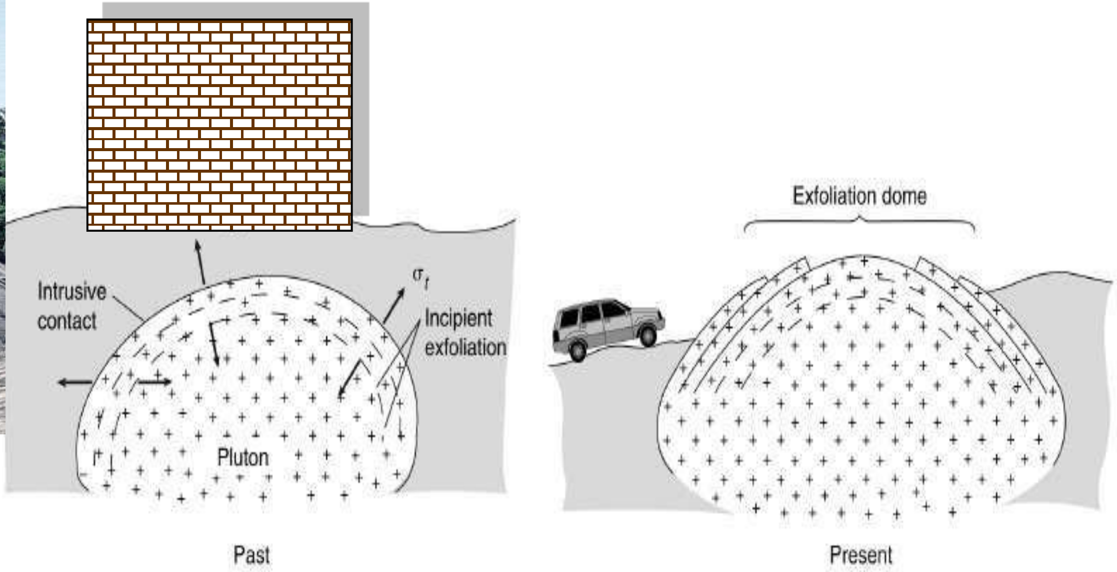
Tectonic joints **: caused by <u>regional stresses in the crust</u> and tend to occur in systematic orientations over fairly broad areas.**

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

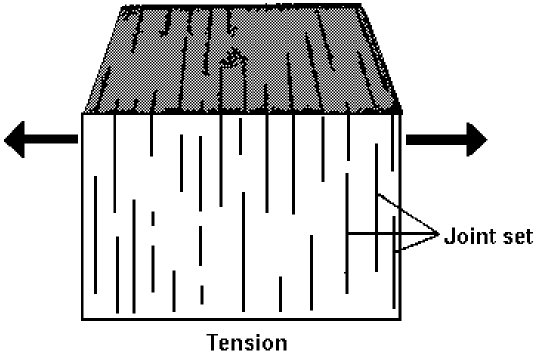
Exfoliation joints: **often occur in <u>intrusive rocks</u>. They are most likely due to the rocks forming deep in the crust under pressure. As the rocks are brought to the surface by uplift and erosion, they expand and fracture.**

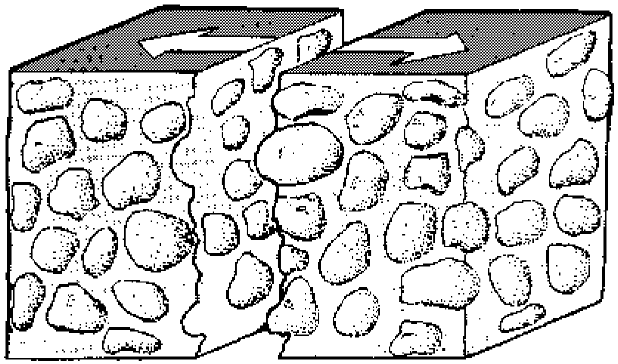


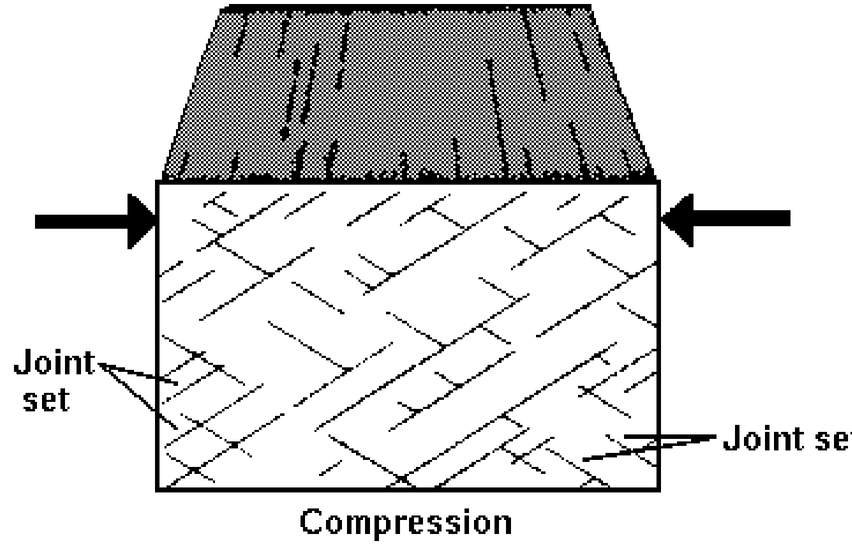
Exfoliation



Joints







Nomenclature of Joints

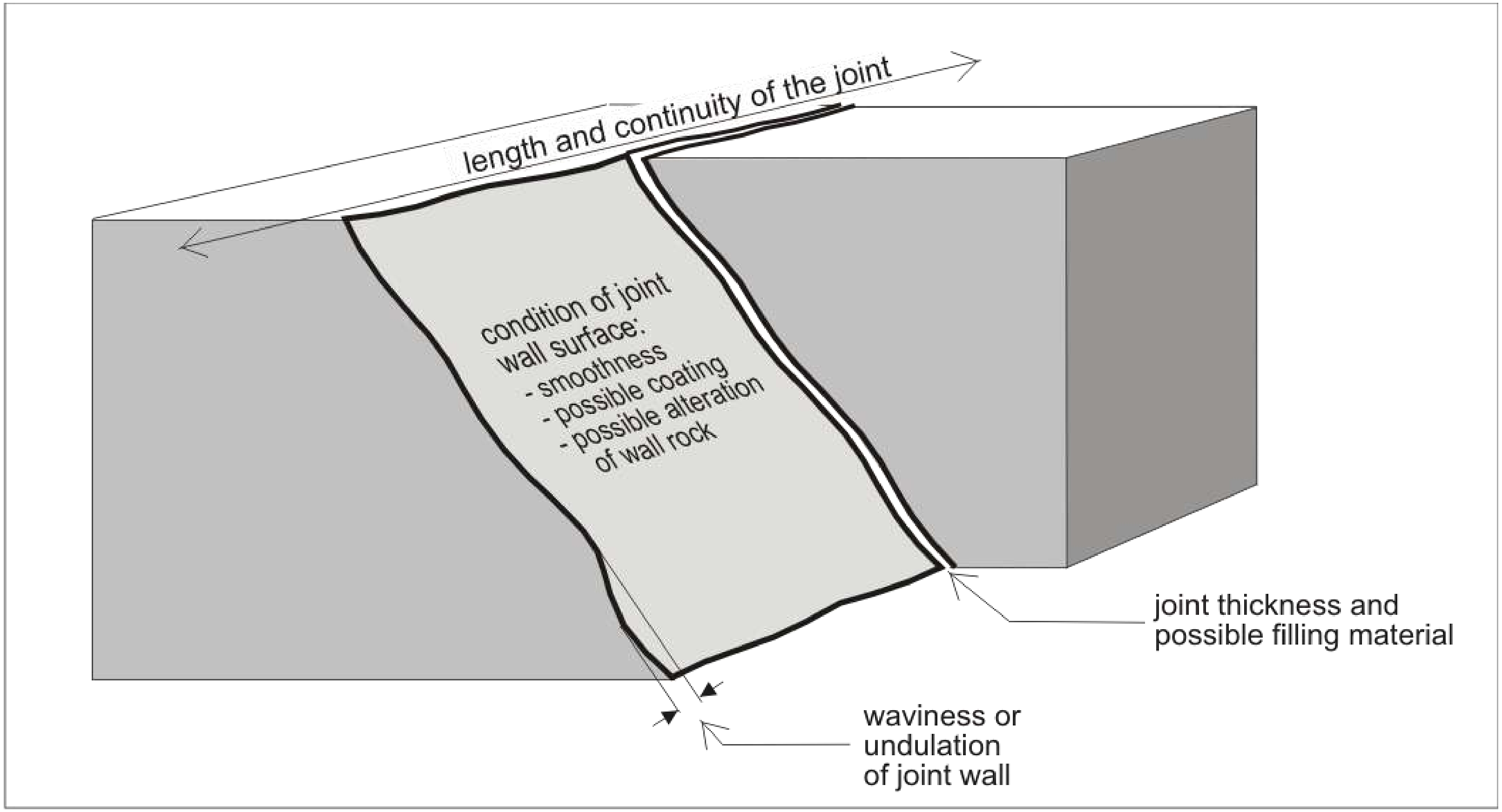
Joints are fractures along which little or no displacement has occurred and are present within all types of rocks. At the ground surface, joints may open as a consequence of denudation, especially weathering, or the dissipation of residual stress.

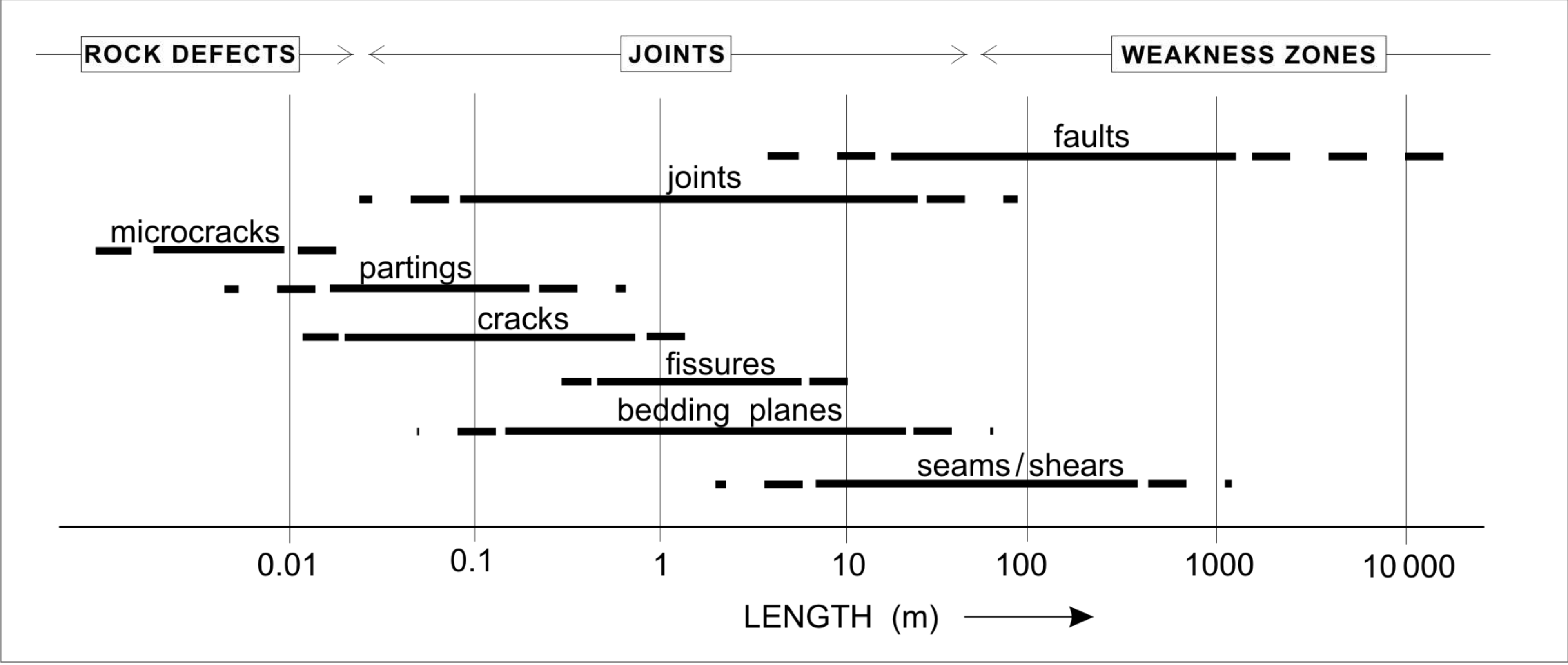
A group of joints that run parallel to each other are termed a joint set, whereas two or more joint sets that intersect at a more or less constant angle are referred to as a joint system. If one set of joints is dominant, then the joints are known as primary joints, and the other set or sets of joints are termed secondary.

The main joint characteristics

The characteristics of joints include:

- **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**





http://www.rockmass.net/articles/geological_features/joints_and_jointing.html

Joints are formed through failure of rock masses in tension, in shear or through some combination of both. Rupture surfaces formed by extension tend to be clean and rough with little detritus.

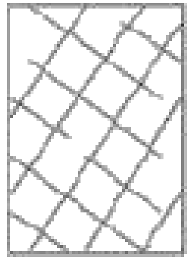
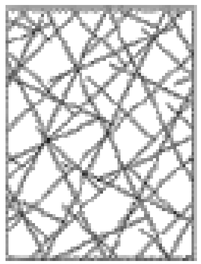
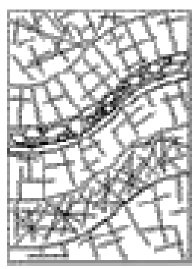
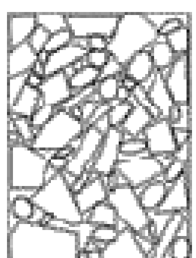
Joints can be measured and characterized in different ways, manly from:
field observations at terrain surface or in tunnel :

drill core logging
seismic or sound velocities

1. Degree of jointing.
This property can be measured as rock quality designation (RQD),

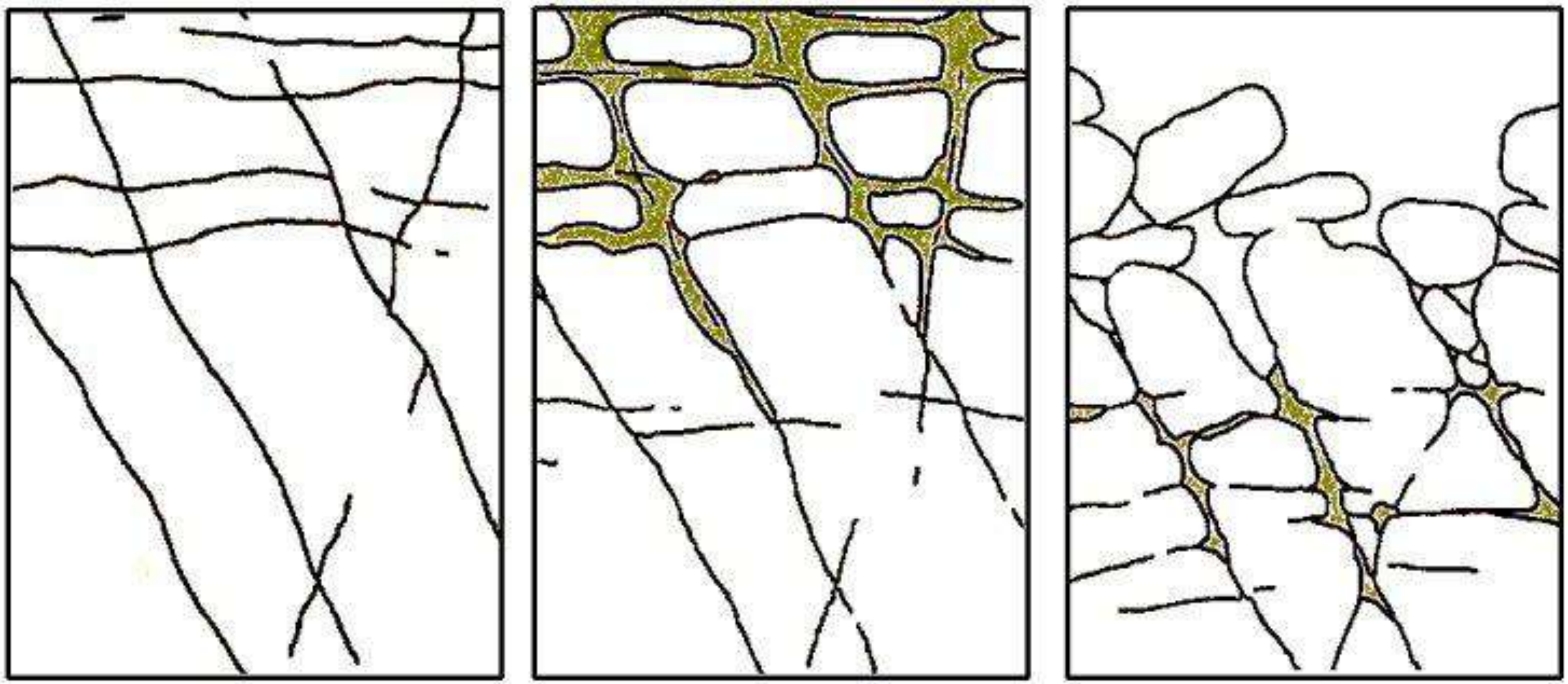
2. Orientation of joints and joint sets.
This has special interest when the joint set is unfavourably orientated parallel or at a small angle to a tunnel or cavern. This feature is used as input to the RMR system

3. Pattern of joints

ROCK MASS STRUCTURE	
	BLOCKY – very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal joint sets
	VERY BLOCKY – interlocked, partially disturbed rock mass with multi-faced angular blocks formed by for or more joint sets.
	BLOCKY/FOLDED – folded and faulted with many intersecting discontinuties forming angular blocks.
	CRUSHED – poorly interlocked, heavily broken rock mass with a mixture of angular and rounded blocks.

Joint spacing are between 2.5 m and 38m

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.

*** الآثار الهندسية للفواصل و الشروخ :-**

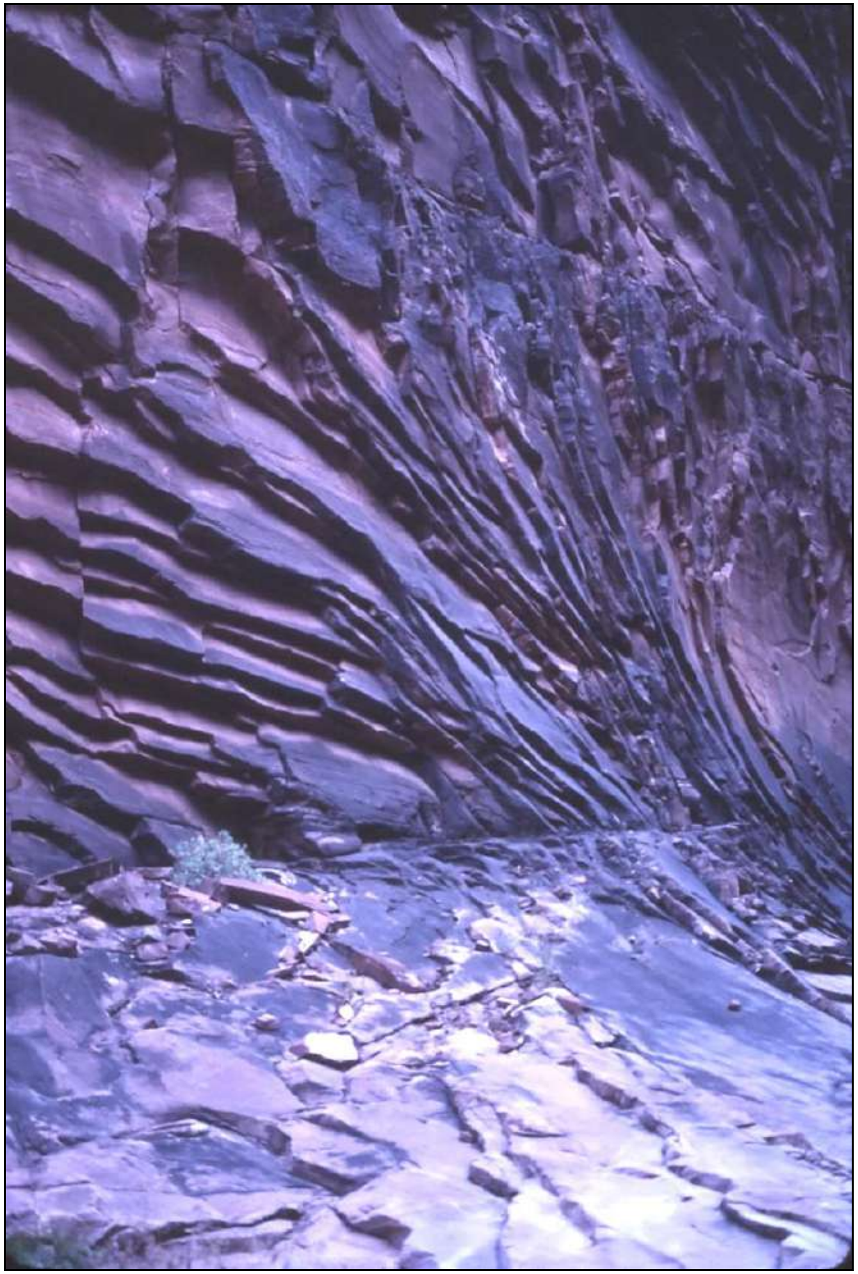
١ـ تسبب حدوث تغير في الخواص الهندسية و الطبيعية للصخور .

٢ـ تعمل الفواصل كقنوات تجميع المياه السطحية أو الجوفية.

٣ـ تملأ الفواصل بمواد رسوبية ذات مقاومة ضعيفة .

Joint: Natural Extensional Fracture

Vein: Fracture filled with mineral precipitate or rarely mud.

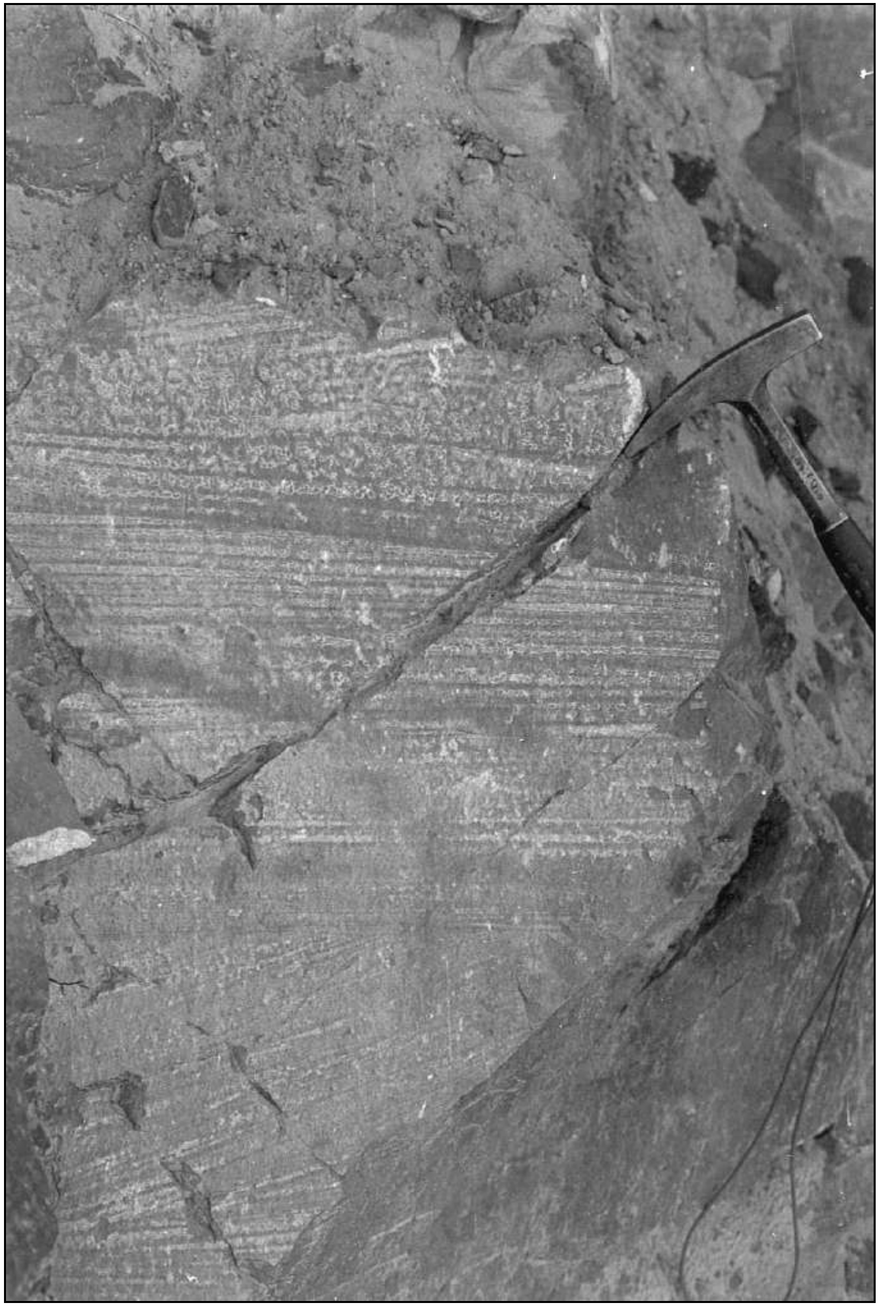


Intensity of joints

- **Joint intensity refers to how numerous joints are; e.g. the physical separation, or, spacing, between adjacent joints**
- **The stiffness of a rock mass depends on the stiffness of the rock fabric AND the joint intensity, aperture, and infilling.**

Eg. Salt within a rock

There are three ways whereby salts within a rock can cause its mechanical breakdown: by pressure of crystallization, by hydration pressure, and by differential thermal expansion. Under certain conditions, some salts may crystallize or recrystallize to different hydrates that occupy a larger space (being less dense) and exert additional pressure, that is, hydration pressure. The crystallization pressure depends on the temperature and degree of supersaturation of the solution, whereas the hydration pressure depends on the ambient temperature and relative humidity. Calculated crystallization pressures provide an indication of the potential pressures that may develop during crystallization in narrow closed channels .



Surface Roughness

healed joints

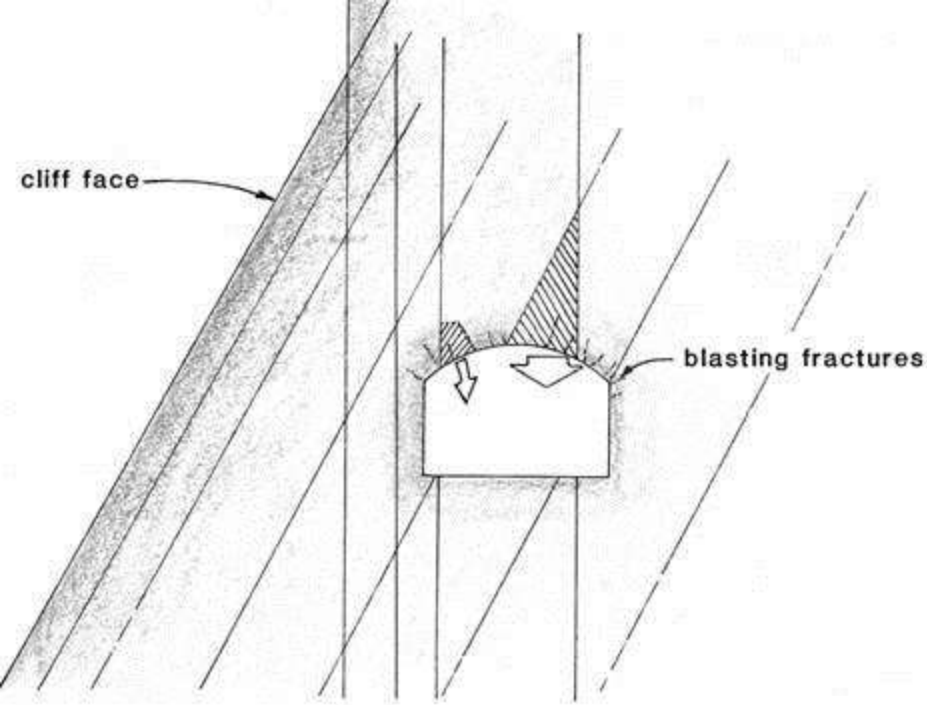
- Groundwater preferentially flows through joints in rock
- The chemistry of that groundwater determines whether the joints experienced solutioning or infilling.
- This shows a healed joint with mineralization halos

The effect of discontinuities in a rock mass can be estimated by comparing the in situ compressional wave velocity, V_{cf}, with the laboratory sonic velocity, V_{cl}, of an intact core sample obtained from the same rock mass. This gives the velocity ratio V_{cf}/V_{cl}. The difference in these two velocities is caused by the discontinuities that exist in the field. For a high-quality massive rock with only a few tight joints, the velocity ratio approaches unity. As the degree of jointing and fracturing becomes more severe, the velocity ratio is reduced . The sonic velocity is determined for the core sample in the laboratory under an axial stress equal to the computed overburden stress at the depth from which the rock material was taken, and at a moisture content equivalent to that of the in situ rock. The field seismic velocity is determined preferably by uphole or crosshole seismic measurements in drillholes or test adits, since by using these measurements it is possible to explore individual homogeneous zones more precisely than by surface refraction surveys.

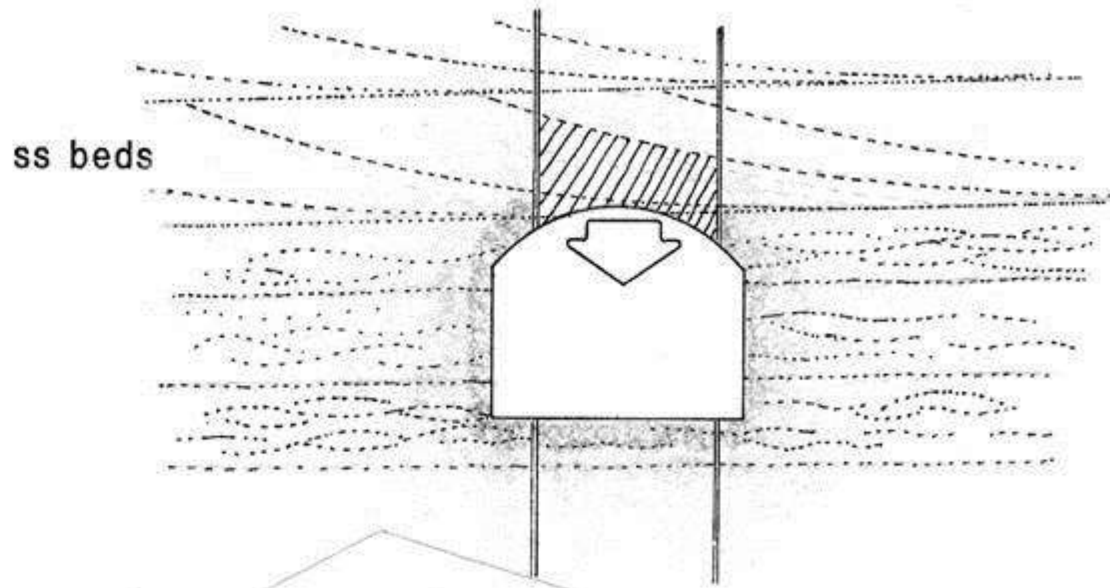
. Classification of rock quality in relation to the incidence of discontinuities

Quality classification	RQD (%)	Fracture frequency per metre	Mass factor (*j*)	Velocity ratio (V_{cf}/V_{cl})
Very poor	0–25	Over 15		0.0–0.2
Poor	25–50	15–8	Less than 0.2	0.2–0.4
Fair	50–75	8–5	0.2–0.5	0.4–0.6
Good	75–90	5–1	0.5–0.8	0.6–0.8
Excellent	90–100	Less than 1	0.8–1.0	0.8–1.0

Tunnel block failure modes caused by the intersection of the tunnel opening with crossing joints



Roof cave-ins in the Glen Canyon Powerplant S during construction in 1958.



Roof pull-out that occurred in the Zion-Mt. Carmel tunnel in 1932.

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

- The depth and length of faults vary greatly. Some faults can be many miles long.

- Earthquakes are caused by **Active faults,** ***that is, faults along which the two sides of the fracture move with respect to each other.***

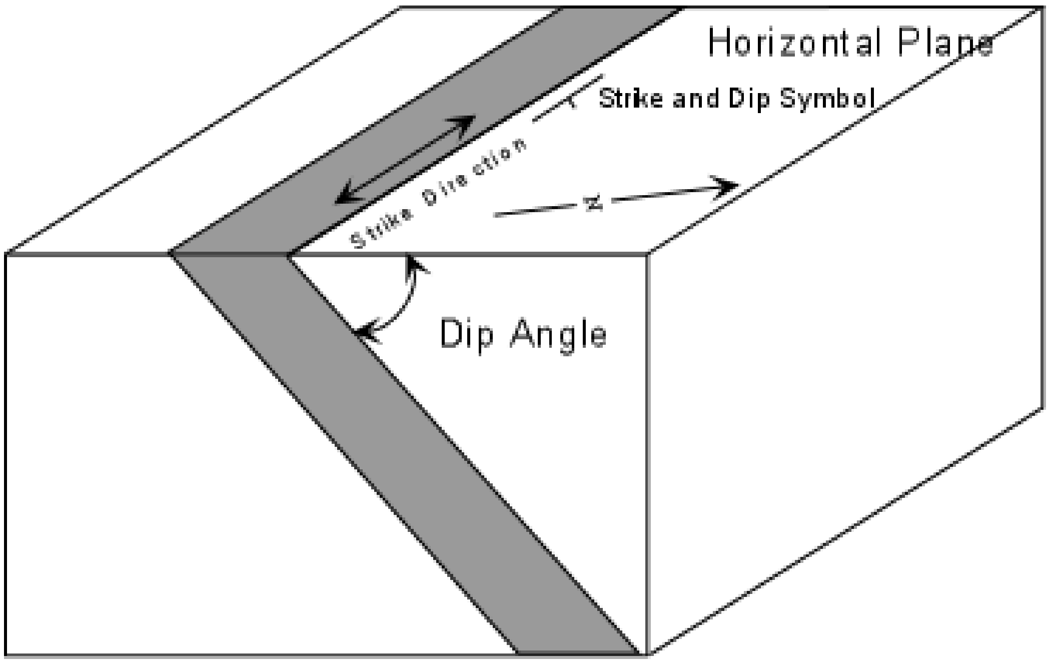
- An earthquake is caused by the sudden movement of the two sides of a fault with respect to another

Define the orientation of a planar feature

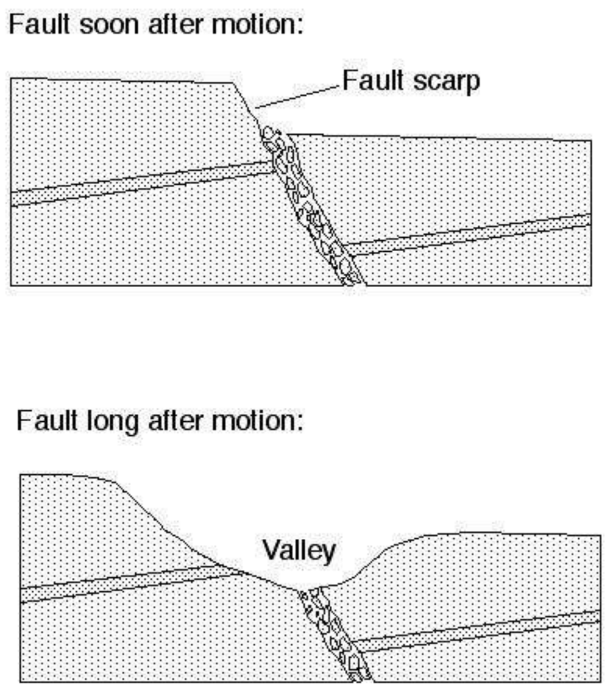
define two terms - strike and dip.

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.**

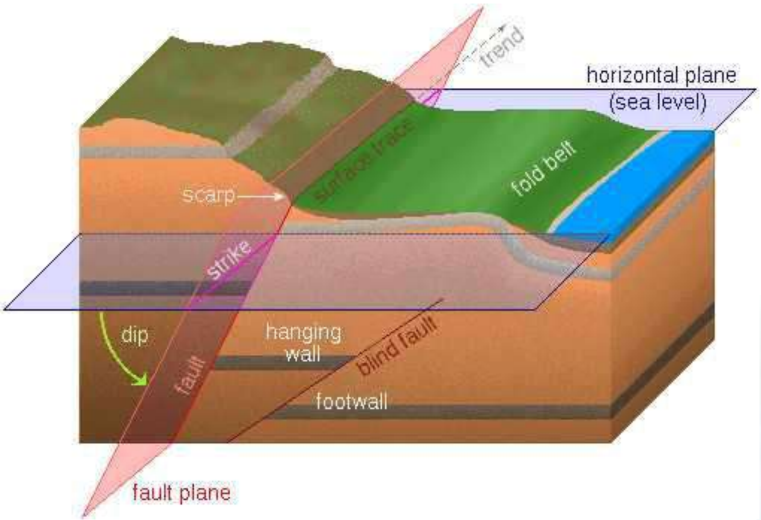


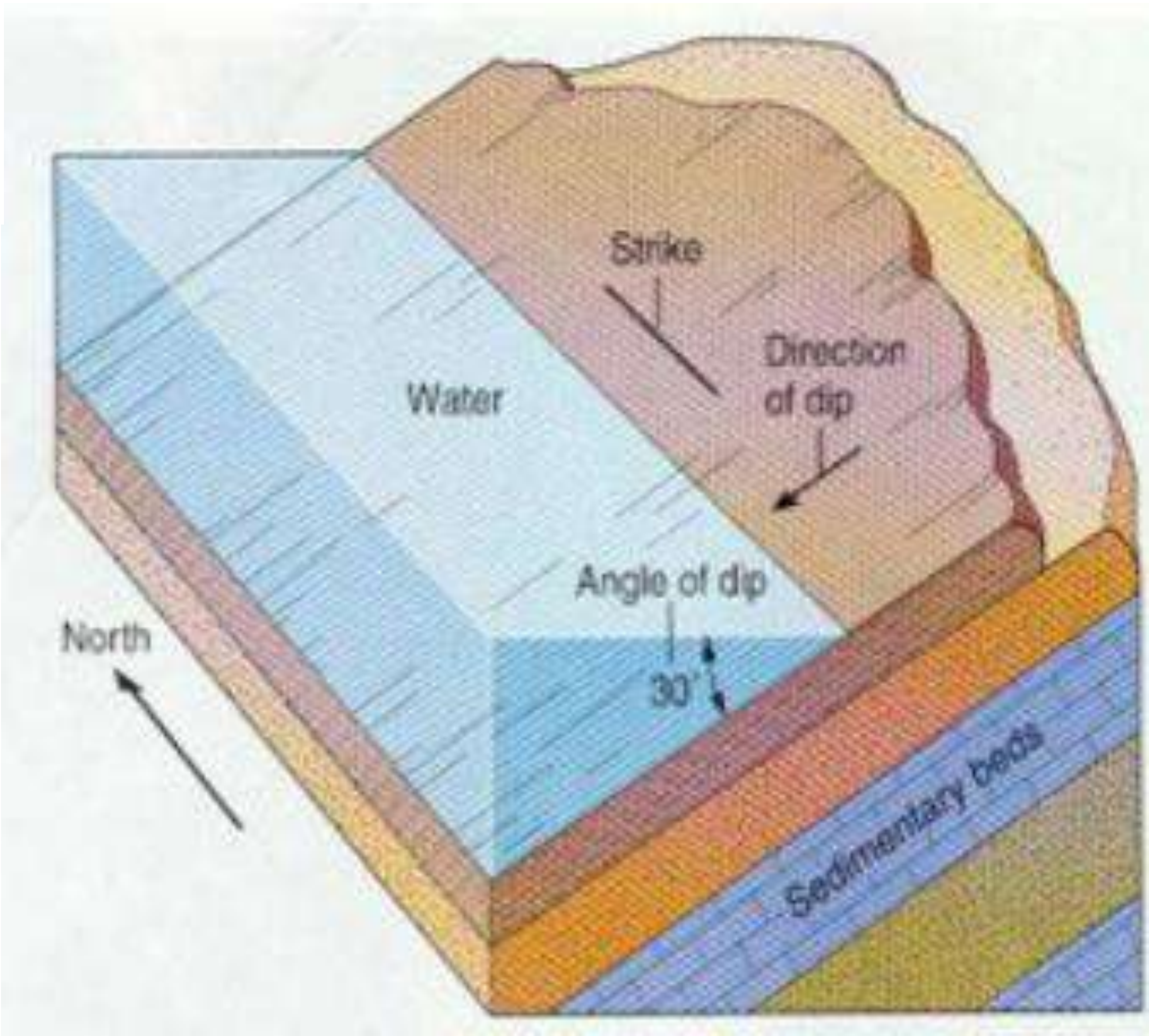
Surface expression of faults



LBR 2/2002

90° dip = vertical fault plane
0° strike = North parallel fault plane



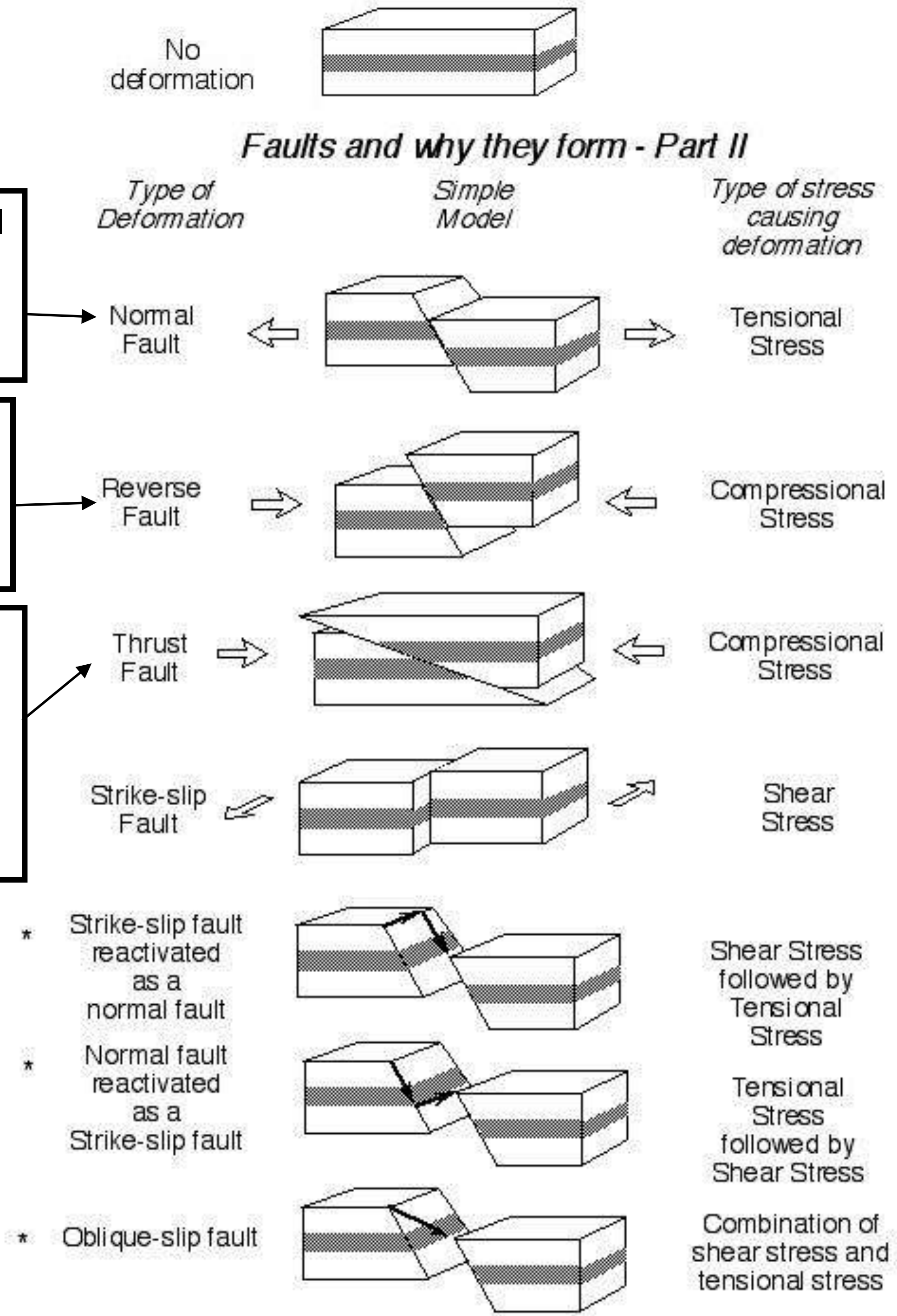


Faults

Normal Faults - result from horizontal tensional stresses in brittle rocks and where the hanging-wall block has moved <u>down</u> relative to the footwall block.

