STRUCTURAL GEOLOGY AND ROCK MECHANICS

LESSON 1. STRUCTURAL GEOLOGY

STRUCTURAL GEOLOGY

The study of factors such as origin, occurrence, classification, type, and effects of various secondary structures like folds, faults, joints, and rock cleavage is different from that of primary structures such as bedding and vesicular structure, which develop in rocks at the time of their formation.

ATTITUDE OF BEDS

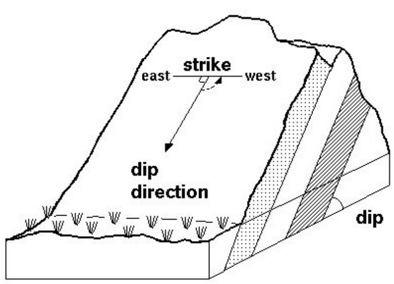
In geology, the **attitude of beds** refers to their **orientation in relation to the horizontal plane**. It is typically described by two parameters: **strike and dip**.

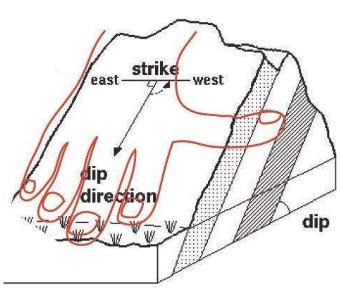
Beds - distinct layers (strata) of sediment or sedimentary rock that formed by deposited sediments over time.

STRIKE AND DIP

Also known as the **attitude of the surface**.

The **strike** is the **compass direction of a horizontal line** on the bedding plane, while the **dip** is the **angle of inclination** of the bedding plane measured from the horizontal plane.





Note: We can also use the Right-Hand Rule to determine the correct direction. The thumb points in the direction of the strike, while the four fingers point downward in the direction of the dip. Using this convention, the dip direction is always 90° to the right of the strike direction.

Geologists often measure strike and dip of a surface using a **Brunton compass or clinometer**.

Dip values always range from **0° to 90°**.

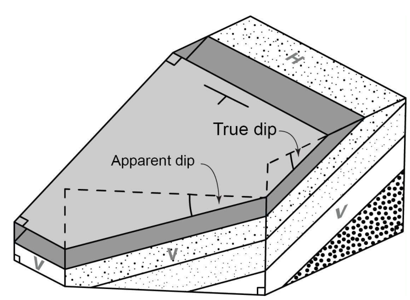
- **0°** defines a completely horizontal plane.
- **90°** describes a vertically oriented plane.

Dip Categories by Angle

- **Shallow:** 0°–20°
- **Moderate:** 20°–50°
- **Steep:** 50°–90°

TYPES OF DIP

- **True Dip:** The maximum amount of slope along a line perpendicular to the strike (the maximum slope with respect to the horizontal). It marks the geographical direction of the quickest descent.
- **Apparent Dip:** Dip angle observed from any direction except the direction of the true dip. Because it is off-angle, the apparent dip of a bed is **always less** than its true dip.



OUTCROPS

The exposed rock is also called **"crops out"** because of the exposed rock. When weathering and erosion expose part of a rock layer or formation, an outcrop appears. Different types of outcrops are **mudstone, fossil, terrane,** and **basalt**

EXAMPLES OF OUTCROP

Outcrop near Yana, India

Granite outcrops at Silesian Stones Mountain in Southwestern Poland

HOW ARE OUTCROPS FORMED?

Outcrops are exposed through various geological processes such as **erosion, uplift**, and **weathering**. Erosion exposes underlying rock layers, creating outcrops visible at the Earth's surface. Uplift, caused by tectonic activity or volcanic processes, can bring deeper rock layers closer to the surface. While, weathering further removes and breaks down surface materials, exposing underlying rock layers.

THREE LEVELS OF OUTCROP CONFIDENCE

LEVEL I: HIGH - Rock units are well exposed, consistent, and have very little variation due to low tectonic activity, making geological observations highly reliable.

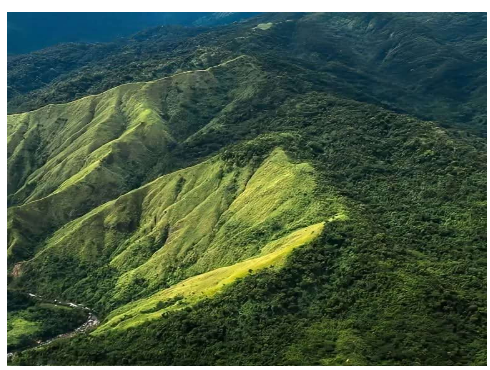
Example: Walcott Quarry in Canada

LEVEL II: INTERMEDIATE - Rock units are mostly consistent but show some predictable structural features, making observation moderately reliable.

Example: Badlands National Park in South Dakota

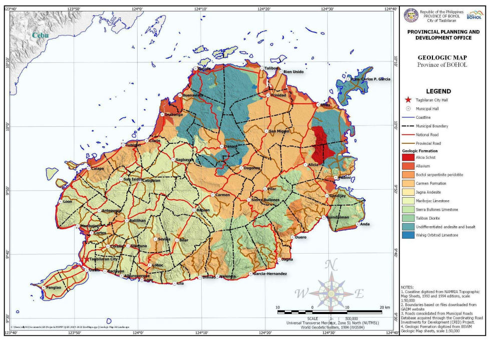
LEVEL III: LOW - Rock units are poorly exposed and difficult to observe.

Example: Sierra Madre mountain range in the Philippines



GEOLOGICAL MAPS

A geologic map or geological map is a special-purpose map made to show various geological features. Rock units or geologic strata are shown by color or symbols. Bedding planes and structural features such as faults and folds are shown with strike and dip or trend and plunge symbols, which give three-dimensional orientations.

