ENGINEERING GEOLOGY II
CE 553

Chapter- I

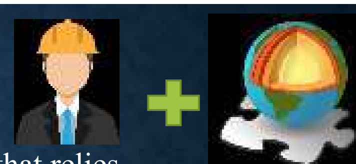
Introduction to Engineering Geology

- Engineering geological system (EGS): Rock and soils, geological structures, geomorphology, hydrogeology, weathering, earthquake & seismicity and geotechnical category of the project, evaluation of engineering geological system (EGS) with reference to the different phases (planning, design, construction and maintenance) of the infrastructure development project
- Important rock forming minerals and their engineering significance
- Application of engineering geology in various civil engineering projects (roads, **irrigation** system, tunnels, dams & reservoirs etc.)
- Engineering geological maps: Their classification and preparation

Deepak Gautam (Engineering Geologist)

बिहीवार, अगस्त 27, 2020

ENGINEERING GEOLOGY????



- Engineering Geology is an applied discipline of geology that relies heavily on knowledge of geologic principles and processes.
- Engineering Geology, basically, is applied geology.
- Specifically, it is the application of geologic information to solving the problems and minimizing the adverse effect in any civil and geo-technical engineering works.
- Basically it includes
  - Evaluation of natural hazards
  - Evaluation of landscape for site selection
  - Evaluation of earth materials for potential issues

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IEAG (INTERNATIONAL ASSOCIATION FOR ENGINEERING GEOLOGICAL AND ENVIRONMENT) DEFINITION

- Engineering geology is defined by the association of engineering geologist as the discipline of applying geological data, techniques and principles to the study both of a) naturally occurring rock and soil materials, and surface and subsurface fluids and b) the interaction of introduced materials and processes with the geological environment so that geological factors affecting the planning design, construction, operation and maintenance of engineering structures and the development projection and remediation of ground- water resources are adequately recognized, interpreted and presented for use in engineering and related practice.

ENGINEERING GEOLOGICAL SYSTEM(EGS)

The various components and features that from the earth constitute the engineering geological system.

Parameters for evaluation of EGS

- *Rocks: **hard and soft***
- *Geological structures: **Primary and Secondary***
- *Soil type*
- *Seismicity*
- *Hydrogeological conditions*
- *Weathering Grade: High grade, Medium grade and Low grade*
- *River morphology*
- *Landforms*

- **Why EGS????**
  - *To avoid excessive investment of time and money in order to get the required geological system EGS is required*
  - *Engineering geological system should be performed in every phases of civil engineering projects*

ENGINEERING GEOLOGICAL TASKS AT DIFFERET PHASES OF THE EGS

Phase	Task for study
Project Definition	Setting of the problem and development of the concept for the project. Preliminary information about regional geology, topography and climate
Prefeasibility	Regional geological information with reference to the existing geological maps air photo interpretation. Inspection Visit to the project area and preliminary geological survey including possible alternative sites
Feasibility	Engineering geological mapping of the project area and along alternative sites surface and subsurface geotechnical information of the selected sites based on the geophysical survey supported with limited core drillings Estimation of the mechanical behavior of the intact rock and rock mass based on the previous experiences and supported by some laboratory tests
Detail Design	Detail engineering geological mapping of the selected alignment, different sites rock mapping of the particular site for the stability analysis and design of the support system in demand Surface and Subsurface information of the site based on adequate geophysical methods and supplementary core drilling. Insitu as well as laboratory tests
Construction Excavation	Engineering geological logging along the tunnel or road corridor Stability analysis and supporting measures Continuous supervision by engineering geologist, civil and mining engineers
Maintenance	Regular inspection and monitoring in view of stability of surface slope after the construction and the stability of the excavation surface of the undergrad structure

GEOTECHNICAL CATEGORY OF THE PROJECT

Its divided into three categories:

Categories 1:

- relatively small structure

- Fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations

-Negligible risk

-Simplified design procedures applied

Categories 2:

- Conventional types of structures with no exceptional risk

-Design includes quantitative geotechnical data and analysis to ensure that the fundamental requirements are satisfied.

Categories 3:

- Structures which fall outside the limits of categories 1 and 2
- Structures in highly seismic area
- Abnormal risks or unusual ground conditions.