Reverse Faults **- result from horizontal compressional stresses in brittle rocks, where the hanging-wall block has moved <u>up</u> relative the footwall block.**

Thrust Fault- **is a special case of a reverse fault where the dip of the fault is less than 15º. Thrust faults can have considerable displacement, measuring hundreds of kilometers, and can result in older strata overlying younger strata.**

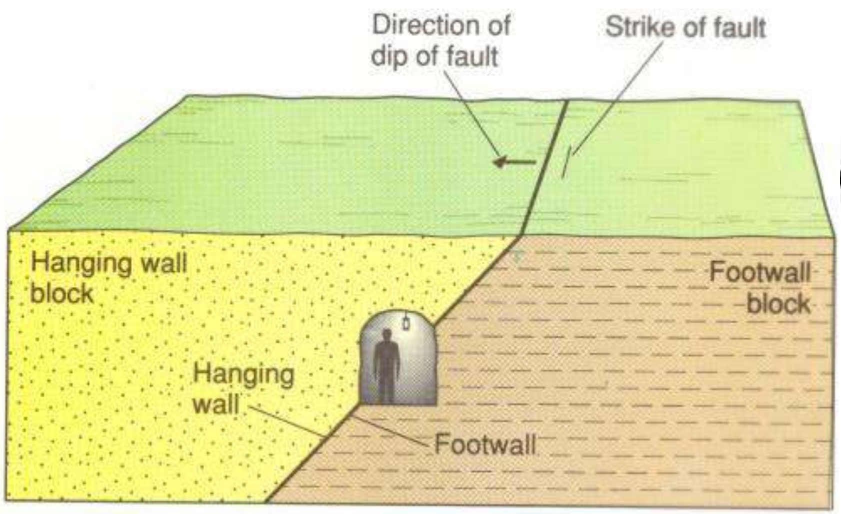


Fault Terminology

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

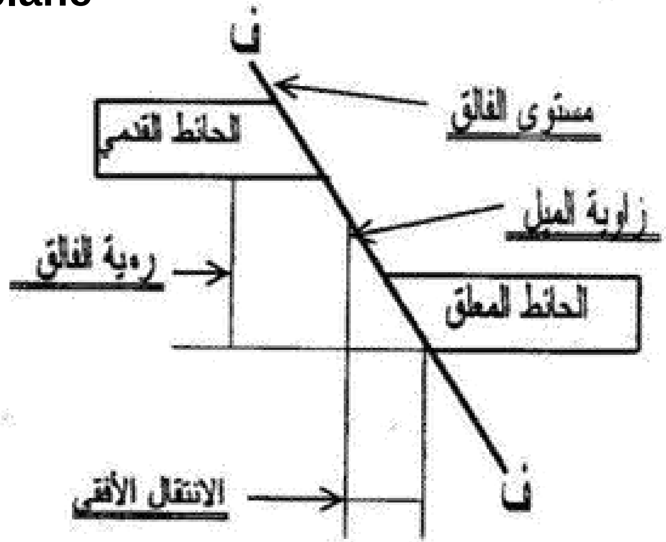
Hanging wall block: rock material above the fault plane

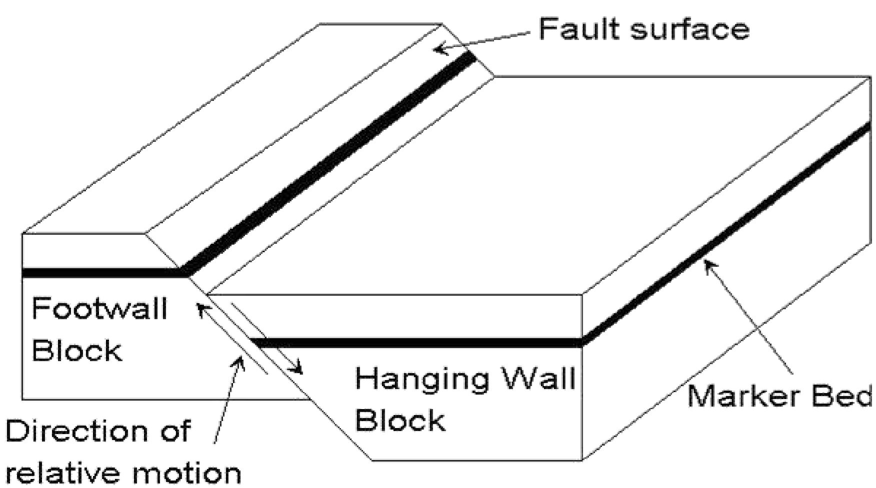
Foot wall: rock material below the fault plane

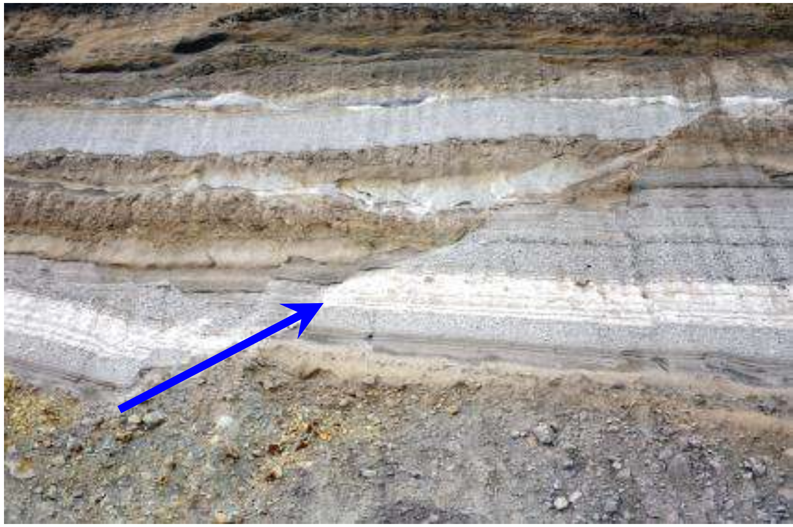


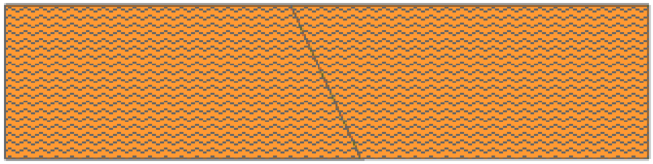
64 Hanging Wall, Footwall Relationship
Figure 15.24

أجزاء الفالق :-

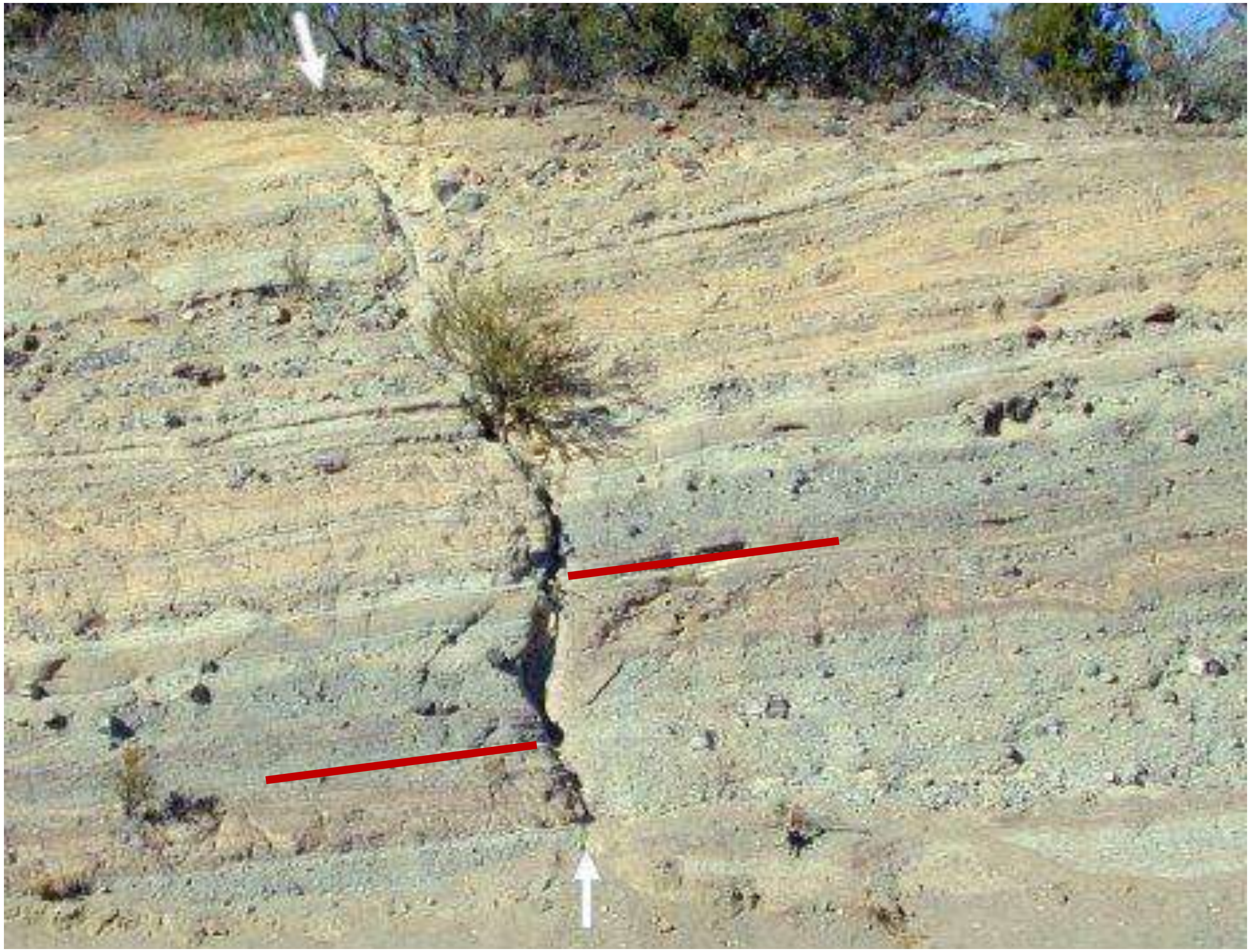


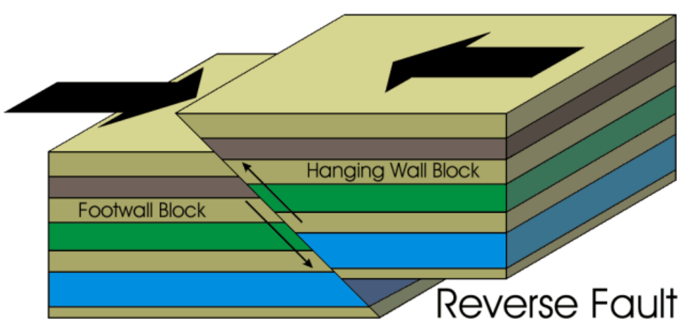


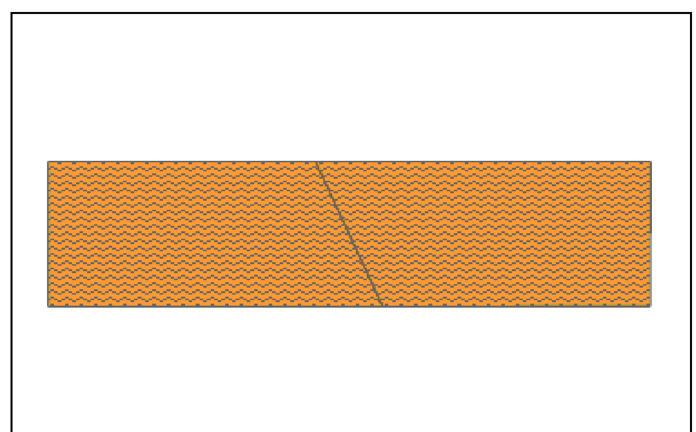


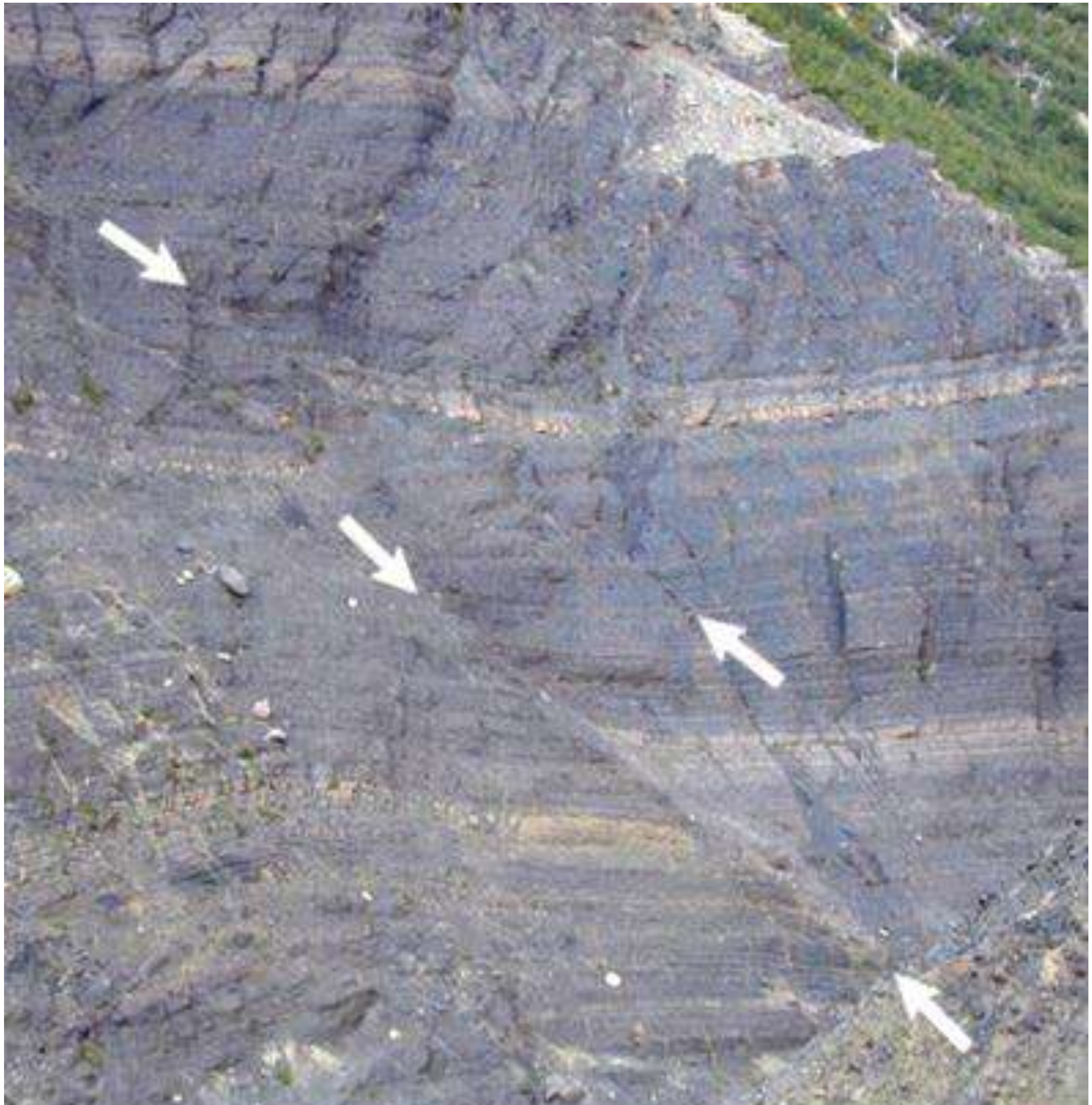


Normal fault




Hanging Wall Block
Footwall Block
Reverse Fault



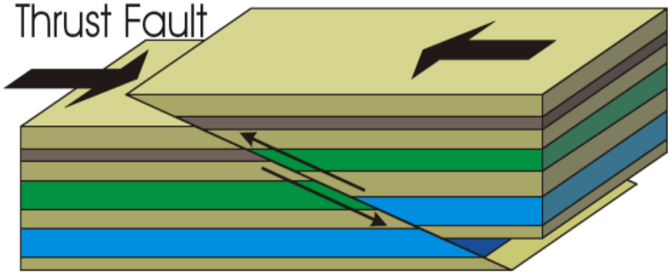


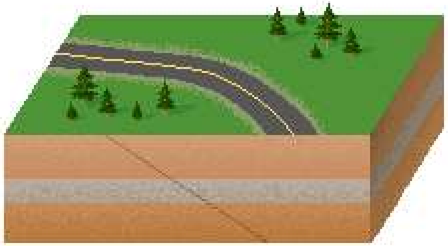
Reverse faults in shale layers,

Reverse Fault Outcrop

Photo by Diane Carlson

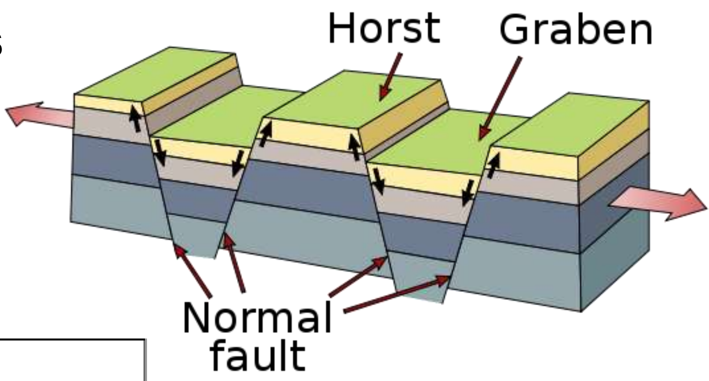
Thrust Fault: **Fault plane is at less than 30 degrees Movement is more horizontal than vertical due to the low angle of the fault plane. Develop due to compressional stress.**

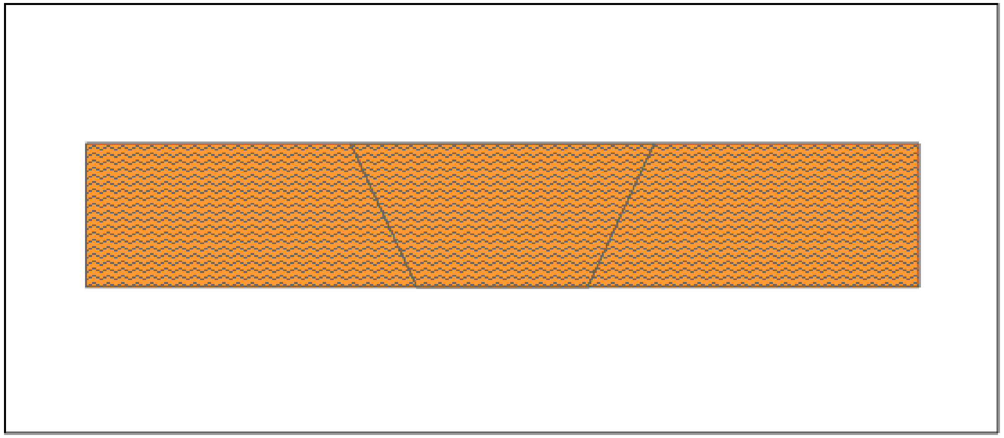




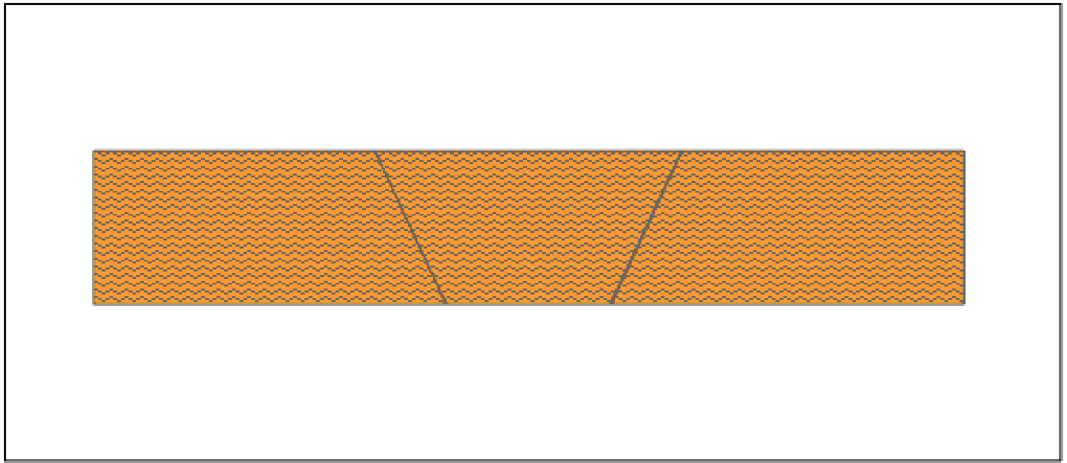
Strike slip fault

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

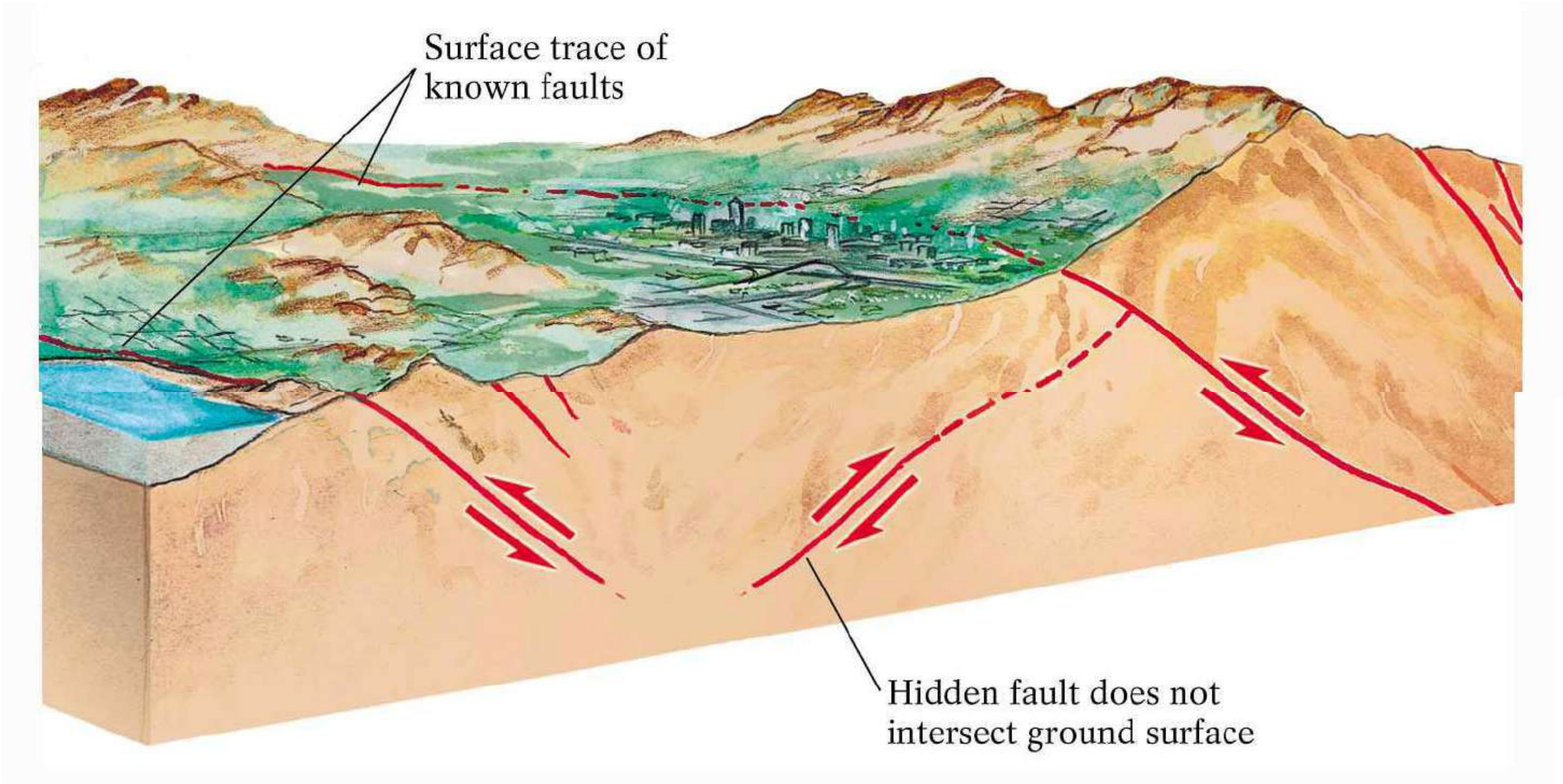




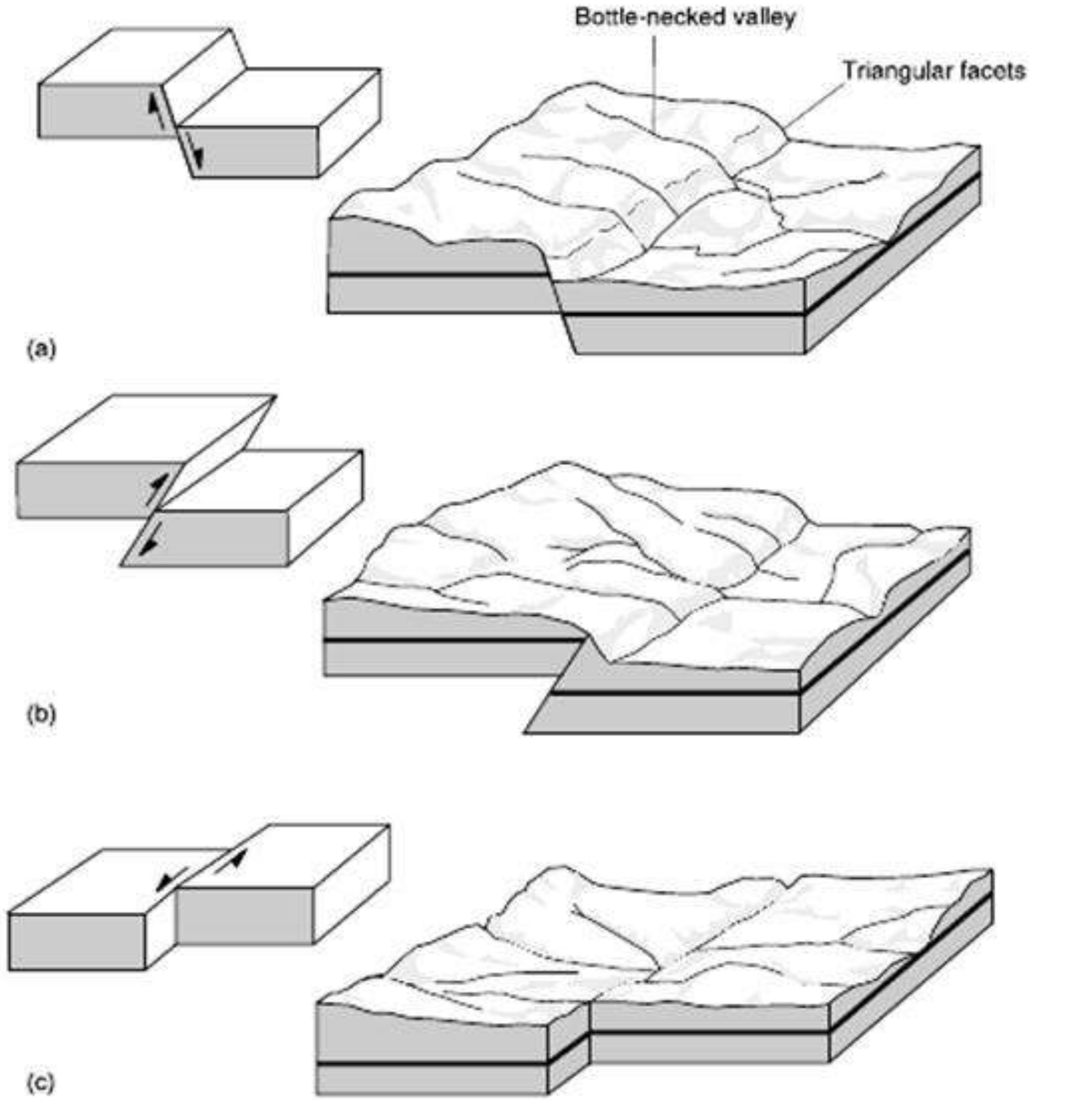
A **horst fault** is the development of two **reverse faults** causing a block of rock to be pushed up



Blind/Hidden faults



Although a fault may not be observable, its effects may be reflected in the topography



(a) Fault scarp formed along normal fault. (b) Reverse fault produces a less distinctive scarp. (c) A strike-slip fault has produced a crush zone that is exploited by a stream. Drainage that once crossed the fault now is offset.

Engineering Geology, by: Bell, F. G.

Importance of Geologic Structures in Civil Engineering Operations

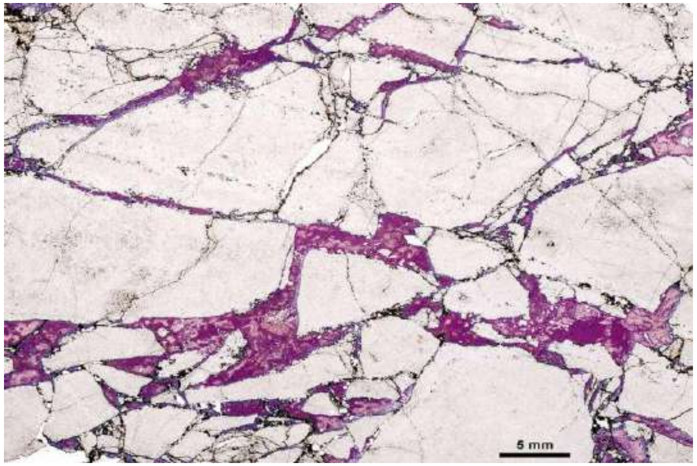
Geologic structures are an evidence of deformation in the rocks formations. Whether they are joints, faults or folds, they are weak zones to be investigated and the appropriate treatment to be resorted to during the construction in a project.

- 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

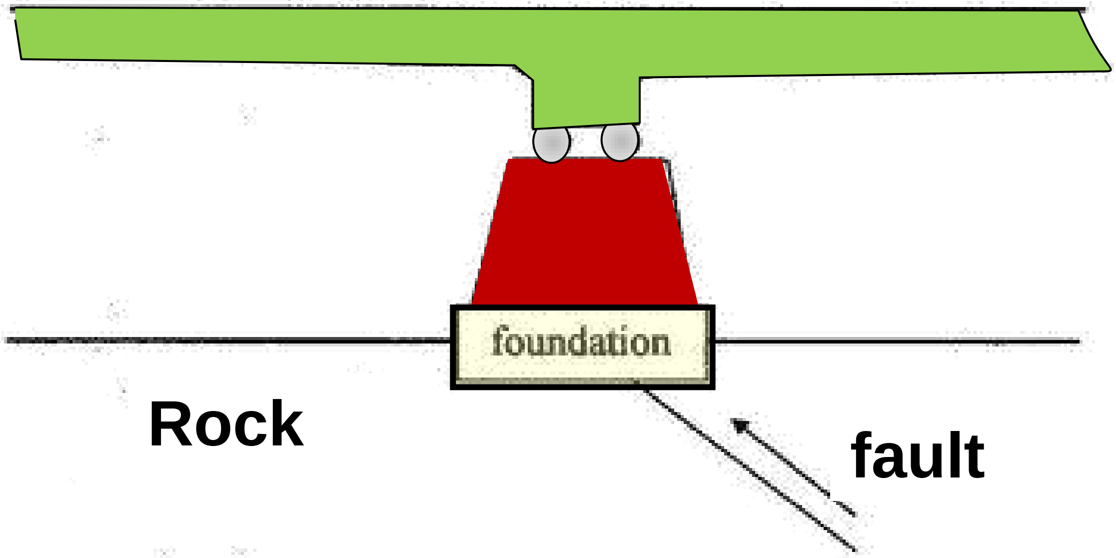
Effect of faults on structures

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

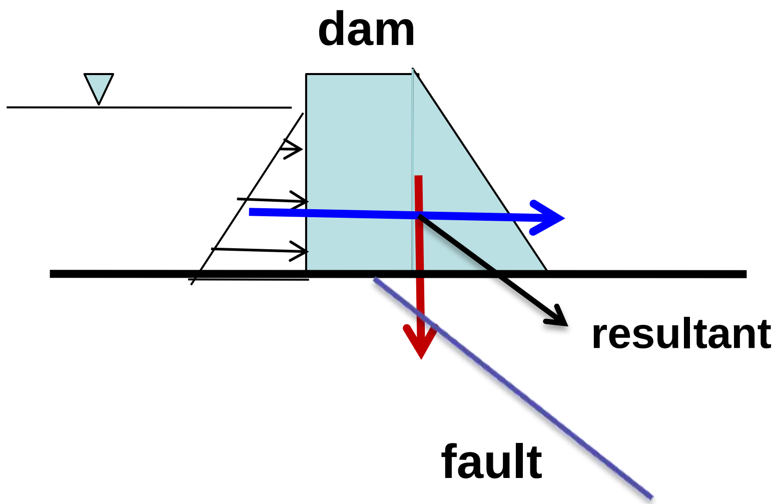


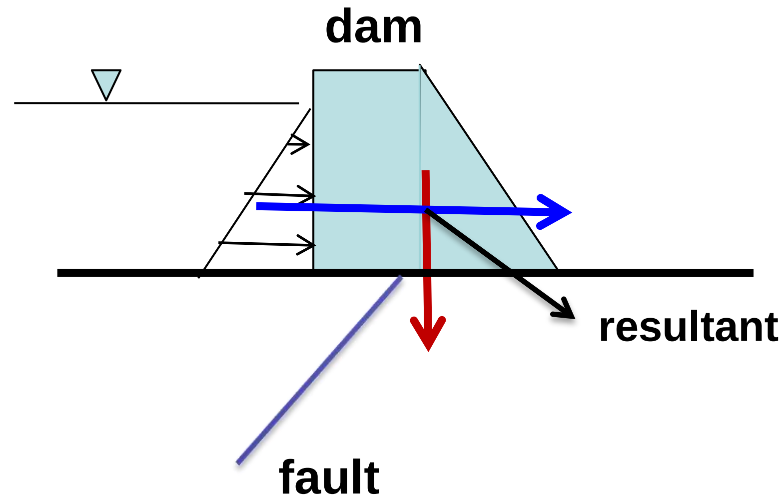
1. Fault under bridge foundation; will cause settlement of the foundation and therefore the project should be re-planed and select place away from the fault



Fault under a concrete dam

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





Resultant direction same as fault
Dangerous condition on the structure

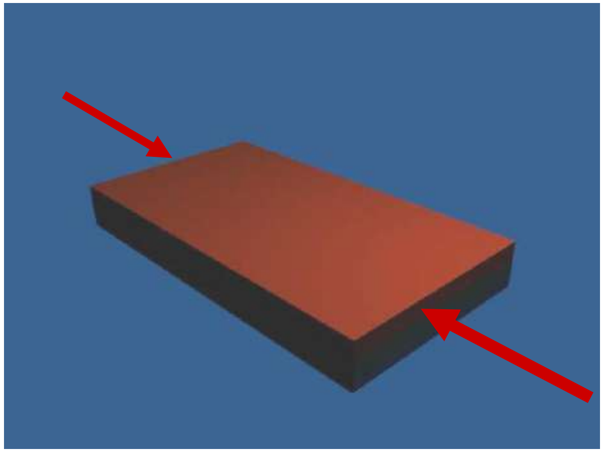
Resultant direction not in the same direction as fault
Not Dangerous and the structure is safe

وضع الفالق لمشروعات الأنفاق:

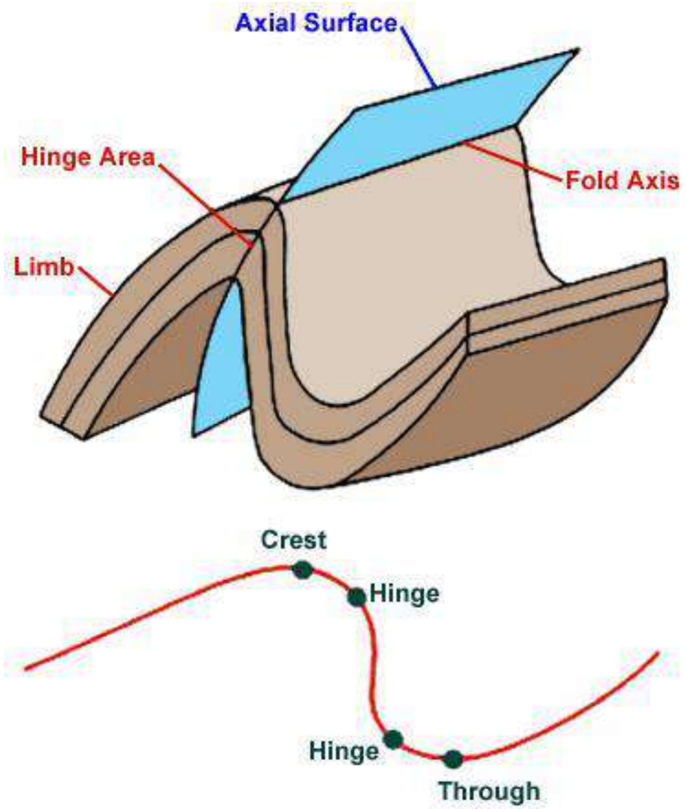
عمر الفالق من العناصر المهمة حيث ان الفالق الحديث يكون فالق نشط و معرض لحدوث حركات مما يعرض النفق للانهيار و بعكس ذلك يكون الفالق غير نشط

يجب تخطيط النفق بحث ألا يمر بالقرب من أي فوالق حتى لو كانت غير نشطة و ذلك لوجود صخور مهشمة في منطقة الفالق مما ينتج عنها مشاكل كثيرة

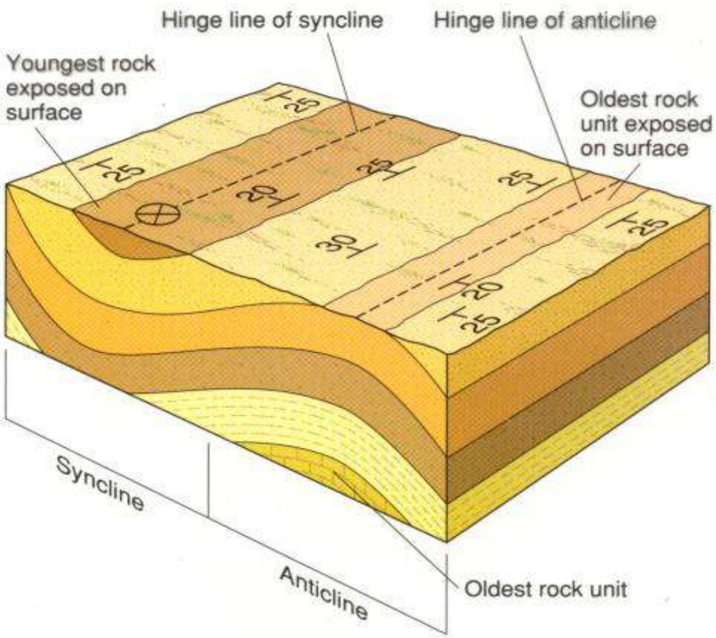
Folds: Ductile Deformation of the Crust forming



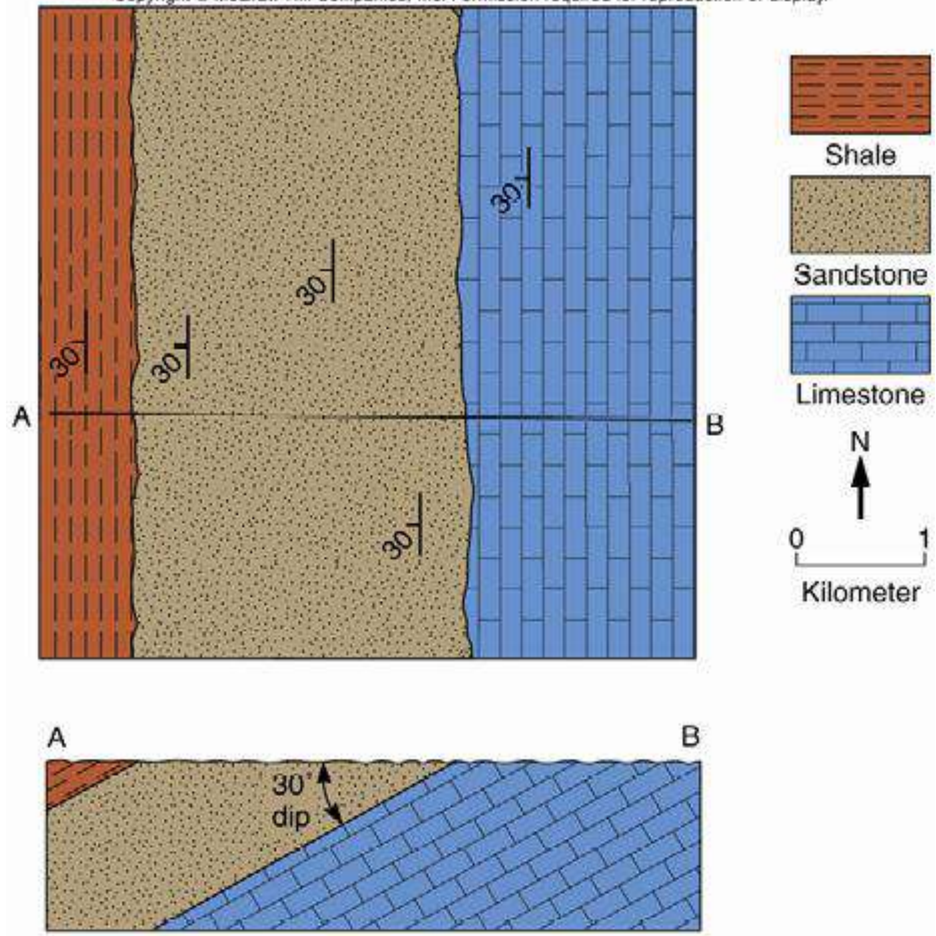
result when plastic rocks are subjected to compression
scale ranges from millimeters to kilometers



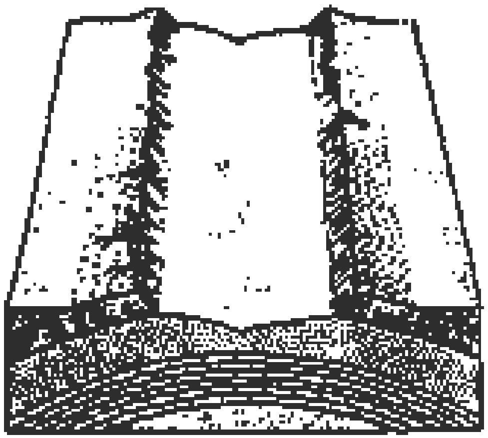
Dip and Strike



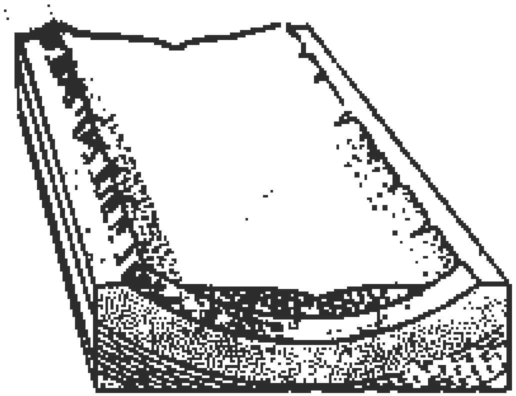
Block Diagram of Anticline and Syncline



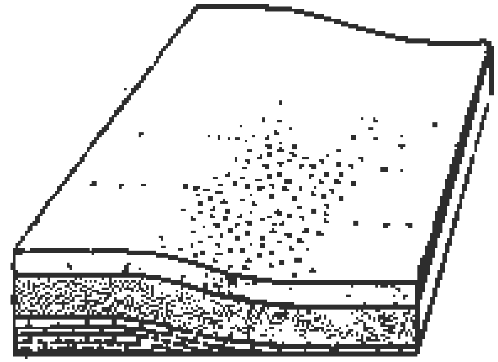
Types of folds



B. ANTICLINE



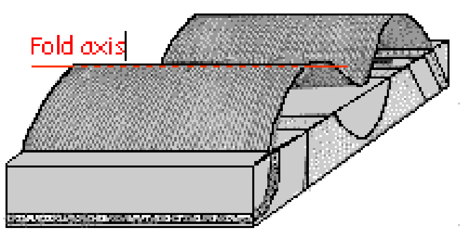
C. SYNCLINE



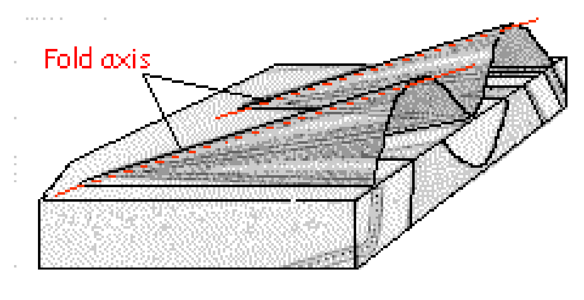
A. MONOCLINE

An **anticline** is a fold arching upward,
a **syncline** is a fold arching downward.
a **monocline** is a special kind of fold with only one limb

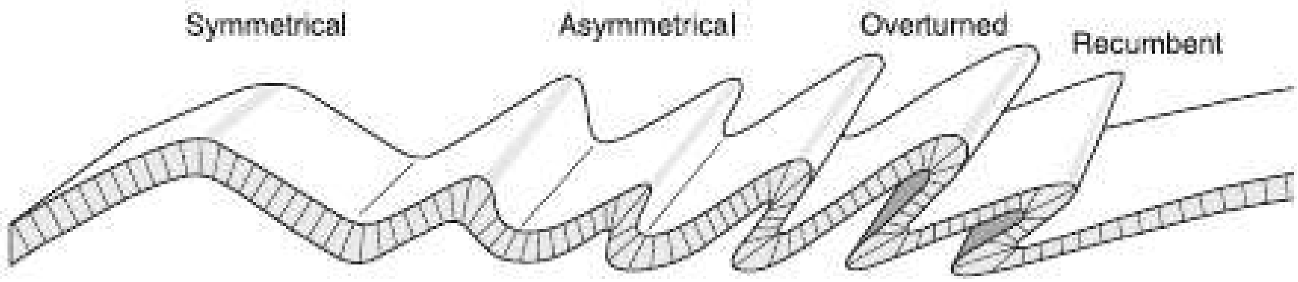
The sides of these folds are called **limbs**. Where the two limbs meet is called the **axis.**



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

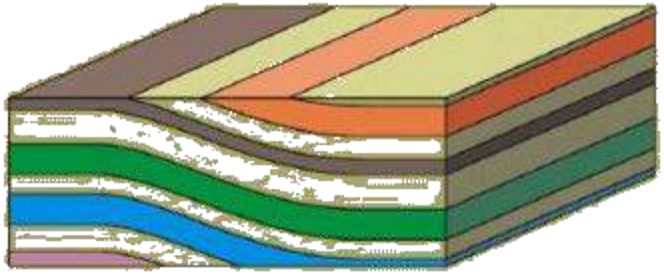


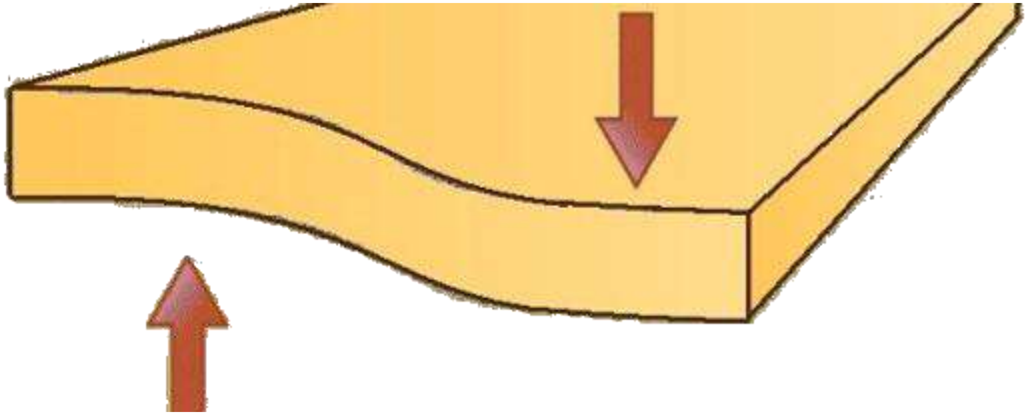
A **plunging fold** is a fold where the axis tilts at an angle.