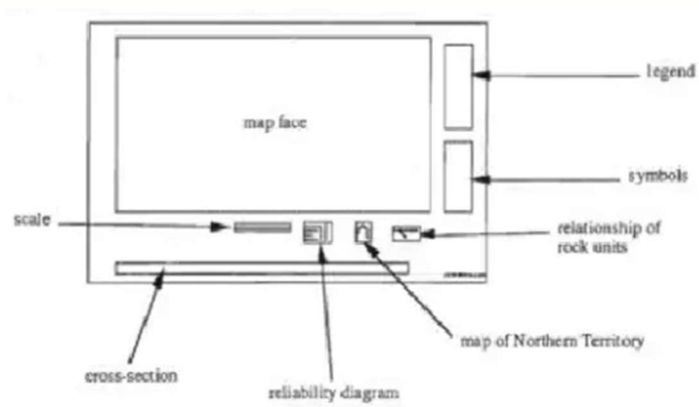


WHAT ARE GEOLOGICAL MAPS AND WHAT ARE THEY USED FOR?

Geologic maps are uniquely suited to solving problems involving Earth resources, hazards, and environments. Geologic maps represent the distribution of different types of rock and surficial deposits, as well as locations of geologic structures such as faults and folds. Geologic maps are the primary source of information for various aspects of land-use planning, including the siting of buildings and transportation systems. And perhaps most importantly for the people of New Mexico, such maps help identify ground-water aquifers, aid in locating water-supply wells, and assist in locating potential polluting operations, such as landfills, safely away from the aquifers.

1. **Resource exploration:** Geological maps can be used to identify areas with potential mineral resources, such as metals, coal, and oil.
2. **Engineering and construction:** Geological maps are used to assess the geologic hazards associated with an area, such as landslides, sinkholes, and seismic activity. This information is essential for designing safe and effective infrastructure.
3. **Environmental management:** Geological maps are used to identify areas with potential environmental hazards, such as contaminated soil and groundwater, and to assess the impact of human activities on natural resources.
4. **Agriculture:** Geological maps can help farmers understand the characteristics of the soil in their area, including its texture, drainage, and nutrient content. This information is important for crop selection and management.
5. **Education and research:** Geological maps are used in education and research to teach and study the geology of an area, including its rock formations, fossils, and geologic history.

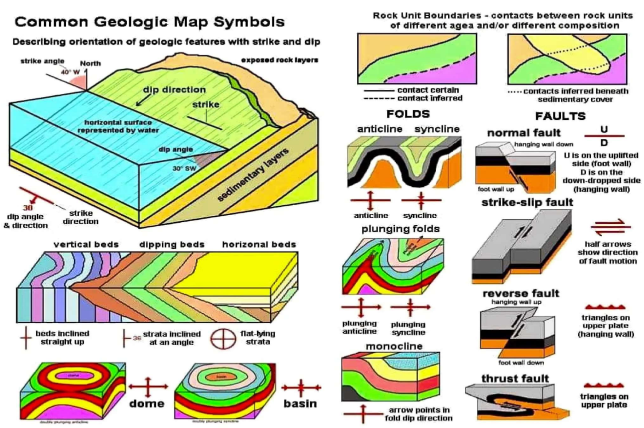
PARTS OF A GEOLOGICAL MAP

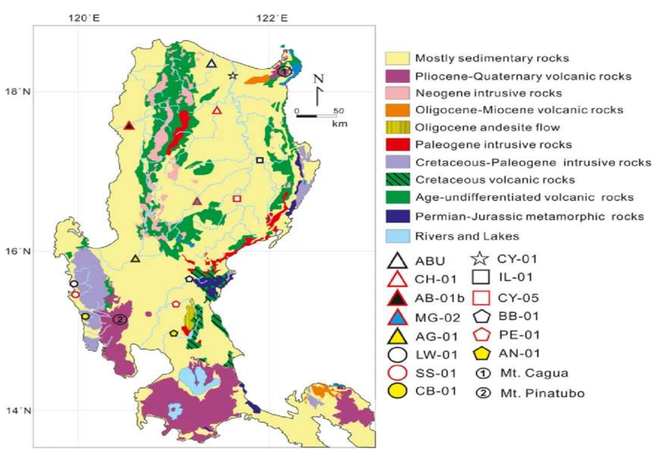


- **Title (and Subtitle):** Identifies the map's main topic, place, and time.
- **Legend:** Explains the meaning of map symbols.
- **Map Scale:** Shows the relationship between map and real-world distances.
- **Credits:** Lists the map's source, author, and other reference details.
- **Mapped Areas:** Displays the geographic features shown on the map.
- **Map Symbols:** Represent different features and locations on the map.
- **Place Name and Labelling:** Identifies and names important locations.

- **North Arrow:** Indicates the map's orientation or direction.
- **Graticule:** Shows lines of latitude and longitude for location reference.

COMMON GEOLOGIC MAP SYMBOLS



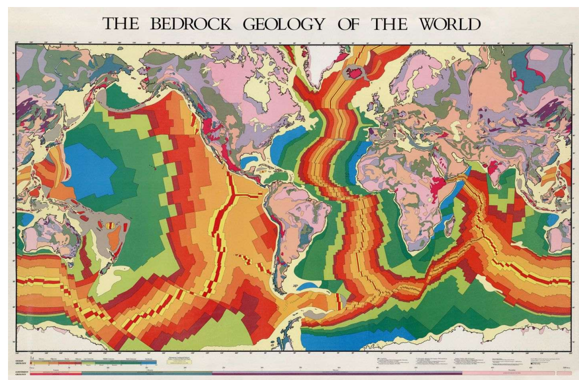


The 3 Major Classifications of Geological Maps:

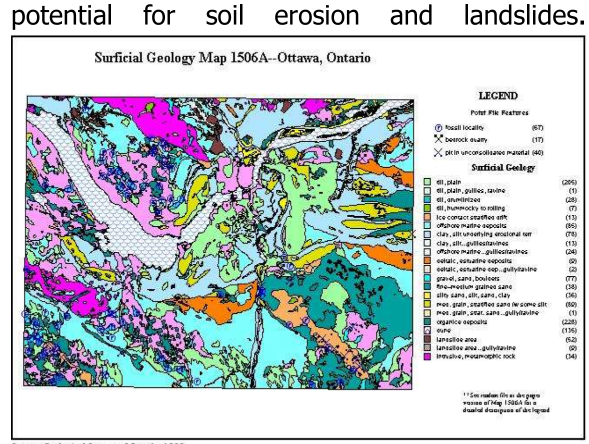
- Classification according to **Scale**
  a. Large Scale: >1:10,000
  b. Medium Scale: 1:10,000 - 1:100,000
  c. Small Scale: <1:100,000
- Classification according to **Purpose**
  a. **Multipurpose** - its information can be used for many purposes, either for one or many components of a geological environment. (i.e. Strength Map)
  b. **Special Purpose Maps** - the information can be used for special purposes only. (i.. Map for tunnels)
- Classification according to **Content**
  a. **Analytical Maps** - evaluating and giving details of some parameters. (Weathering Grade, Joint Map, Seismic Hazard).
  b. **Comprehensive Maps** - maps depicting all principal components of the engineering geology environment.