ROCK FORMING MINERALS

There are only few minerals (less than 100) form the great amount of the rocks of the earth crust. These most common minerals have been grouped as *rock forming minerals*.

Among these rock forming minerals, only about 25 minerals make almost 99.5% of the rocks.

There are 10 groups of these most common rock forming minerals.

About 8% of the earth crust is made up of silicate minerals.

Silicate minerals

1. **The Feldspar Group**

   $(Na, K, Ca)AlSi_3O_8$

2. **Pyroxene Group**

   $(Ca,Na,Al,Li)SiO_3$

3. **Amphibole Group**

   $(Ca,Mg,Fe,Mn,Na,K)_7(Si_4O_{11})(OH)_2$

4. **Mica Group**

   $(K,Na,Li,Mg,Fe)Al_3Si_3O_{10}(OH)_2$

OXIDE MINERALS

Oxide minerals are second large occurring rock forming minerals.

1. **Quartz (SiO_2)**

It is hard and resistant to weathering. It has no cleavage and partings. It has different colored varieties that have economic importance.

2. **Corundum (Al_2O_3)**

It is very hard and resistant mineral. It has a number of gem varieties.

3. **Spinel ($MgAl_2SiO_4$)**

It is also hard as quartz and resistant.

Carbonate Minerals

There are a few carbonate minerals, which are very important rock forming minerals:

1. **Calcite ($CaCO_3$)**

Limestone is composed of high percentage of calcite. Marble is recrystallized form of calcite.

•

2. **Dolomite [Ca,Mg$(CO_3)_2$]**

It occurs in massive forms with extending for kilometers across. It contains a significant amount of magnesium and can be used economically.

3. **Magnesite ($MgCO_3$)**

It is useful as refractory material and source of magnesium.

Others Group:

1. Sulphate Group e.g. gypsum
2. Phosphate Group e.g. apatite
3. Halide Group e.g. Fluorite
4. Sulphide Group e.g. galena, cinnabar
5. Native minerals e.g. gold, graphite, diamond sulphur

ENGINEERING SIGNIFICANCE OF ROCK FORMING MINERALS

Topographical controls

- **Erosion rate of rock forming minerals**
- **Topographical breaks - steepness or smoothness**
- **Karst Topography – controlled by Limestone**
- **Groundwater control**

Strength of Rock Forming Minerals

- **Hard and soft nature of different minerals**
- **Engineering design and site investigation controlled by strength of minerals**
- **Quality of construction materials are controlled by strength of minerals**
- **Clay minerals like kaolinites swells with water and therefore creates hazardous site for engineering structures.**
- **The rock containing silicates are generally resistant towards weathering.**

ENGINEERING GEOLOGICAL MAP???

- *An engineering geological map is a type of geological map which provides a generalized representation of all those components of a geological environment of significance in land use planning and in design, construction and maintenance as applied to civil and mining engineering*

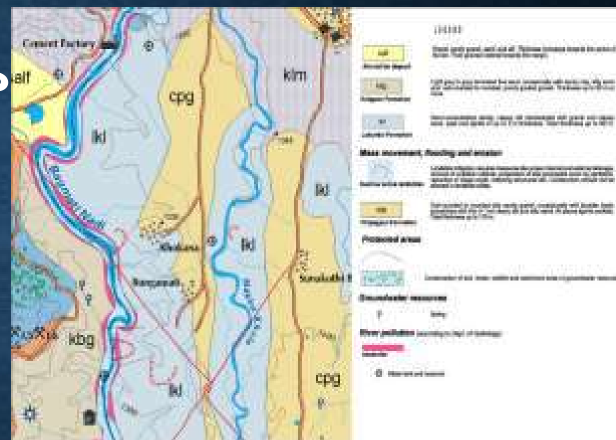


Fig: Engineering geological map of Kathmandu valley

GEOLOGICAL FEATURES REPRESENTED ON ENGINEERING GEOLOGICAL MAP

- The character of the rocks and soils, including their distribution, stratigraphically and structural arrangement, age, genesis, lithology, physical state and their physical and mechanical properties
- Hydrogeological conditions, including the distribution of water bearing soils and rocks, zones of saturated open discontinuities, depth of water table and its range of fluctuation, regions of confined water and piezometric levels, storage coefficients, direction of flow, springs, rivers, lakes and the limits and occurrence interval of flooding, pH, salinity, corrosiveness
- Geomorphological conditions, including surface topography and important elements of landscape
- Geodynamic phenomena, permafrost, slope movements, formation of karstic conditions, suffusion, subsidence, volume changes in soil, data on seismic phenomena including active faults, current regional tectonic movements and volcanic activity