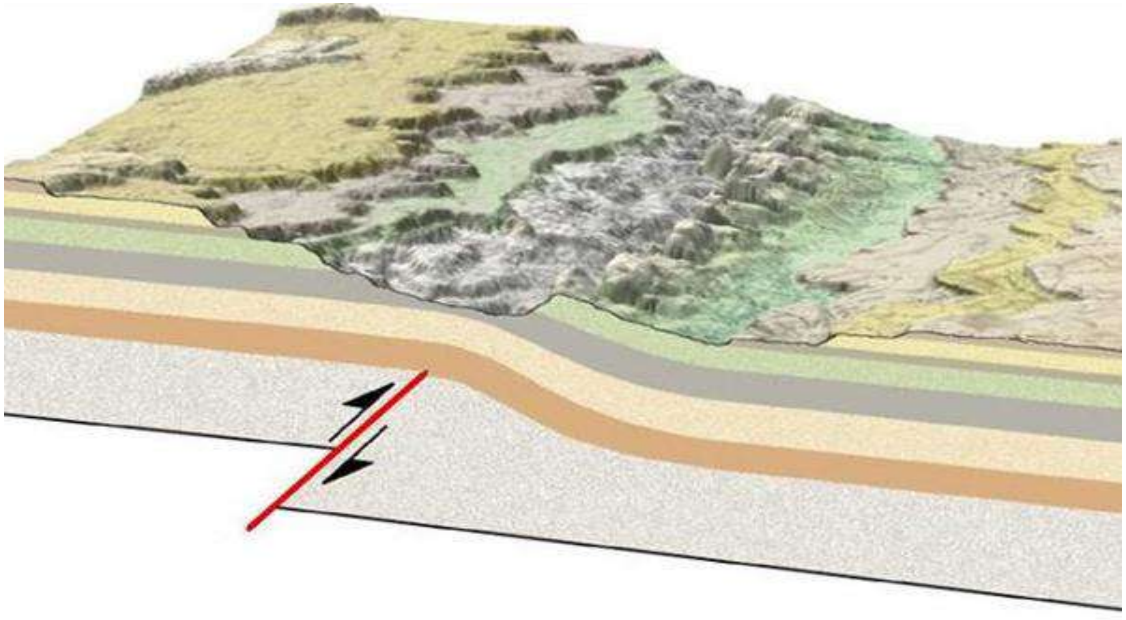
Minor Structures Associated with Folding

Cleavage is one of the most notable structures associated with folding and imparts to rocks the ability to split into thin slabs along parallel or slightly sub-parallel planes of secondary origin. The distance between cleavage planes varies according to the lithology of the host rock, that is, the coarser the texture, the further the cleavage planes are apart. Two principal types of cleavage, namely, flow cleavage, and fracture cleavage, have been recognized.



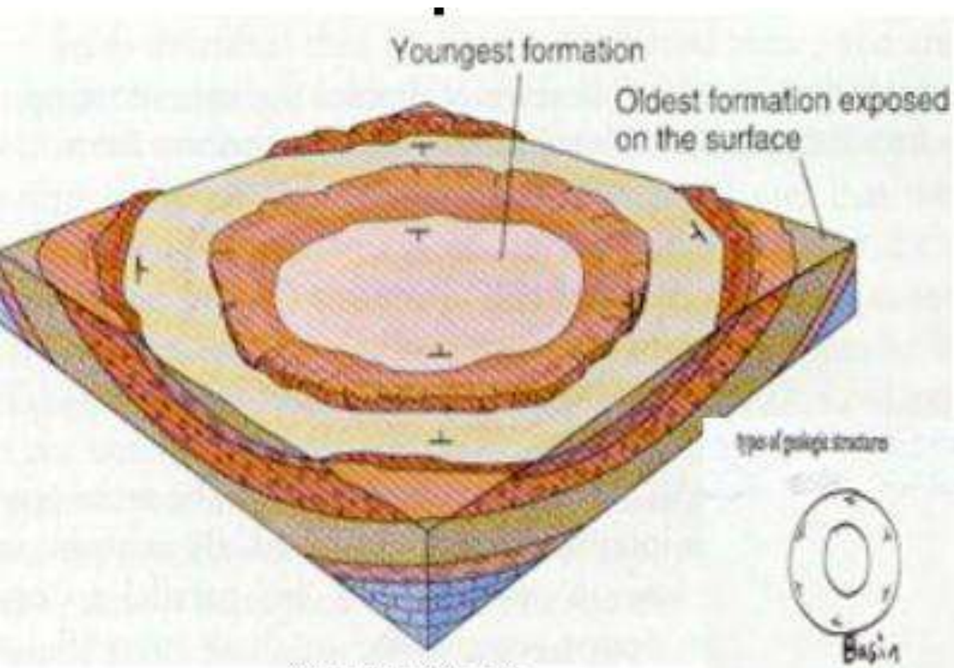


monocline

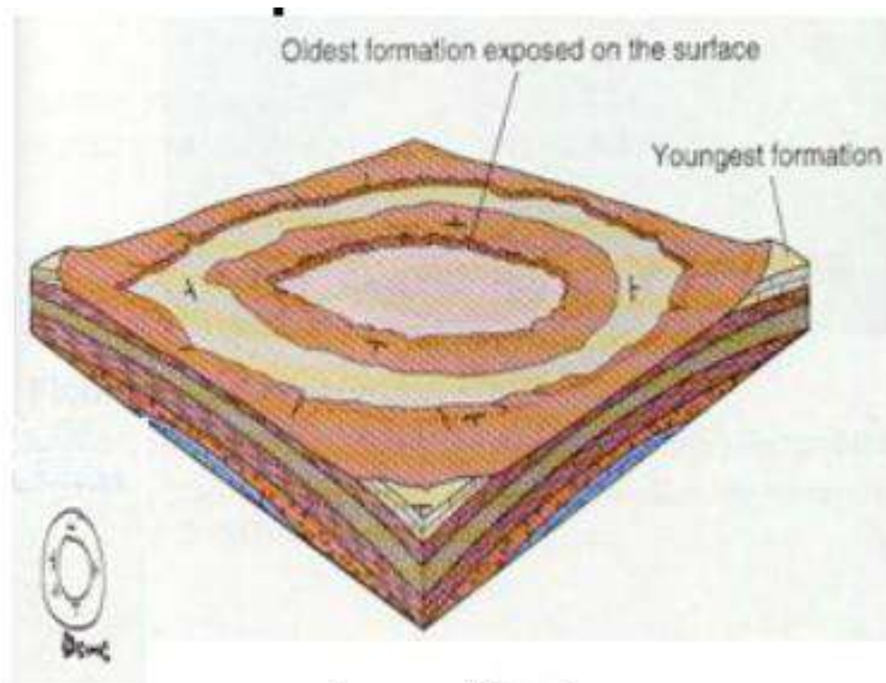


structural dome: a structure in which the beds dip away from a central point

structural basin: a structure in which the beds dip toward a central point

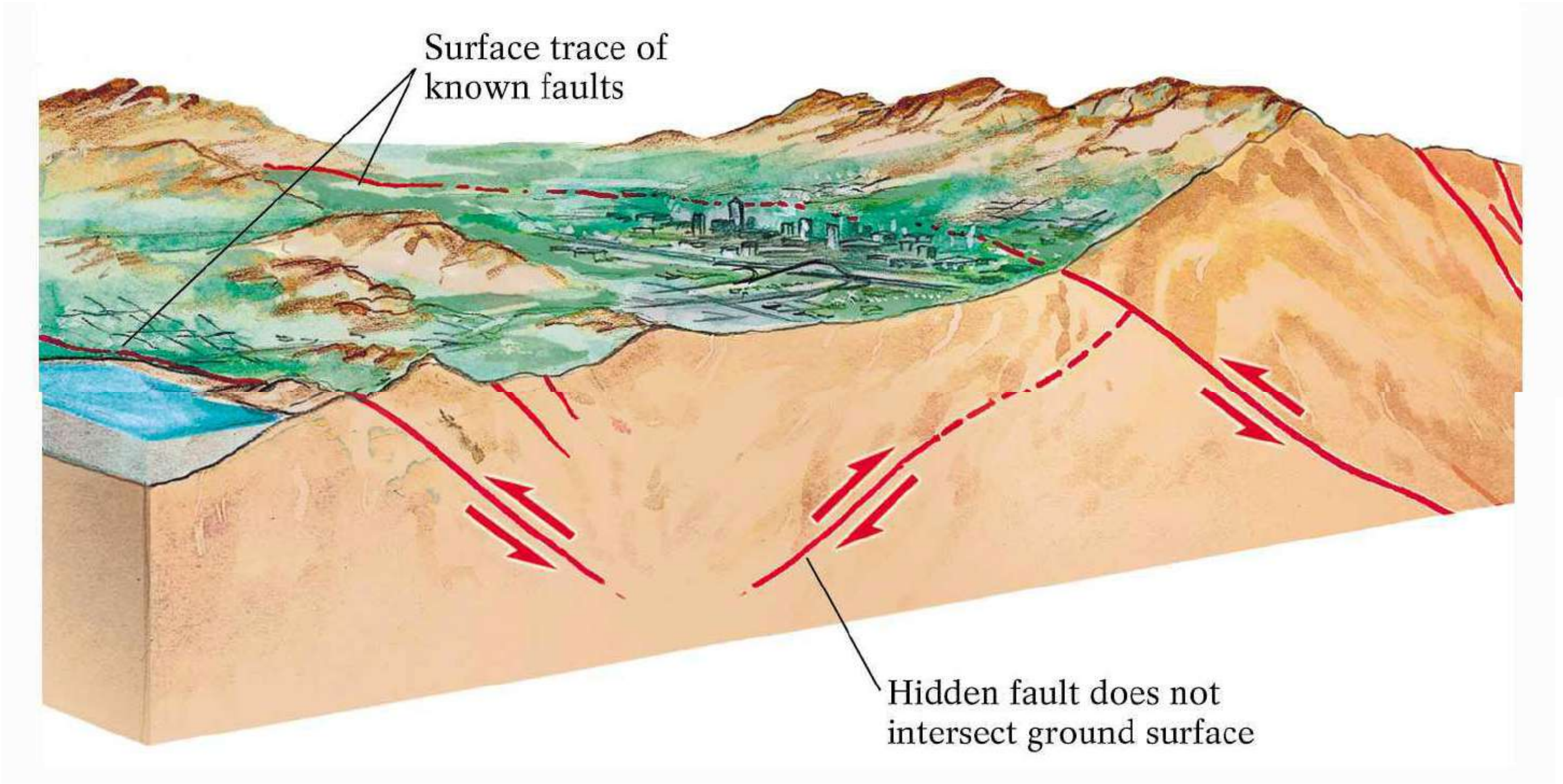


Structural basin



Structural dome

Blind/Hidden faults

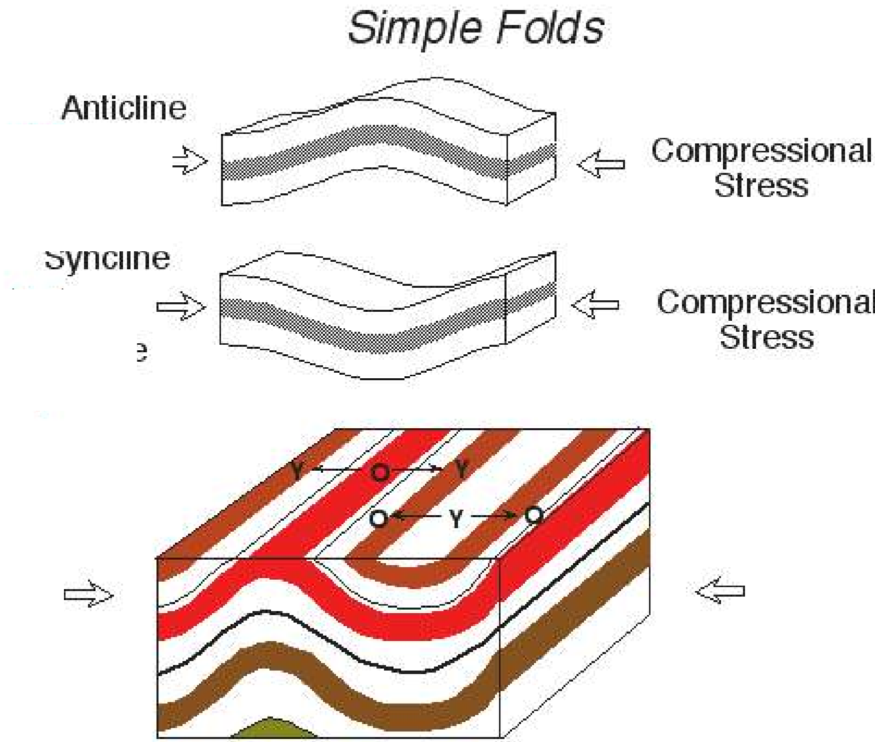


Why folds are important to be studied by engineers?

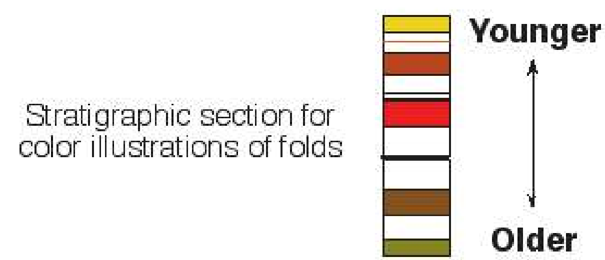
At the upper surface of an anticline folds there will be tensile stresses causing cracks in rocks or layers

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

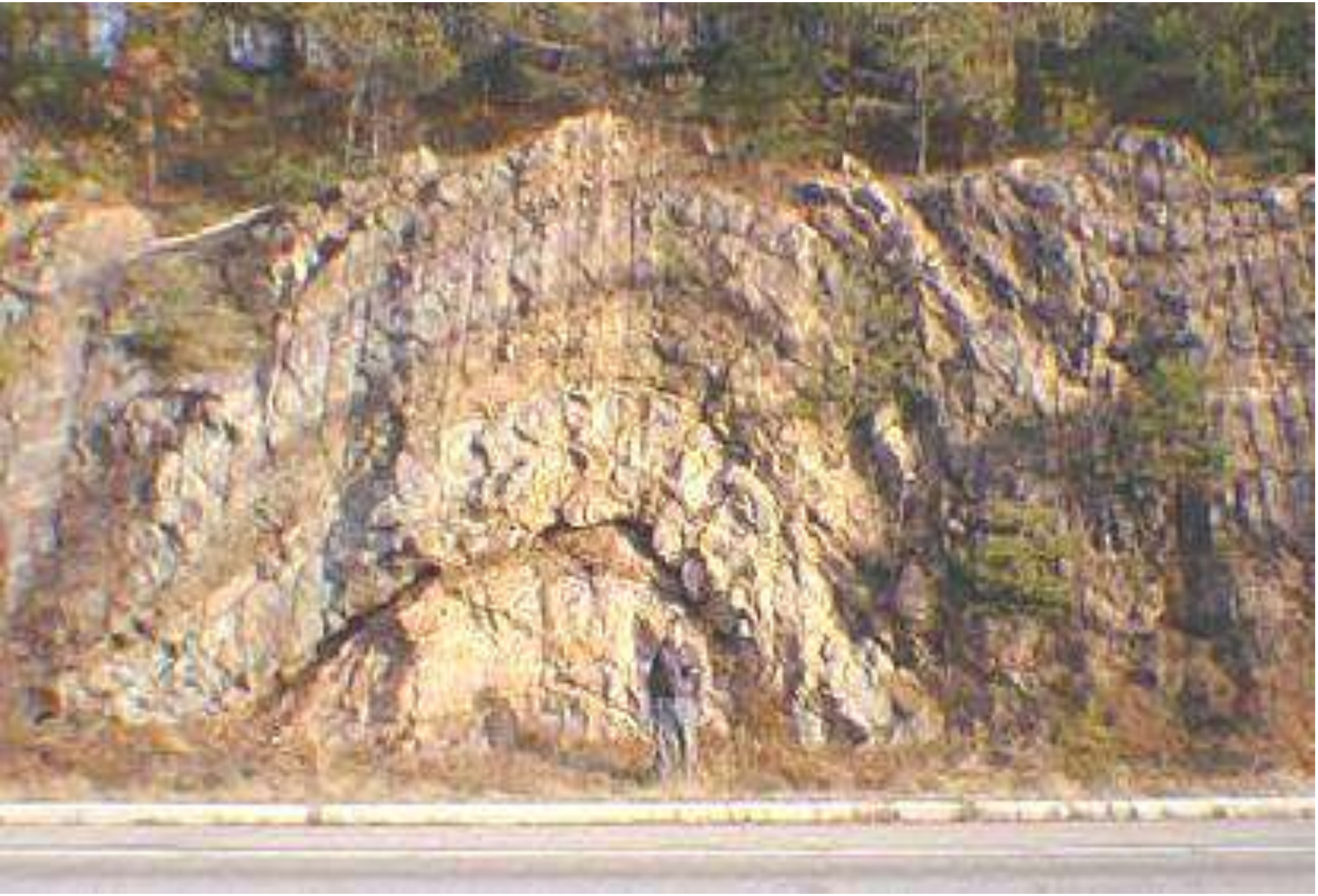
The syncline folds can collect water and so changing its behavior

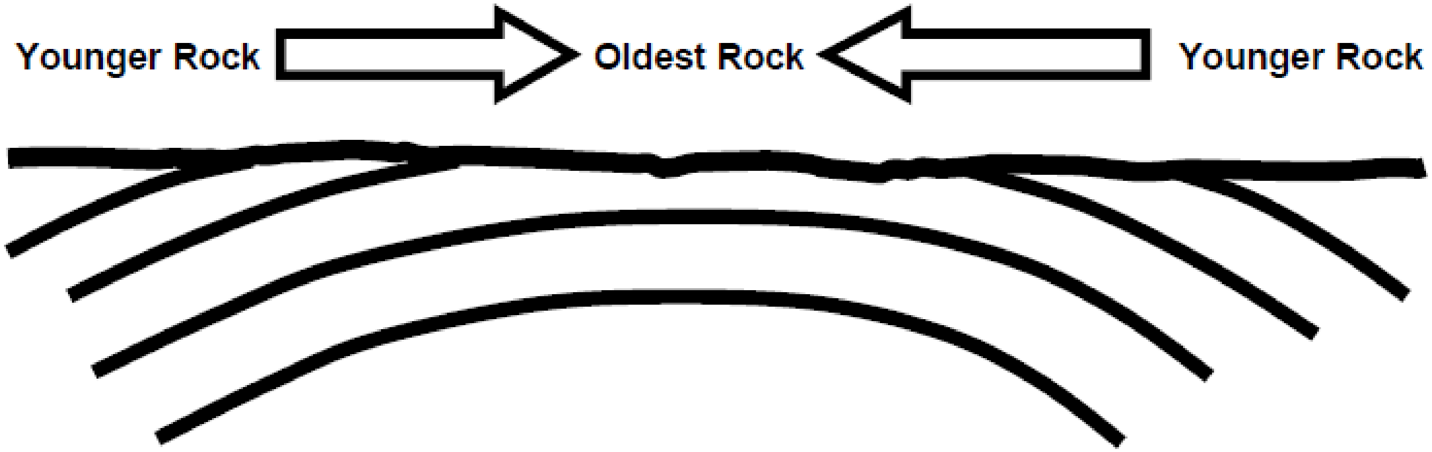


Anticline and Syncline in 3-dimensional view



LBR 9/4/2001; rev 2/2002

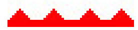
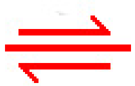


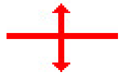
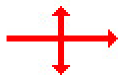
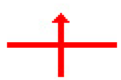
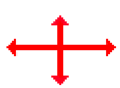
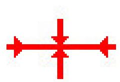


partially eroded anticline (upfold) exposed at Earth's surface

An anticline is an upfold with the oldest rocks exposed in the axial region of the fold

eroded synclines display the opposite age trend:
the rock layers become progressively younger as one moves from the limbs toward the axial region of a syncline

Geologic Fault Symbols				
Type of Fault	**Map Symbol**	**Definition**	**Type of Regional Stress**	**Geologic Associations**
normal	U D (U on uplifted side, D on down-dropped side)	hanging wall down, footwall up	tension	• zones of crustal extension • divergent plate boundaries • edges of horsts and grabens • Basin and Range region
thrust	 (triangles on upper plate)	hanging wall up, footwall down	compression	• zones of crustal compression • convergent plate boundaries
reverse	 (triangles on upper plate)	high-angle (45° or more dip) thrust fault	compression	• zones of crustal compression • convergent plate boundaries
strike-slip	 (half-arrows)	rocks on either side move horizontally in opposite directions	shear	• continental margins undergoing oblique (not straight on) plate convergence • transform plate boundaries
oblique-slip	U  D	combines horizontal and vertical motion	combination	• orogenic mountain belts • continental margins undergoing oblique (not straight on) plate convergence

Geologic Fold Symbols			
Type of Fold	**Map Symbol**	**Definition**	**Appearance of Beds in Map View**
anticline		up fold	• roughly parallel stripes • dip away from center (away from axis) • oldest at center (along axis) • youngest farthest from center
plunging anticline		up fold with tilted axis	• roughly a U-shaped pattern • plunges in direction U points • oldest at center (along axis) • youngest farthest from center
syncline		down fold	• roughly parallel stripes • dip toward center (toward axis) • oldest farthest from center • youngest at center (along axis)
monocline		strata tilted in one direction	• all dip in same direction
structural dome		upward bulge in layered rocks	• roughly a bull's eye pattern • dip away from center • oldest in center • youngest farthest from center
structural basin		downward bulge in layered rocks	• roughly a bull's eye pattern • dip toward center • youngest in center • oldest farthest from center

Stratigraphy

Stratigraphy is the study of the rock layers and the order of events that happened to them. Not only does this include deposition of the layers and the order that they were deposited but also anything that happened to the rocks, like faults, folding, tilting, and eroding

Rules for Stratigraphy

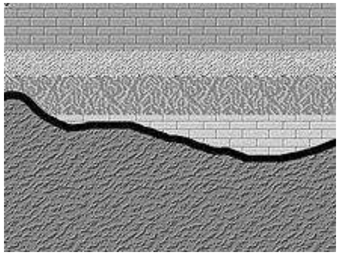
1. Oldest rock layers are on the bottom.
2. Start listing things from oldest to youngest
4. Rocks originally formed in horizontal layers - ***So if anything is not horizontal and flat something happened to them. This needs to be noted.***
5. Anything that crosses another formation must be younger
6. final stage is erosion which is currently acting on the surface.

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

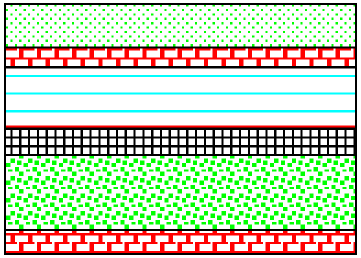
- Unconformities represent a break (missing time/period) in rock record
- Three types of unconformity
  - Dis-conformity
  - Angular unconformity
  - Non-conformity

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.



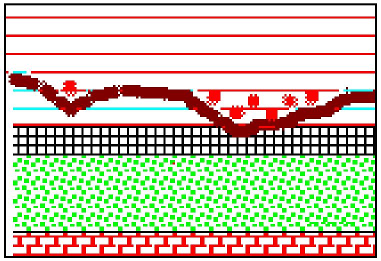
Conformity

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.



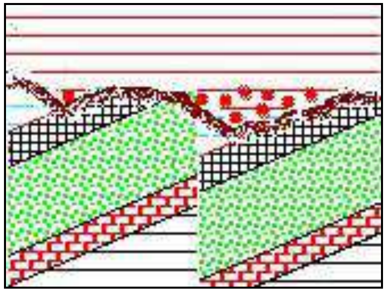
Disconformities

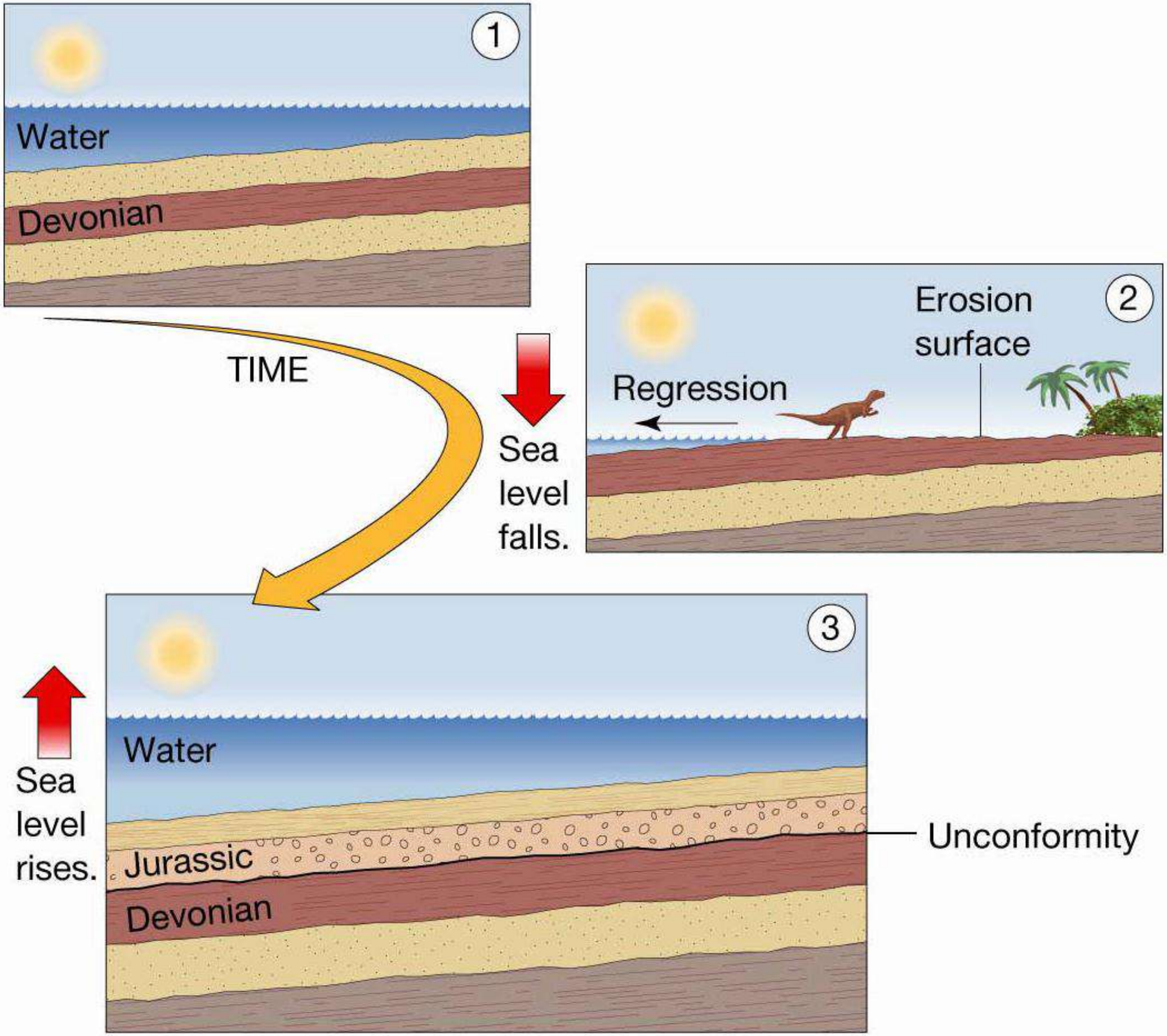
Bedding is parallel on both sides of the contact but evidence shows a break (erosion, uplift) has occurred. In this sketch the break is evident in the erosional relief at the contact and by the clasts of older rocks in the younger strata. In some cases the surface is flat and there are no clasts but 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.



Angular unconformity

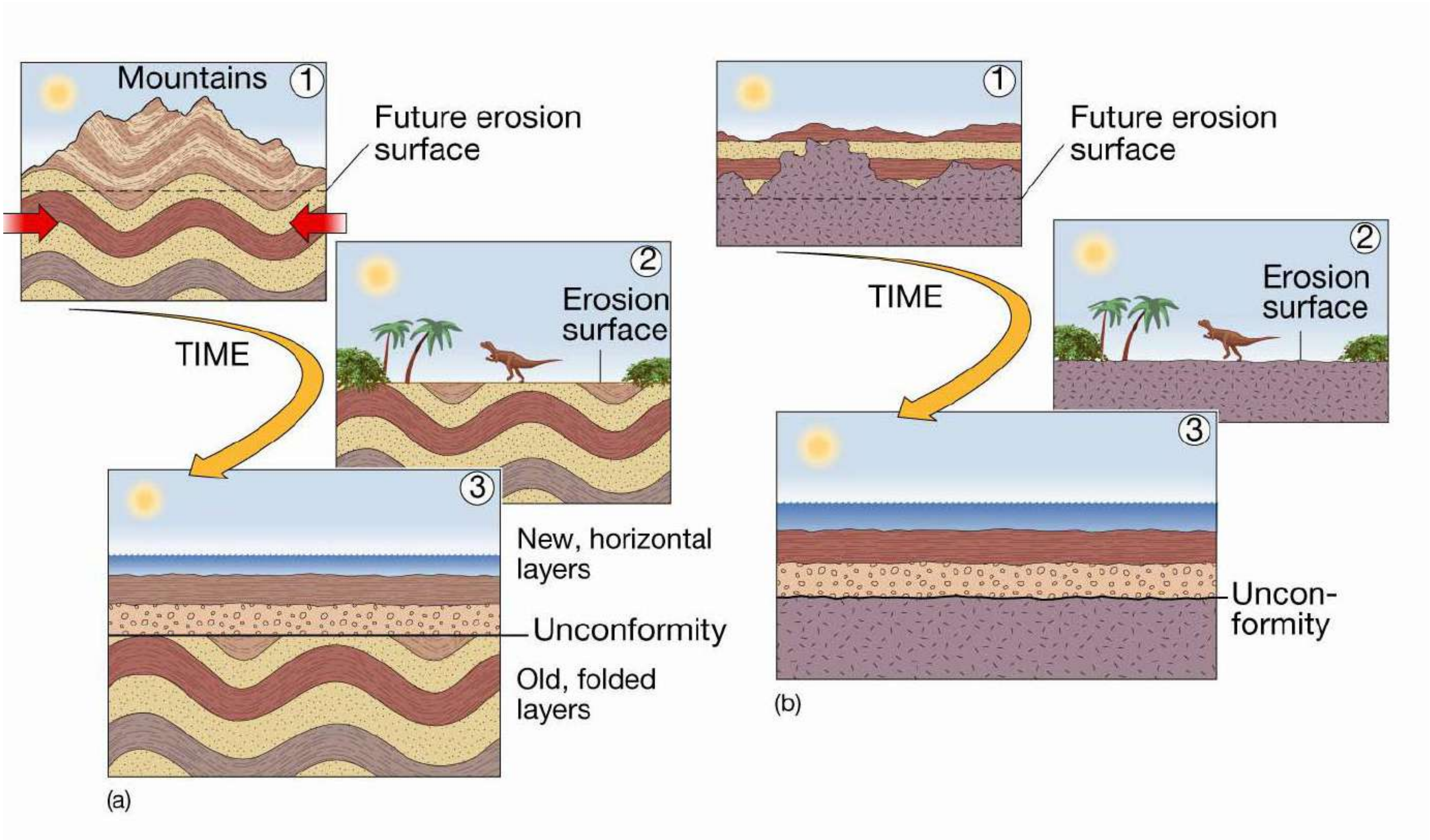
Bedding below the contact is NOT parallel to bedding above the contact. This indicates that deformation of the older beds occurred before the upper beds were deposited. In this sketch the deformation consists of tilting and faulting. Either could occur by itself or the beds could be folded..



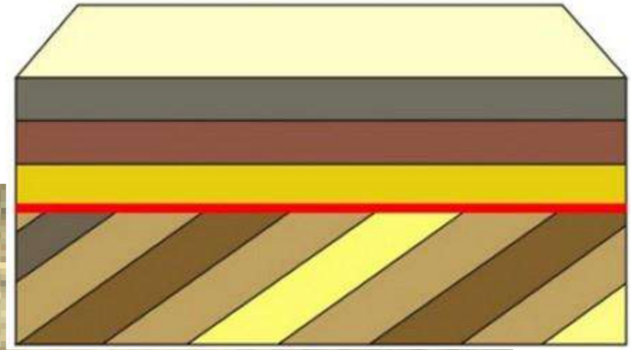


http://instruct.uwo.ca/earth-sci/201a/Lecture%203.pdf

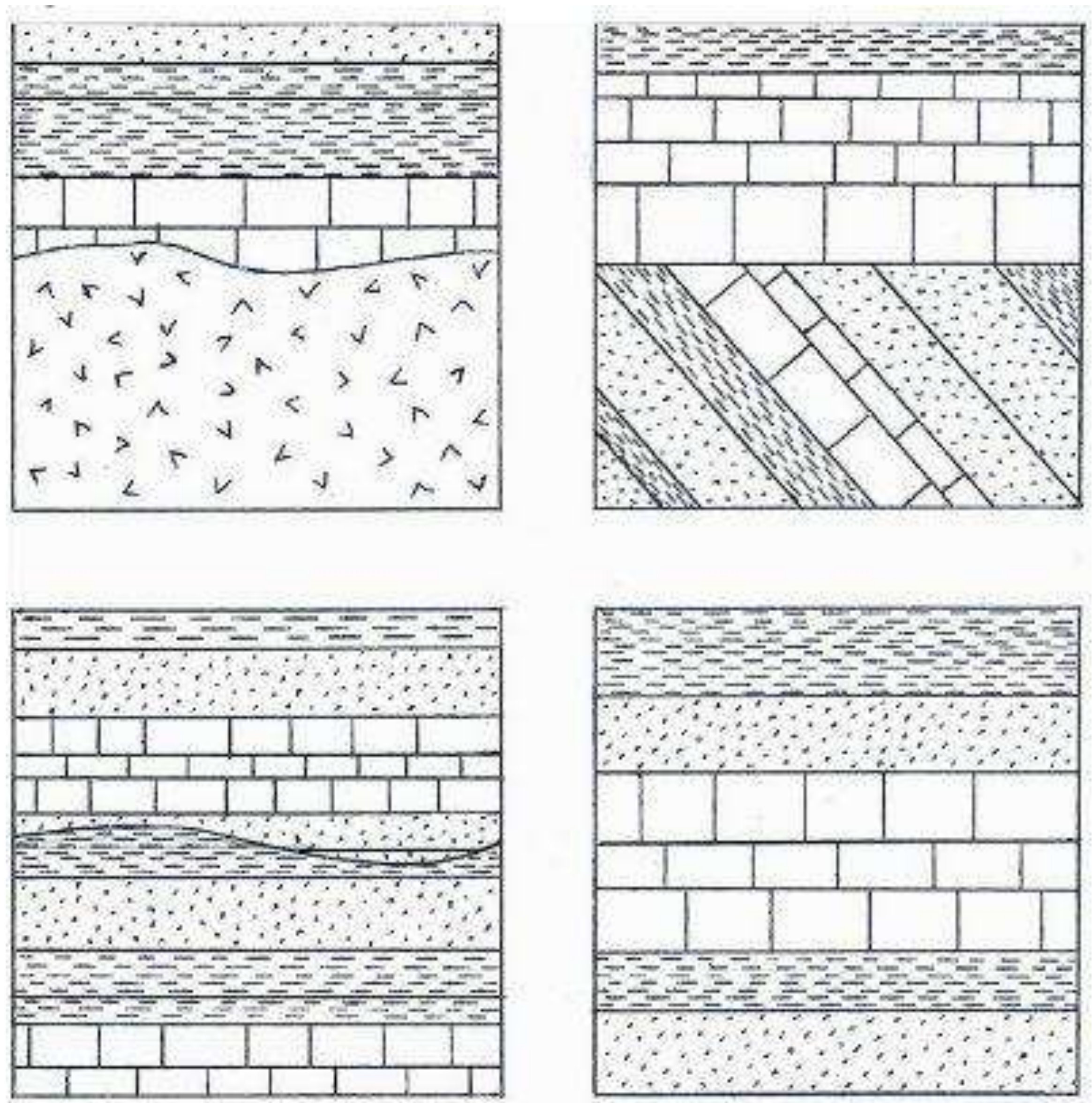
Formation of angular unconformity and nonconformity



Angular unconformity



Angular Unconformity

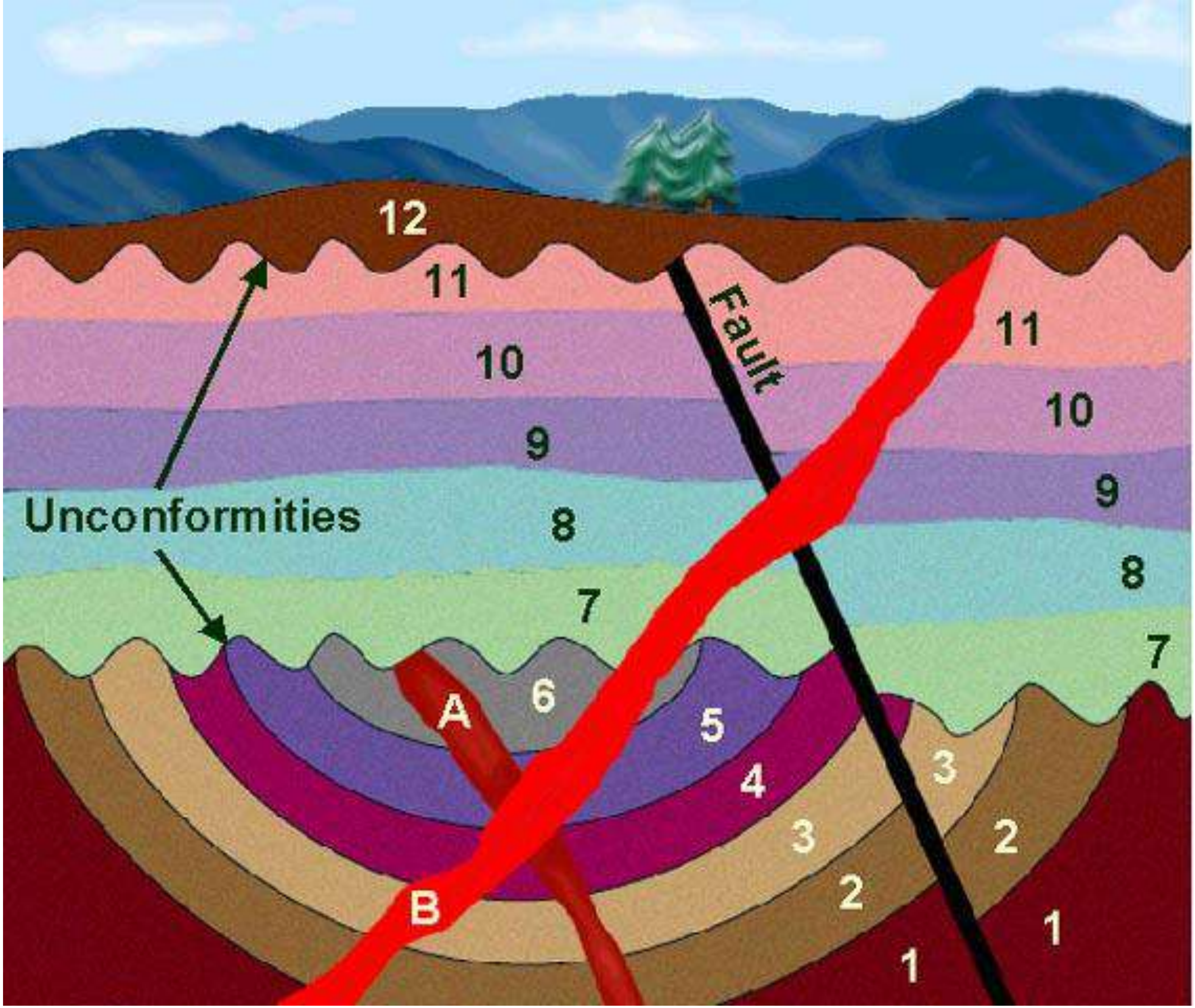


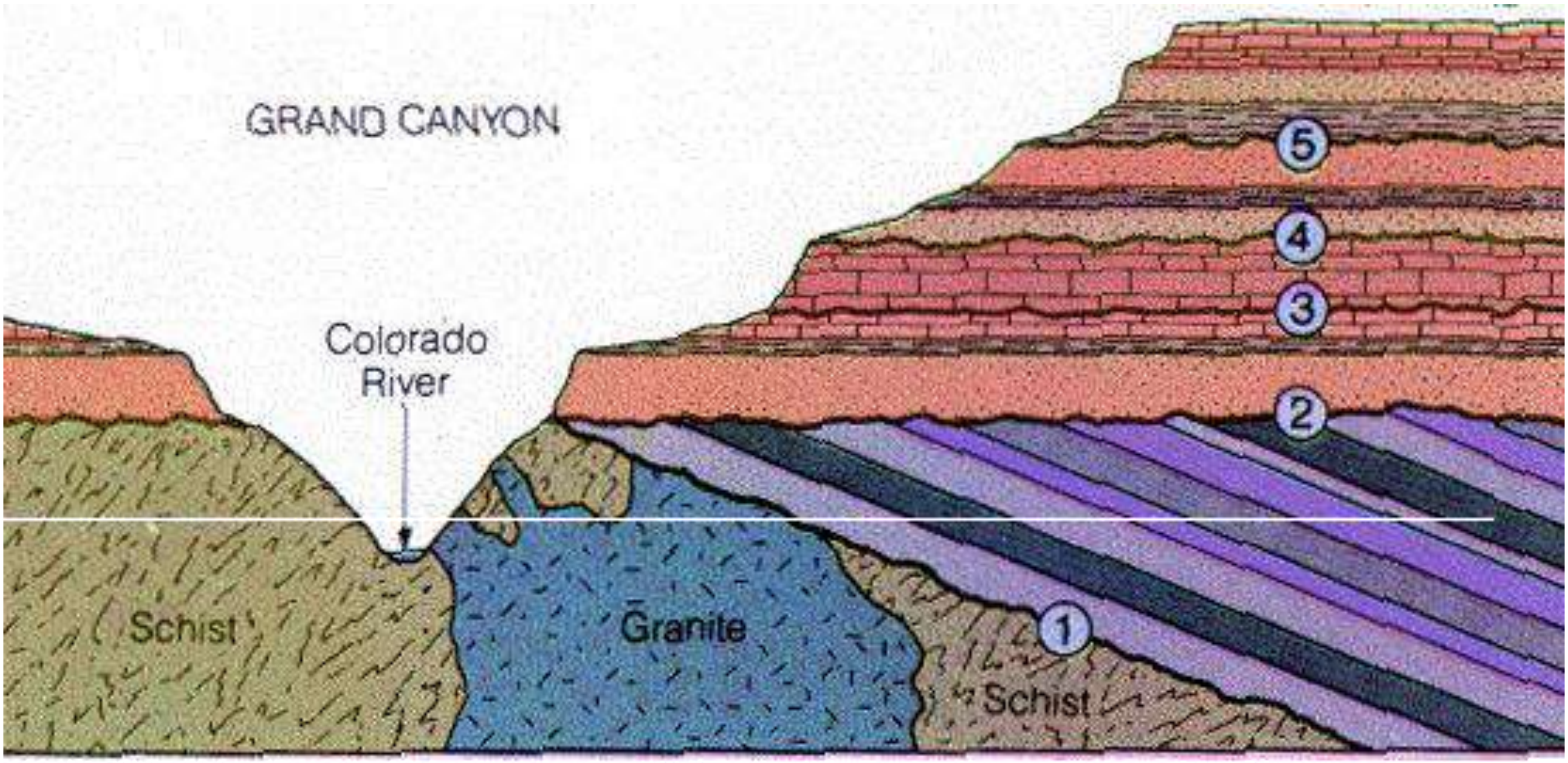
Top left: nonconformity

Top right: angular unconformity

Bottom left: disconformity

Bottom right: paraconformity


12
11
Fault
11
10
10
9
9
Unconformities
8
8
7
7
A
6
5
3
4
3
2
2
B
1
1


GRAND CANYON
Colorado River
5
4
3
2
1
Schist
Granite
Schist

Engineering Geology

Engineering Geology is backbone of civil engineering

11. Earthquakes

Eng. Iqbal Marie

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:

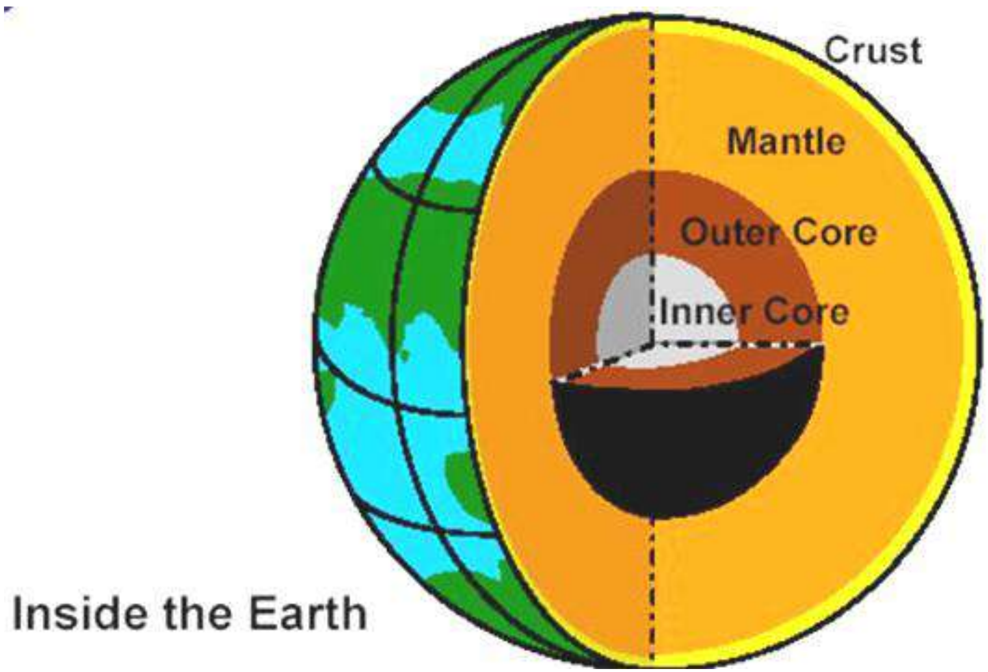
temperature= 2500° C

pressure: ~ 4million atmosphere

density: ~13.5 gm/ cm^3

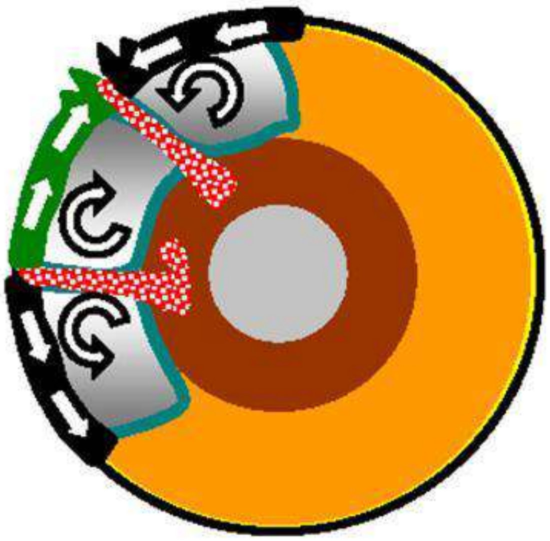
Earth surface [properties]:

temperature= 25° C
pressure: 1 atmosphere
density: ~1.5 gm/c^3



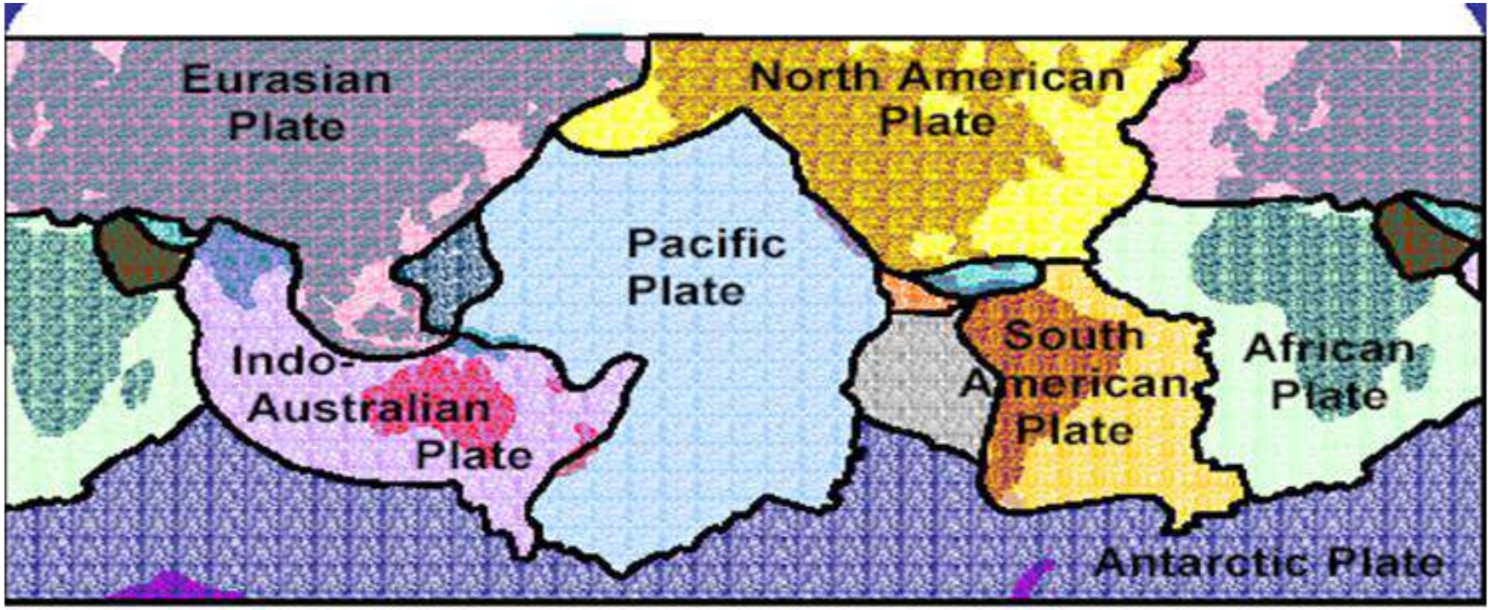
Convection Currents:

Heat from deep inside the Earth heats up the lower mantle. This increase in heat results in a decrease in density. <u>This decrease in density causes the lower mantle material to rise</u>. Mantle material near the crust comes in contact with cooler material. <u>During this contact, heat energy is transferred from the warmer material to the cooler</u> material. Once cooled, the material is <u>denser, causing it to sink</u> and come into contact with the heat from the interior of the Earth where it heats up, becomes less dense, and rises once again.



Local Convective Currents in the Mantle

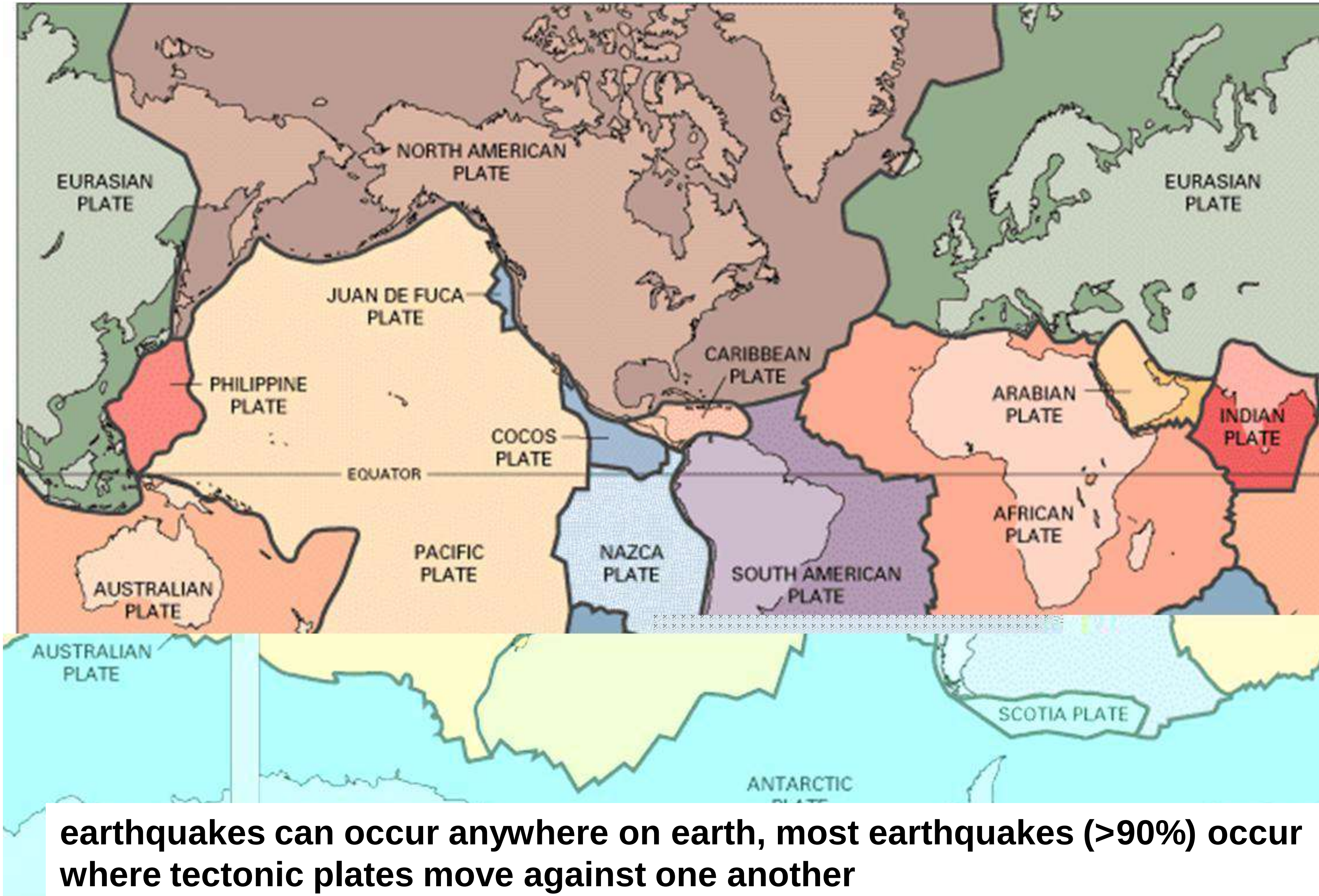
The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. This sliding of Earth's mass takes place in pieces called *Tectonic Plates.* The surface of the Earth consists of seven major tectonic plates and many smaller ones



Major Tectonic Plates on the Earth's surface

Plate Tectonics

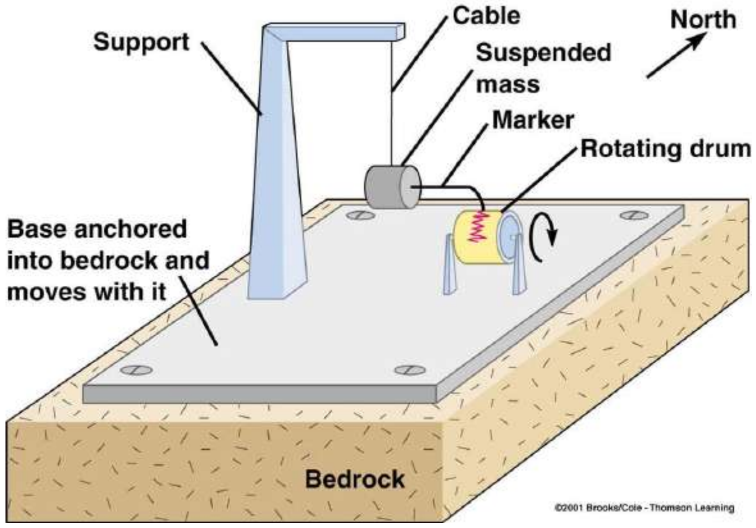
Wegener's continental drift hypothesis stated that the continents had once been joined to form a single supercontinent

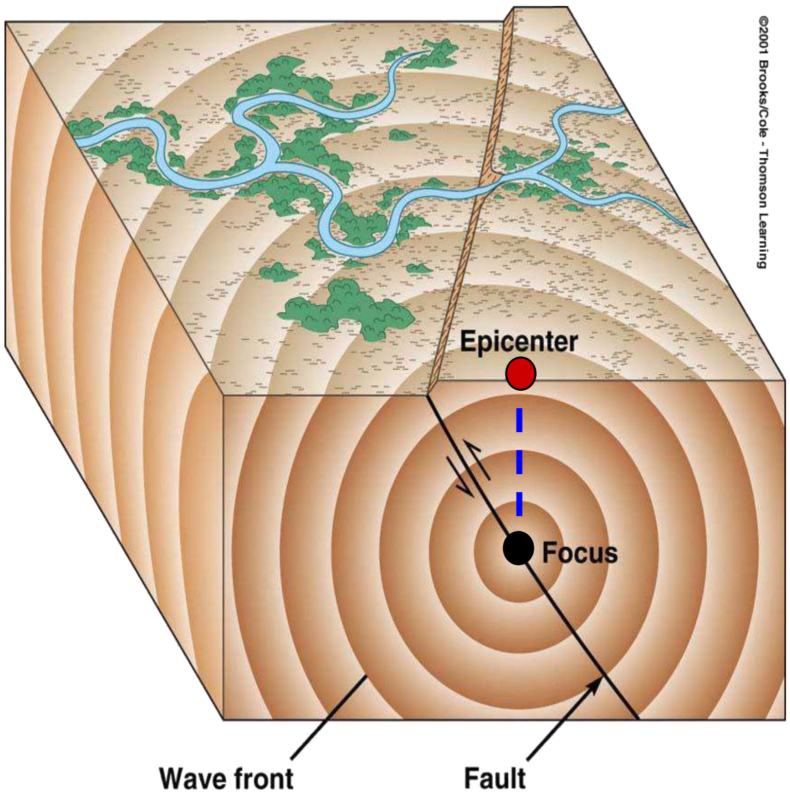


earthquakes can occur anywhere on earth, most earthquakes (>90%) occur where tectonic plates move against one another

Seismology: is the study of earthquakes and seismic waves that move through and around the earth

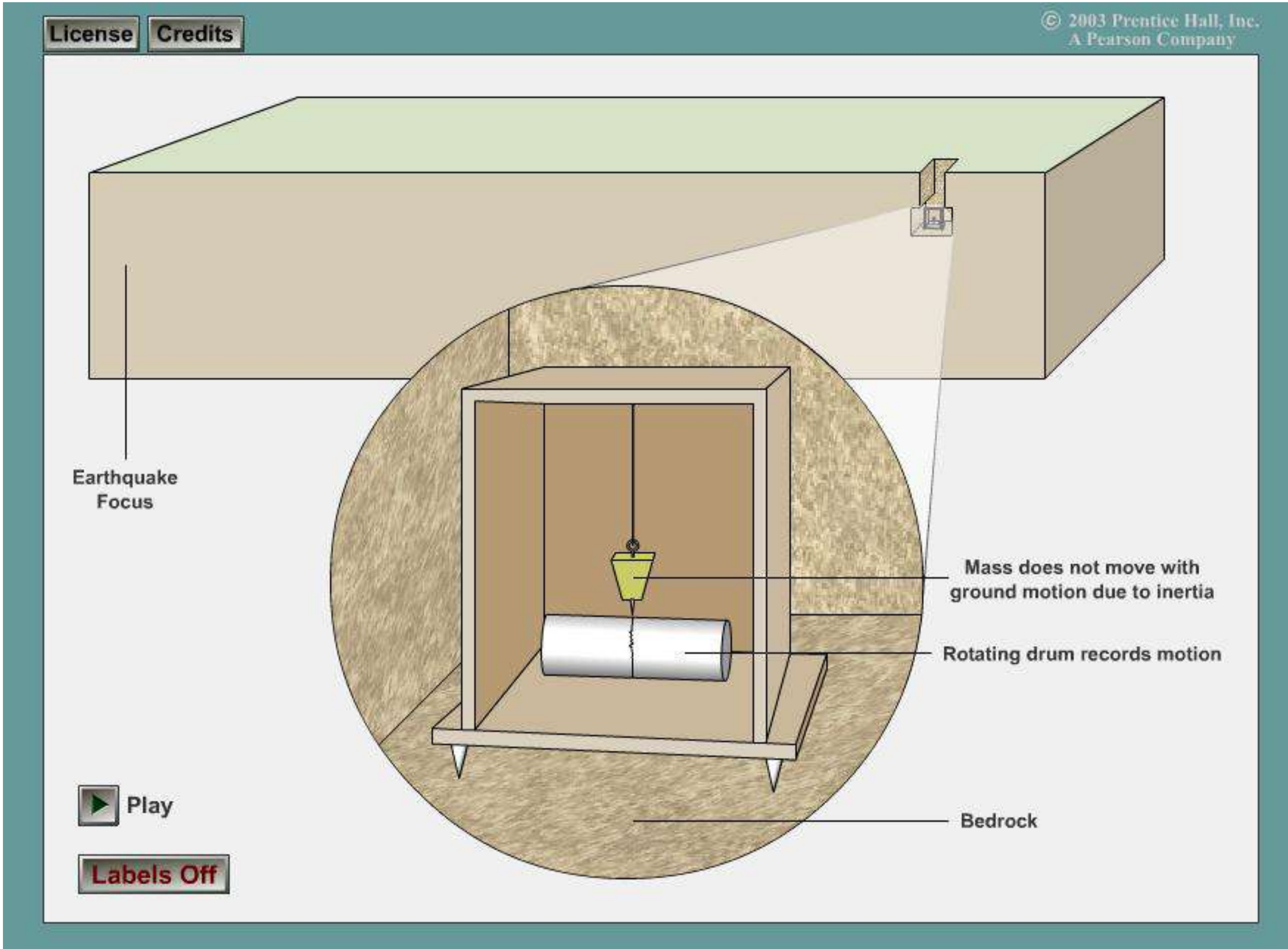
Earthquakes: is a **natural geologic phenomenon** caused by the sudden and rapid movement of a large volume of rock. Most earthquakes are caused by slippage along fractures in Earth's crust called **faults.**





Seismographs : record earthquake events

- **Focus or hypocenter :** The point within Earth where faulting begins,
- **Epicenter**: The point directly above the focus on the surface

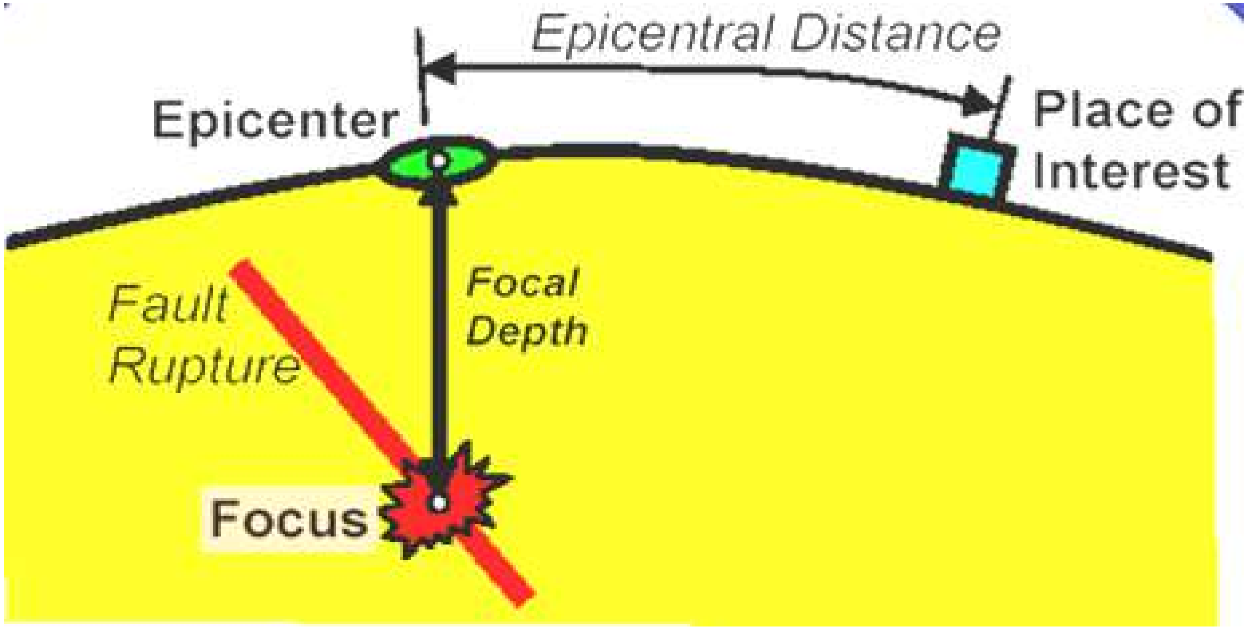

License
Credits
© 2003 Prentice Hall, Inc.
A Pearson Company
Earthquake Focus
Mass does not move with ground motion due to inertia
Rotating drum records motion
Bedrock
Play
Labels Off

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.

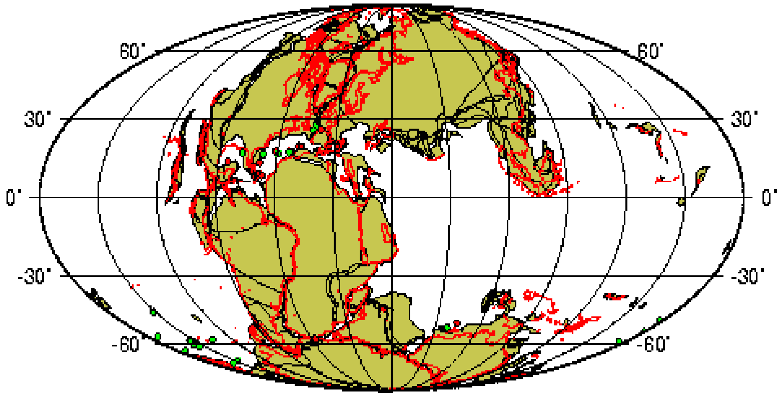
Most of the damaging earthquakes have shallow focus with focal depth less than 70km

Distance from epicenter to any point of interest is called the **Epicentral Distance**



http://www.odsn.de/odsn/services/paleomap/animation.html

Earth's Major Roles

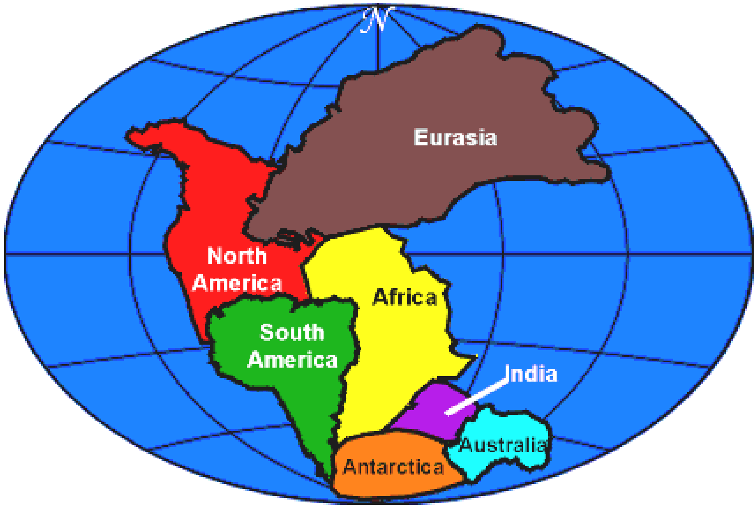


According to the **plate tectonics theory**, **the** **uppermost mantle, along with the overlying crust, behaves as a strong, rigid layer**. **This layer is known as the lithosphere.**

A **plate** is one of numerous rigid sections of the lithosphere that move as a unit over the material of the asthenosphere.

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

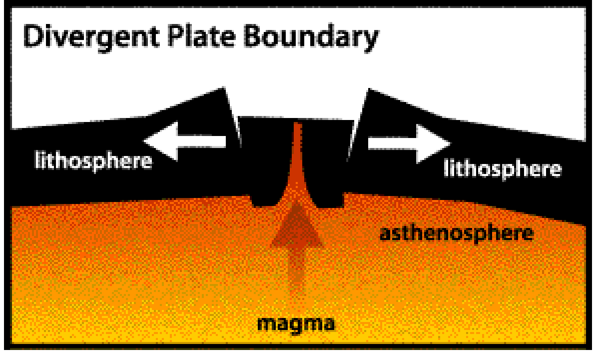
The boundaries along each plate are referred to as margins

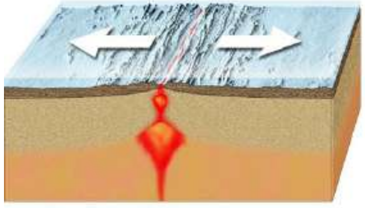


Types of Plate Boundaries

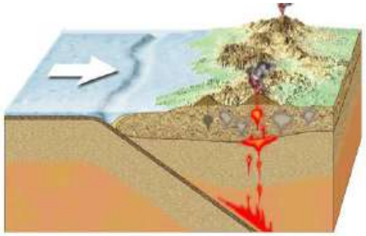
Different types of stresses are associated with each type of margin

- **Divergent boundaries** (also called spreading centers) are the place where two plates move apart. divergent-plate margins have tensional stresses
- **Convergent boundaries** <u>form where two plates move together.</u> (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 <u>margins where two plates grind past each other without the production or destruction of the lithosphere</u>.(As the San Andreas Fault which runs through California.) transform-plate margins have shear stresses



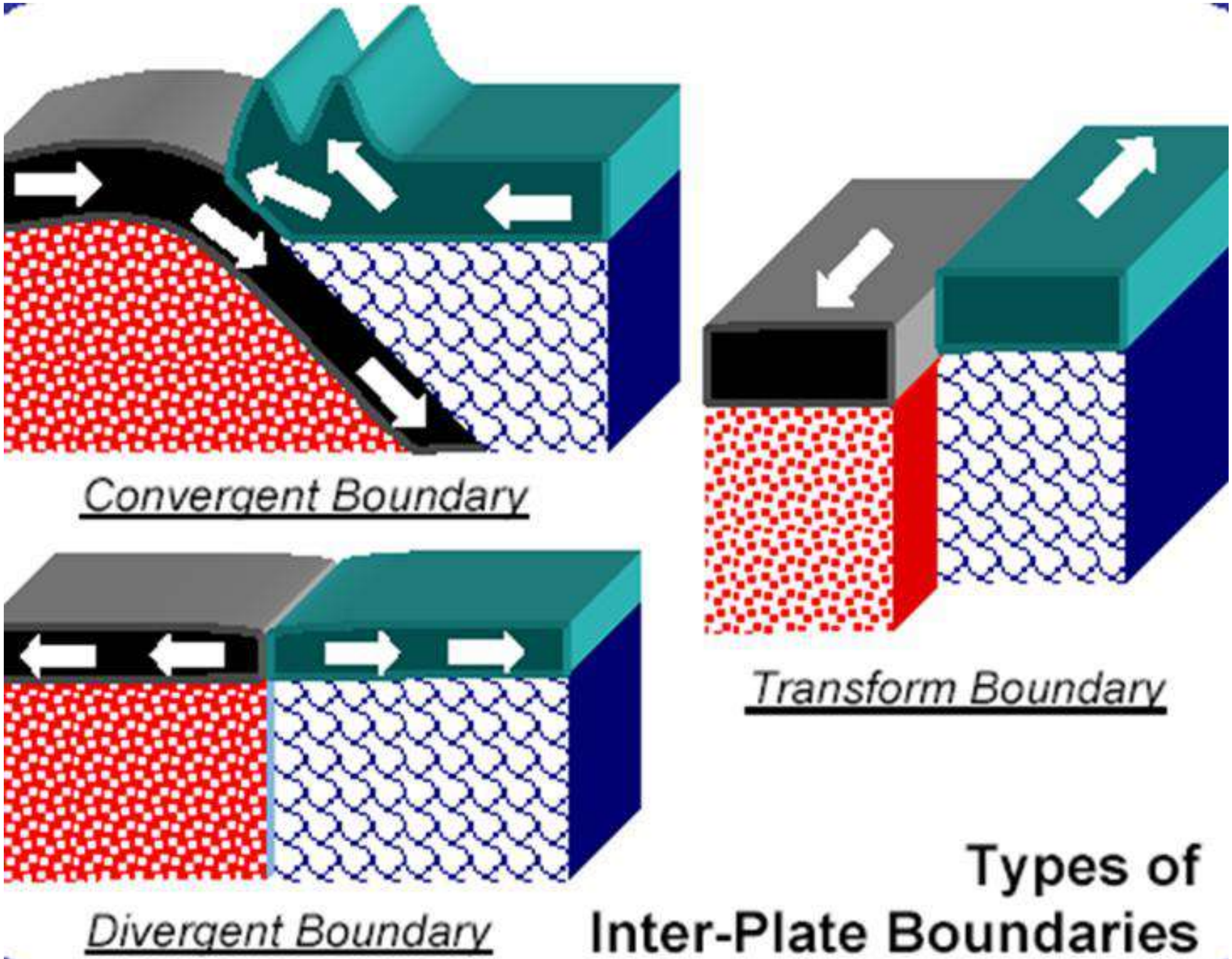


Divergent boundary



Convergent boundary

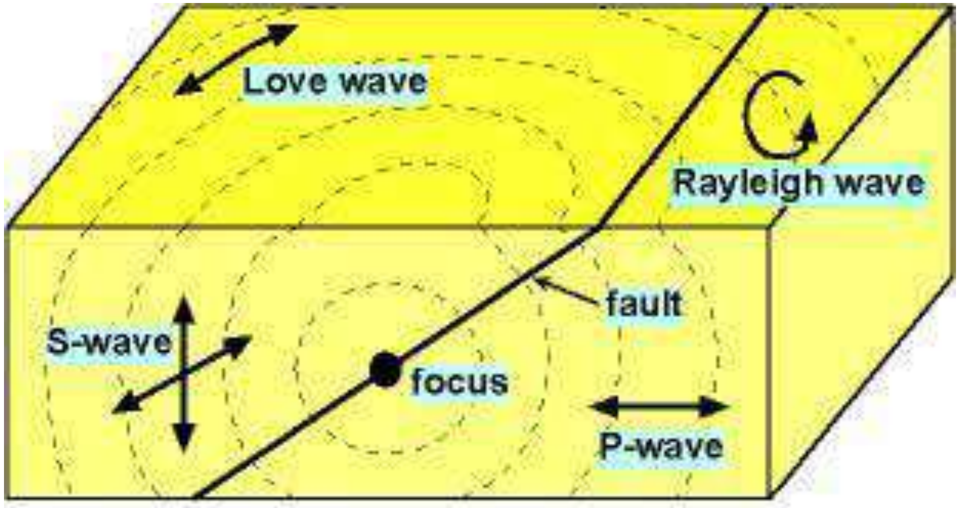
Transform fault boundary


Convergent Boundary
Transform Boundary
Divergent Boundary
Types of
Inter-Plate Boundaries

Most earthquakes are produced by the rapid release of elastic energy stored in rock that has been subjected to great stress. Once the strength of the rock is exceeded, it suddenly ruptures, causing the vibrations of an earthquake. Earthquakes most often occur along existing faults when the frictional forces on the fault surfaces are overcome.

Seismic waves

Four types of seismic waves are generated when faulting triggers an earthquake. All the seismic waves are generated at the same time, but travel at different speeds and in different ways. Body waves penetrate the earth and travel through it, while surface waves travel along the surface of the ground.

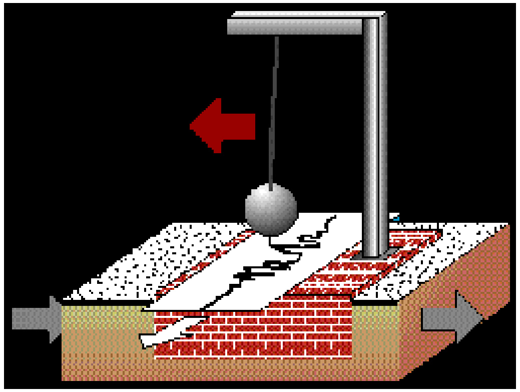


Directions of body waves (P and S) and surface waves (Rayleigh and Love) generated by an earthquake.

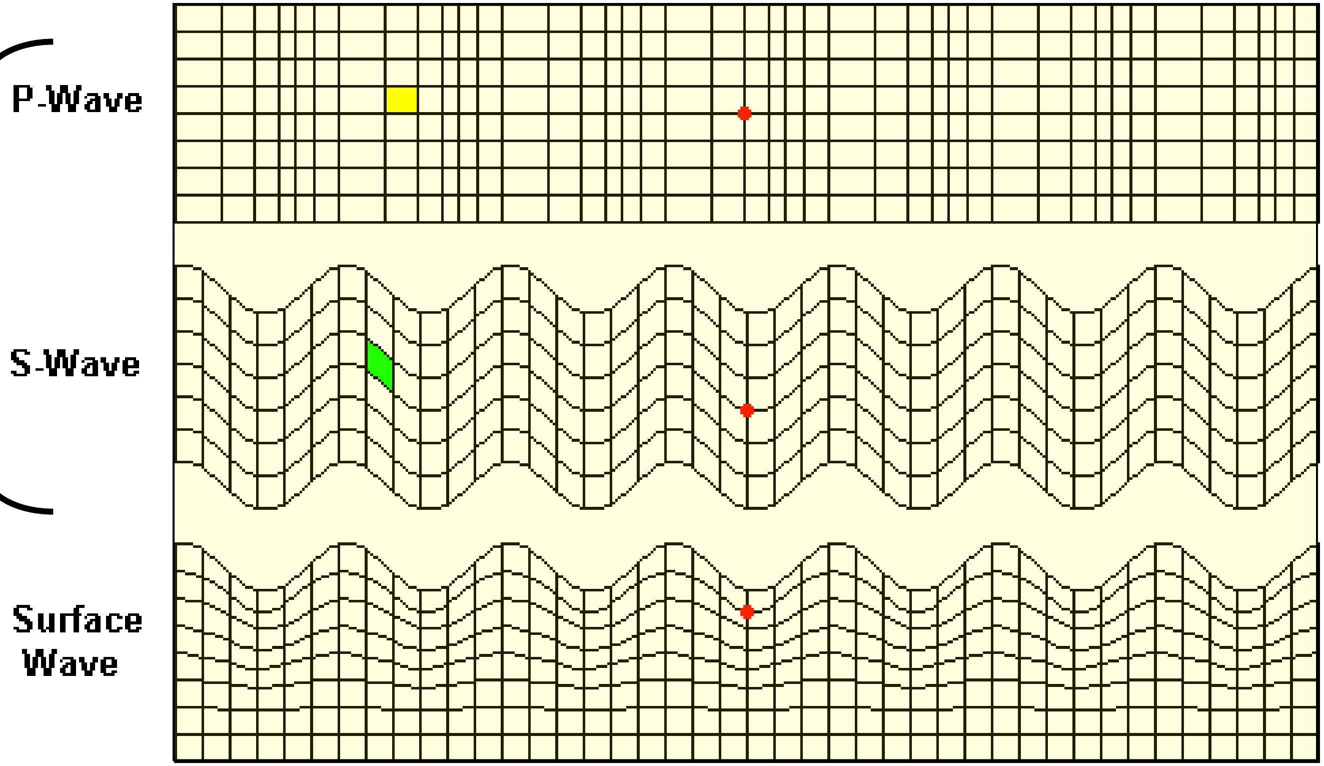
Seismic Waves:

Body waves: P and S

Surface waves: R and L

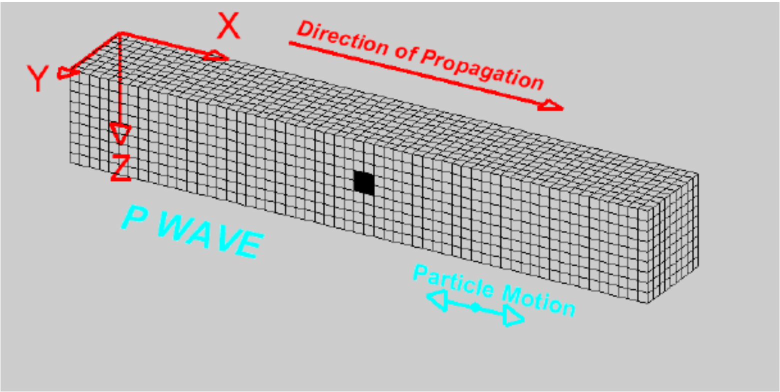


Body waves



Earthquakes generate waves that travel through the earth

body waves, arrive before the surface waves emitted by an earthquake. These waves are of a **higher frequency than surface waves**



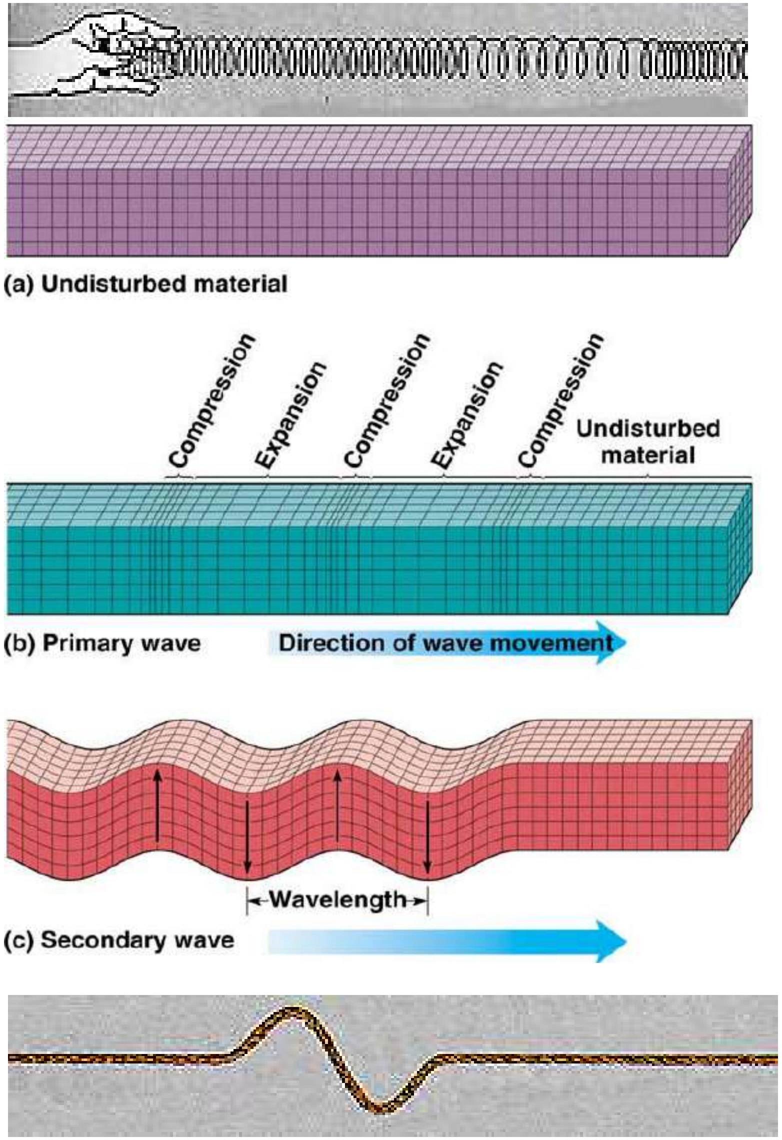
Body waves

P or primary waves

- fastest waves
- travel through the interior of the earth in solids, liquids, or gases
- compressional wave, material movement is in the same direction as wave movement

S or secondary waves

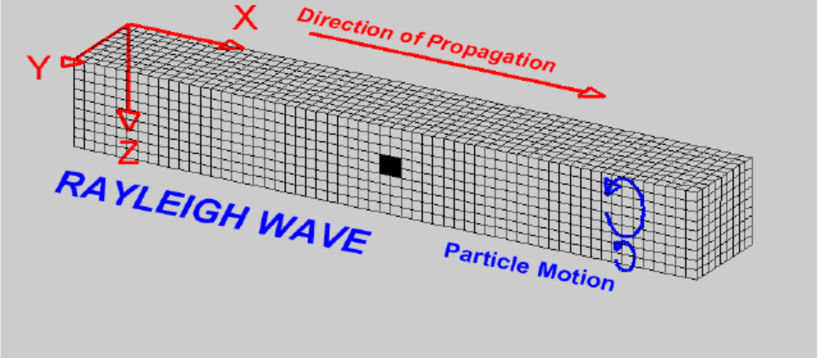
- slower than P waves
- travel through solids only
- shear waves - move material perpendicular to wave movement



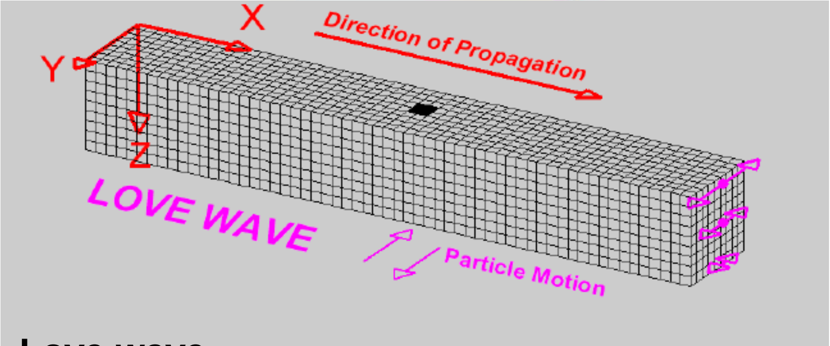
Surface Waves: R and L waves

- Travel just below or along the ground's surface(Travelling only through the crust)
- Slower than body waves; rolling and side-to-side movement
- responsible for the damage and destruction associated with earthquakes to buildings, bridges, and highways.