Different Types of Geological Maps

1. **Bedrock maps**: These maps show the location and distribution of different types of rock formations at or near the Earth's surface. Bedrock

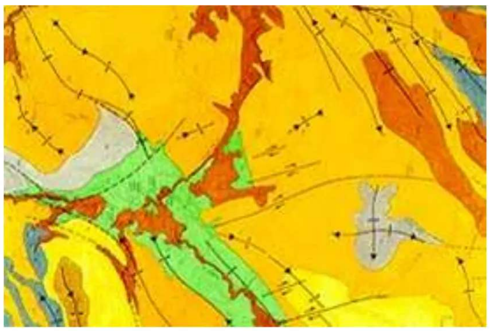


maps can be used to identify the age, composition, and structure of rocks in an area, as well as their potential for use as natural resources.
2. **Surficial maps**: These maps show the distribution of different types of surficial materials, such as soils, sediments, and glacial deposits. Surficial maps can be used to study the history of climate change, the location of natural resources like water and minerals, and the potential for soil erosion and landslides.

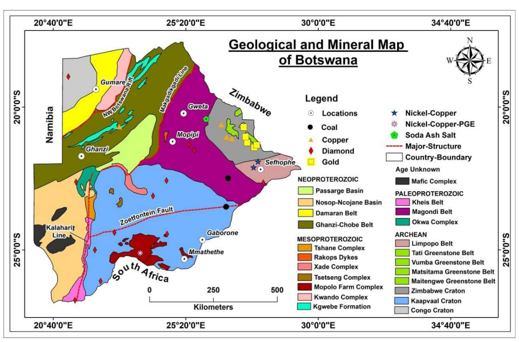


Source: Geological Survey of Canada, 1982

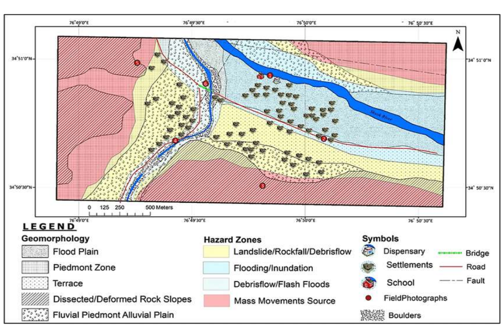
3. **Structural maps**: These maps show the orientation and location of different types of geologic structures, such as faults and folds. Structural maps can be used to study the history of tectonic activity in an area, as well as the potential for earthquakes and other natural hazards.



4. **Mineral maps**: These maps show the location and distribution of different types of minerals and mineral resources in an area. Mineral maps can be used to study the geology of an area, as well as the potential for economic development through mining and other resource extraction.



5. **Geologic hazard maps**: These maps show the potential for natural hazards, such as earthquakes, landslides, and volcanic eruptions, in an area. Geologic hazard maps can be used to identify areas that are at risk for these types of events, as well as to develop strategies for mitigating their effects.



LESSON 2. GEOLOGICAL STRUCTURES

FOLDS, FAULTS, & JOINTS + Their bearing on Engineering Construction

Folds: geologic structures formed by ductile deformation

Engineering Considerations involved in Dealing with Folded Rocks

A civil engineer has to be very cautious while he/she is handling or excavating through the folded rocks, because whenever the folds are disturbed, they release the stored energy and may damage the site in various ways. Moreover, *folded rocks are generally highly fractured*, particularly along the axial parts. These fractures not only make the rocks weak, but also act as channel-ways for the surface waters to percolate through them.

FAULTS: GEOLOGIC STRUCTURES FORMED BY BRITTLE DEFORMATION

When rocks undergo brittle deformation, they fracture. If no appreciable lateral displacement has occurred along fractures, they are called **joints**. If lateral displacement occurs (i.e., rocks on one side of the fracture move relative to rocks on the other side), these fractures are referred to as **faults**.

DIP-SLIP AND STRIKE-SLIP

- **Strike-Slip Fault**

In a strike-slip fault, movement is horizontal along the fault plane. It happens along the strike of the fault plane, hence the name. There is no vertical motion involved. Purely strike-slip faults usually have a vertical fault plane.

- **Dip-Slip Fault**

The two masses of rock that are cut by a fault are called fault blocks, and each fault block gets a special name depending on whether it is above or below the fault. The hanging wall is the block located above the fault plane, and the footwall is the block located below the fault plane.

Engineering Considerations Involved in Dealing with the Faulted Rocks

Faulted rocks generally offer unstable sites from engineering considerations, not only because there have been displacements along the fault(s) in the past, but also because further fresh movements may take place at any time in the future. An engineer, as a general rule, tries to avoid locating any of his major structures on a fault or even in its vicinity.

FOLDS, FAULTS, AND UNCONFORMITIES ON GEOLOGICAL MAPS AND CROSS-SECTIONS

On a geological map, you can spot more complex structures in the following ways:

Folds: **Horizontal folds** will appear as repeating bands of beds that are arranged in mirror image on either side of the fold axis. **Plunging folds** are the easiest to spot, because they make a wavy pattern on the surface of the map. You can tell an anticline from a syncline by looking for strike and dip symbols, looking for the map symbols for those types of folds, or simply noticing whether the beds are older toward the centre of the fault (an anticline), or going away from the axis (a syncline).