Engineering geological maps should include interpretative cross sections and an explanatory text and legends.They may also include documentation data which have been collected for the preparation of map.More than one map sheet may be required to show all this information

Basic components of geological maps

- *The map*
- *The legend*
- *Geological cross section of the map*
- *Explanatory text*
- *Title of the map*
- *Scale of the map*
- *North direction table including the data and location of the project*

CLASSIFICATION OF ENGINEERING GEOLOGICAL MAPS

Purpose

Engineering geological map

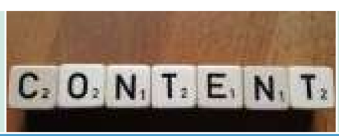
Analytical maps

Provides details about individual components of the area. e.g. map showing degree of weathering, seismic hazard etc.

Comprehensive maps

Depicts all the principle components of the area. Geological information only are depicted.

- **Special purpose:** *providing information either on one specific aspect of engineering geology of for one specific purpose*
- **Multipurpose**: *Providing information covering many aspects of engineering geology for a variety of planning and engineering purposes*



- **Analytical map**: *giving details of or evaluating individual components od the geological environment. Their content is as a rule, expressed in title, for example map of weathering grades, jointing map, seismic hazard map*
- **Comprehensive map**: *Those are of two kinds- they may be maps of engineering geological conditions depicting of all principal components of engineering geological map or they may be engineering geological zoning, evaluating and classifying individual territorial units. These two types may be combined in scale maps*
- **Auxiliary map:** *these present the factual data. E.g.: documentation maps, structural contour maps*
- **Complementary maps:** *These include geological, tectonic,geomorphological, pediological, geophysical and hydrogeological map*

scale

- **Large scale:** *1:10000 and greater*
- **Medium scale**:*less than 1:10000 and greater than 100000*
- **Small scale:** *1:100000 and less*


Stay safe
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Ch-2:Engineering geology in Himalayas

- Major discontinuities system of the Nepal Himalaya and their engineering significance
- Major engineering geological problems of Nepal Himalayas
- Importance of engineering geological information system in Nepalese context