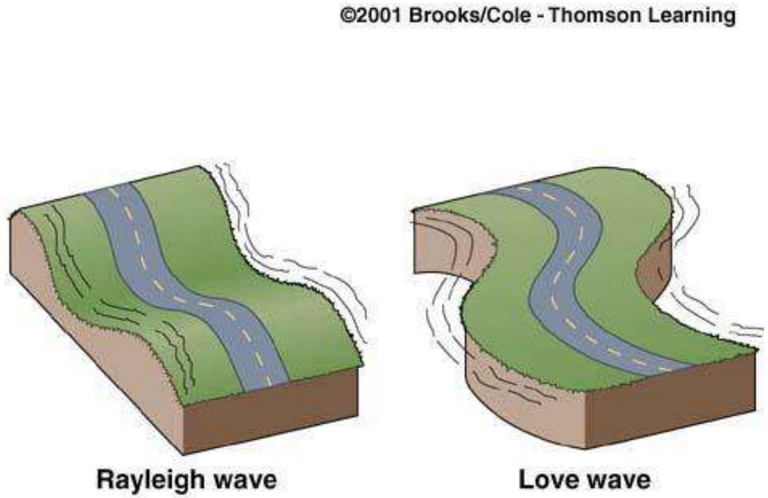
Love wave are the fastest surface wave and moves the ground from side-to-side. Confined to the surface of the crust, Love waves produce entirely horizontal motion



(a) Rayleigh wave



Love wave

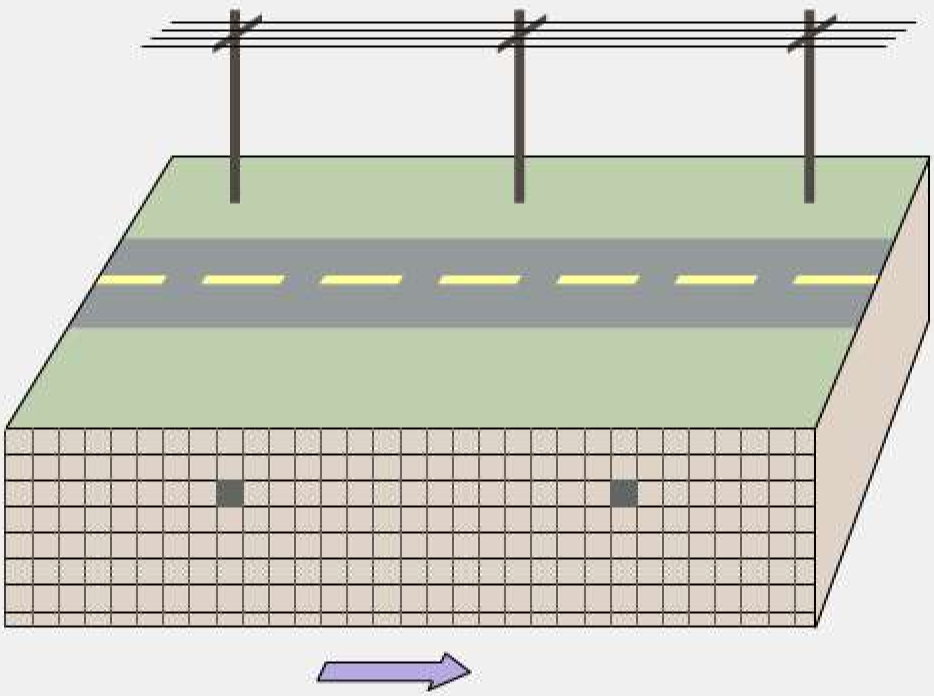


(c)

Most of the shaking felt from an earthquake is due to the Rayleigh wave

http://www.geo.mtu.edu/UPSeis/waves.html

S wave



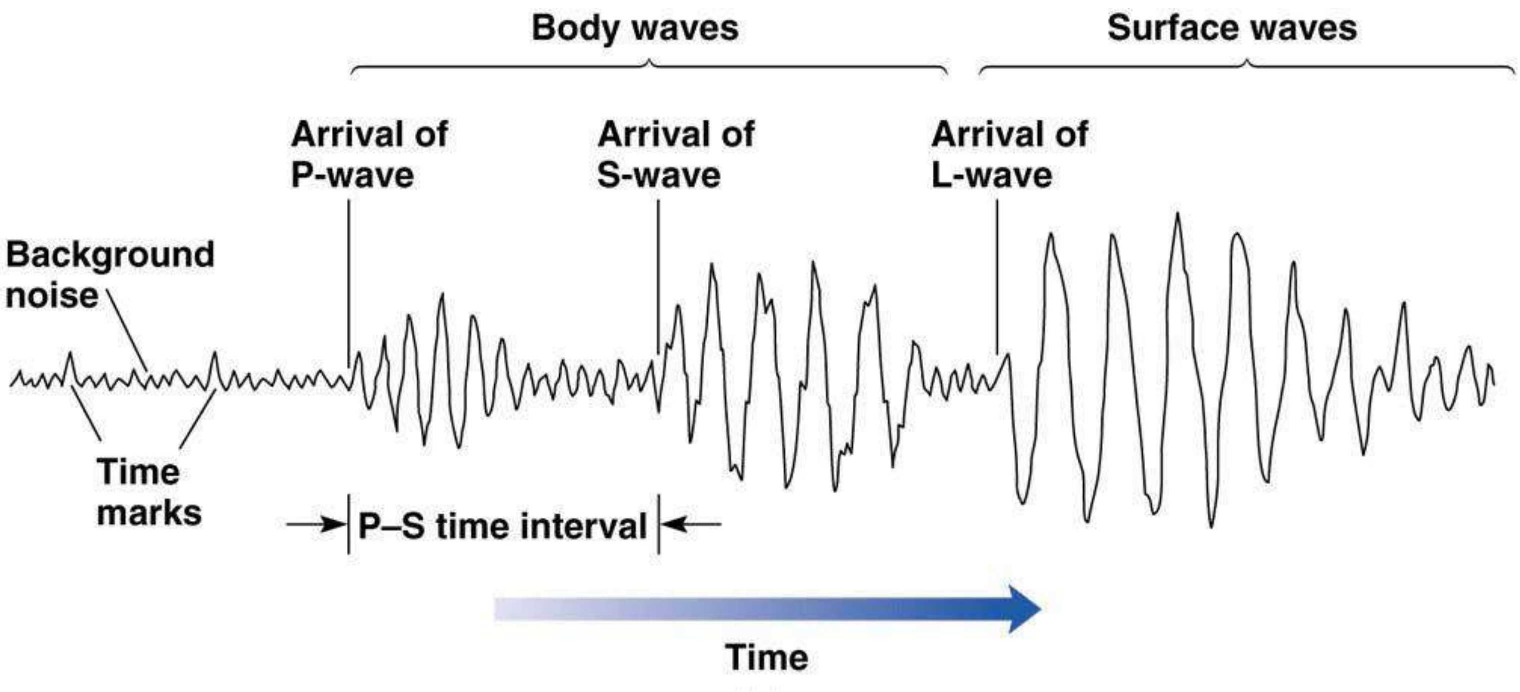
Reset

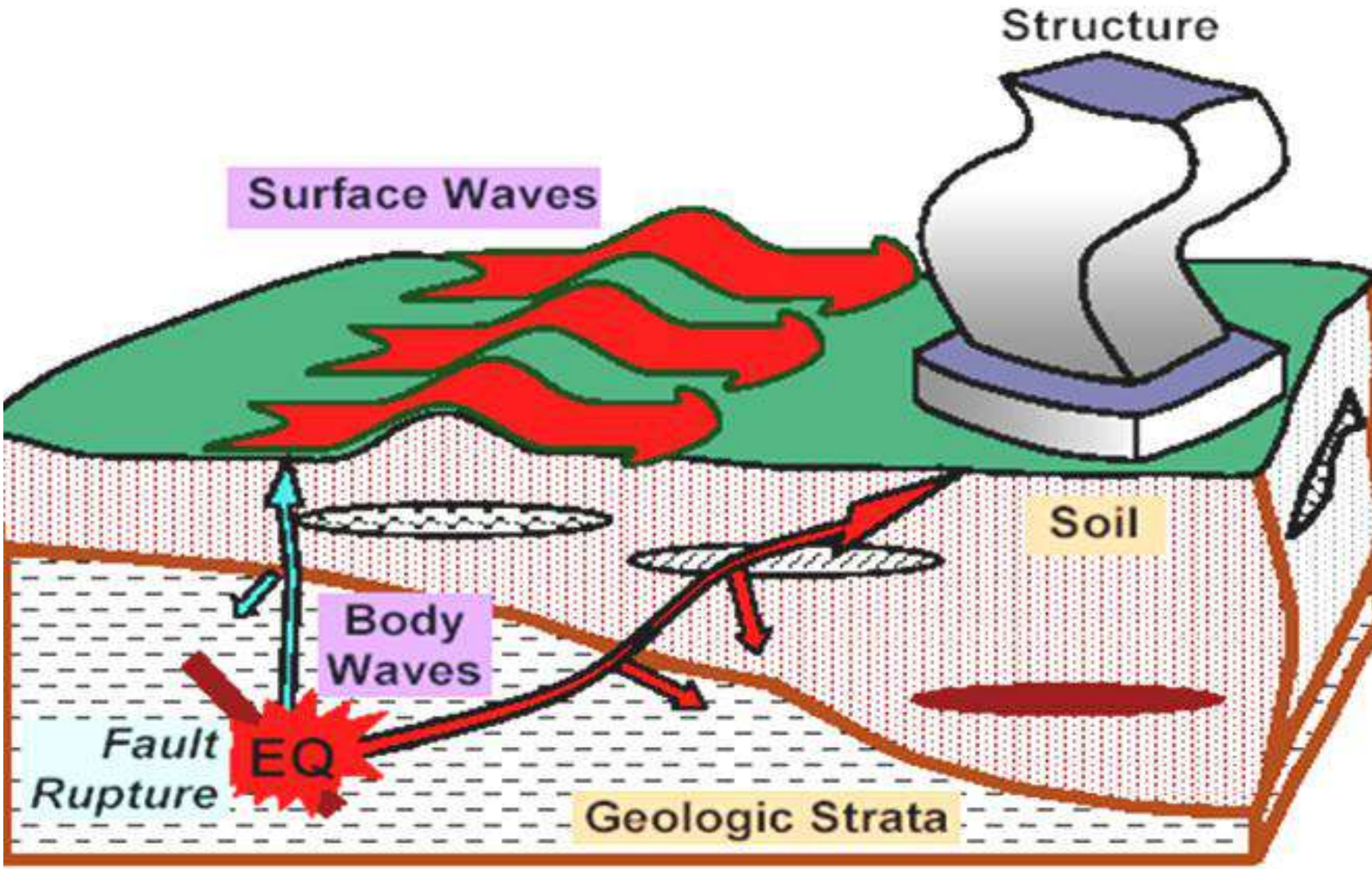
P wave

Locating the Earthquake's Epicenter

Seismic wave behavior

- P waves arrive first, then S waves, then L and R
- Average speeds for all these waves is known
- After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.



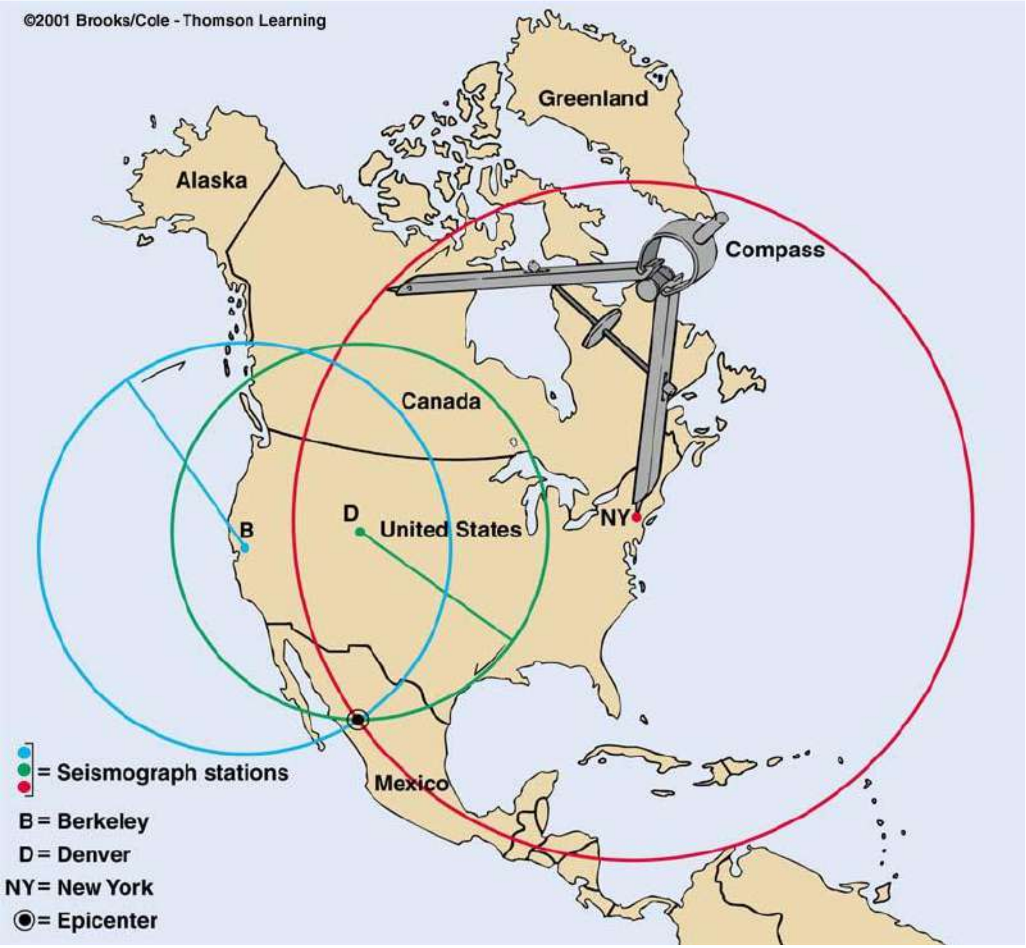


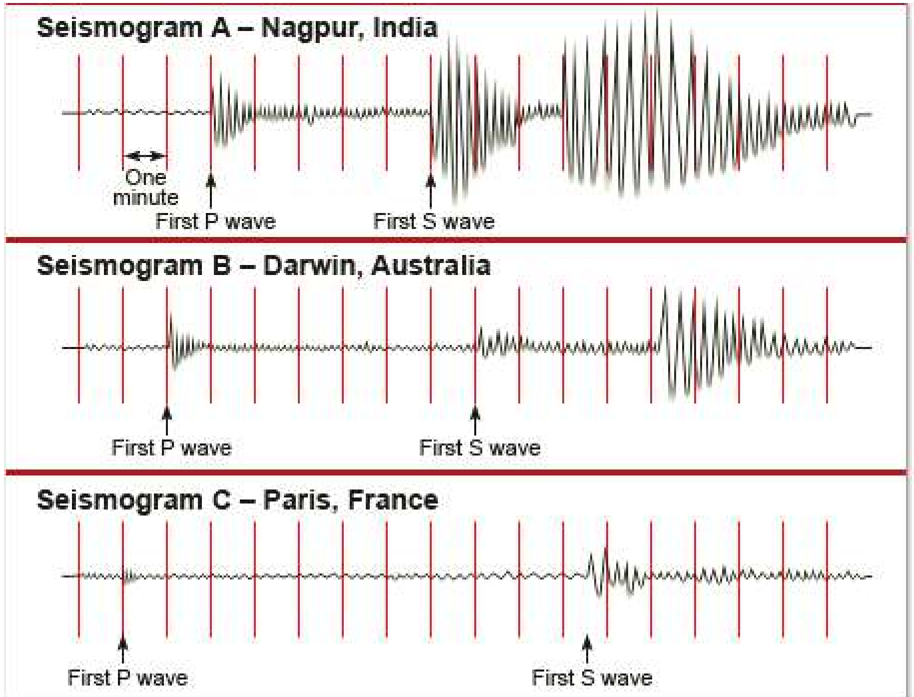
Arrival of Seismic Waves at a Site

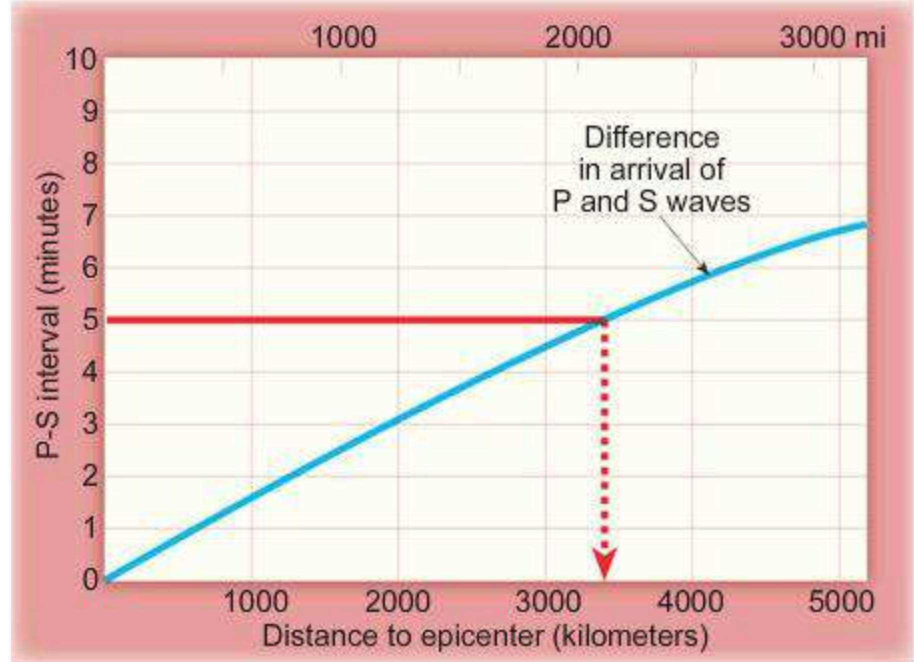
Earthquake's Epicenter Location

The method used for locating an earthquake's epicenter relies on the fact that P waves travel at a higher velocity than S waves

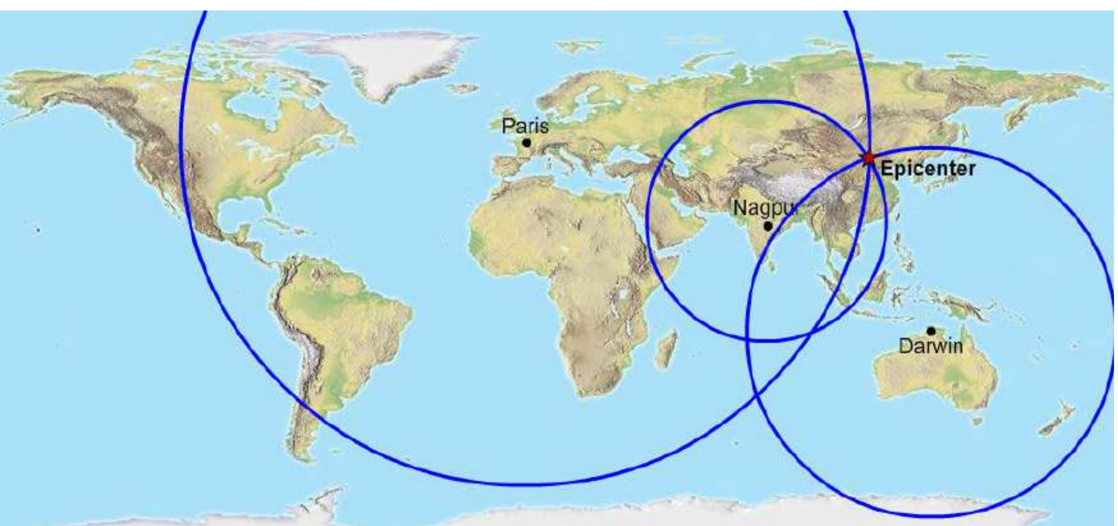
- **Three seismograph stations are needed to locate the epicenter of an earthquake**
- **A circle where the radius equals the distance to the epicenter is drawn**
- **The intersection of the circles locates the epicenter**

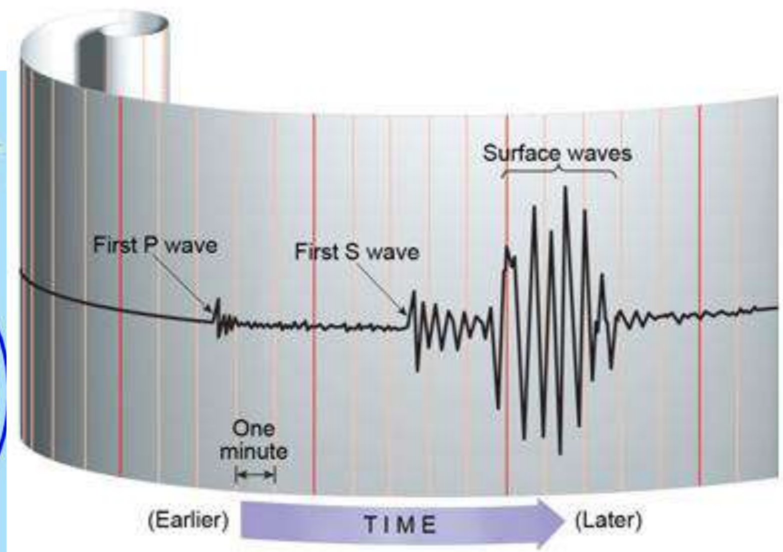






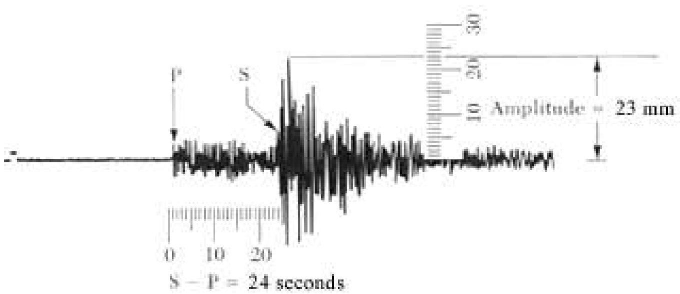
Travel-time graph.

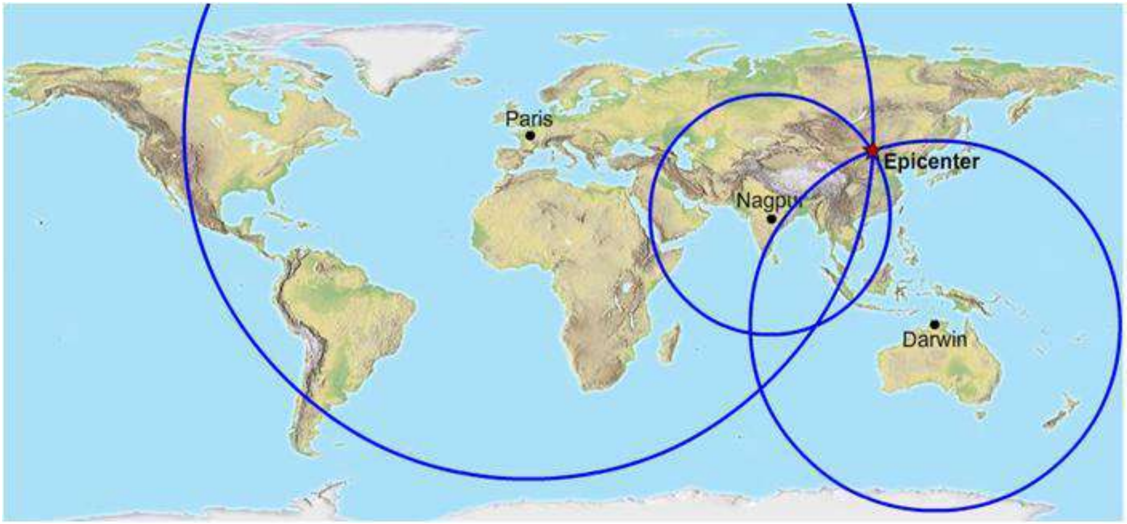




Typical seismogram.

1. Locate the S-wave arrival time and the P-wave arrival time using the seismograph.
2. Subtract the P-wave arrival time from the S-wave arrival time to get the amount of time between the arrival of the two types of waves (the S-P interval).
3. Use a graph showing the relationship between the time difference of an earthquake's waves and the distance from the epicenter, to find out how far the seismograph station was from the earthquake's epicenter.
4. Draw a circle around the location of the station. The epicenter lies on this circle
5. Repeat steps 1-4 for two other seismographs, taken at two other stations.
6. Find the point where the three circles intersect . This is the epicenter of the earthquake





Measuring the Strength of an Earthquake

There are many ways to measure the size of an earthquake. Some depend on the amount of damage caused by the earthquake while others depend on the amount of seismic energy emitted by the earthquake. There are two popular earthquake scales.

The Mercalli Intensity Scale

The Richter Magnitude Scale

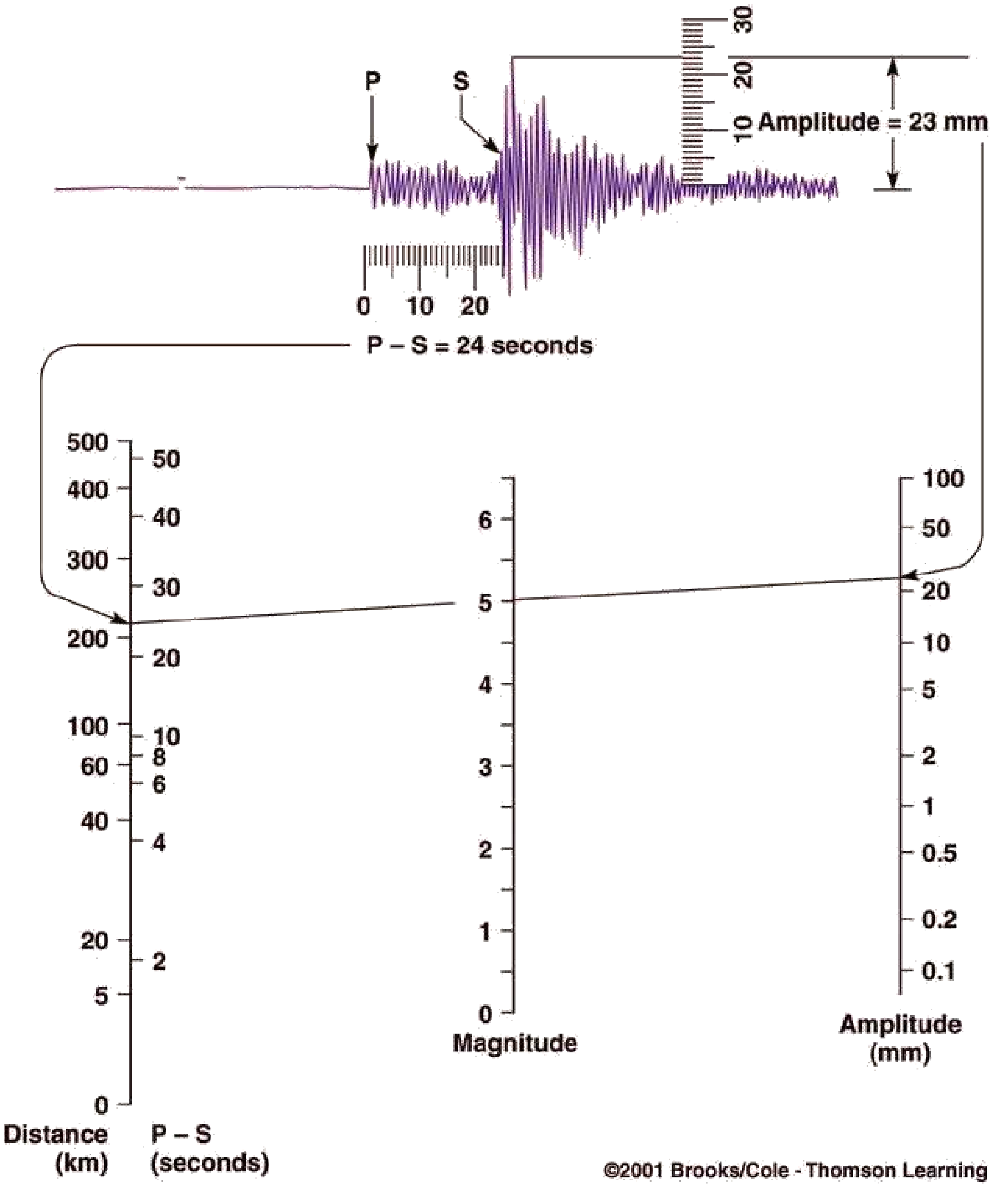
In order to standardize the study of earthquake severity, workers developed various intensity scales that considered damage done to buildings, as well as secondary effects—landslides and the extent of ground rupture.

By 1902, Giuseppe Mercalli had developed a relatively reliable intensity scale, which in a modified form is still used today. The Modified Mercalli Intensity Scale was developed using California buildings as its standard, but it is appropriate for use throughout most of the United States and Canada to estimate the strength of an earthquake. For example, if some well-built wood structures and most masonry buildings are destroyed by an earthquake, a region would be assigned an intensity of X on the Mercalli scale

Measuring the Strength of an Earthquake

Magnitude

- Richter scale measures total amount of energy released by an earthquake; independent of intensity
- Amplitude of the largest wave produced by an event is corrected for distance and assigned a value on an opened logarithmic scale



Magnitude Scales

In order to compare earthquakes across the globe, a measure is needed that does not rely on parameters that vary considerably from one part of the world to another, such as building design.

Richter Magnitude **In 1935 Charles Richter of the California Institute of Technology developed the first magnitude scale using seismic records. It is established by measuring the amplitude of the largest seismic wave (P, S, or surface wave) recorded on a seismogram. Because seismic waves weaken as the distance between the earthquake focus and the seismograph increases. Richter developed a method that accounted for the decrease in wave amplitude with increased distance. Theoretically, as long as equivalent instruments were used, monitoring stations at various locations would obtain the same Richter magnitude for every recorded earthquake.**

The energy released by a M6.3 magnitude earthquake is equivalent to that released by the 1945 Atom bomb dropped in Hiroshima

Earthquakes are often classified into different groups based on their size (Table 1). Annual average number of earthquakes across the Earth in each of these groups is also shown in the table; it indicates that on an average one *Great Earthquake* occurs each year.

Table 1: ***Global occurrence of earthquakes***

Group	Magnitude	Annual Average Number
Great	8 and higher	1
Major	7 – 7.9	18
Strong	6 – 6.9	120
Moderate	5 – 5.9	800
Light	4 – 4.9	6,200 (estimated)
Minor	3 – 3.9	49,000 (estimated)
Very Minor	< 3.0	M2-3: ~1,000/day; M1-2: ~8,000/day

Modified Mercalli Scale		Richter Magnitude Scale
I	Detected only by sensitive instruments	1.5
II	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing	2
III	Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibration like passing truck	2.5
IV	Felt indoors by many, outdoors by few, at night some may awaken; dishes, windows, doors disturbed; autos rock noticeably	3
V	Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects	3.5 4
VI	Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small	4.5
VII	Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos	5
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed	5.5
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken	6
X	Most masonry and frame structures destroyed; ground cracked, rails bent, landslides	6.5 7
XI	Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent	7.5
XII	Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up in air	8

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.

The Richter scale is a logarithmic scale, meaning that the numbers on the scale measure factors of 10.

eg. an earthquake that measures 4.0 on the Richter scale is 10 times larger than one that measures 3.0. On the 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.

<table>
<tr><th>Modified Mercalli Intensity
(at the epicenter)</th><th>I</th><th>II</th><th>III</th><th>IV</th><th>V</th><th>VI</th><th>VII</th><th>VIII</th><th>IX</th><th>X</th><th>XI</th><th>XII</th></tr>
<tr><td rowspan="3">Richter Magnitude</td><td colspan="2" rowspan="3">2</td><td rowspan="3">3</td><td rowspan="3"></td><td rowspan="3">4</td><td colspan="2">5</td><td></td><td colspan="2">7</td><td></td><td></td></tr>
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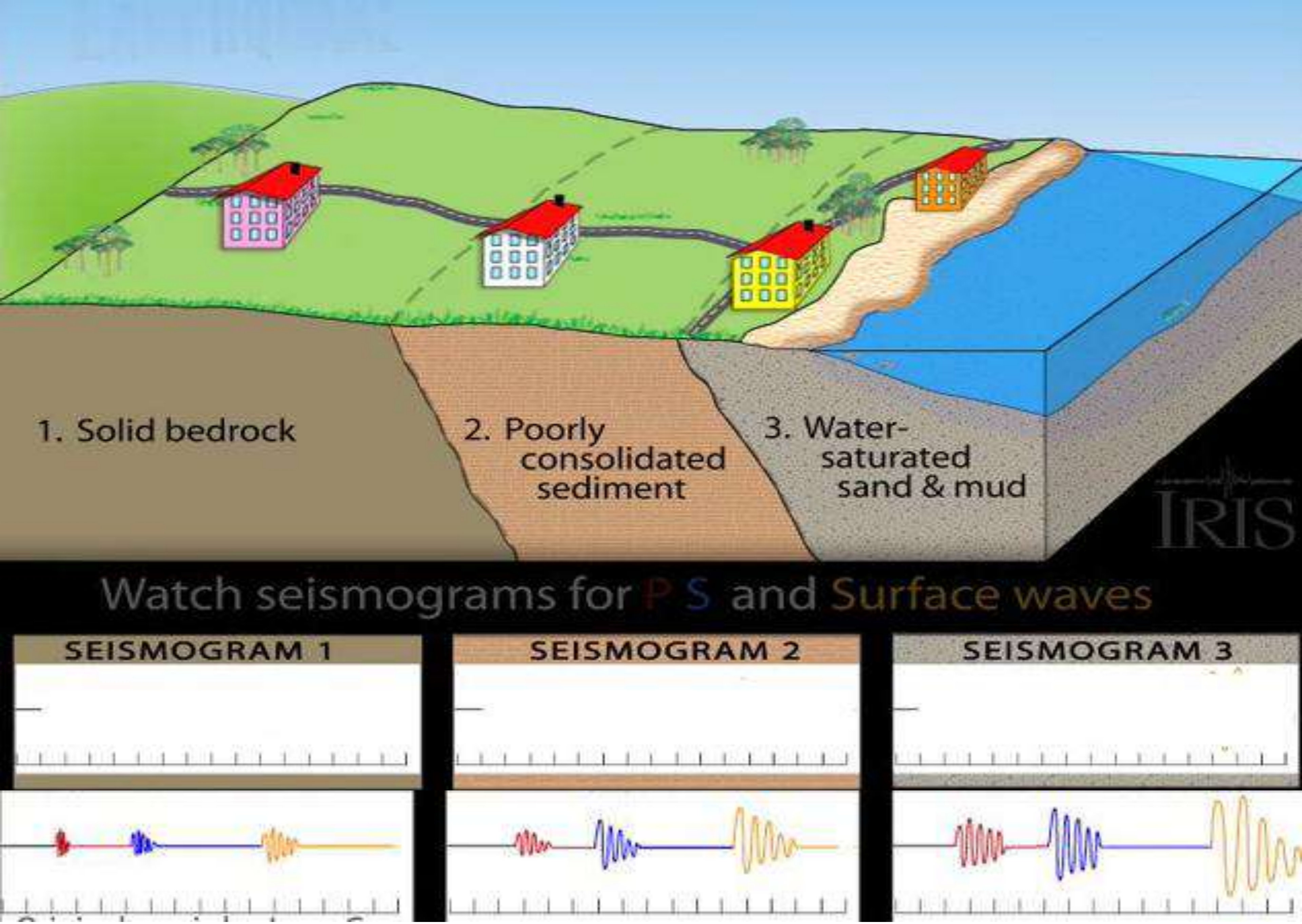
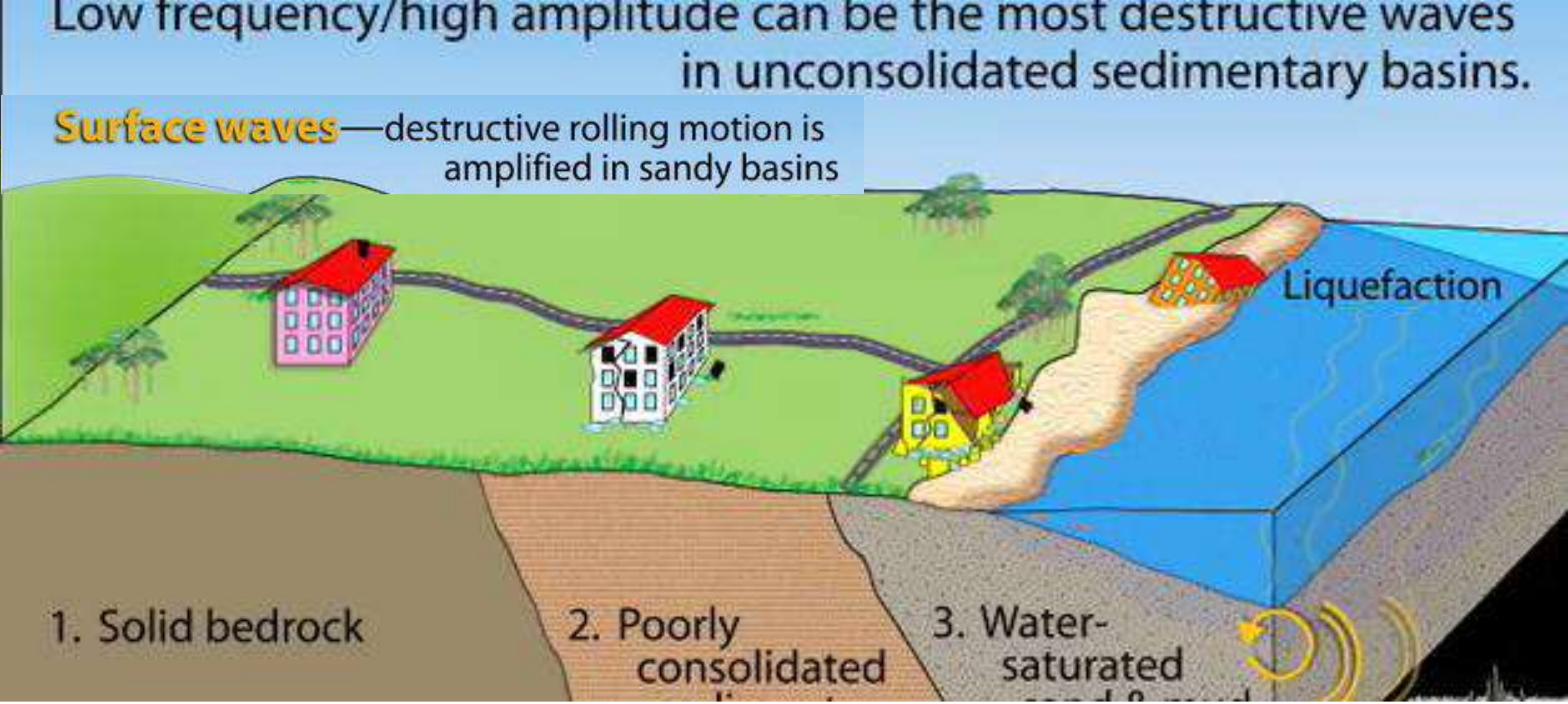
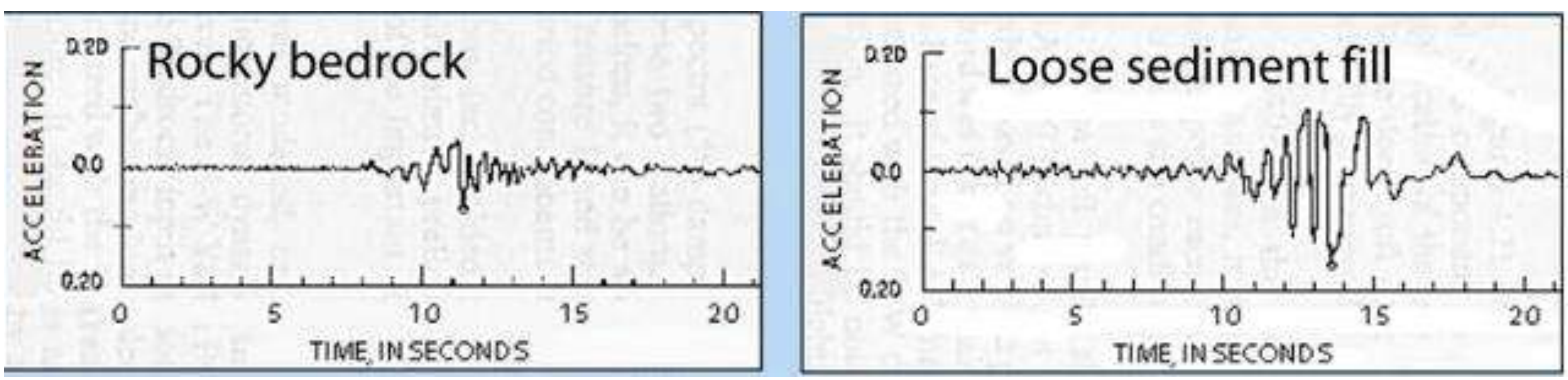

1. Solid bedrock
2. Poorly consolidated sediment
3. Water-saturated sand & mud
IRIS
Watch seismograms for P S and Surface waves
SEISMOGRAM 1
SEISMOGRAM 2
SEISMOGRAM 3


Low frequency/high amplitude can be the most destructive waves in unconsolidated sedimentary basins.
Surface waves—destructive rolling motion is amplified in sandy basins
Liquefaction
1. Solid bedrock
2. Poorly consolidated
3. Water-saturated


Rocky bedrock
ACCELERATION
0.20
0.0
0.20
0
5
10
15
20
TIME, IN SECONDS
Loose sediment fill
ACCELERATION
0.20
0.0
0.20
0
5
10
15
20
TIME, IN SECONDS

Hazards associated with earthquakes (direct and Indirect effects)

- **Ground shaking** :

  Frequency of shaking differs for different seismic waves.

  High frequency body waves shake low buildings more.

  Low frequency surface waves shake high buildings more.

  Intensity of shaking also depends on type of subsurface material.

  Unconsolidated materials amplify shaking more than rocks do.

  Fine-grained, sensitive materials can lose strength when shaken. They lose strength by ***liquefaction***.

  Buildings respond differently to shaking depending on construction styles, materials

  Wood -- more flexible, holds up well

  Earthen materials -- very vulnerable to shaking.

- **Ground displacement:**

  Ground surface may shift during an earthquake (esp. if focus is shallow).

  Vertical displacements of surface produce ***fault scarps***.

  Landslides: mudflow, slope failure;

- **Tsunamis (NOT tidal waves)**

  Tsunamis are huge waves generated by earthquakes undersea or below coastal areas.

  If earthquake displaces sea surface, wave is generated that can grow as it moves over sea surface.