Unconformities: Geological maps reveal unconformities through sudden changes in bed orientation or strike and dip symbols, while **faults** are indicated by offset or non-mirrored repeating beds. Unlike **folds**—which repeat beds as mirror images—faulting maintains the same sequence order, and post-erosion views of dip-slip faults can visually mimic strike-slip motion.

JOINTS

Joints may be defined as cracks or fractures present in the body of a rock, along which there has been no relative movements as happen in the case of faults

Genetic Classification

- **Tensional Joint**

A type of joint that forms when rocks are subjected to tensile stresses, causing them to stretch and fracture.

- **Shear Joint**

A type of connection or junction between two structural elements where the primary force or load is applied parallel to the plane of the joint.

Geometric Classification

- **Strike Joint**

The strike of the joint is in the same direction of the rock.

- **Oblique/Diagonal Joint**

The strike of the joint is at an inclined angle with the strike of the rock.

Engineering Considerations Involved in Dealing with Jointed Rocks

For construction of any major civil engineering structure in any area, it is absolutely necessary to investigate the rock joints thoroughly, mainly because joints act as sources of weakness for the rocks, and also as sources of leakage through the rocks. Hence, if the proposed foundation rocks for a dam or a reservoir happen to be heavily jointed, and if the water-table of the region is low, then the leakage from the reservoir to the underground may be very heavy, finally resulting in abandoning the proposed site, and choosing a better one. The Joints in rocks play a very important role in landslides in hilly regions, because they serve as slip surfaces.

LESSON 3. INTRODUCTION TO ROCK MECHANICS

ROCK MECHANICS

Rock mechanics is a multidisciplinary field of geotechnical engineering that focuses on the behavior of rocks under various conditions, including stress, strain, and deformation. It plays a pivotal role in various industries such as mining, civil engineering, petroleum engineering, and environmental science.

KEY CONCEPTS IN ROCK MECHANICS

01 Stress and Strain
Stress is the amount of force acting on a specific area of rock, while strain is how the rock actually responds to that force. When stress overpowers the rock's strength, strain occurs as a change in shape, a change in volume, or even cracking and breaking.

STRESS
It is the force applied to an object.

Types of stress:
COMPRESSION - Directed stress that pushes rocks together.
TENSION - Directed stress that pulls rock apart in opposite directions.
SHEAR - Directed stress that pushes one side of a body of rock in one direction, and the opposite side of the body of rock in the opposite direction.

STRAIN
It is the deformation of a material from stress.

Types of strain:
ELASTIC STRAIN -the temporary and reversible deformation of a material due to stress
DUCTILE STRAIN
the deformation that cannot be reversed, even if the stress applied stops
FRACTURE -also called rupture. A rock that has ruptured has abruptly broken into distinct pieces.

02 Rock Properties
The physical and mechanical characteristics that determine how a rock behaves under different conditions.

03 Failure Criteria
The methods used to predict when and how a rock will fail under different loading conditions. They establish the maximum amount of stress a rock can withstand before it cracks, fractures, or collapses.

04 Rock Mass Behavior
refers to how an entire mass of rock reacts to natural and human-made forces. Factors such as rock type, fractures, joints, groundwater, and weathering all influence whether the rock mass remains stable or becomes susceptible to deformation or failure.

TYPES OF ROCK MECHANICS STUDIES

1. Experimental Rock Mechanics
involves testing rock samples in laboratories to determine their physical and mechanical properties.
2. Numerical Modeling
uses computer software and mathematical simulations to predict how rocks and rock masses will behave under different loading and environmental conditions.
3. Field Studies
involve collecting information directly from the construction or project site to understand actual rock conditions.

APPLICATIONS OF ROCK MECHANICS

1. Mining and Quarrying
- Keeping Mines Safe: Prevents cave-ins, roof collapses, and rock explosions in underground tunnels.
- Stable Pit Walls: Calculates the safe steepness for huge open-pit mine walls so they don't slide.
- Controlled Blasting: Designs explosives to shatter rock efficiently without damaging surrounding areas.

2. Civil Engineering
- Tunnels & Subways: Helps engineers safely dig highway and train tunnels through mountains and bedrock.
- Strong Foundations: Ensures heavy structures like skyscrapers, bridges, and massive dams don't sink or crack the rocks underneath.
- Rockfall Prevention: Keeps loose rocks on highway cliffs from falling onto traffic using bolts, nets, and anchors.

3. Petroleum Engineering

- Safe Well Drilling: Keeps deep oil and gas wells open so the rock walls don't collapse on the drill bit.
- Fracking (Hydraulic Fracturing): Cracks open tight underground rocks to release trapped oil and natural gas.
- Stopping Ground Sinking: Prevents the ground at the surface from sinking when oil and gas are pumped out from below.

4. Geological Engineering

- Natural Disaster Prevention: Predicts and stops landslides, rockslides, and sinkholes.
- Underground Storage: Ensures safe long-term storage for toxic or nuclear waste deep inside stable rock formations.
- Clean Energy: Helps tap into deep heat from the Earth for geothermal energy and seals carbon emissions underground.

LESSON 4. PHYSICAL AND MECHANICAL PROPERTIES OF ROCKS

UNDERSTANDING THE PHYSICAL AND MECHANICAL PROPERTIES OF ROCKS: AN INTRODUCTION

In the realm of rock mechanics, understanding the physical and mechanical properties of rocks is paramount. These properties define how rocks behave under various conditions and play a crucial role in engineering and geological applications. This presentation delves into the fundamentals of physical properties, mechanical properties, and porosity of rocks.

PHYSICAL PROPERTIES OF ROCKS

Physical properties are the measurable characteristics used to describe, identify, and classify rocks. They provide the foundation for understanding rock behavior before any load or stress is applied.

1. POROSITY (Φ)

Porosity is the volume percentage of void space within a rock relative to its total volume. It is one of the most critical parameters in hydrogeology, petroleum engineering, and environmental science.

$$\Phi = \frac{Void\ Volume\ (V_1)}{Total\ Volume\ (V)}$$

Types of Porosity:

- **Primary Porosity**: Inherent to the rock's original formation process (e.g., intergranular pores in sandstone)
- **Secondary Porosity**: Develops later via dissolution, fracturing, or weathering (e.g., vugs in limestone)

Implications:

1. Fluid Storage: Higher porosity means greater capacity to store water, oil, or gas in reservoir rocks
2. Flow Rates: Connected pores control how quickly fluids migrate through the rock matrix
3. Pore Pressure: Fluid-filled pores generate internal pressure that directly reduces effective rock strength

2. DENSITY

Density is defined as the mass of a substance per unit volume. In rock mechanics, it is commonly expressed as **specific gravity** — the ratio of rock density to that of water.