Formation of Himalaya

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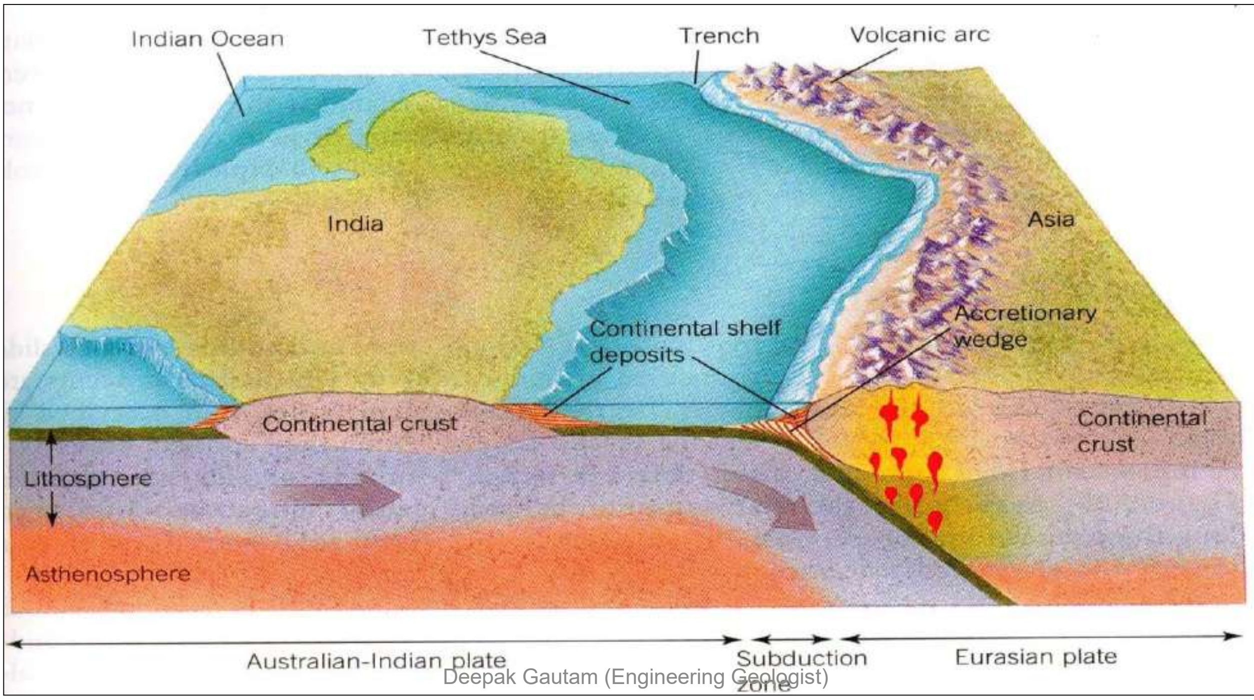