- **Lifeline hazards: Indirect Effects**

  fire, hazardous gas, loss of drinking/ fire-fighting water;

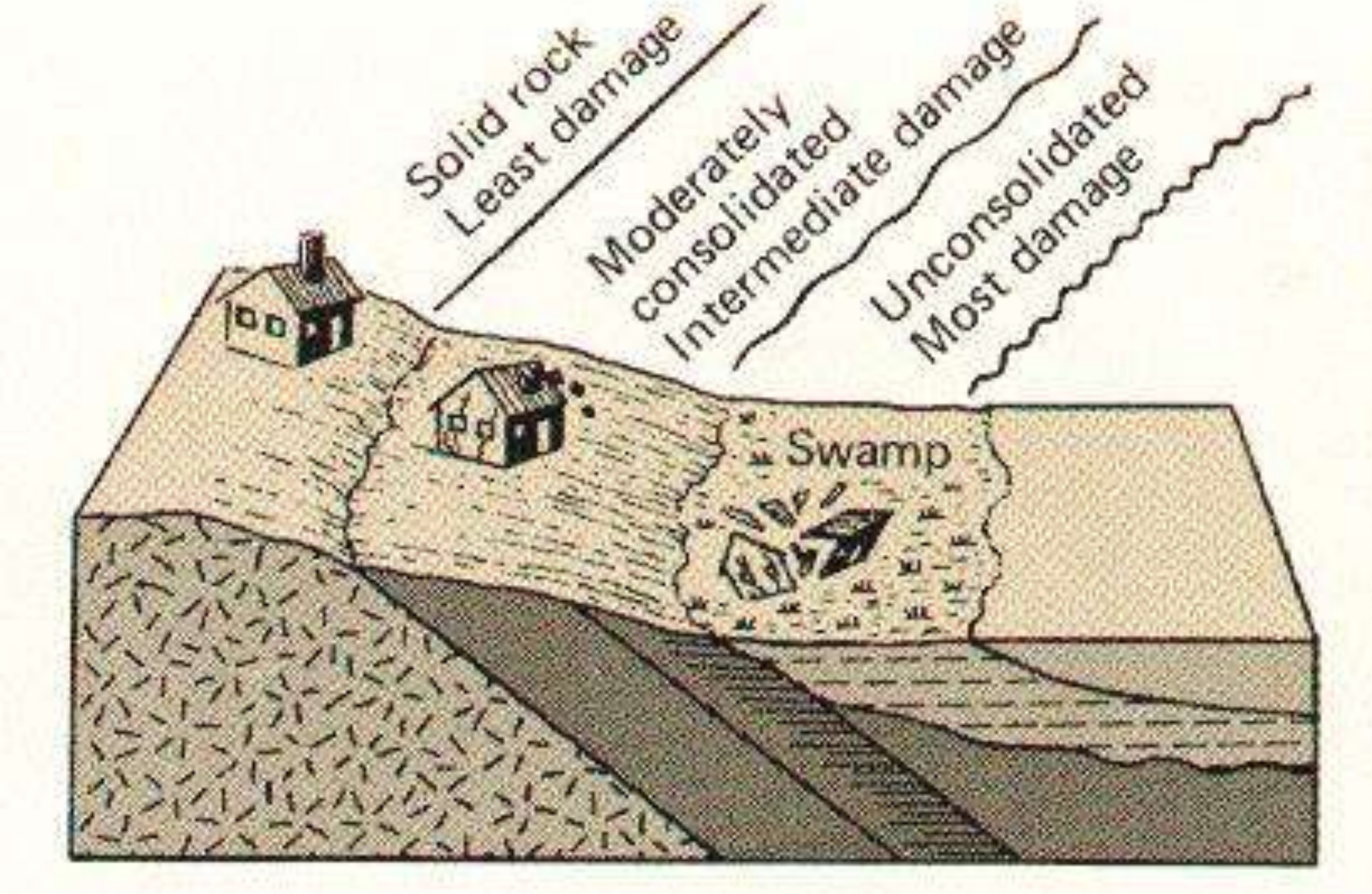
- **Structural hazards**:

  damage of engineering works (buildings, bridges, highways, etc.);

The structural engineer should be aware of the different seismic hazards and should advise the client of potential damage involved in locating structures at certain sites. Thus the first step in the design procedure of a future structure should be the analysis of the suitability of the site selected with proper consideration for the potential of any one of the above types of damage

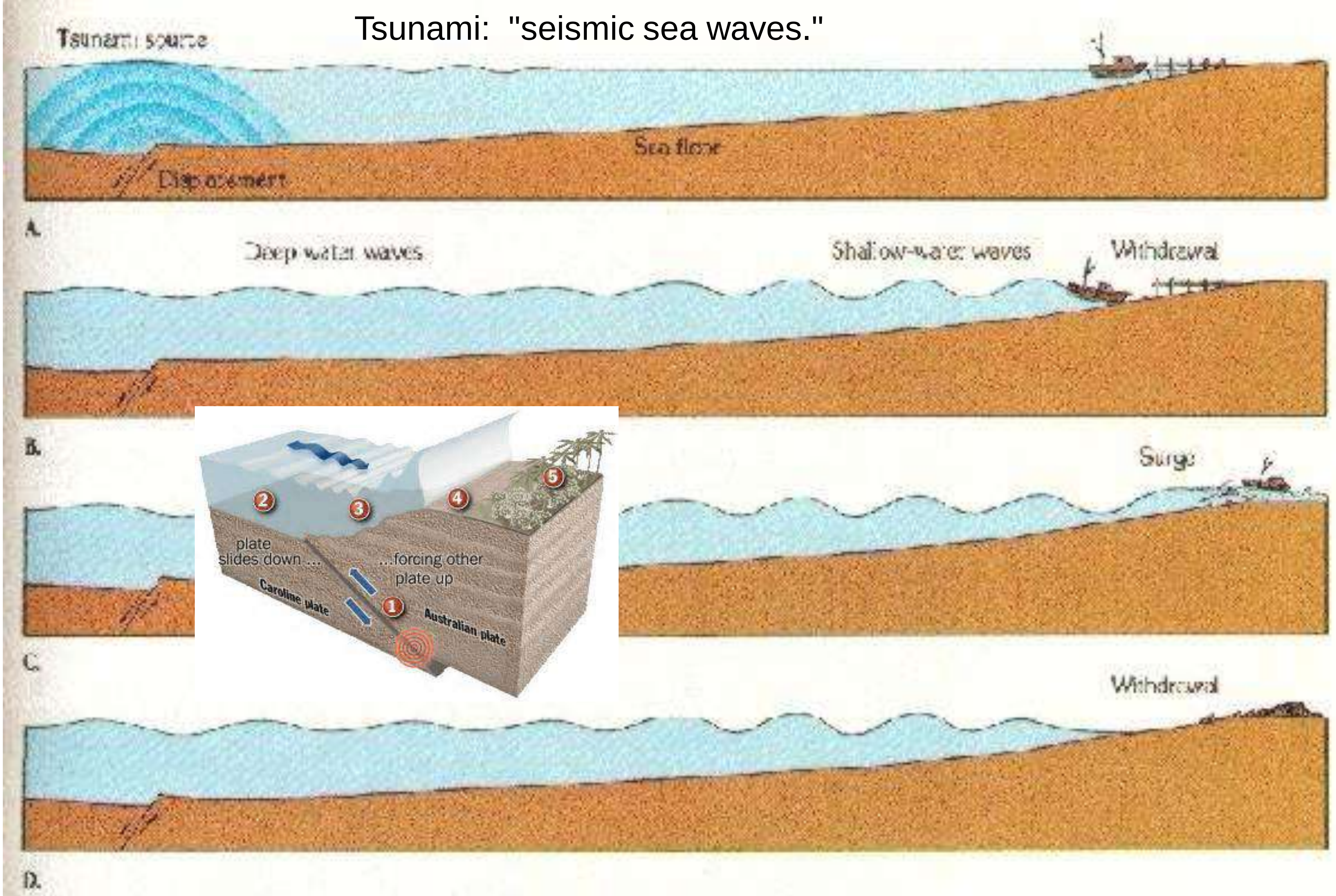
The Geology of Earthquakes

Robert S. Yeats
Kerry Sieh
Clarence R. Allen



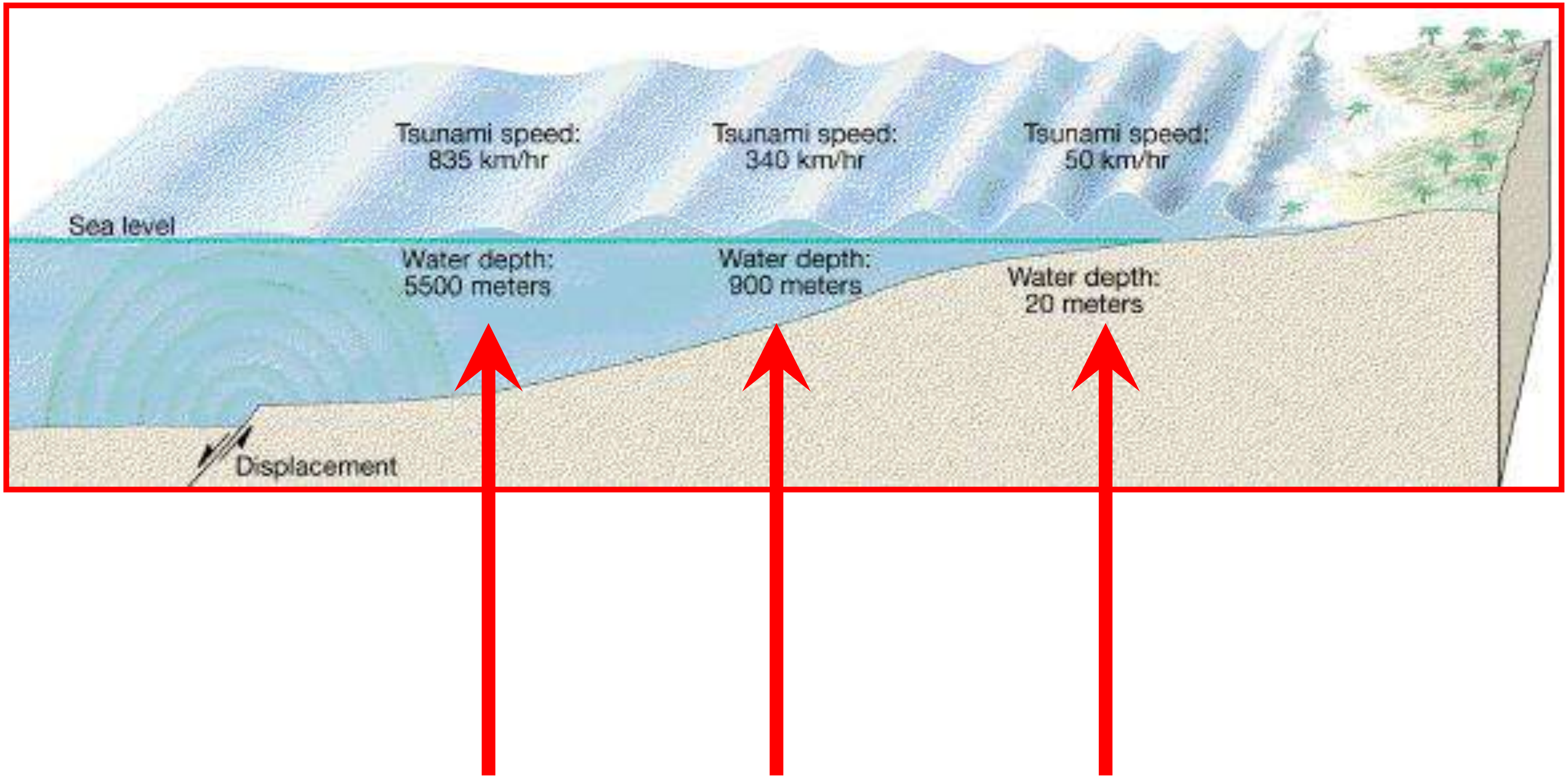
(from The Changing Earth - Introduction to Geology (2nd ed.), by Mears, Jr., D. Van Nostrand Co., 1977).

Tsunami: "seismic sea waves."



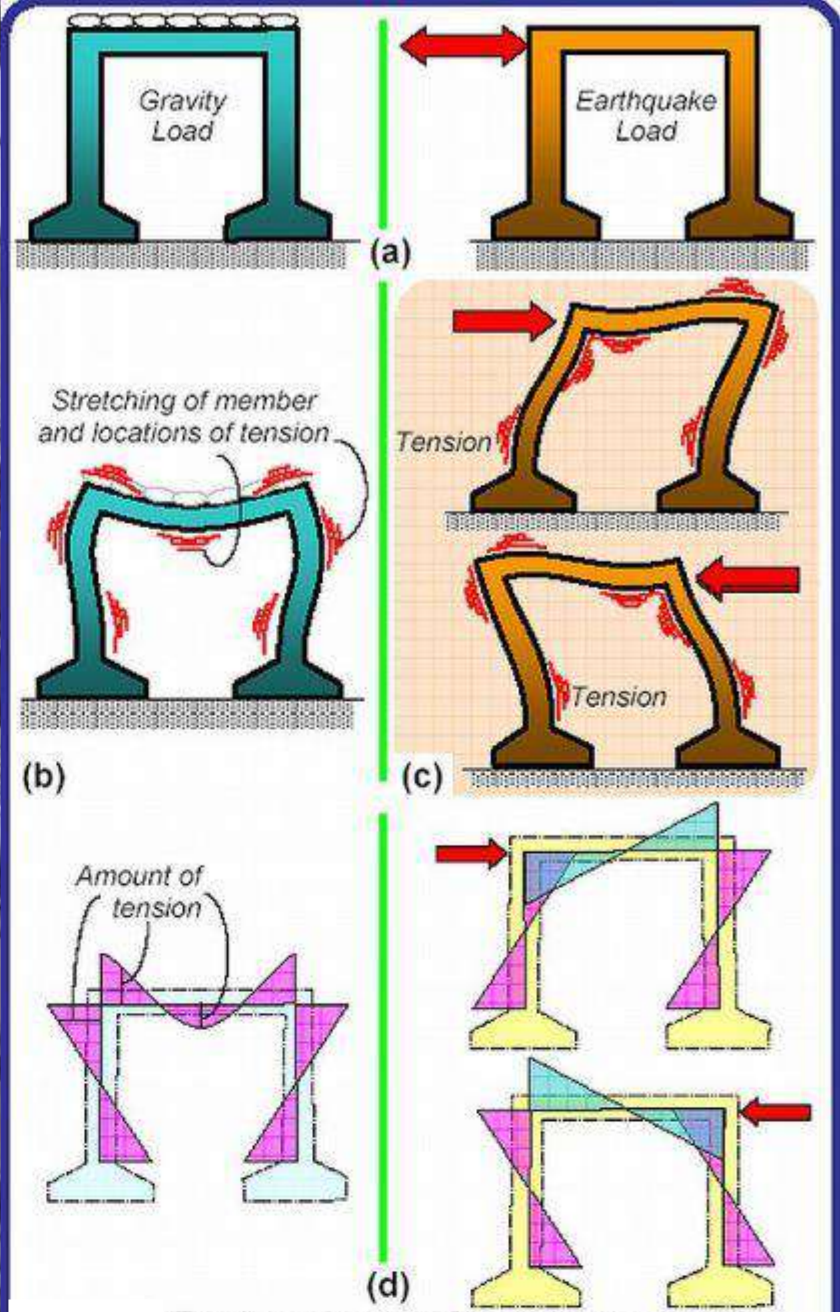
Schematic drawing of a tsunami generated by displacement of the ocean floor. The size and spacing of the swells are not to scale *(from The Earth - An Introduction to Physical Geology (2nd ed.), by Tarbuck & Lutgens, Merrill Publishing Co., 1984).*

Tsunami Movement



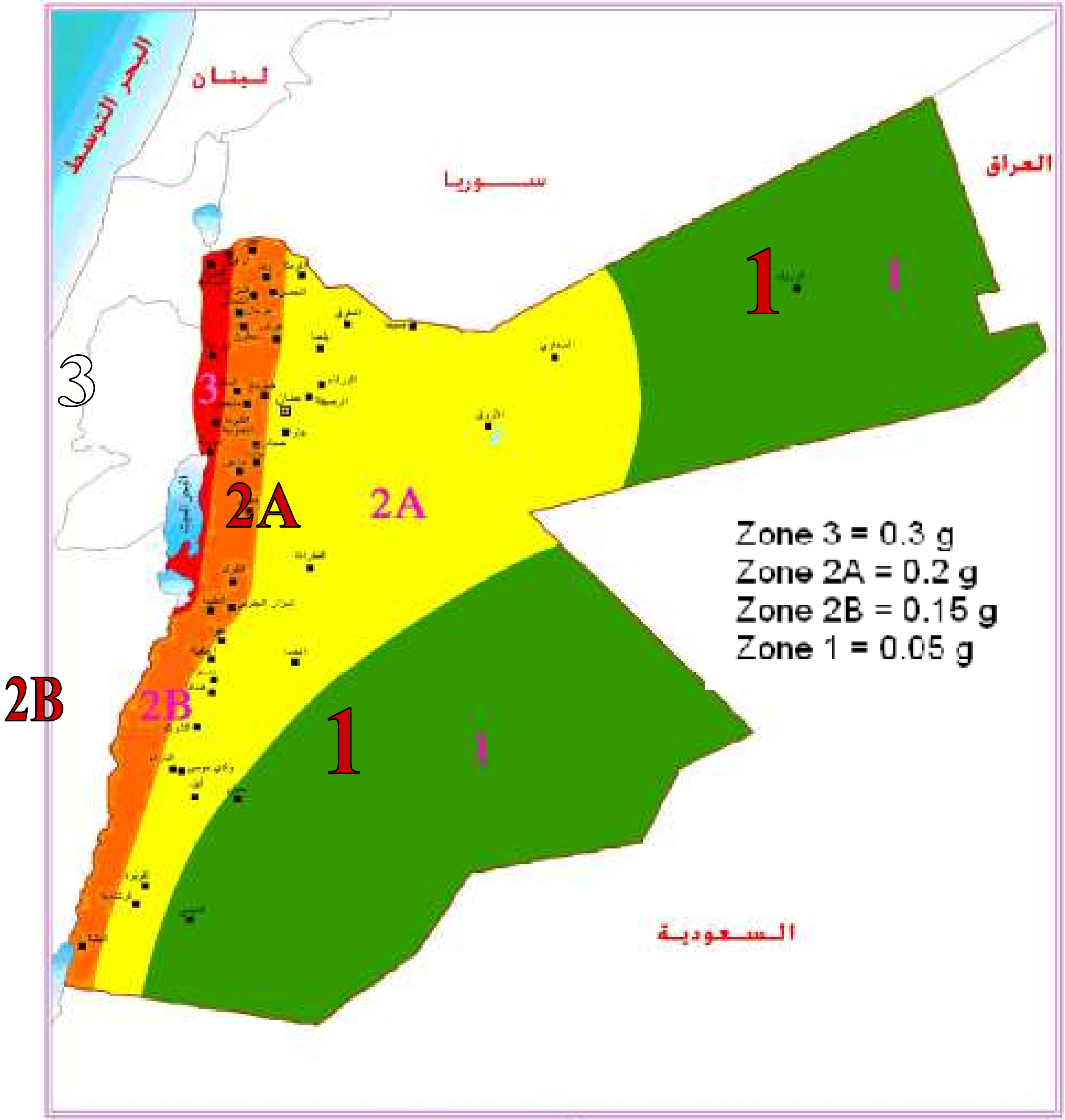
2008 Sichuan China Earthquake

Where buildings are constructed in close proximity to one another, damage due to pounding between the buildings is possible



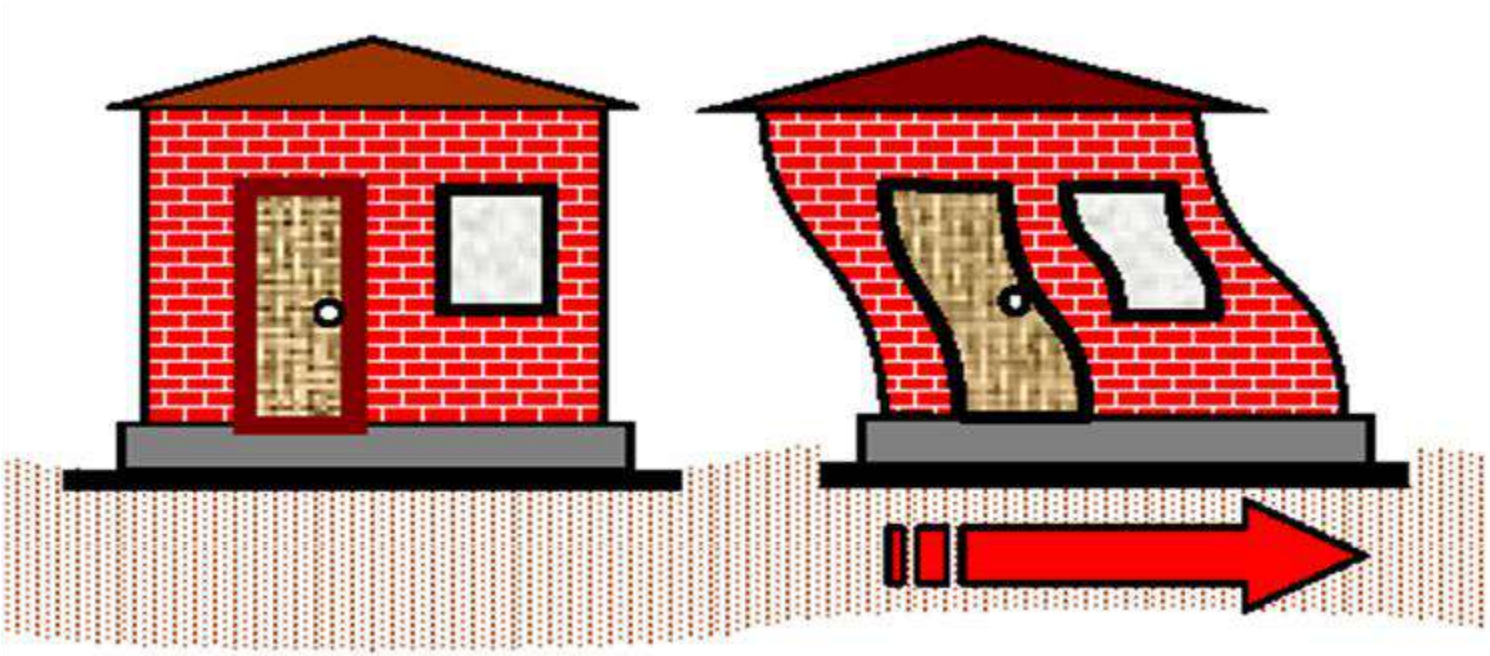
Earthquake shaking reverses tension and compression in members – *reinforcement is required on both faces of members.*

slides

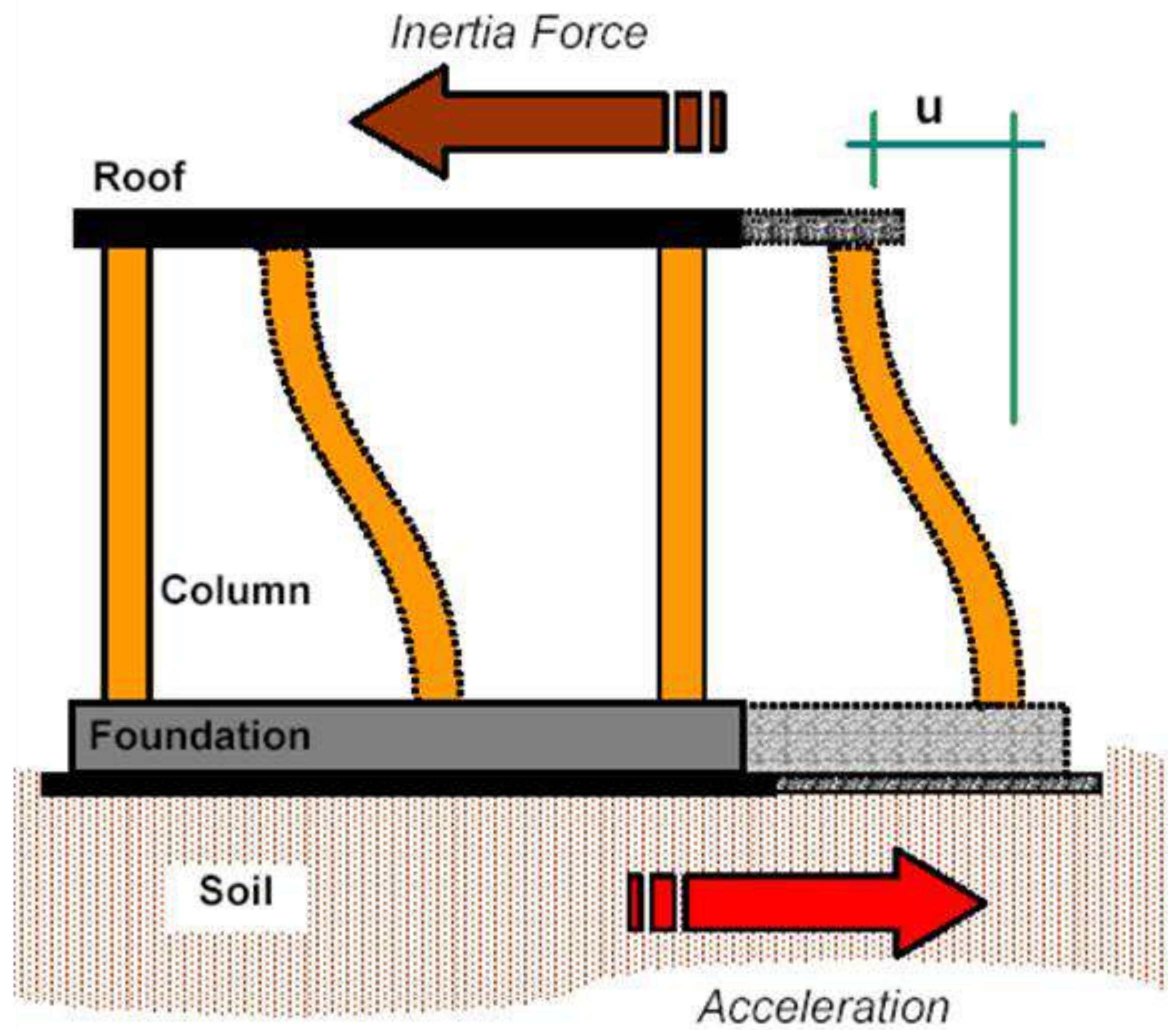


خارطة التقسيم الزلزالي في الأردن التي صدرت في العام ٢٠٠٦ :

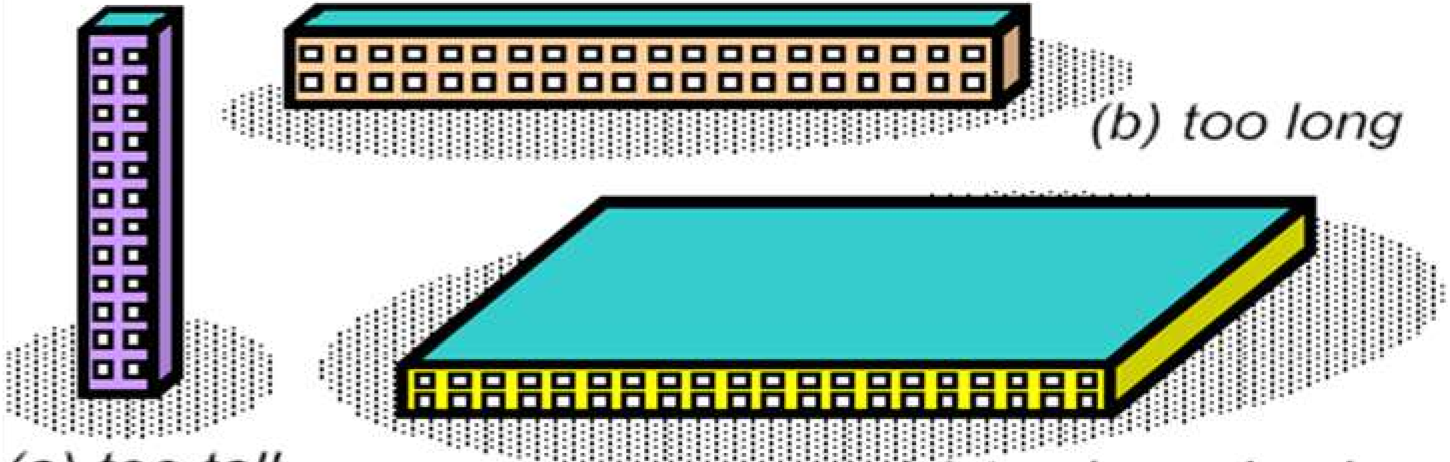
Seismic effects on Structures



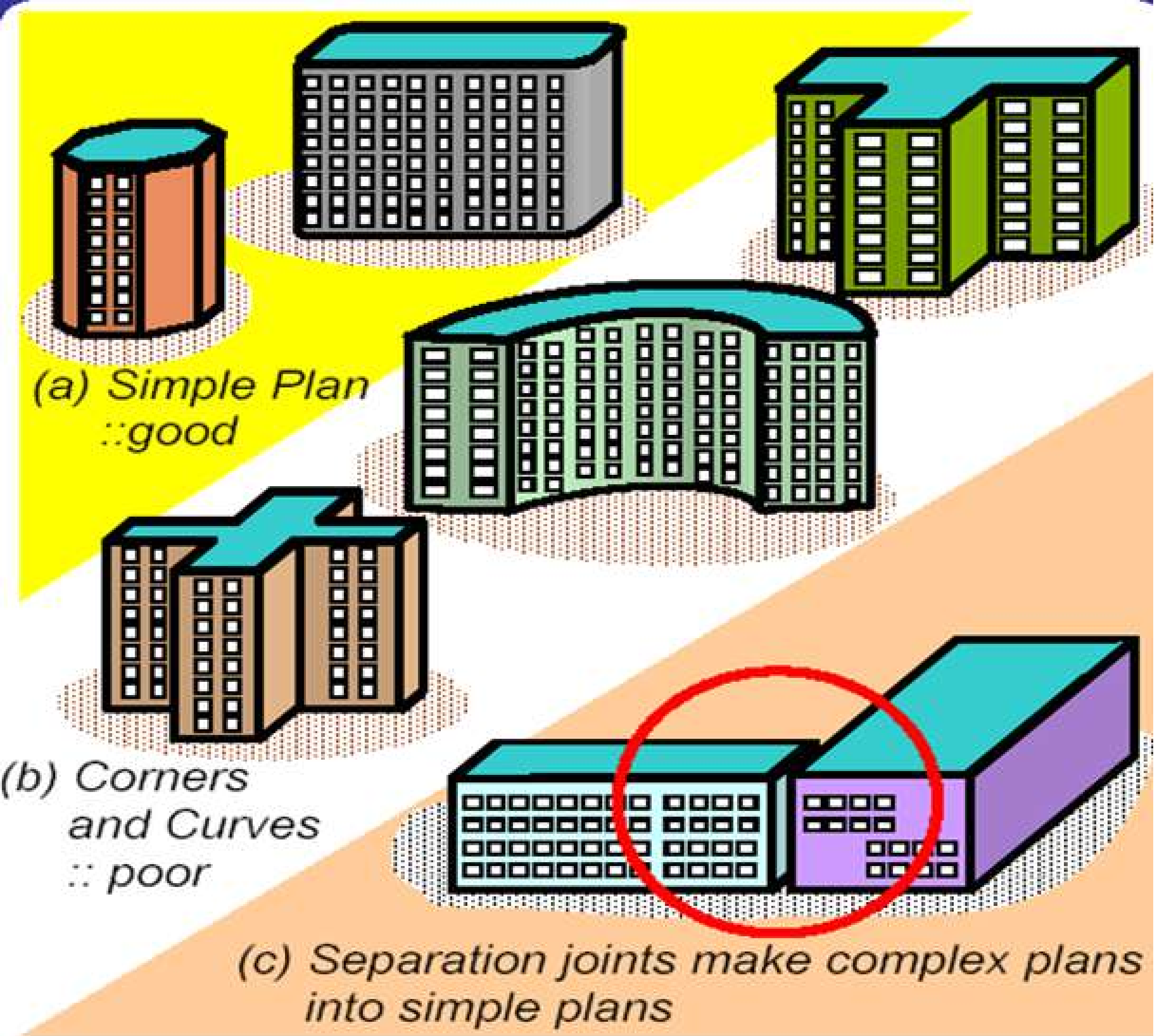
Effect of inertia is a building when shaken at its base



Inertia force and relative motion within a building



Buildings with one of their overall sizes much larger or much smaller than the other two, do not perform well during earthquakes.



Simple plan shape buildings do well during earthquakes.

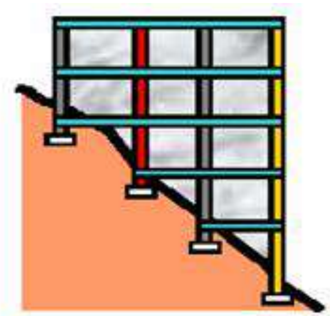
Pounding can occur between adjoining buildings due to horizontal vibrations of the two buildings.

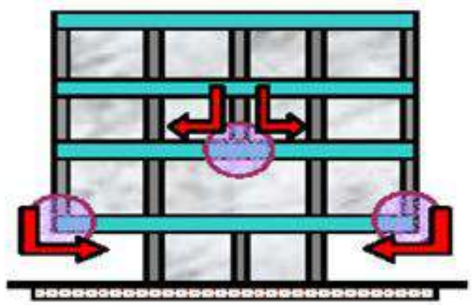
Some engineering designs have poor behavior in earthquakes:

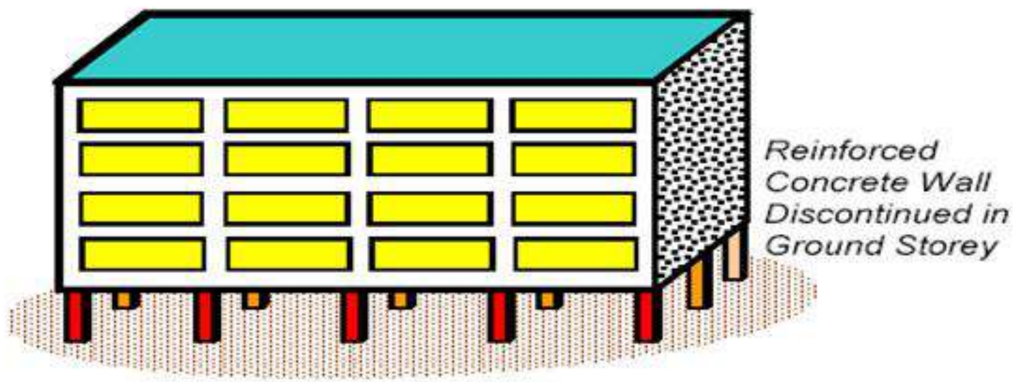
1. Buildings on slops with unequal columns lengths will cause twisting and damage in the shorter columns.

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)

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.


(c) Slopy Ground


(d) Hanging or Floating Columns



(e) Discontinuing Structural Members

Sudden deviations in load transfer path along the height lead to poor performance of buildings.

Earthquake resisting buildings

The major objective of seismic design in codes through the world

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.

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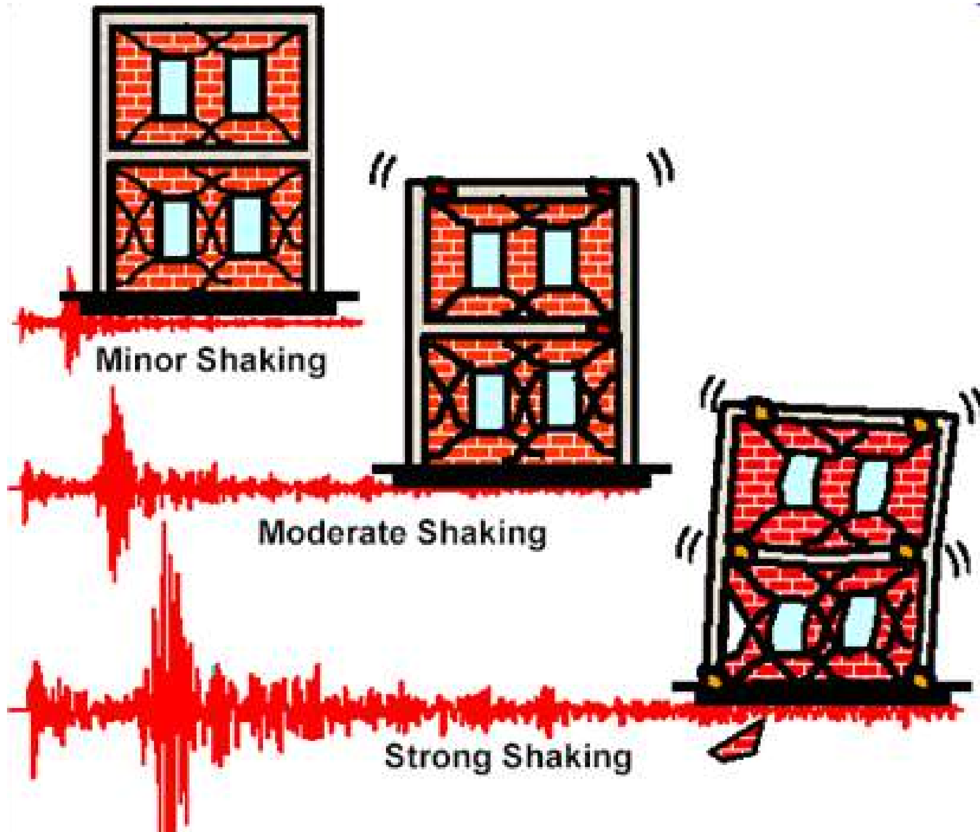


: **Performance objectives under different intensities of earthquake shaking –** *seeking low repairable damage under minor shaking and collapse-prevention under strong shaking.*

Click on the Execute button below to start the *Virtual Earthquake* application.

http://www.sciencecourseware.com/VirtualEarthquake/

Execute VirtualEarthquake

Choose any one of the following regions to generate a set of seismograms for an earthquake:

1. ◉ San Francisco area
2. ○ Southern California
3. ○ Japan region
4. ○ Mexico

Submit Choice

Go through this and submit the results

Final Tabulation of Data

If you would like to receive a Certificate of Completion as a Virtual Seismologist, complete the form below and click the "Get Certificate" button.

Enter your name: your name in english (ID numeber)

Enter your institution: Hashemite University

Enter your city & state: Zarqa

E-mail Certificate to Your Instructor ☑

Instructor's e-mail address: iqbal@hu.edu.jo

Your e-mail address:
(If you want a copy e-mailed to you)

Get Certificate

** When u send the e-mail let the subject of ur e-mail be ur ID number (ur serial number)

Engineering Geology

Engineering Geology is backbone of civil engineering

Topographic Maps

Eng. Iqbal Marie

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.**

4. Outcrops: are those places where a geologic formation is exposed at the Earth's surface.

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:**

isolines

Meteorological Quantity:	pressure	temperature	wind speed	dew-point temperature	topography	etc.
Name of Contour Line:	isobar	isotherm	isotach	isodrosotherm	contour	

***Each contour line has a value associated with it and is usually labeled with that value*.**

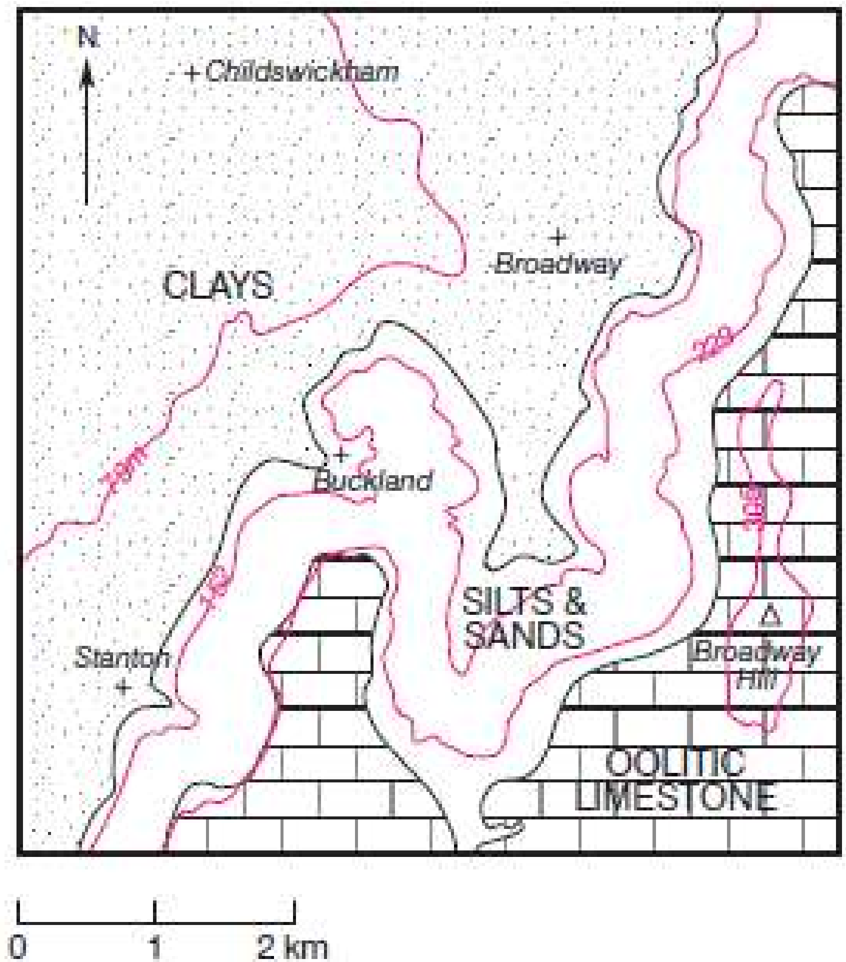
***Contour maps show contour lines with values at regular intervals, including some standard reference value*. The contour interval is arbitrary but should be chosen so that the contour map shows enough contours to reveal the pattern clearly without being crowded with too many contour lines**

contour map should always include *a title or caption that identifies the quantity shown and the contour interval used*.

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 and**
- **companies exploiting minerals.**



A topographic map: known as a **contour map**, It shows the shape of the land using contour line ,that connect points of equal elevation;

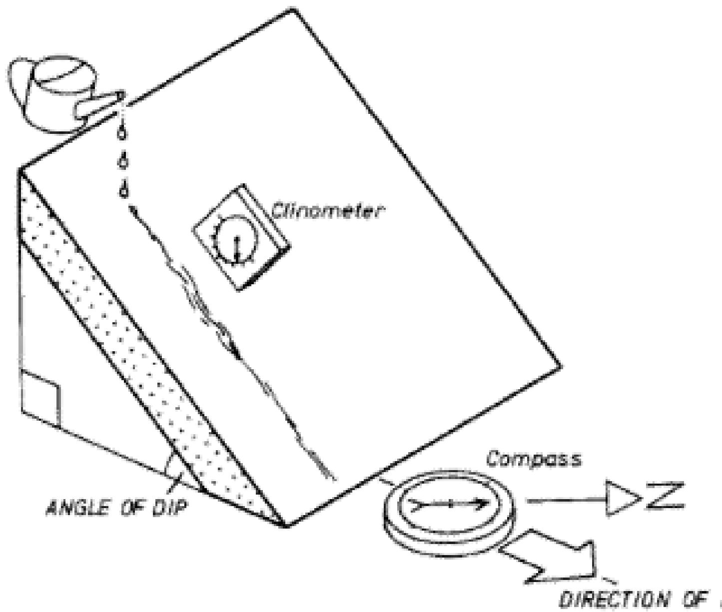
The *dip* is the slope of a geological surface.
There are two aspects to the dip of a plane:

- **the *direction of dip*, which is the compass direction towards which the plane slopes; and**
- **the *angle of dip*, which is the angle that the plane makes with a horizontal plane**

- **contour interval: The vertical distance between contour lines and is an even number such as 10, 50, or 100 feet (or meters).**

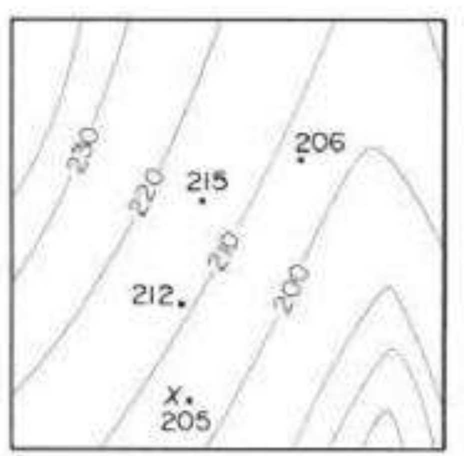
*** a contour interval is not the distance between the two lines –**

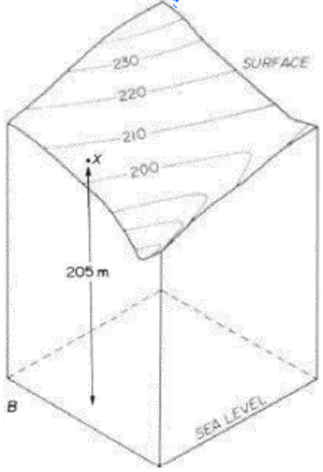
to get the distance you need to use the map scale.



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**.

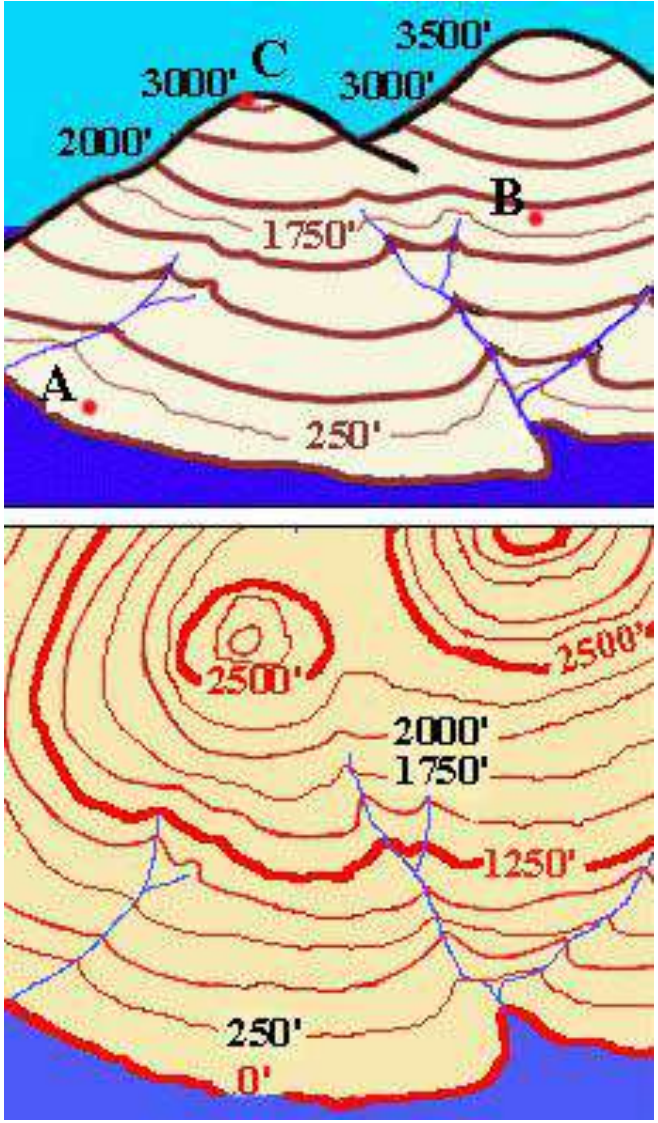
Elevations of single points that have been accurately surveyed to the nearest foot are also shown. These points, called a **bench mark** or **B.M.**, have been surveyed by a survey crew and are usually set on the Earth's surface in the field with an approximately 3 inch diameter brass marker set in concrete. Bench marks are stamped with the date of construction and survey, as well as the elevation of a mark on the brass plate.