Most crustal rocks fall between 2.6 – 2.7 g/cm^3. Rocks with high porosity, such as sandstone, tend toward the lower end of this range

Specific gravity is dimensionless and makes cross-material comparison straightforward.

THREE TYPES OF DENSITY

- **DRY DENSITY**

Weight of a completely dry rock per unit volume — all pores are empty of water. Represents the minimum density state.

- **BULK DENSITY**

Weight of a rock with its natural moisture content per unit volume — some pores hold water, others hold air. The most commonly reported field value.

- **SATURATED DENSITY**

Weight per unit volume when all pores are completely filled with water. Represents the maximum density state for a given rock.

The following are the typical bulk density values (measured in grams per cubic centimeter, g/cm^3) of some common building stones.

Rock Type	**Bulk Density (g/cm3)**
Granite	2.66-2.72
Basalt	2.74-3.00
Limestone	2.54-2.64
Sandstone	2.22-2.40

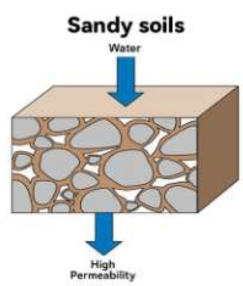
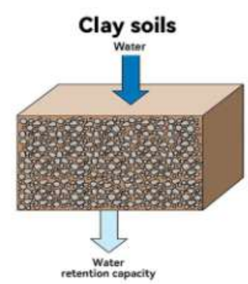
Basalt is consistently the densest across both sources because its fine-grained igneous minerals pack tightly together. **Sandstone** is the least dense due to higher porosity, while granite and limestone fall in between.

APPLICATIONS OF DENSITY

- **Material Selection:** Density guides the choice of rock type for structural components, balancing weight with load-bearing requirements
- **Soil and Rock Classification:** Density measurements help distinguish rock types and quality in borehole logging and site investigation
- **Foundation Design:** Accurate density data informs bearing capacity calculations and determines appropriate foundation depth
- **Stability Analysis:** Density is a key input in slope stability models, retaining wall design, and underground excavation planning

3. PERMEABILITY

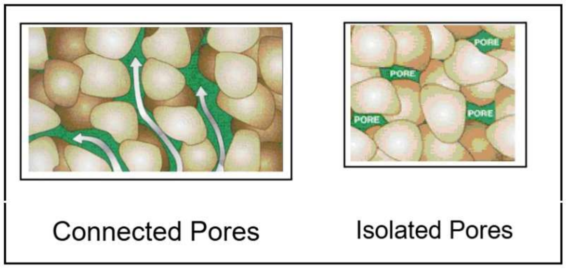
Permeability is the ability of a rock or sediment to allow fluids, such as water, oil, or gas, to flow through its interconnected pore spaces or fractures. It is determined by how well the pores are connected rather than simply by the amount of pore space present. A rock with interconnected pores allows fluids to move easily, whereas a rock with isolated pores restricts fluid flow.

High Permeability	Low Permeability
A rock has high permeability when fluids can move through it easily because the pore spaces or fractures are well connected. Examples: • Gravel • Sand • Well-sorted sandstone • Fractured limestone 	A rock has low permeability when fluids cannot easily pass through it and greater pressure is required for flow. Low permeability commonly occurs in rocks with poorly connected pores or very fine grains. Examples: • Clay • Shale • Unfractured granite 

Factors Affecting Permeability

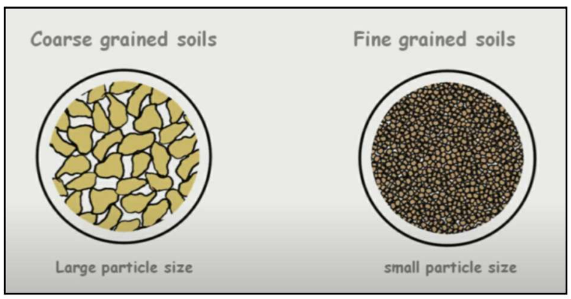
The permeability of rocks depends on several factors:

1. Pore Connectivity



Permeability increases when pore spaces are interconnected. Rocks with isolated pores may have high porosity but very little permeability.

2. Grain Size



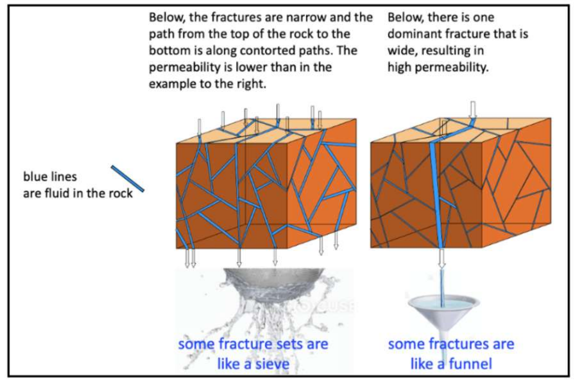
Coarse-grained materials generally have higher permeability because they contain larger pore spaces than fine-grained materials.

General order:
Gravel > Sand > Silt > Clay

3. Sorting

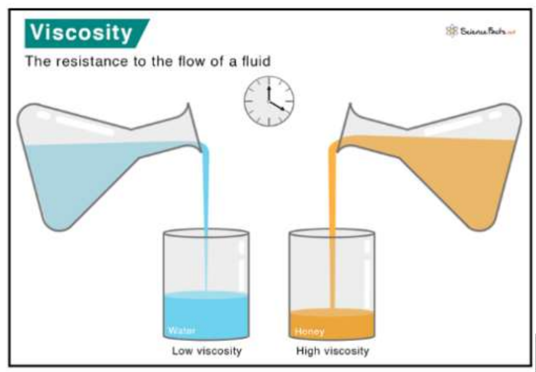
Well-sorted sediments have particles of similar size, creating continuous pathways for fluid flow. Poorly sorted sediments contain smaller particles that fill pore spaces, reducing permeability.