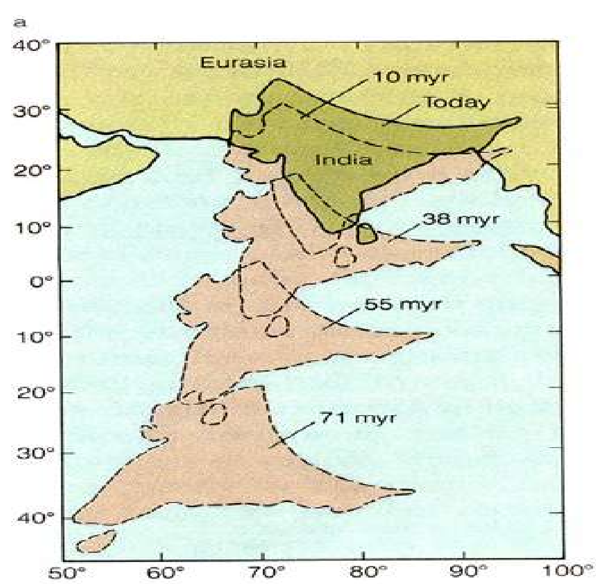
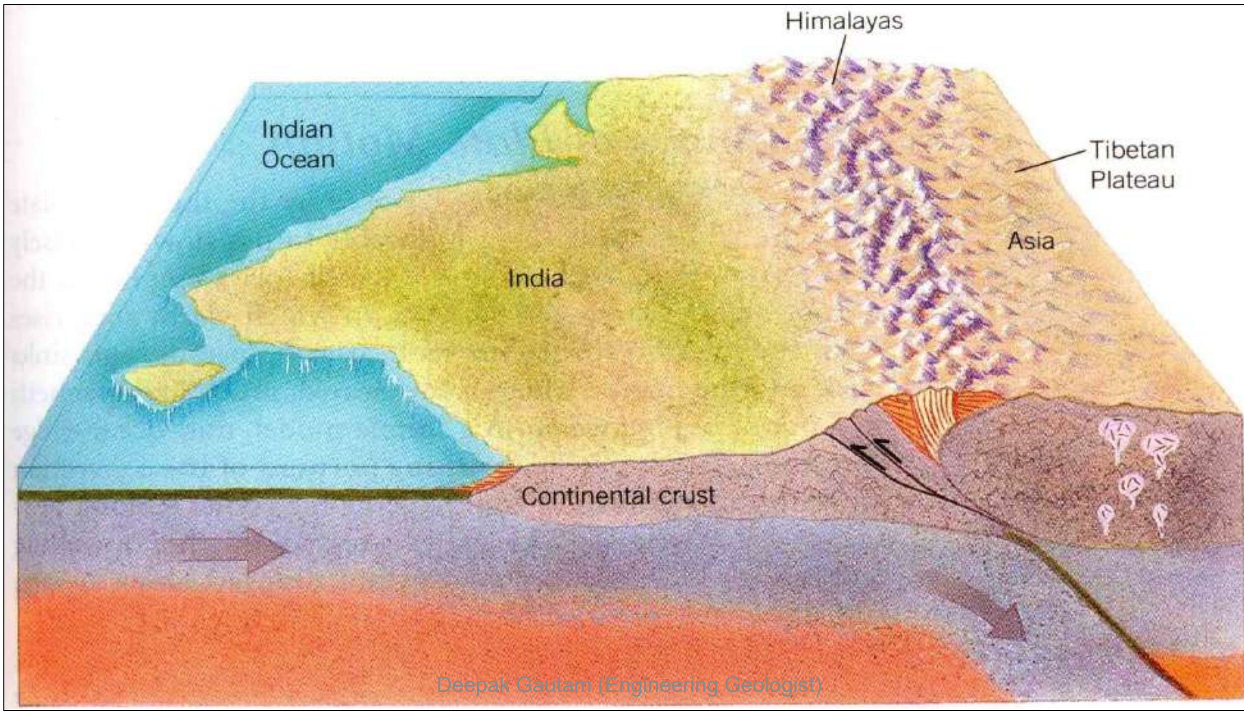
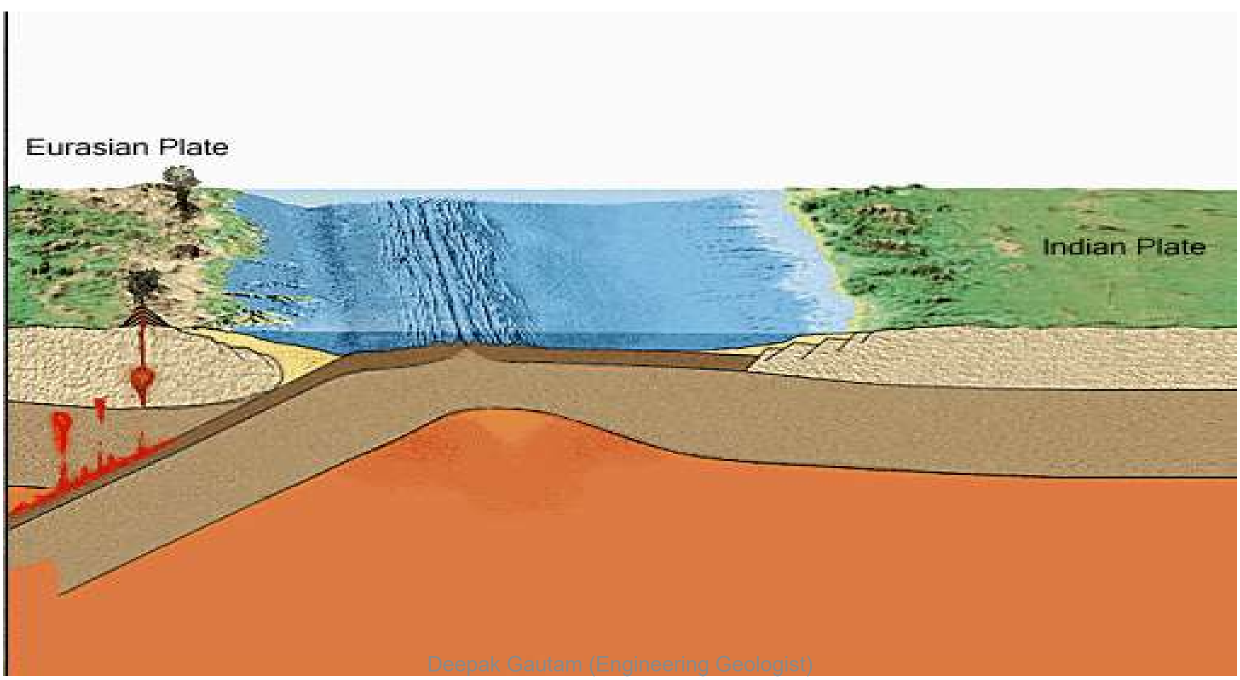