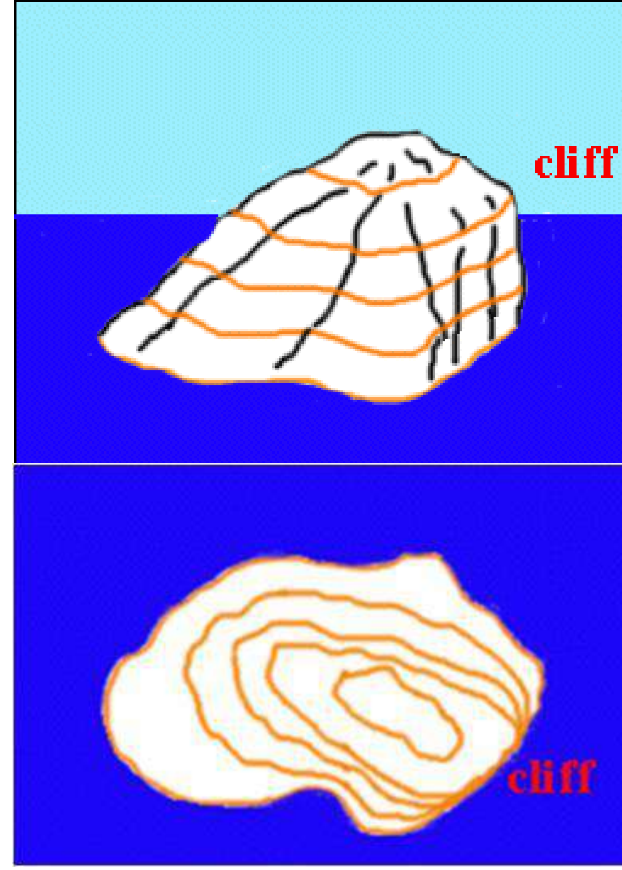




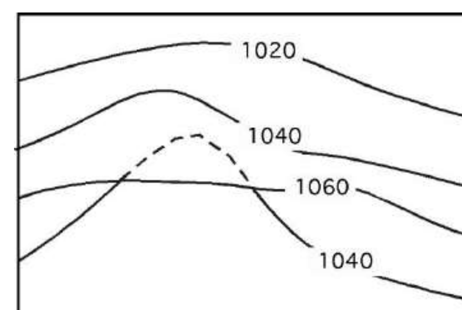
Characteristics of contour lines

1. Contour lines are continuous.
2. A series of V-shape indicates a valley and the V's point to higher elevation.
3. A series U shape indicates a ridge. The U shapes will point to lower elevation.
4. Evenly spaced lines indicate an area of uniform slope.
5. A series of closed contours with increasing elevation indicates a hill and a series of closed contours with decreasing elevation indicates a depression.
6. Closed contours may be identified with a +, hill, or -, depression.
7. Closed contours may include hachure marks. Hachures are short lines perpendicular to the contour line. They point to lower elevation.
8. Common practice is to identify the major elevations lines, or every fifth line, with a bolder, wider, line. index contour line
9. When contour lines overlap, the lower elevation contour should be dashed for the duration of the overlap.
10. If the contour lines are close together, then that indicates that area has a steep slope





The rule of V's: sharp-pointed vees usually are in stream valleys, with the drainage channel passing through the point of the vee, with the vee pointing upstream. This is a consequence of erosion.



http://depthome.brooklyn.cuny.edu/geology/core332/maps2.htm

Elevation from Contours

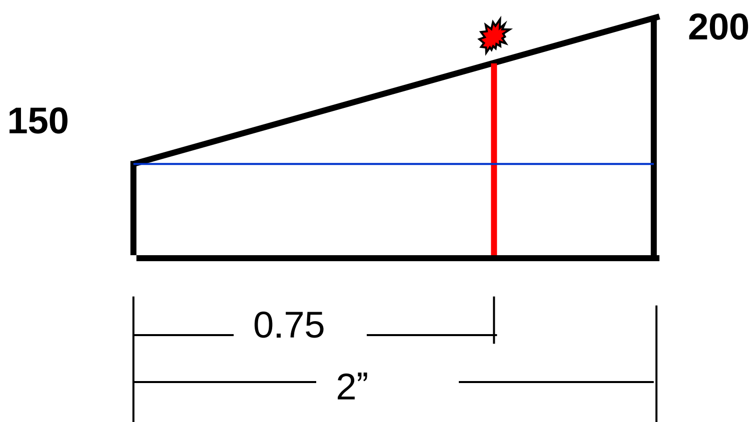
Elevations of points between contours can be determined by interpolation.

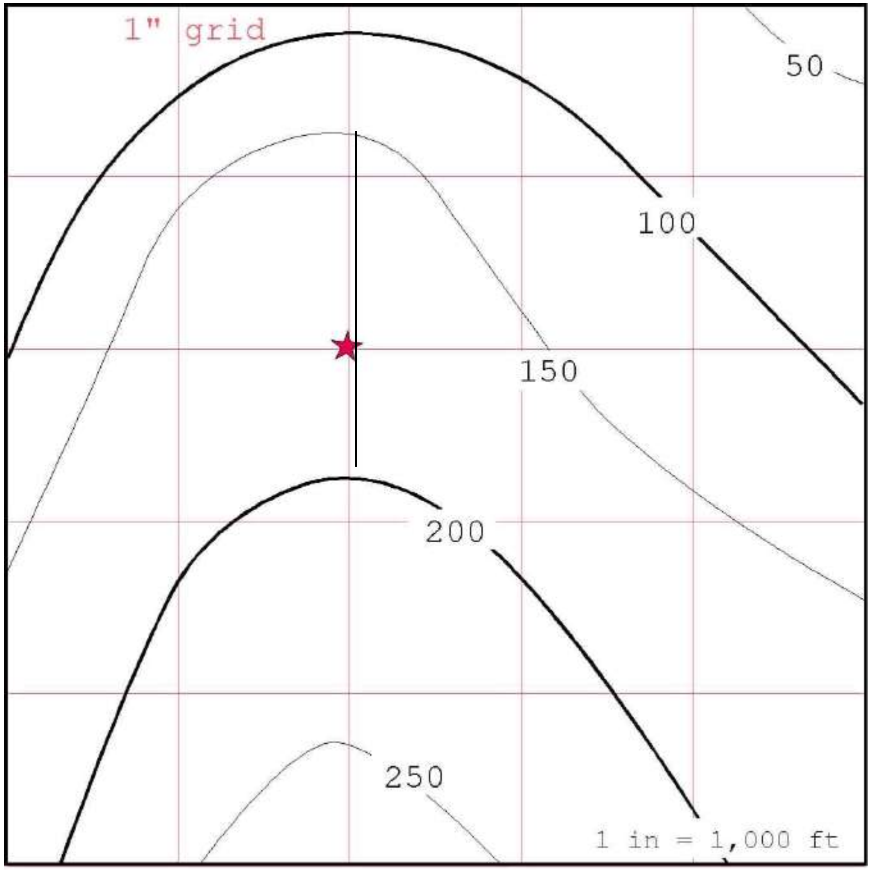
$$\text{Elevation} = 150 + \left[(200 - 150) \text{ x } \left(\frac{0.75}{2} \right) \right]$$

$$= 150 + (50 \text{ x } 0.375)$$

$$= 150 + 18.75$$

$$= 168.75 \text{ or } 169 \text{ ft}$$

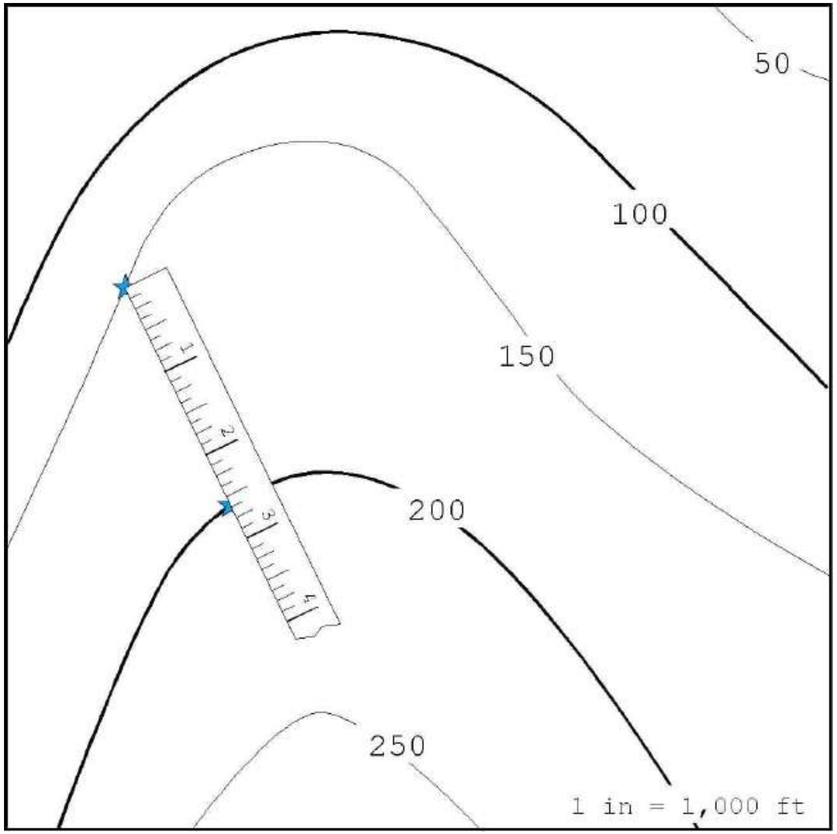




Slope from Contours

The percent slope can be determined from the contour lines on a topographic map as:

$$\% \text{slope} = \left(\frac{\text{Rise}}{\text{Run}} \right) x\, 100$$



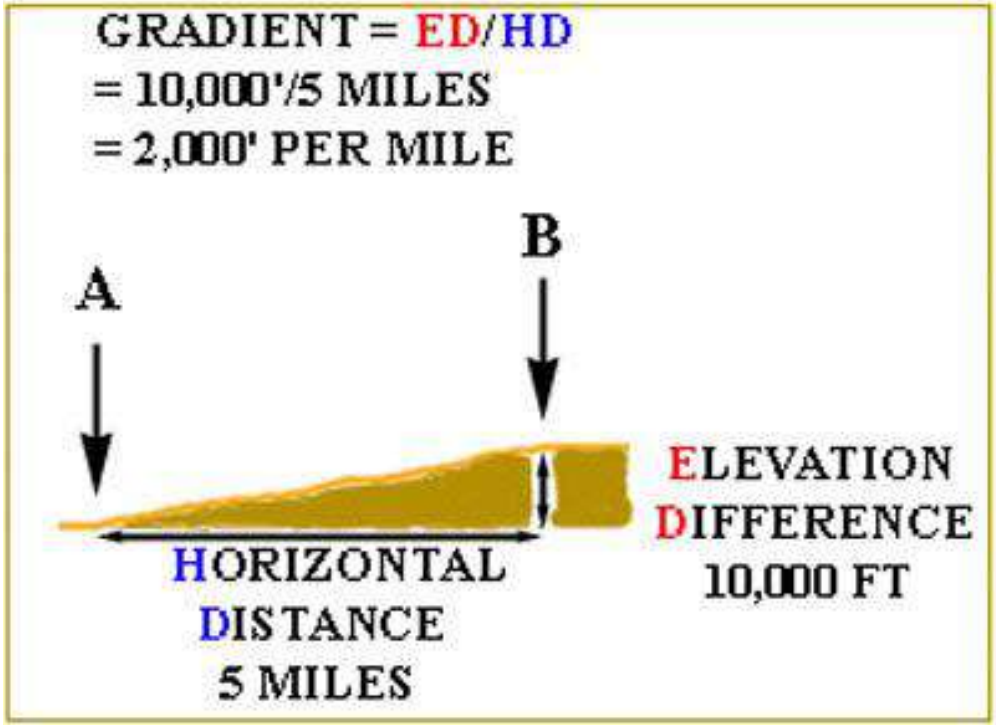
Eg.

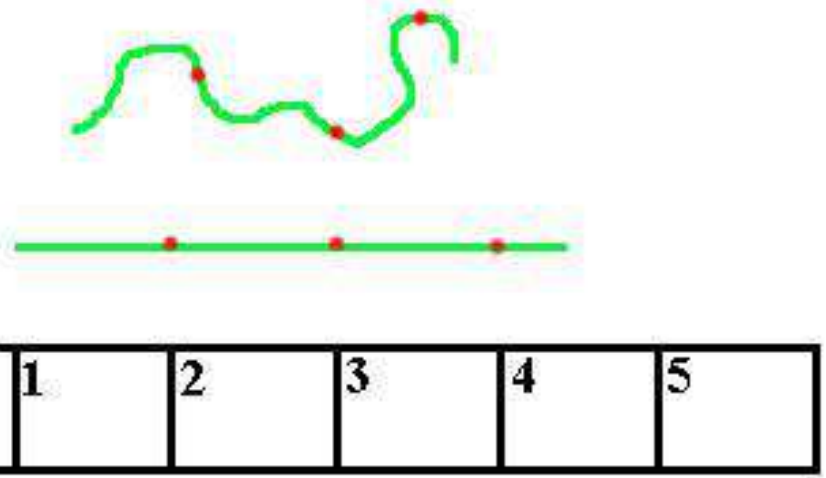
Rise = 200 - 150 = 50 ft

Run = 2.625 in x 1,000 ft/in

$$\% \text{slope} = \left(\frac{200 \text{ ft} - 150 \text{ ft}}{2625 \text{ ft}} \right) x\, 100$$

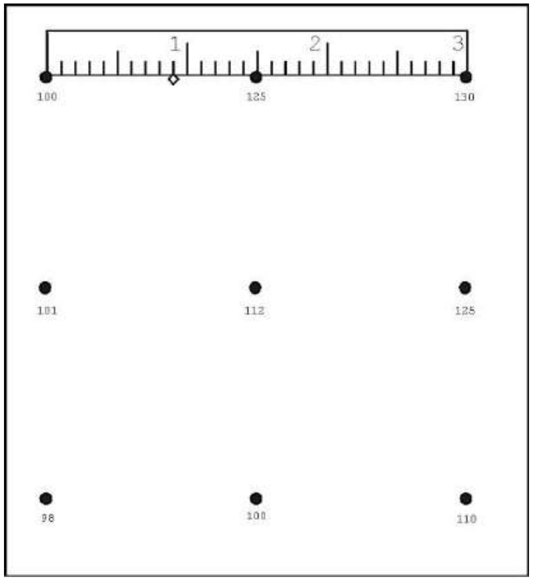
$$= 1.9\,\%$$

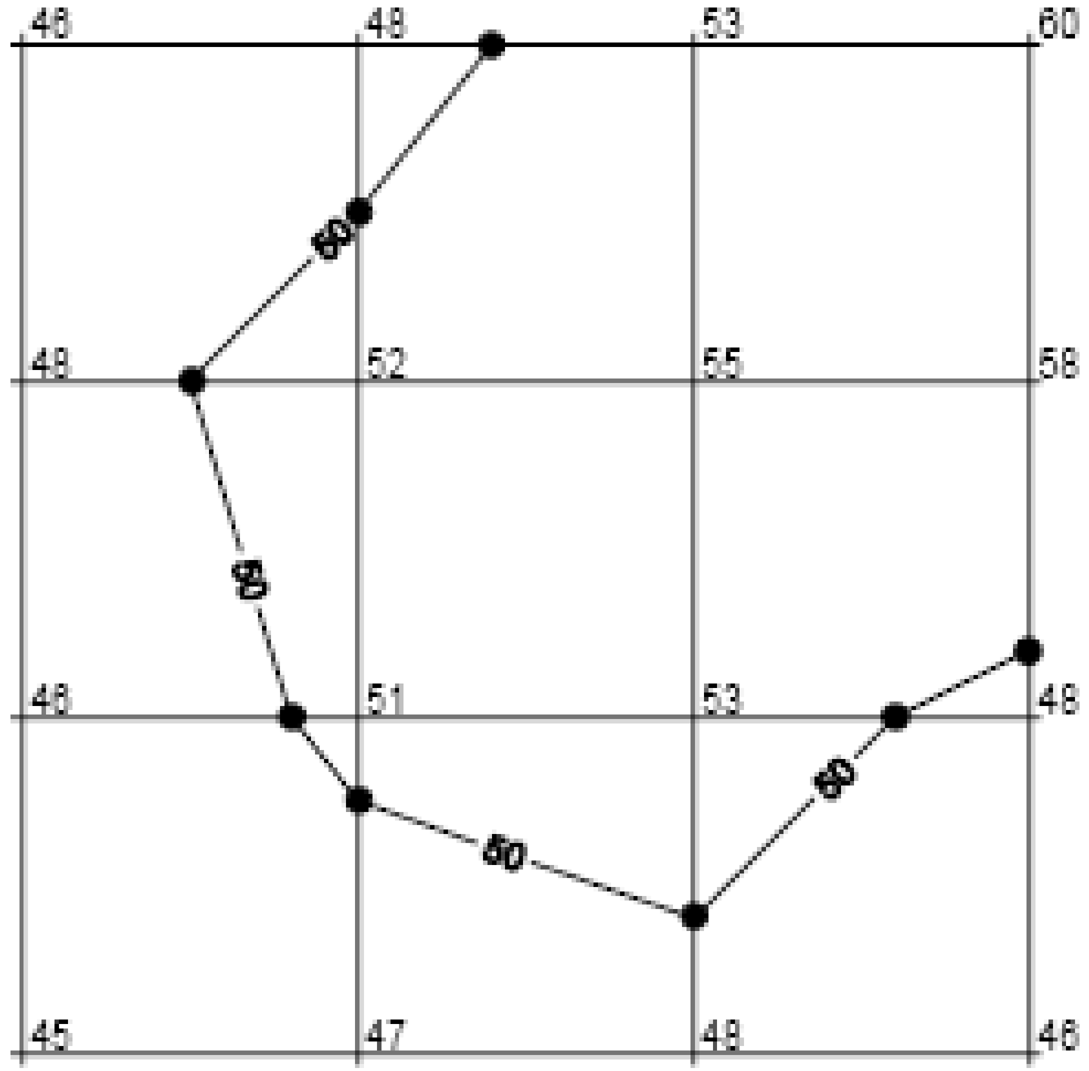


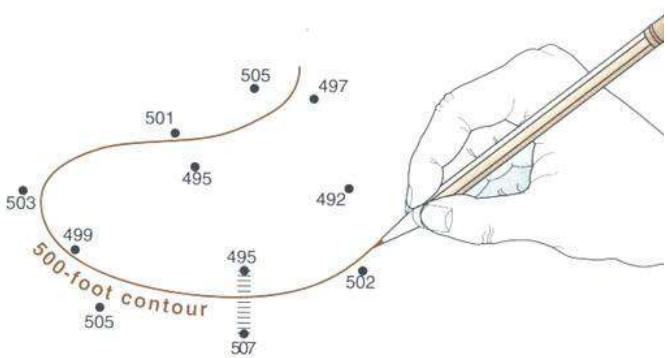


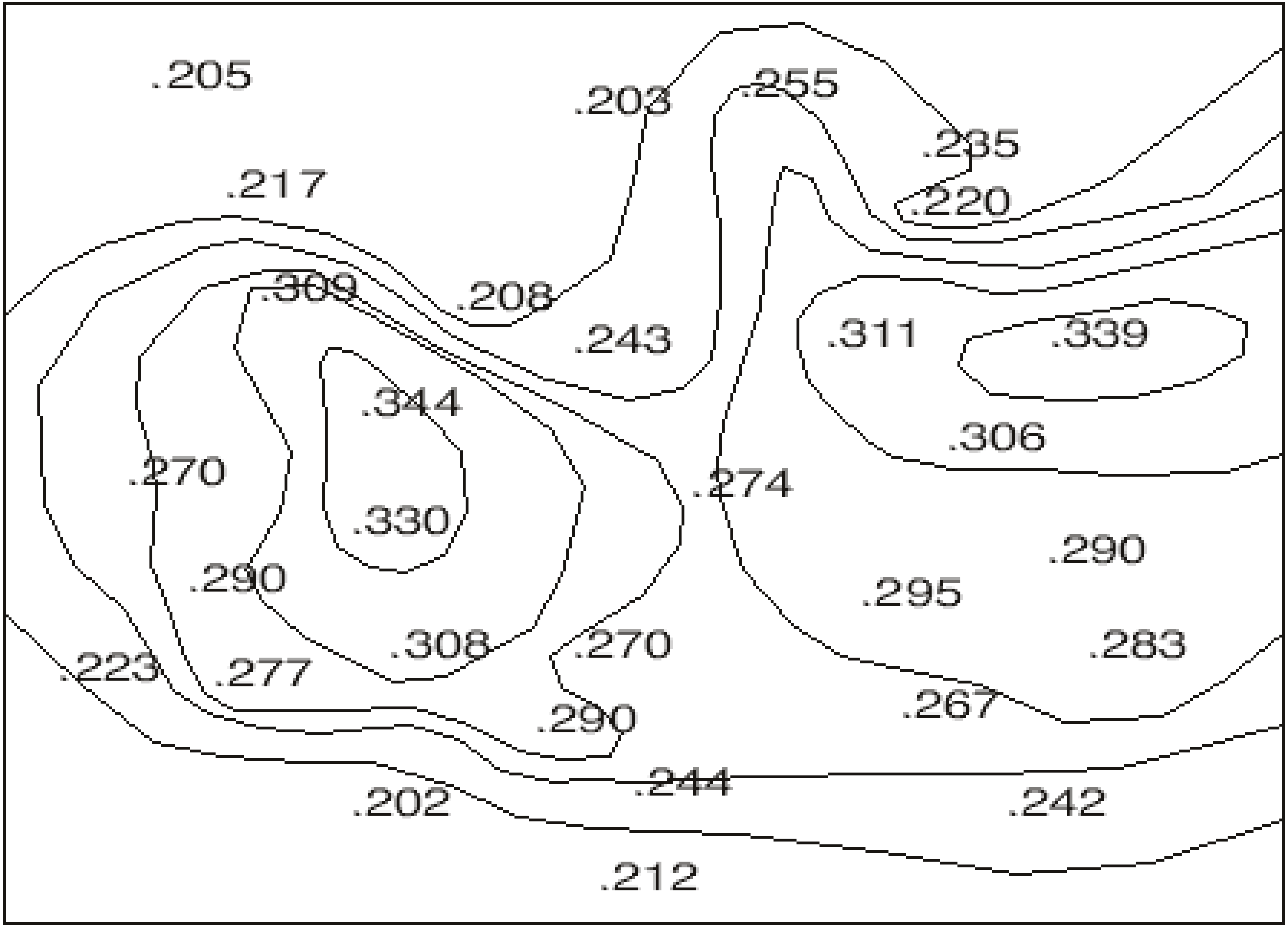
The string is about 3.4 units long

Interpolation by Calculation and measurement





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.270
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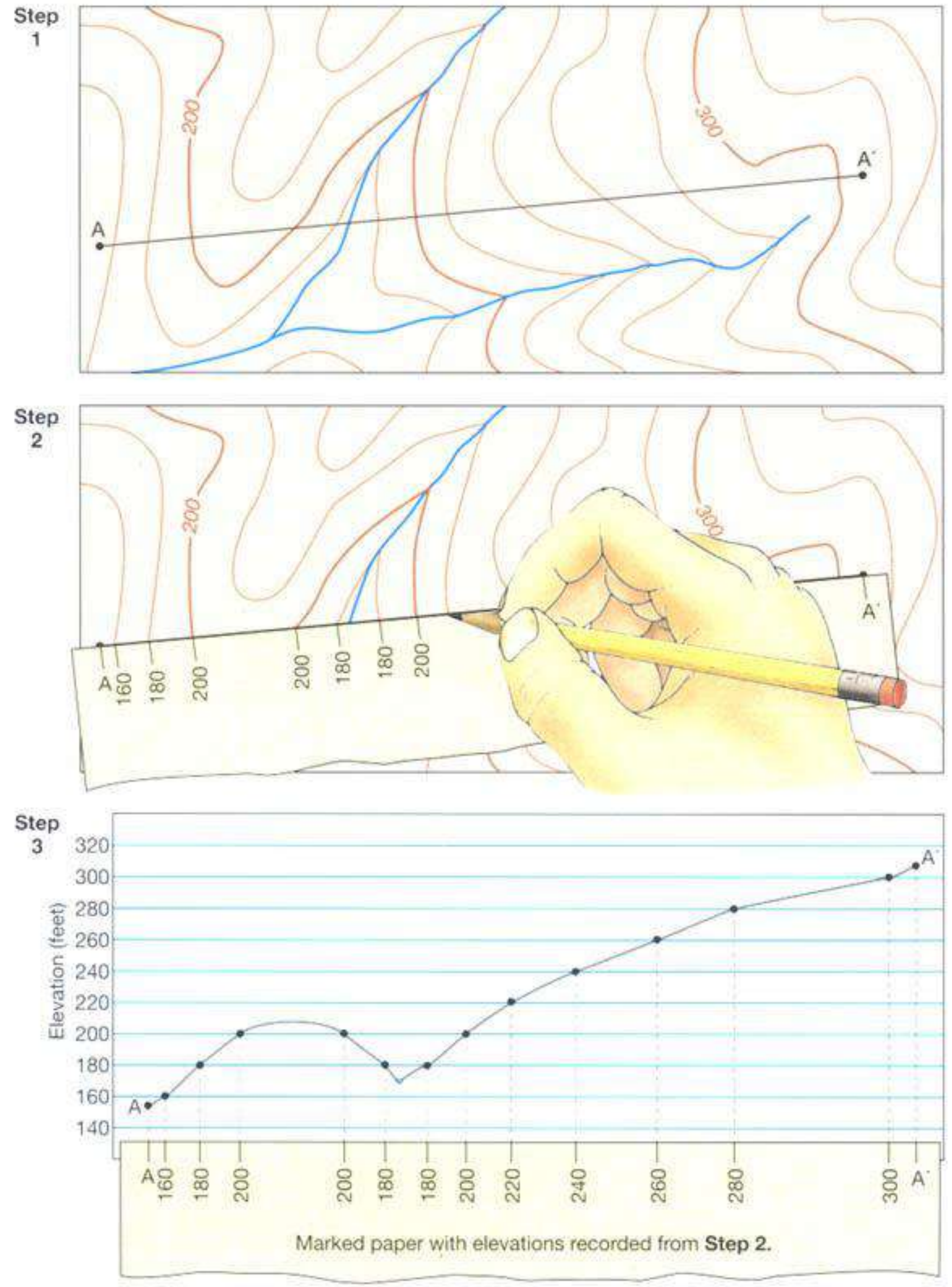
.242
.212

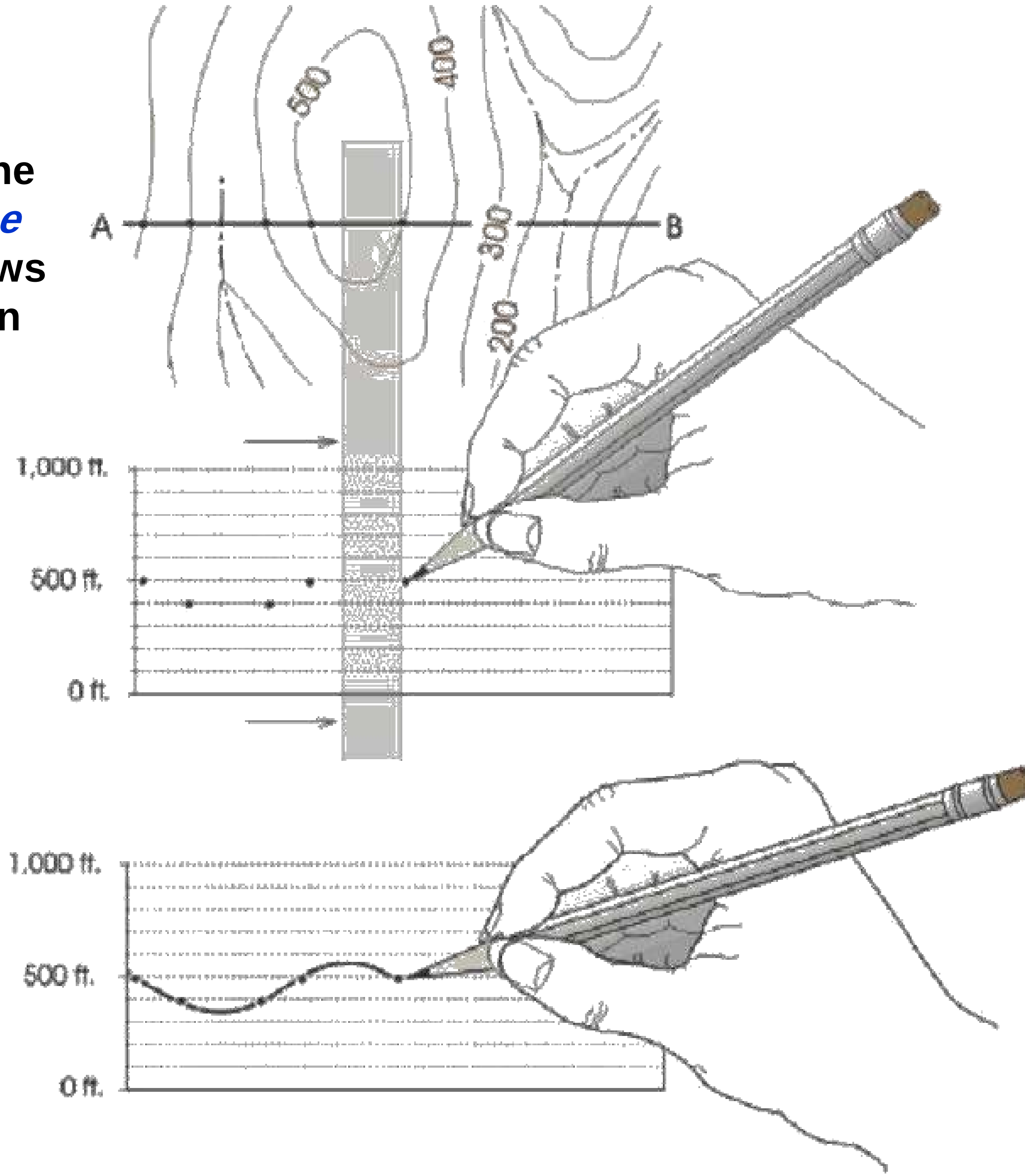
Geologic cross sections

The cross section represents a plane perpendicular to horizontal. It's location is indicated by a line A A' on the geologic map to which it refers. If more than one cross section is indicated on the map, the second might be B to B', etc.



Topographic Profile

A topographic profile shows the *intersection of the land surface with a vertical plane.* Such views of the land surface can be seen in road-cuts, quarries,



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
- Depression
- River mileage marker

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

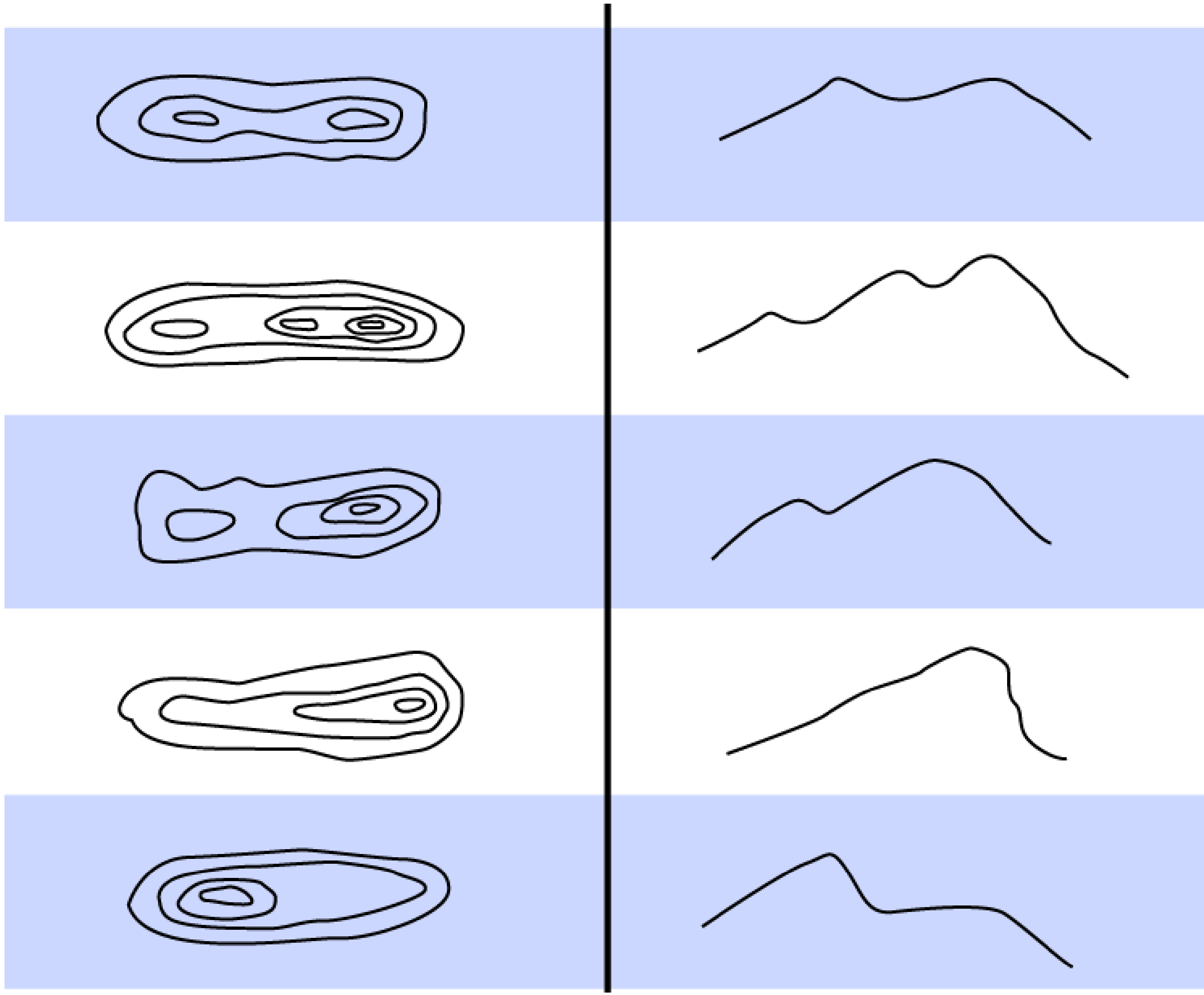
Vegetation

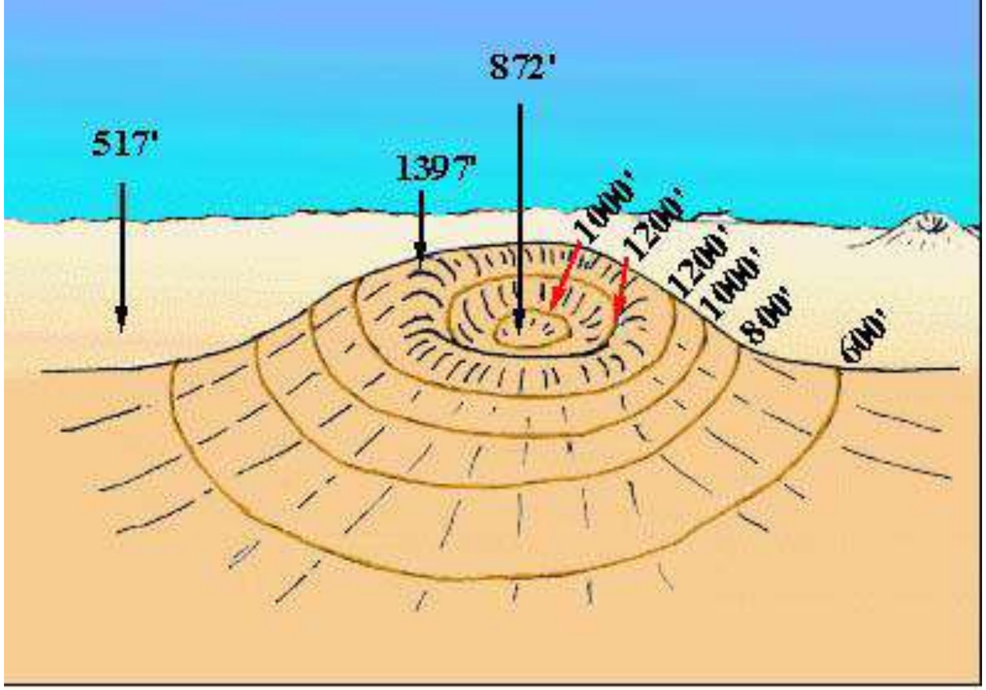
- Woodland
- Shrubland
- Orchard
- Vineyard

U.S. Geological Survey used in compiling this information.

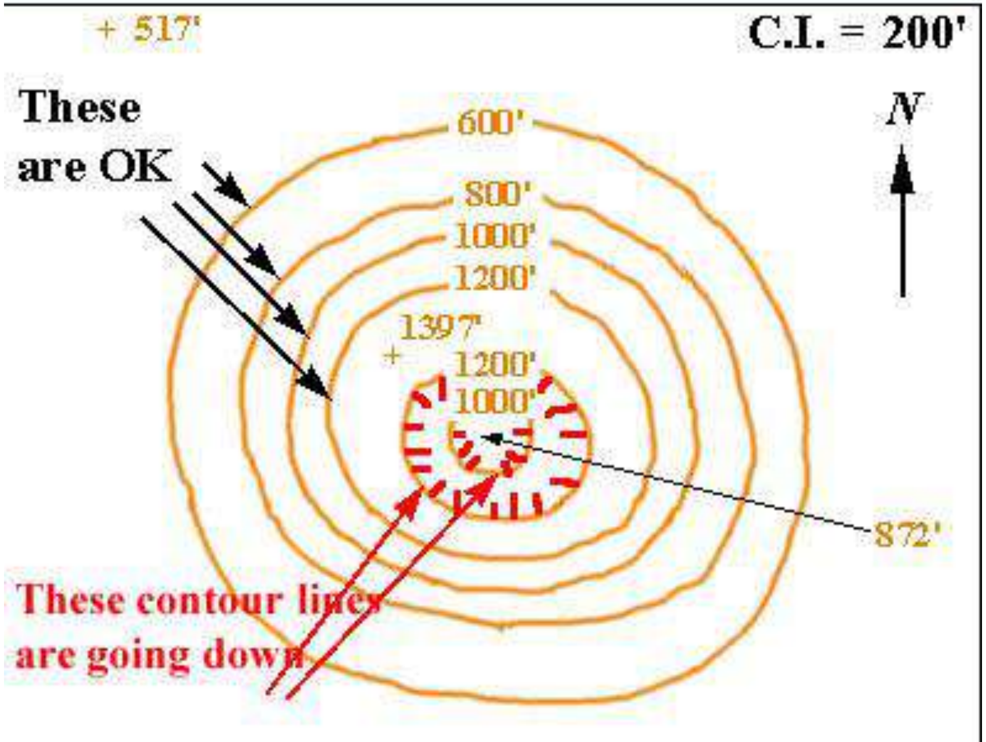
Colors indications on contour maps.

- **Water is shown in blue.**
- **Densely populated areas are shown in gray or pink.**
- **Wooded areas are in green and open areas in <u>white</u>.**
- **Individual buildings are solid <u>black shapes</u>.**

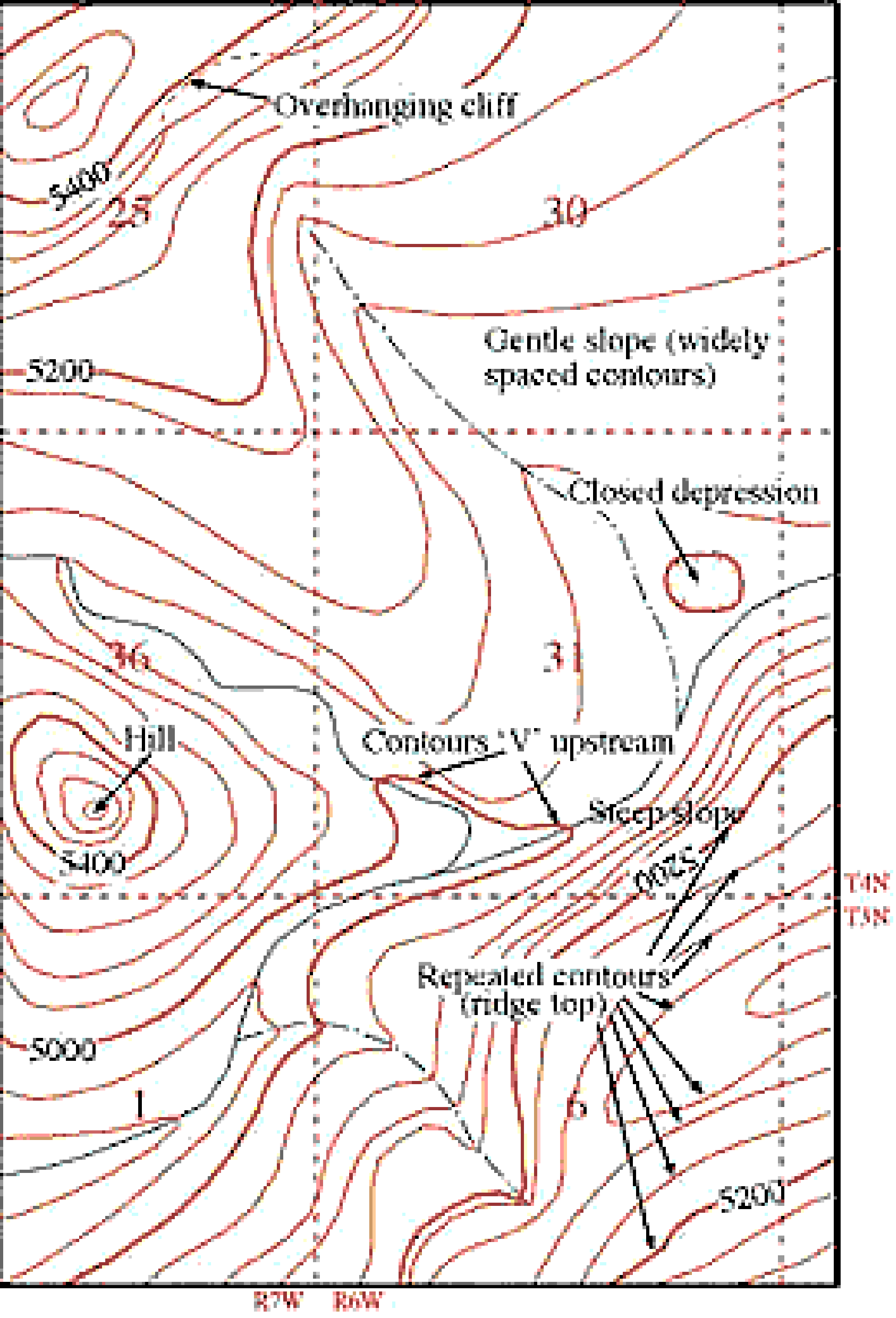




872'
517'
1397'
1000'
1200'
1200'
1000'
800'
600'



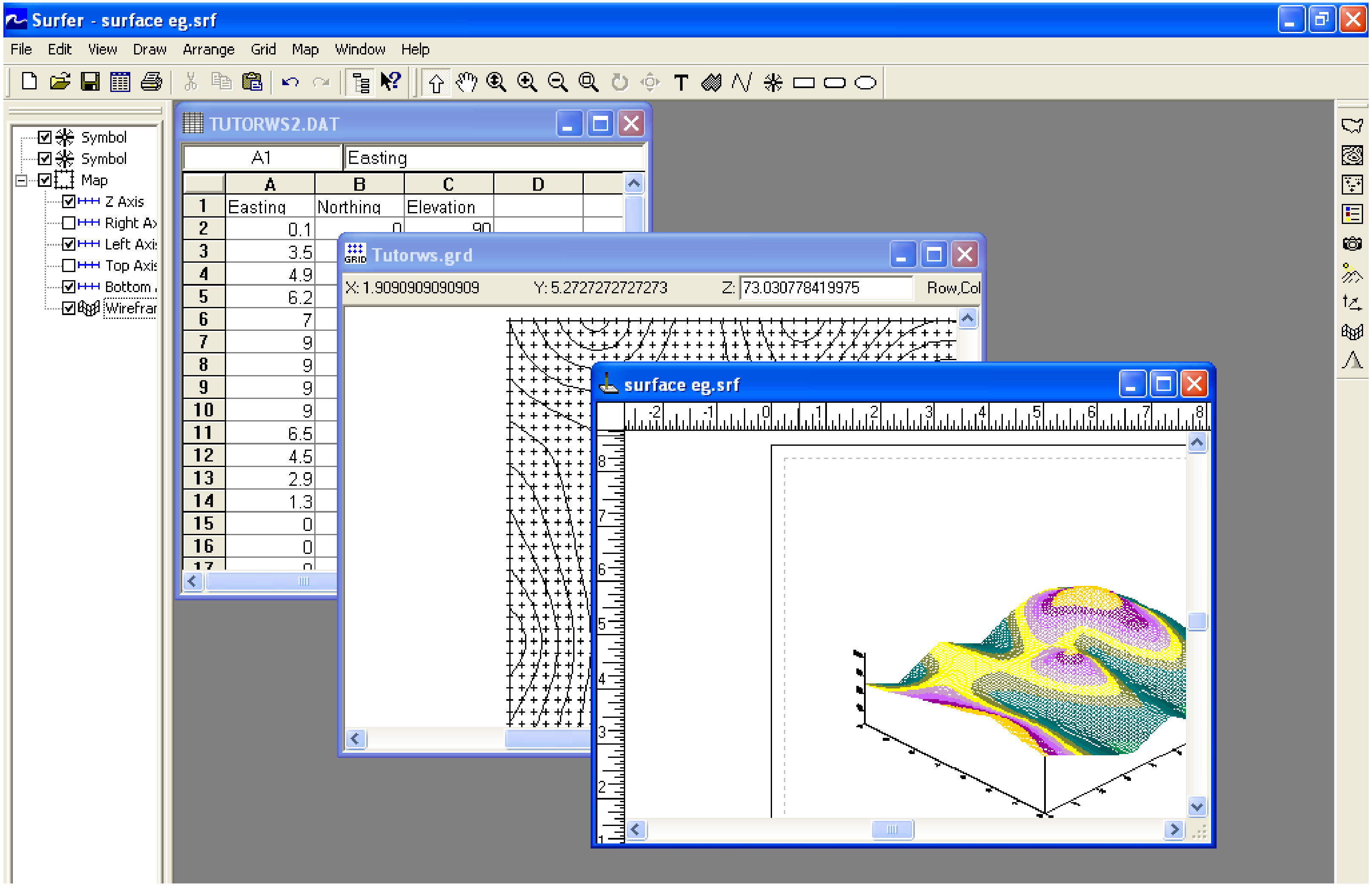
+ 517'
C.I. = 200'
These are OK
N
600'
800'
1000'
1200'
1397'
1200'
1000'
872'
These contour lines are going down



http://imnh.isu.edu/digitalatlas/geog/basics/topo.htm

Surfer Software

Surfer's outstanding gridding and contouring capabilities have made Surfer the software of choice for working with XYZ data.