4. Fractures and Joints



Fractures and joints create additional pathways for groundwater movement. Even rocks with low matrix permeability may become highly permeable when fractured.

5. Fluid Properties



The movement of fluids also depends on fluid viscosity. Fluids with lower viscosity flow more easily than those with higher viscosity.

Applications of Permeability

Permeability is an important property in Civil Engineering because it helps engineers predict how water and other fluids move through rocks and soils. It is commonly applied in:

- **Groundwater flow and aquifers** – to evaluate the movement and storage of groundwater for water supply and environmental studies.
- **Dam and reservoir engineering** – to assess seepage through foundations and prevent excessive water leakage.
- **Tunnel and underground construction** – to estimate groundwater inflow and design appropriate drainage systems.

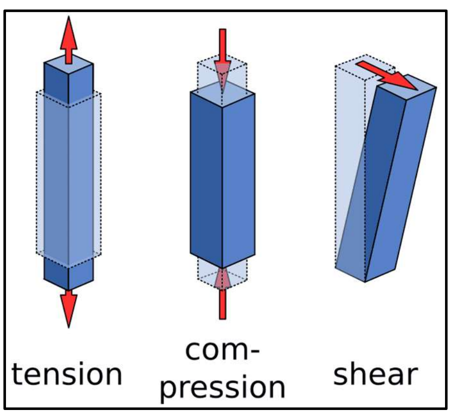
- **Foundation engineering** – to determine the drainage characteristics of the ground and reduce problems caused by excess pore water pressure.
- **Oil and gas reservoirs** – to evaluate how easily hydrocarbons can flow through reservoir rocks, helping determine the productivity of oil and gas fields.

MECHANICAL PROPERTIES OF ROCKS

- Mechanical properties describe how rocks respond when subjected to external forces or loads. These properties determine whether a rock can support structures, resist deformation, or fail under applied stress.

1. STRENGTH

Strength is the ability of a rock to resist applied stress without breaking or undergoing permanent failure. Rock strength is influenced by its mineral composition, grain bonding, weathering, fractures, and geological history.
Strength may be categorized as follows:



(a). Compressive Strength

- Compressive strength is the maximum compressive stress a rock can withstand before failure. Since rocks naturally resist compression better than tension, this is usually their greatest strength.

(b). Tensile Strength

- Tensile strength is the ability of a rock to resist forces that pull it apart. Rocks generally have much lower tensile strength than compressive strength, making them more susceptible to cracking under tension.

(c). Shear Strength

- Shear strength is the resistance of a rock to sliding or failure along planes such as joints, bedding planes, or faults. It is important in evaluating the stability of rock slopes and underground excavations.

APPLICATION OF STRENGTH

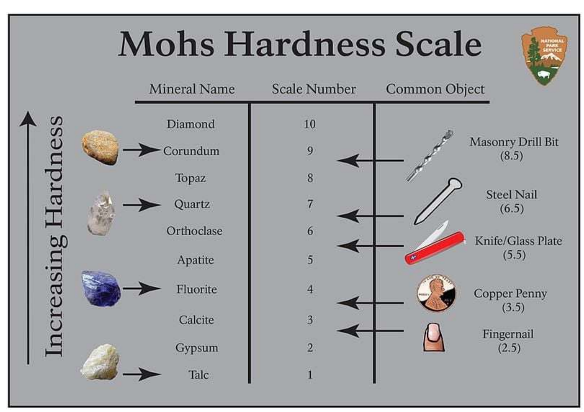
- **Tunnel Design -** rock strength helps engineers determine whether the surrounding rock can safely support a tunnel or if additional support is needed.
- **Rock Quality Designation (RQD) -** rock strength, together with RQD, helps evaluate the quality and condition of a rock mass for construction.
- **Underground Excavations -** rock strength helps engineers assess the stability of excavations and choose suitable support systems to ensure safety.

2. HARDNESS

Hardness is the resistance of a rock or mineral to scratching, abrasion, or wear. It reflects the hardness of the minerals composing the rock as well as the rock's texture and cementation.

Unlike strength, hardness describes resistance to surface damage rather than resistance to structural failure.

The hardness of a rock is influenced by the hardness of the component grains composing it, as well as grain size, shape, arrangement, and binding minerals.



Because rocks are composed of different minerals, their overall hardness depends on the hardness and proportion of the minerals present.

APPLICATIONS OF HARDNESS

- **Drilling and Excavation** - hardness determines the type of drilling and excavation equipment required on a construction site. Hard rocks such as granite and basalt require stronger drill bits, more powerful machinery, and greater energy to cut or break, while softer rocks can be excavated more easily. Understanding rock hardness helps engineers estimate excavation time, equipment wear, and construction costs.
- **Construction Materials** - rocks are widely used as construction materials because they resist abrasion, weathering, and mechanical wear. Rocks with high hardness, such as granite and basalt, are commonly used as aggregates in concrete and asphalt, road base materials, railway ballast, and building stones due to their durability and long service life.

3. ELASTICITY

Elasticity in rocks refers to the ability of a rock to deform reversibly under stress and return to its original shape once the stress is removed.

Young's Modulus: Young's modulus, also known as the modulus of elasticity, is a measure of a material's stiffness. It quantifies the relationship between stress and strain in the elastic region of deformation.

Hooke's Law: Elasticity in rocks follows Hooke's law, which states that the strain of a material is directly proportional to the stress applied to it within the elastic limit.

Anisotropy: Rocks can exhibit anisotropic elasticity, meaning their elastic properties vary with direction. This is particularly true for rocks with preferred orientation of mineral grains or structural features.

Seismic Waves: Elastic properties of rocks play a crucial role in the propagation of seismic waves. Seismic velocities are directly related to the elastic moduli of rocks, which helps in interpreting subsurface geology in seismic surveys.