Shifting of Indian plate




Himalayas
Indian Ocean
Tibetan Plateau
Asia
India
Continental crust
Deepak Gautam (Engineering Geologist)


Eurasian Plate
Indian Plate
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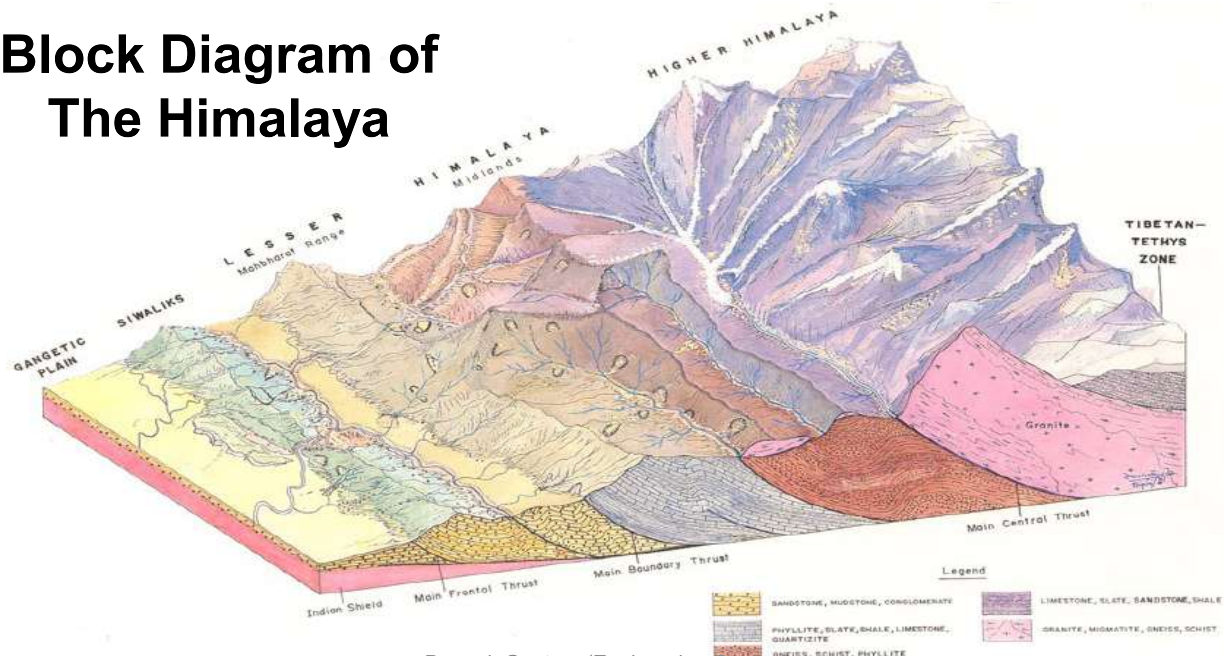
Block Diagram of The Himalaya



The Nepal Himalaya

- The longest division of the Himalaya

The Himalayan range extends about 2400km from Indus River is west to Aasam in the east.

- Extended about 800 Km (Nepal Himalaya)

- Starts from west at the Mahakali River

- Ends at the east by the Tista River

Longitudinal Division of Himalayan Range

Divided into five tectonic zones

- **Gangetic Plain (Terai)**

Himalayan Frontal Thrust
HFT

- **Sub-Himalayan Zone (Siwaliks)**

Main Boundary Thrust
MBT

- **Lesser Himalayan Zone**

Main Central Thrust
MCT

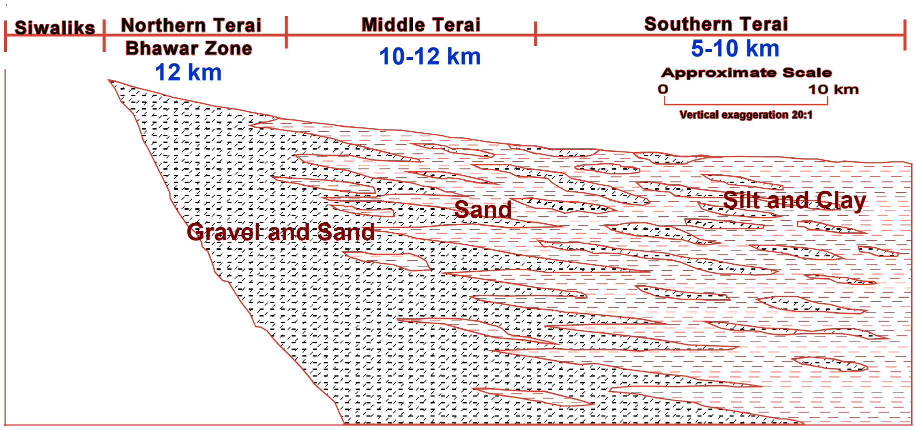
- **Higher Himalayan Zone**

South Tibetan Detachment System
STDS

- **Tibetan-Tethys Zone**

Terai Zone (Gangetic Plain)