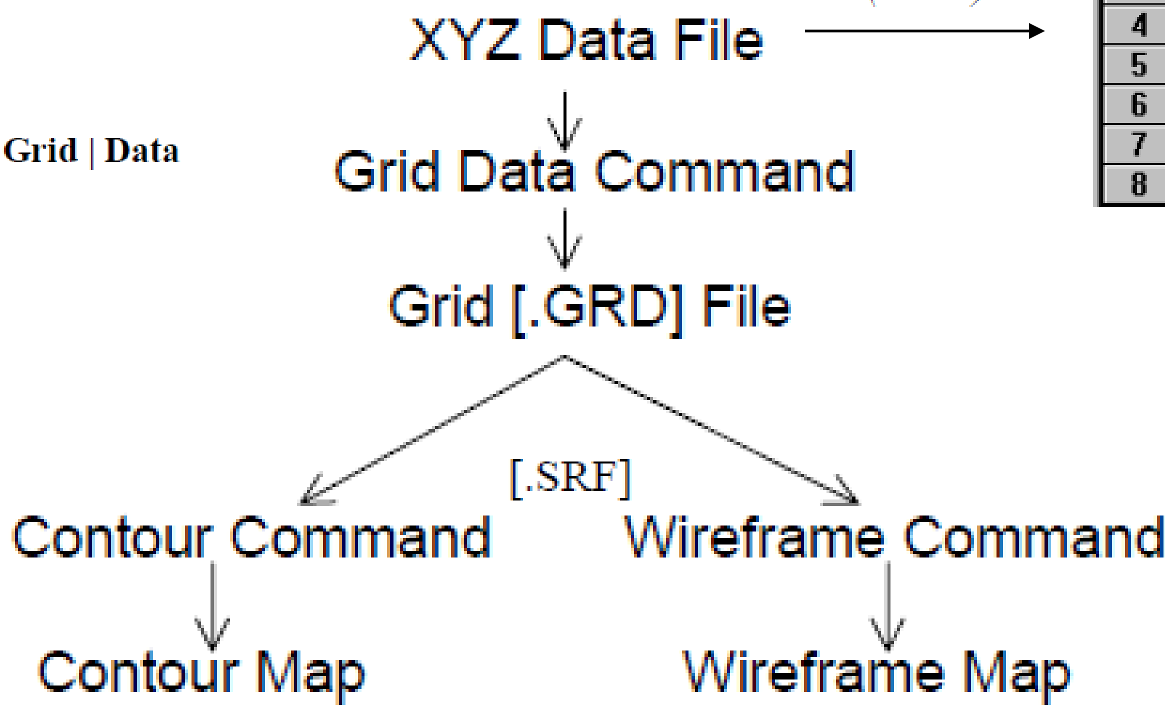


File Types:

four basic file types: data, grid, boundary, and Surfer .SRF files.

	A	B	C
1	X Data	Y Data	Z Data
2	0.1	0	90
3	9	3	48
4	1.3	7	52
5	4.7	1	66
6	1.7	5.6	75
7	6	1	50
8	2.5	3.6	60

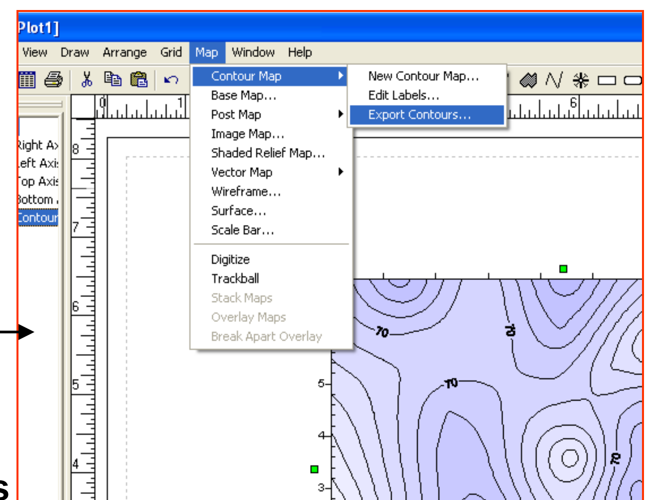
Choose the **Grid | Data** command.



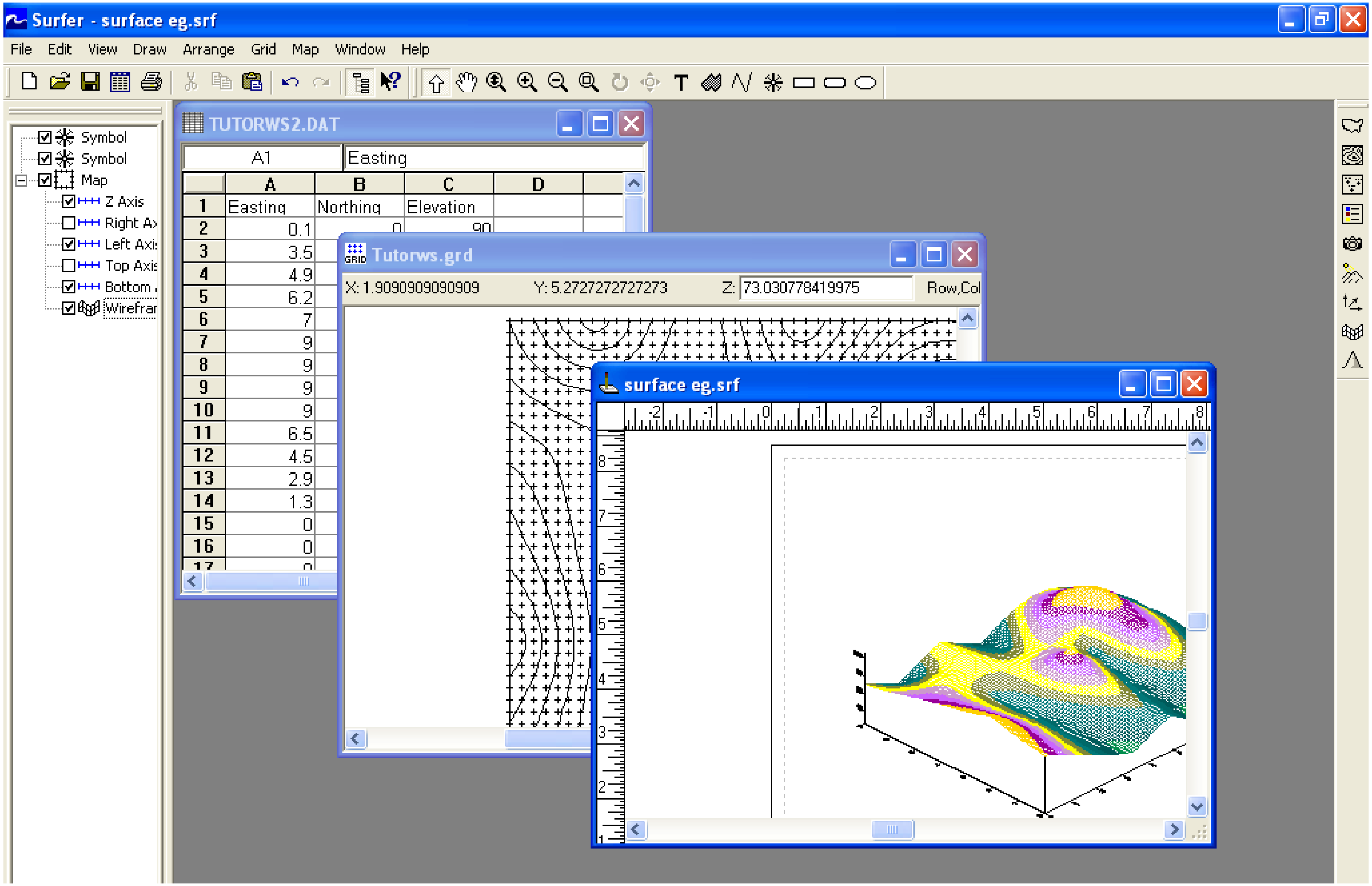
Exporting 3D Contours

When you have completed a contour map in the plot window, you can export the contour lines with associated Z values to an AutoCAD DXF file.

Choose **Map | Contour Map | Export Contours**



Surfer's outstanding gridding and contouring capabilities have made **Surfer** the software
of choice for working with XYZ data.



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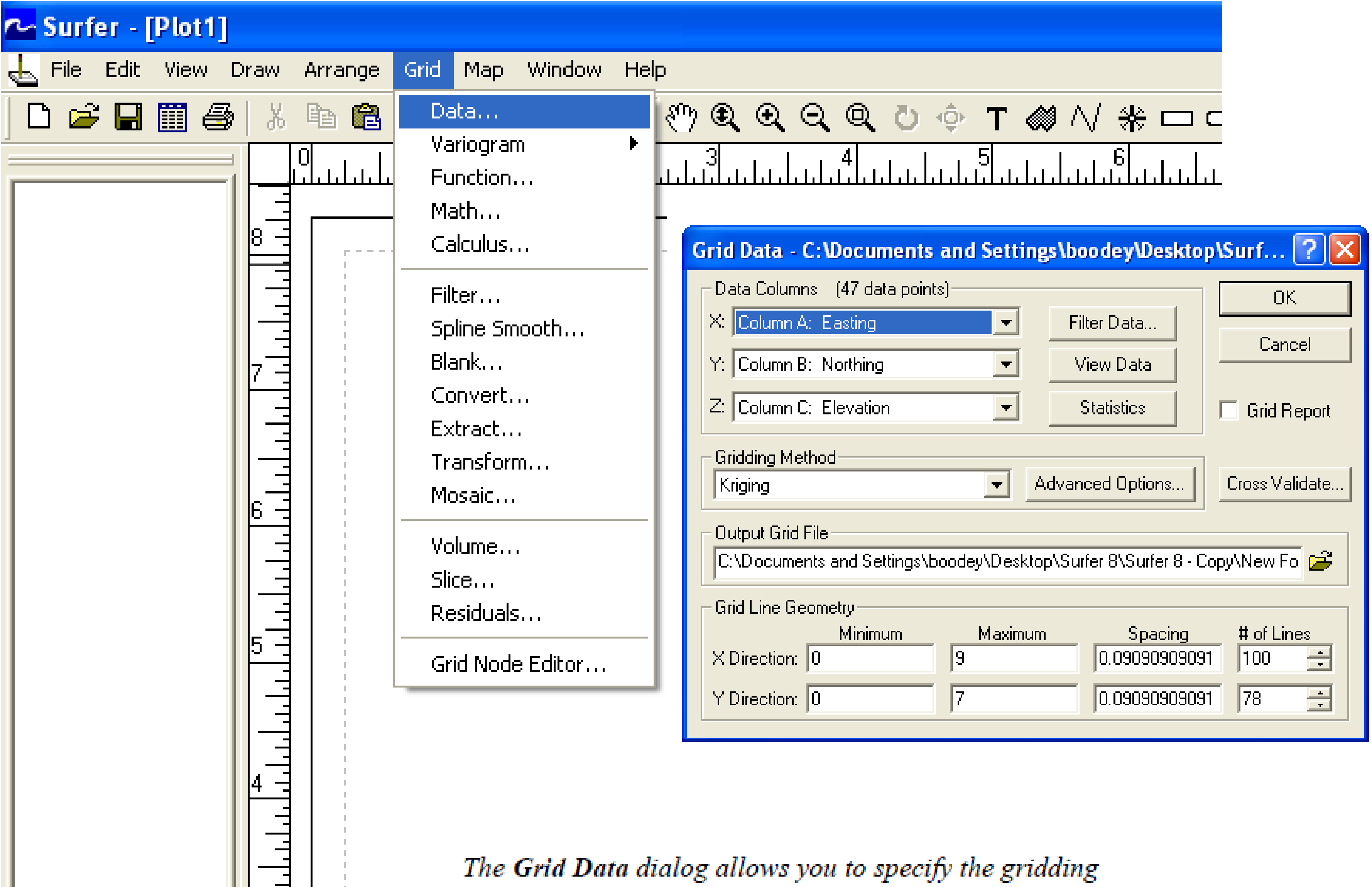
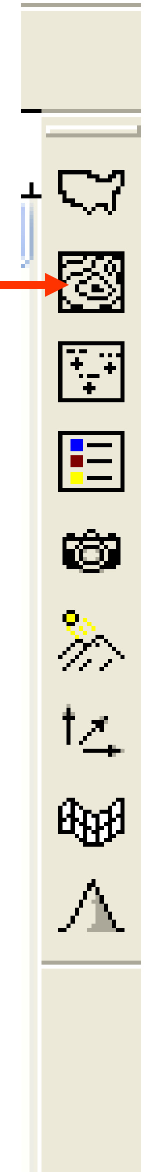


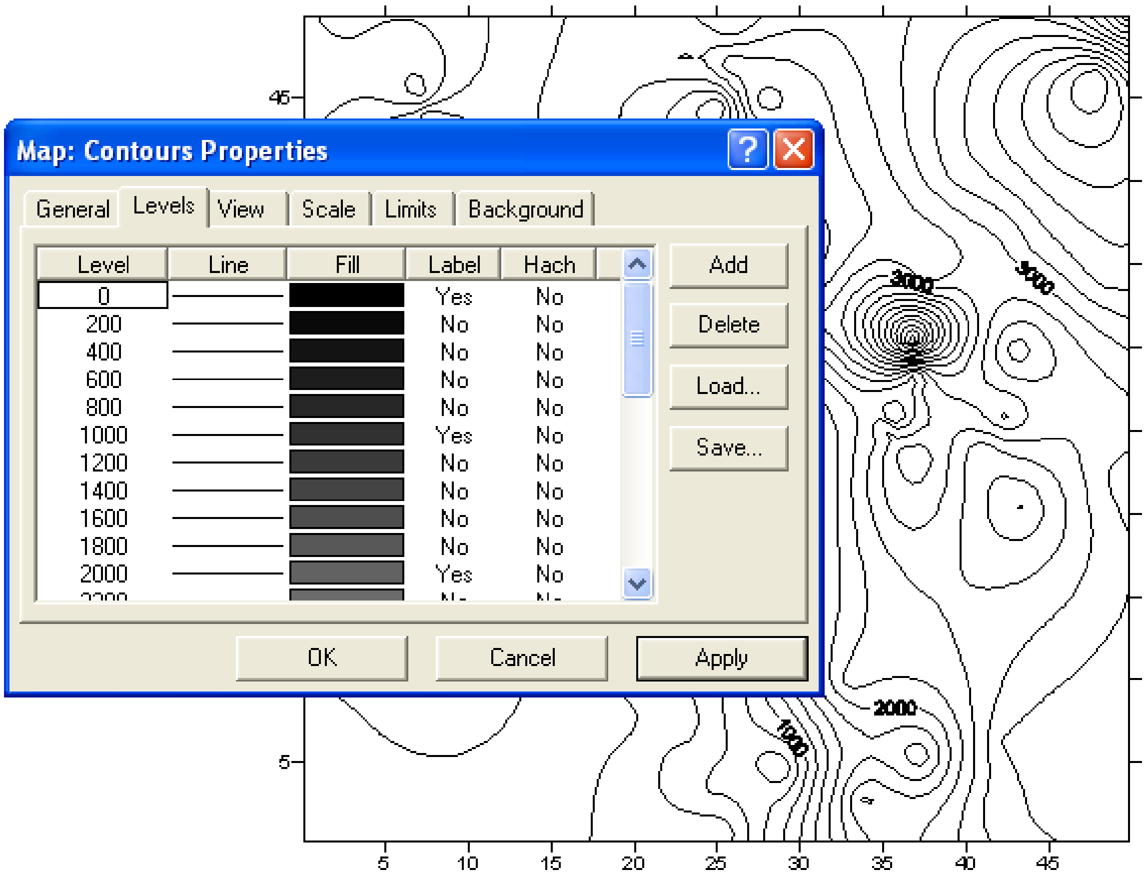
*The **Grid Data** dialog allows you to specify the gridding parameters to use when creating the grid file.*

Creating a Contour Map

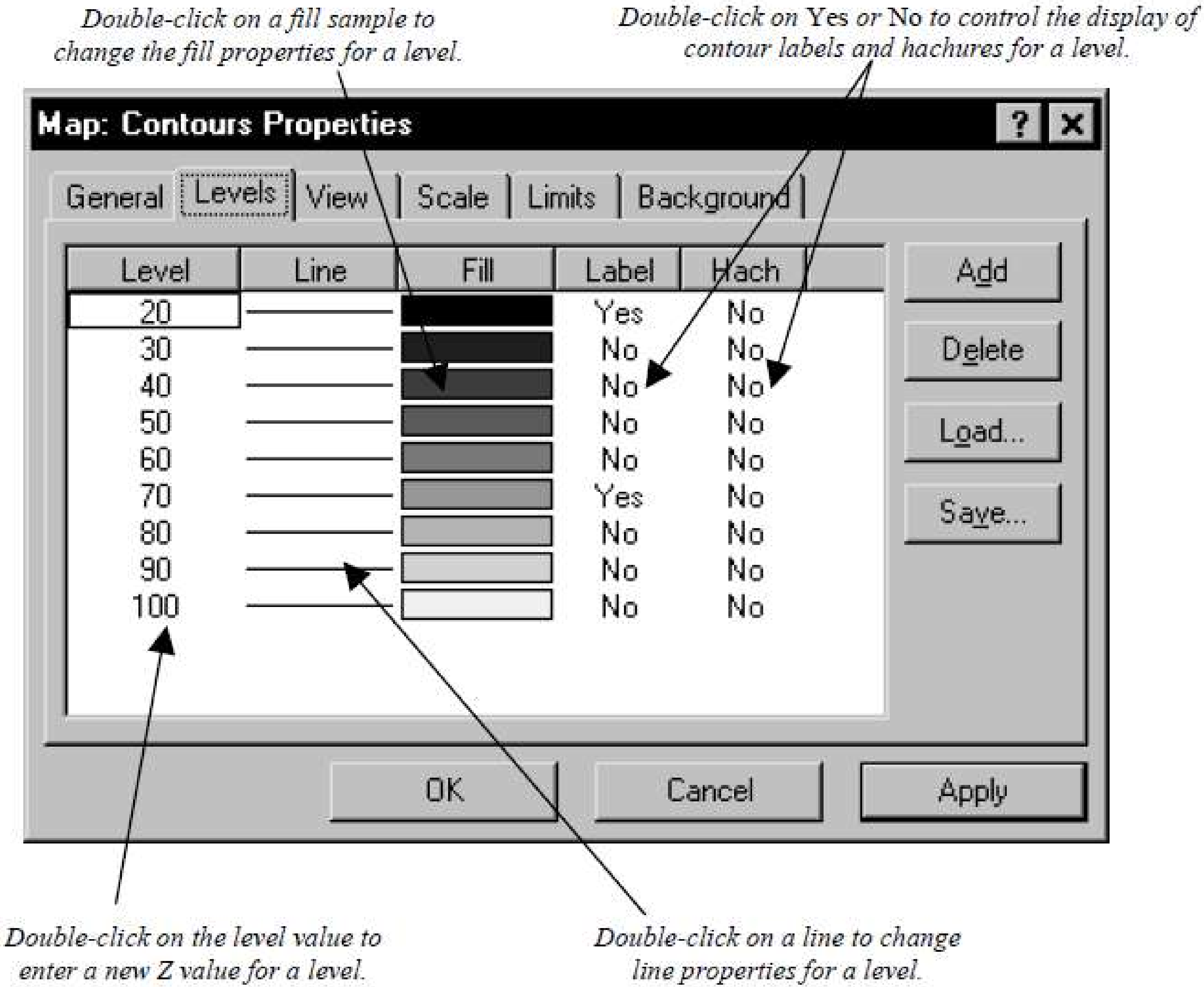
is a two-dimensional representation of three-dimensional data. The first two dimensions are the XY coordinates, and the third dimension (Z) is represented by lines of equal value.

Choose the **Map | Contour Map | New Contour Map** command, or
Then select the created grid file
Click the *Open* button to create a contour map..

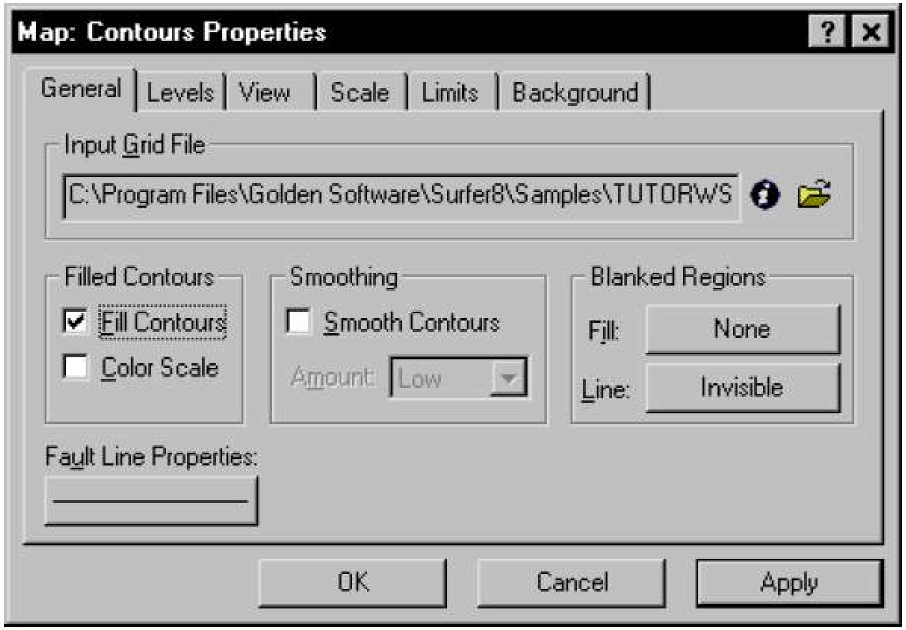




After creating a map, you can change the map properties – so double click inside the limits of the contour map

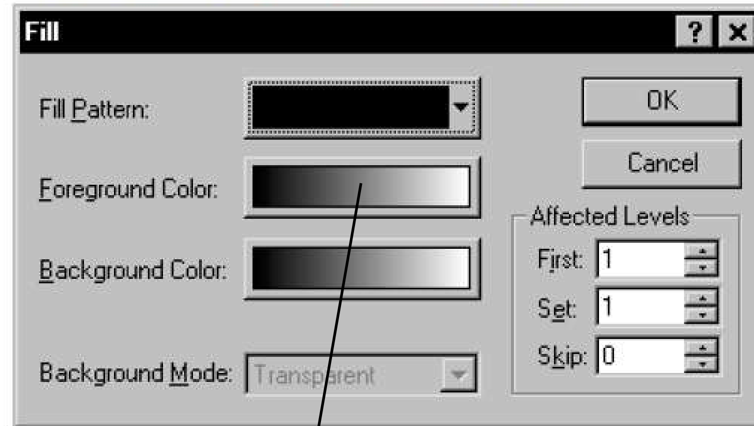


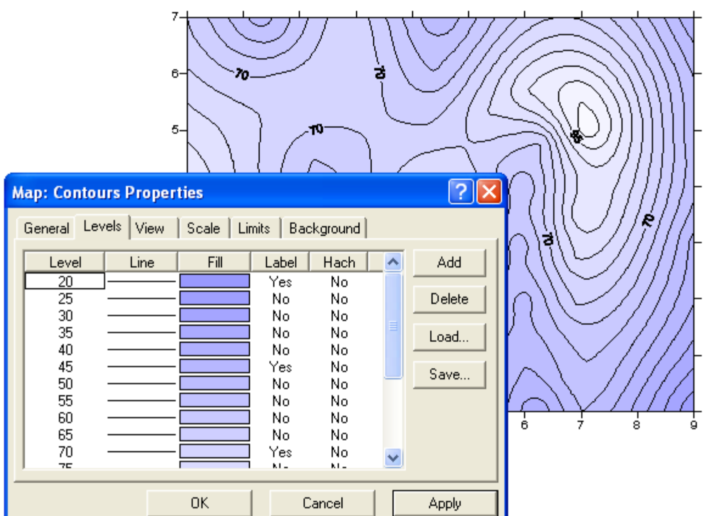
Double-click on a fill sample to change the fill properties for a level.
Double-click on Yes or No to control the display of contour labels and hachures for a level.
Map: Contours Properties
General
Levels
View
Scale
Limits
Background
Level
Line
Fill
Label
Hach
20
30
40
50
60
70
80
90
100
Yes
No
No
No
No
Yes
No
No
No
No
No
No
No
No
No
No
No
No
Add
Delete
Load...
Save...
OK
Cancel
Apply
Double-click on the level value to enter a new Z value for a level.
Double-click on a line to change line properties for a level.

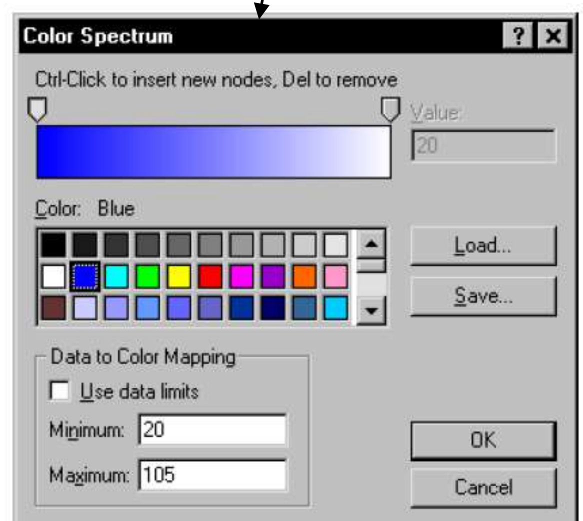


Make sure the **Fill Contours** *box is checked on the* **General** *page to add fill between the contour lines.*

On the **Levels** page, click the *Fill* button to open the **Fill** dialog.





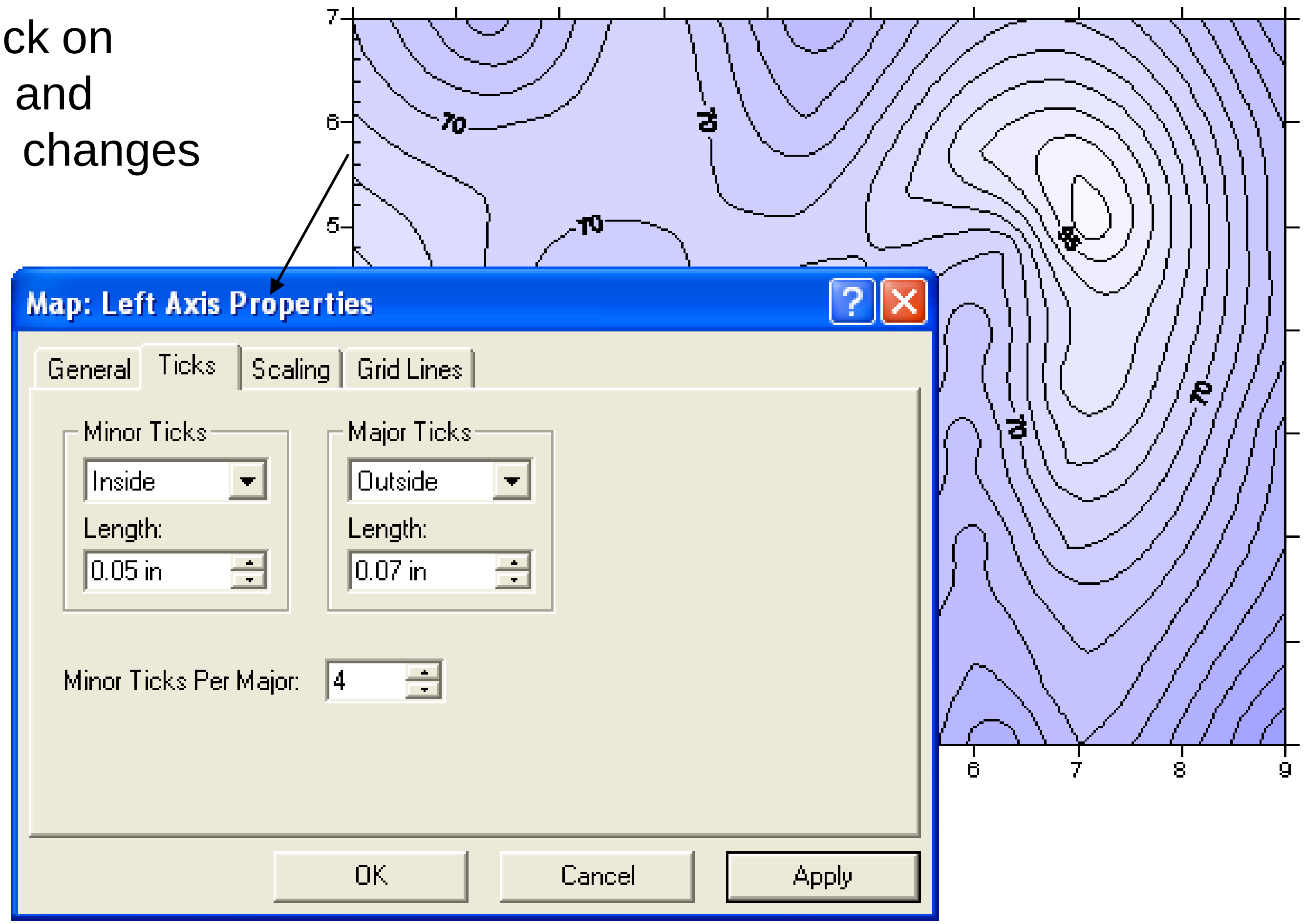


To change the color spectrum, click the left anchor button and then click blue in the color palette.

Modifying an Axis

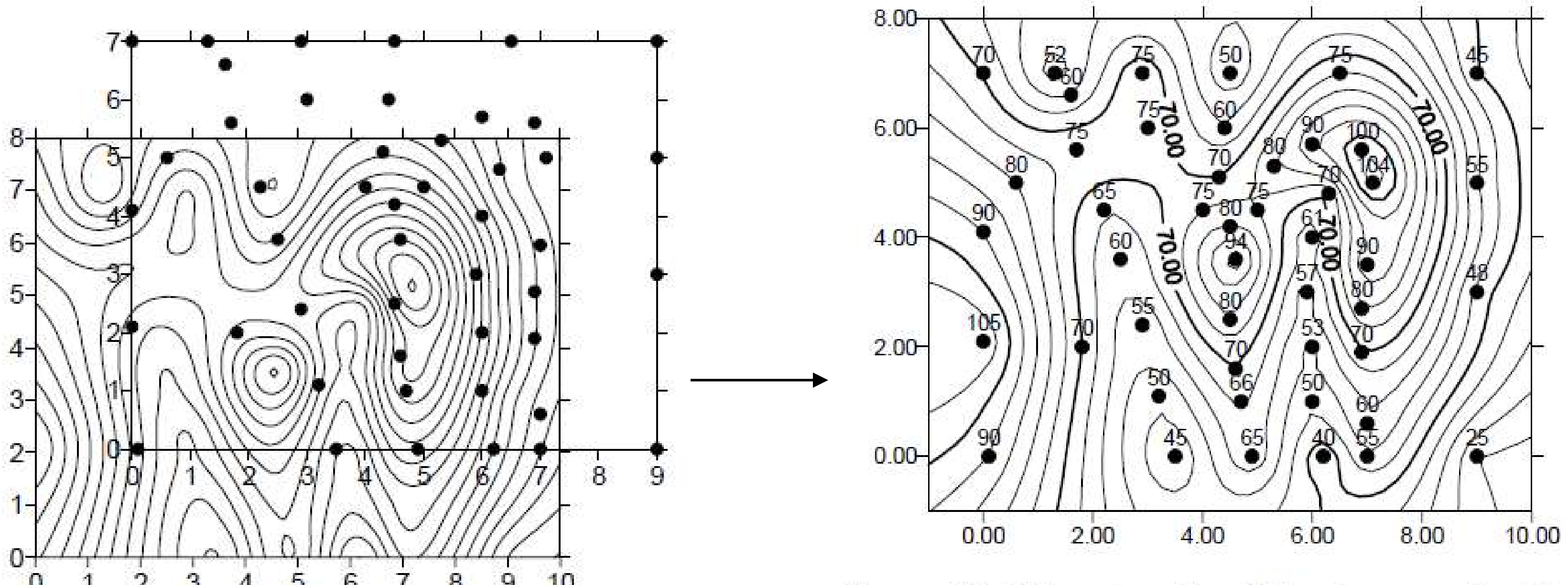
Every contour map is created with four axes: the bottom, right, top, and left axes. You can control the display of each axis independently of the other axes on the map

double click on each axis and make the changes



Overlaying Maps

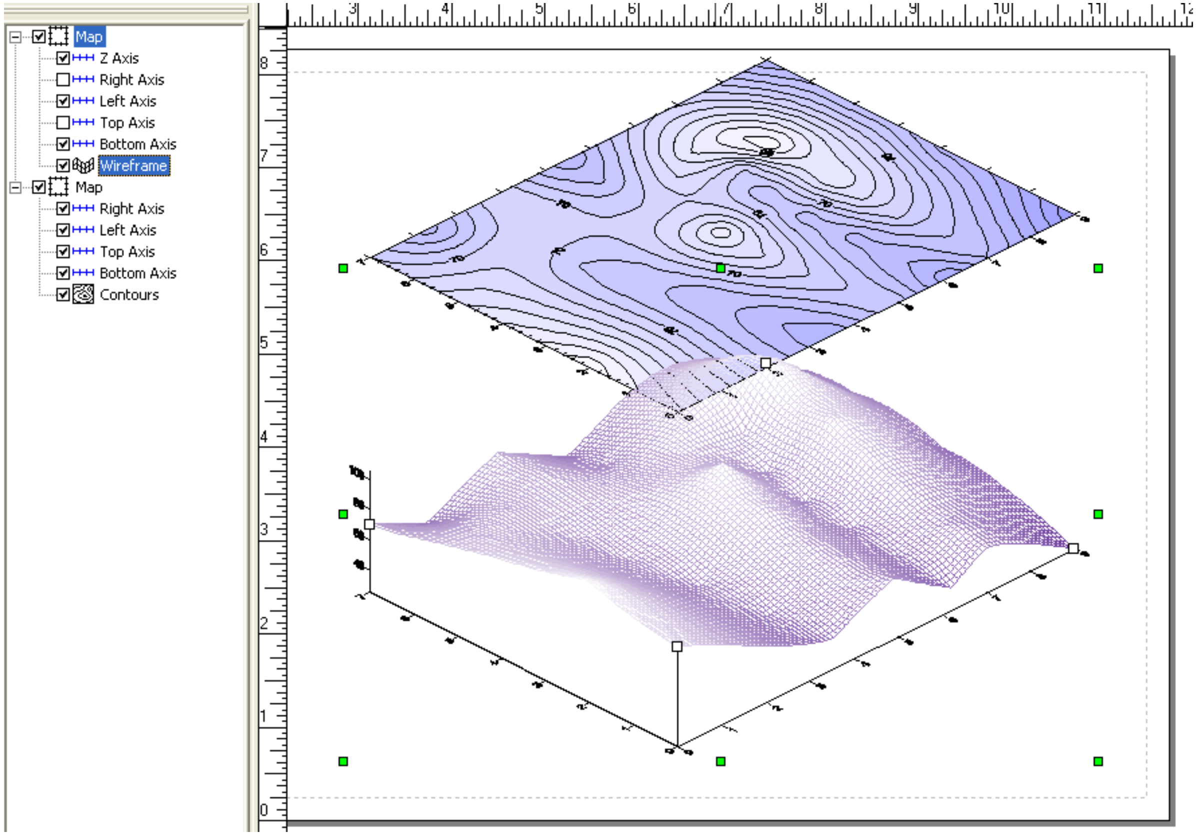
Click **Edit | Select All** to select both maps.
 Choose the **Map | Overlay Maps** command to combine the two maps into a single composite map.



You can add labels to post maps through the post map properties dialog.

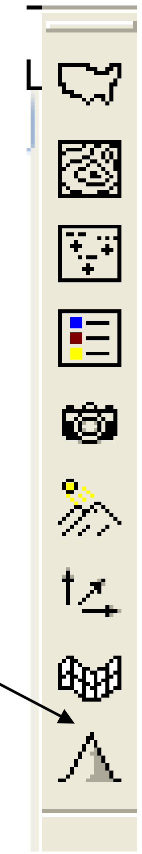
Creating a Wireframe

1. Select the **File | New** command, or click the button.
2. Select *Plot Document*, in the **New** dialog and click OK. A new empty plot window is displayed.
3. Select the **Map | Wireframe** command or click the button.
4. Choose the grid file



Creating a Surface

1. Select the **File | New** command,
2. Select *Plot Document*, in the **New** dialog and click OK. A new empty plot window is displayed.
3. Select the **Map | Surface** command or click the



Creating a Data File with Digitize

plot window, the **Map | Digitize** command can be used to create a data file from map XY coordinates. The **Digitize** command is used to collect coordinates from the map, and create a [.BNA] or [.BLN] file

To digitize points from a map:

1. Select a map.
2. Select **Map | Digitize**.
3. The arrow pointer changes into a cross hair pointer.
4. Digitize points by clicking with the left mouse button on the map. You can zoom in on the map for greater precision in digitizing.
5. The digitized points appear as temporary small red crosses in the window. The digitized point coordinates appear as text in a report window.
6. Save the contents of the report window to save the digitized points.

Breaklines and Faults

Breaklines and faults are a means to show discontinuities in the surface. Select gridding methods support breaklines and/or faults. Breaklines and faults are defined with blanking files.

If your grid is not dense enough, the breakline or fault will not show very well in the map. If you cannot see any indication of the breakline or fault (i.e. contours do not bend properly), regrid the data with a denser grid.

To include the breakline or fault as a line on your map, use **Map | Base Map** and choose your blanking file. Select all maps and use **Map | Overlay Maps** to position the line correctly.
Contour maps have a *Fault Line Properties* button, so you do not need to use a base map to show faults on contour maps.

The following gridding methods support breaklines:

Inverse Distance to a Power	Radial Basis Function
Kriging	Moving Average
Minimum Curvature	Data Metrics
Nearest Neighbor	Local Polynomial

Boundary Files

Boundary files contain XY location data such as state boundaries, rivers, or point locations. Boundary files can be used to create layers overlaid on other map types, or to specify the boundary limits for blanking, faults, breaklines, or slice calculations. Boundary files can be created from a wide variety of vector formats.

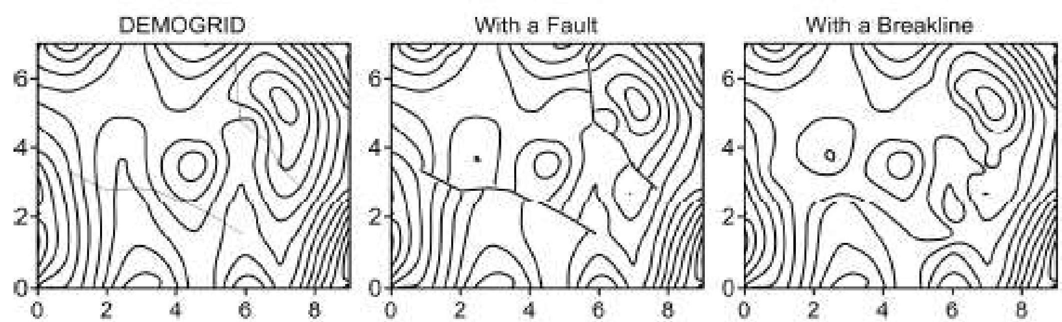
Breaklines

Breaklines are used when gridding to show discontinuity in the grid. **A breakline is a three-dimensional .BLN boundary file that defines a line with X, Y, and Z values at each vertex.**

Faults

Faults are used to show discontinuity when gridding, similar to breaklines. **A fault is a two-dimensional boundary file in .BLN format that defines a line with X and Y values at each vertex.** Faults do not contain Z values. And, unlike a breakline, faults are barriers to information flow. Data on one side of a fault is not used when calculating grid node values on the other side of the fault.

The following gridding methods support faults: *Inverse Distance to a Power, Minimum Curvature, Nearest Neighbor,* and *Data Metrics*.



All three maps were gridded with the Minimum Curvature gridding method. The lines on the far left image were used as a fault and breakline in the other two images. Note the contours stop at the fault line and cross the location where the breakline would be.

Defining Breaklines and Faults with Blanking Files

You can create a blanking file to define a breakline or fault in the **Surfer** worksheet or any text editor. These blanking files do not require the blank inside or blank outside flag.

```
3               ← header
2.97 8.32 10
3.38 7.25 20    ← XYZ vertices
3.04 5.31 30
```

A breakline uses Z values in a blanking file.

<u>Breaklines</u>

Enter a header containing the number of vertices in the breakline, followed by the XYZ coordinates of each vertex, one per line.

```
3               ← header
2.97 8.32
3.38 7.25       ← XY vertices
3.04 5.31
```

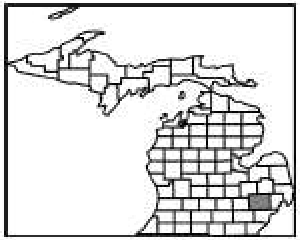
A fault is defined by a blanking file.

<u>Faults</u>

Enter a header containing the number of vertices in the fault, followed by the XY coordinates of each vertex, one per line.

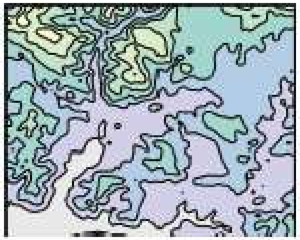
Map Types

Several different map types can be created, modified, and displayed with **Surfer**. These map types include base, contour, post, classed post, image, shaded relief, vector, 3D surface, and 3D wireframe maps. A description and example of each map is listed below.



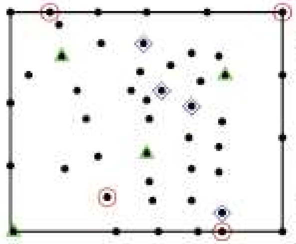
Base Map

Base maps display boundaries on a map and can contain areas, curves, points, text, images, or metafiles. Base maps can be overlaid with other map layers to provide details such as roads, buildings, streams, city locations, areas of no data, and so on. Base maps can be produced from several file formats. Individual base map objects can be edited, moved, reshaped, or deleted.



Contour Map

Contour maps are two-dimensional representations of three-dimensional data. Contours define lines of equal Z values across the map extents. The shape of the surface is shown by the contour lines. Contour maps can display the contour lines and colors or patterns between the contour lines.



Post Map

Post maps and classed post maps show data locations on a map. You can customize the symbols and text associated with each data location on the map.

Classed Post Map

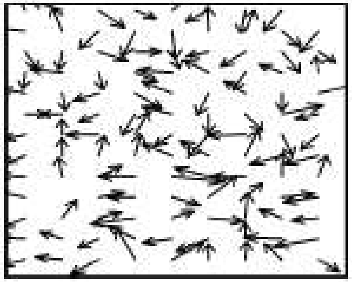
Classed post maps allow you to specify classes and change symbol properties for each class. Classes can be saved and loaded for future maps.

Image Map

Image maps are raster images based on grid files. Image maps assign colors based on Z values from a grid file. Blanked regions on the image map are shown as a separate color or as a transparent fill. Pixels can be interpolated to create a smooth image.

Shaded Relief Map

Shaded relief maps are raster images based on grid files. Shaded relief maps assign colors based on slope orientation relative to a light source. **Surfer** determines the orientation of each grid cell and calculates reflectance of a point light source on the grid surface. The light source can be thought of as the sun shining on a topographic surface.



Vector Map

Vector maps display direction and magnitude data using individually oriented arrows. At any grid node on the map, the arrow points in the downhill direction of the steepest descent and the arrow length is proportional to the slope magnitude. Vector maps can be created using information in one grid file (i.e. a numerically computed gradient) or two different grid files (i.e. each grid giving a component of the vectors).

3D Surface Map

3D surface maps are color three-dimensional representations of a grid file. The colors, lighting, overlays, and mesh can be altered on a surface. Multiple 3D surface maps can be layered to create a block diagram.