APPLICATIONS OF ELASTICITY

Geomechanical Modeling
Seismic Interpretation
Rock Deformation Studies

4. PLASTICITY

Definition: Plasticity in rocks refers to the ability of a rock to undergo permanent deformation without fracturing under applied stress beyond its elastic limit.

Yield Strength: Yield strength is the stress at which a material begins to deform plastically. Beyond this point, the material undergoes permanent deformation.

Plastic Deformation Mechanisms: Rocks deform plastically through mechanisms such as dislocation glide, twinning, and grain boundary sliding, depending on factors like mineral composition, temperature, and pressure.

Strain Hardening: In plastic deformation, rocks can undergo strain hardening, where the material becomes stronger and more resistant to further deformation after initial yielding.

Ductility: Ductility refers to the ability of a material to deform plastically without failure. Rocks with higher ductility can undergo more extensive plastic deformation before fracturing.

APPLICATIONS OF PLASTICITY

Rock Engineering
Geotechnical Engineering
Structural Geology

LESSON 5. DYNAMIC PROPERTIES OF ROCKS

Definition: Dynamic properties of rocks describe how rocks behave when subjected to rapidly changing or sudden forces rather than slowly applied forces.

Examples of Dynamic Forces

- Earthquakes
- Explosions
- Blasting operations
- Machine vibrations

- Impact loading

DYNAMIC VS. STATIC LOADING

Dynamic Loading	Static Loading
• Sudden	• Slowly applied force
• Rapid deformation	• Gradual deformation
• Short duration	

DYNAMIC RESPONSE OF ROCKS

When rocks experience dynamic loading, they may:

- Deform elastically
- Develop cracks rapidly
- Fracture suddenly
- Transmit seismic waves
- Dissipate energy through damping

Important Concept: Dynamic loading often causes failure at lower stress levels than static loading because of:

- Inertia effects
- Strain-rate effects

DYNAMIC PROPERTIES

1. Elastic Modulus

Measures the stiffness of a rock.

indicates:

- Resistance to deformation
- Ability to return to its original shape after unloading
- Capacity to withstand elastic strain

Rock Examples

1. Granite (High modulus)
2. Sandstone (Moderate modulus)
3. Shale (Lower modulus)

INTERPRETATION

Higher Elastic Modulus = Stiffer rock = Smaller deformation

Lower Elastic Modulus = More flexible rock = Greater deformation

2. *Dynamic Strength*

The ability of a rock to resist failure under dynamic loading.

Dynamic Loading Effects

- Produces rapid crack growth
- Causes failure at lower stress levels than static loading
- Depends on loading rate

Dynamic strength affects:

1. Tunnel stability
2. Blasting
3. Earthquake resistance

3. *Damping*

The ability of rocks to absorb and dissipate vibration energy.

Benefits:

- Reduces vibration amplitude
- Converts mechanical energy into heat
- Helps prevent excessive shaking

High Damping = Better vibration control

Low Damping = Vibrations travel farther

Example

Soft sedimentary rocks usually damp vibrations more than hard crystalline rocks.

4. *Resonance Frequency*

Every rock mass has its own natural frequency.

What Happens?

When external vibrations match the rock's natural frequency:

- Vibrations become amplified
- Damage may occur

Used in:

1. Earthquake engineering
2. Dam construction
3. Building foundations
4. Mining operations

FACTORS INFLUENCING DYNAMIC BEHAVIOR

1. *Rock Type & Mineralogy*

Affected by:

- Mineral composition
- Grain size
- Porosity

Influences:

- Stiffness
- Strength

2. *Confining Pressure*

Higher pressure generally:

- Increases rock strength
- Increases resistance to failure

3. *Temperature*

High temperature:

- Reduces stiffness
- Reduces strength

4. *Moisture Content*

Water:

- Weakens rocks
- Makes rocks more susceptible to failure

5. *Loading Rate*

Faster loading:

- Usually increases apparent stiffness
- Usually increases apparent strength

APPLICATIONS

1. **Seismic Hazard Assessment**

Engineers use dynamic rock properties to:

- Analyze seismic wave propagation
- Predict ground movement during earthquakes
- Design earthquake-resistant structures
- Reduce risks to lives and infrastructure

Example

Knowledge of resonance frequency helps prevent excessive structural vibrations during earthquakes.

2. **Rock Blasting and Fragmentation**

Benefits:

- Improves blasting efficiency
- Produces desired rock fragment sizes
- Minimizes unwanted ground vibrations
- Enhances mining safety

3. **Petroleum Exploration**

Used to:

- Conduct seismic surveys
- Locate oil and gas reservoirs
- Evaluate underground rock formations
- Improve drilling and extraction efficiency

4. **Civil Engineering**

Dynamic rock properties are essential in designing and constructing:

- Tunnels
- Dams
- Bridges
- Building foundations
- Slopes and retaining structures

PURPOSE

To ensure structures remain stable and safe during:

- Earthquakes
- Blasting
- Heavy machine vibrations

QUICK MEMORIZATION

Dynamic Forces **(BIMEE)**

- Blasting
- Impact loading
- Machine Vibrations
- Earthquakes
- Explosions

Dynamic Properties **(SEND)**

- Strength
- Elastic Modulus
- Natural Frequency (Resonance Frequency)
- Damping

Factors Affecting Dynamic Behavior **(CoLoRoTeMo)**

- Confining Pressure
- Loading Rate
- Rock Type & Mineralogy
- Temperature
- Moisture Content

Applications **(SPRC)**

- Seismic Hazard Assessment
- Petroleum Exploration
- Rock Blasting & Fragmentation
- Civil Engineering

TYPE OF WAVE THEORY

Wave theory is a fundamental concept in physics that describes the propagation of energy through a medium or space. Waves manifest in various forms and exhibit diverse behaviors depending on their characteristics and the medium through which they travel. This report aims to provide a comprehensive overview of different types of waves, their properties, and applications across various fields.

Seismic waves are energy waves produced by an earthquake that travel through the Earth and cause the ground to shake.

Seismic waves are classified into two main groups:

1. Body Waves

- Travel through the Earth's interior.
- Faster than surface waves and arrive first during an earthquake.
- Divided into:

Primary (P) Waves – Compressional or push-and-pull waves that travel through solids, liquids, and gases.