- Northern Terai (Bhabhar Zone)
- Middle Terai (Marshy) Zone
- Southern Terai Zone

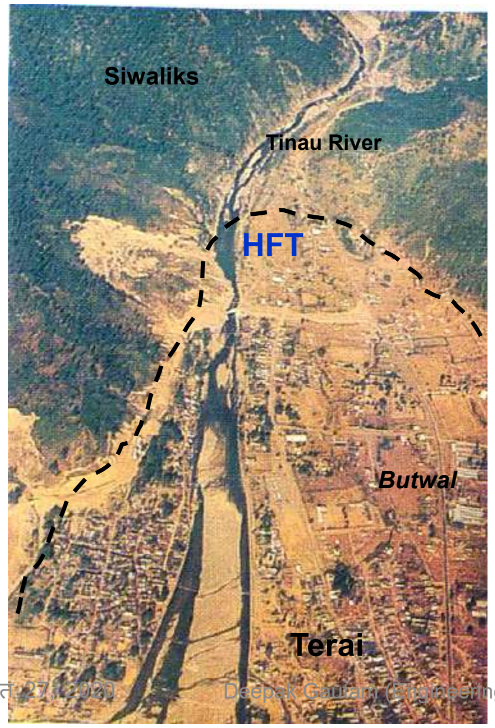


Division of Terai Zone

Major problems in terai zone

- Flood
- Liquifaction
- Bank cutting or scouring
- Subsidences
- Channel shifting of river
- Earthquake
- Excessive deposit of

Sediments.



Himalayan Frontal Thrust (HFT) Separating Terai (S) from Siwaliks (N) at Butwal area.

It is the tectonic contact between Siwalik and Terai zone. This fault is considered active. Its originated around 1.6 million years ago

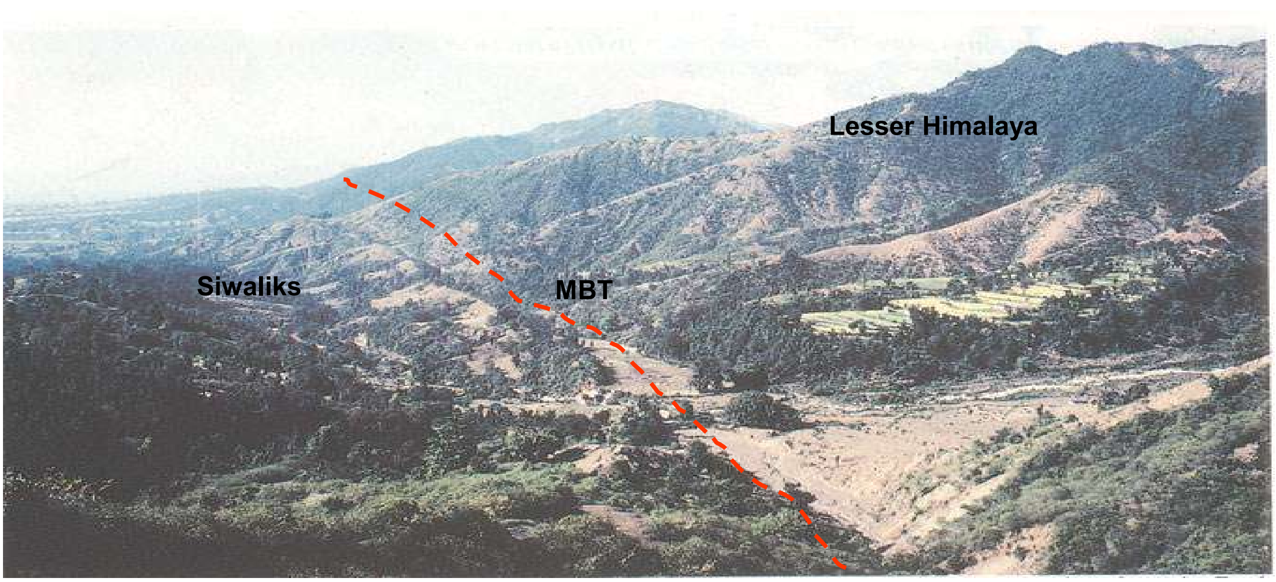
The Sub-Himalayan Zone (Siwaliks)