Secondary (S) Waves – Shear or side-to-side waves that travel only through solids.

2. Surface Waves

- Travel along the Earth's surface.
- Slower than body waves but cause the greatest damage during earthquakes.
- Divided into:

Love Waves – Move the ground horizontally from side to side.

Rayleigh Waves – Move the ground in a rolling motion, causing both vertical and horizontal movement.

FACTORS AFFECTING WAVE VELOCITY

Wave velocity and elastic moduli are significant parameters in materials science and engineering. When creating and evaluating materials for a variety of applications, it is essential to understand the factors influencing wave velocity in addition to the static and dynamic moduli of elasticity and direction.

- **WAVELENGTH (λ)**

Distance between identical points on consecutive waves.

- **FREQUENCY (F)**

Number of waves that pass a point per unit of time.

- **WAVE VELOCITY**

Wave velocity in common usage refers to speed, although, properly, velocity implies both speed and direction.

- **WAVE TYPE**

According to Wave Theory, the Wave Type may influence the velocity of waves. Body waves such as (s-waves) and (p-waves) are both moving fast through the rigid material and move slowly through the denser material, but only the speed of p-waves is directly proportional to the compressibility of the material.

- **ELASTICITY, DENSITY AND TEMPERATURE**

Wave velocity is directly proportional to elasticity and temperature inversely proportional to density.
Raising the Temperature of the medium (which decreases its density) has the effect of increasing the velocity of sound waves through the medium since wave velocity increases as the density decreases and the temperature increases; this happens particularly below the Earth's surface, such as the mantle.

ROCK MATERIAL

Studies show the types of rocks are also factors that may affect wave velocities.

Condie (2016) demonstrates that compressional wave velocities in crustal rocks generally increase from lighter rocks to dense mafic and ultramafic compositions, showing that seismic velocity is primarily driven by rock type rather than metamorphic grade.

DEPTH

Seismic wave velocities increase with depth in the continental crust from 6.0 to 6.2 km/s at depths of less than 10 km to 6.6 km/s at 25 km depth. Lower crustal velocities range from 6.8 to 7.2 km/s, and in some cases show a bimodal distribution.

POISSON'S RATIO

Because seismic wave velocities are related to rock density and density is related to rock composition, the measurement of these velocities provides an important limitation on the composition of both the oceanic and continental crust.

STATIC AND DYNAMIC MODULI OF ELASTICITY

MODULUS OF ELASTICITY

Elastic modulus, or just modulus, is another name for the measurement of the elasticity of a material.

YOUNGS MODULUS

The mechanical characteristic of solid materials known as Young's modulus, or Young modulus, quantifies the compressive or tensile stiffness when a force is applied longitudinally.

DYNAMIC MODULI

The dynamic moduli of rock are those calculated from the elastic wave velocity and density.

STATIC MODULI

The static moduli are those directly measured in a deformational experiment.

Static strain may reach 10^(-2) whereas dynamic wave propagation experiment strain is approximately 10^(-7).

LESSON 6. GROUTING

GROUTING

Grouting is a process in civil engineering that involves injecting a fluid material into the subsurface to fill voids, strengthen formations, or control groundwater flow.

TYPES OF GROUTING

1. Cement Grouting: Cement is a commonly used grouting material and involves the injection of a mixture of cement, water, and sometimes sand into gaps. The material forms a compact mass after hardening, providing additional support and strength to the construction. This type of grout is ideal for filling voids in concrete structures (also known as concrete grouting), repairing cracks, and improving the load-bearing capacity of foundations.

2. Chemical Grouting: In this type, specific chemical compounds, such as polyurethane or acrylate, are injected into voids. These chemicals expand upon contact, filling gaps and sealing against water infiltration. This type of grout is particularly useful for waterproofing, soil stabilization, and repairing underground structures.

3. Structural Grouting: This type focuses on creating a solid connection between structural components, such as columns and beams. It's commonly used to anchor bolts, reinforce concrete elements in high-stress areas, and fill cracks or gaps in existing structures.

4. Bentonite Grouting: This type of material employs a mixture of bentonite clay and water to form a gel-like substance. It is a popular choice for sealing wells and boreholes due to its swelling properties, as it expands when interacting with water, effectively sealing off cavities.

5. Bituminous Grouting: This involves the use of a bituminous compound, which helps seal and waterproof roofs, foundations, and basement structures, providing excellent water resistance. It provides excellent durability and resistance against UV radiation and harsh weather conditions. This type of grout is used in scenarios where water penetration needs to be minimized, such as in tunnels and underground structures.

6. Resin Grouting: This type of material utilizes epoxy, polyurethane, or other liquid resins that harden to form a strong bond when cured. These resins offer high tensile and compressive strength, making them suitable for a range of applications. It is often used in repairing cracks in concrete, due to its excellent adhesive properties and strength.

GROUTABILITY

- Soil/Void Size (D_{15}): The grain diameter at which 15% of the base soil is finer
- Grout Particle Size (D_{85}): The diameter at which 85% of the particulate grout material (like cement suspension) is finer
- Formula: Expressed as GR = D_{15}/D_{85}, where a higher value indicates better penetrability and lower risk of particle blockage. Generally, a ratio

of $D_{15} / D_{85} > 11$ to 20 indicates a readily groutable soil.

Grouting Materials and Techniques:

Common grouting materials include cement-based grouts, chemical grouts, and polymer grouts.

Techniques such as permeation grouting, pressure grouting, and compaction grouting are used based on project requirements and site conditions.

Applications of Grouting:

- **Material Selection:** Consider density, permeability, and strength when selecting grouting materials.
- **Soil and Rock Classification:** Density and permeability influence soil and rock classification for grouting design.
- **Foundation Design:** Density and strength of underlying soil or rock affect foundation design.
- **Stability Analysis:** Grouting can improve stability by filling voids and strengthening formations.
- **Fluid Flow:** Permeability affects fluid movement through soil or rock, essential for drainage and seepage control.
- **Transportation Engineering:** Density and strength impact road construction and durability.

CONCLUSION

In summary, structural geology informs our understanding of rock structures, while rock mechanics ensures the stability and safety of structures built upon or within rocks.

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