- **Delimited on the south by the Main Frontal Thrust (MFT) and on the north by the Main Boundary Thrust (MBT)**
- **Fluvial deposits of 23 Ma to 1.6 Ma old**

Siwaliks can be classified as

- Lower Siwaliks **(Greenish grey fine-grained sandstone and siltstone with mudstone)**
- Middle Siwaliks **(Medium to coarse-grained salt-and-pepper sandstones with colorful mudstone)**
- Upper Siwaliks **(Conglomerate and boulder beds and subordinately sand and silt beds)**

Alternating Bands in Lower Siwaliks



Main Boundary Thrust (MBT) in Dang

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Major problems in Siwaliks

- Mass movement
- Creep
- Debris flow
- earthquake
- Erosion (Gully and River)
- Weathering

Lesser Himalayan Zone

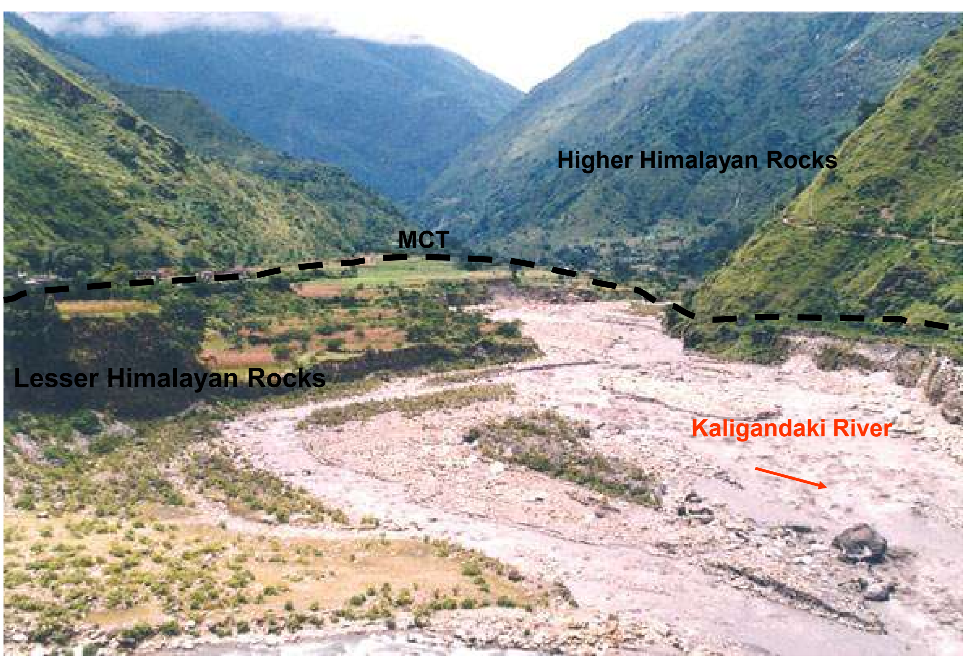
This zone Mainly contains

- **Unfossiliferous, sedimentary, and metasedimentary rocks:**

  Such as slate, phyllite, schist, quartzite, limestone, dolomite, etc of very old age (1600 Ma to 22 Ma)
- **There are also some granitic intrusions in this zone**
- **In Eastern Nepal, high grade metamorphic rocks (gneiss and schist)**
- **In Central Nepal, Medium to high grade metamorphic rocks**
- **In western Nepal around Gandaki and Bheri River, Low grade of metamorphic rocks (quartzite, slate, and phyllite)**
- **In Far western Nepal, again high metamorphic rocks are reappear.**

Major problems in lesser himalaya

- Mass movement:
  - Rock slide,
  - Rock fall
  - Rock toppling
  - Debris avalanche,
  - Deep gully erosion,
  - Wedge failure
- Flash flood
- Earthquake
- Toe cutting
- Debris flow
- Weathering



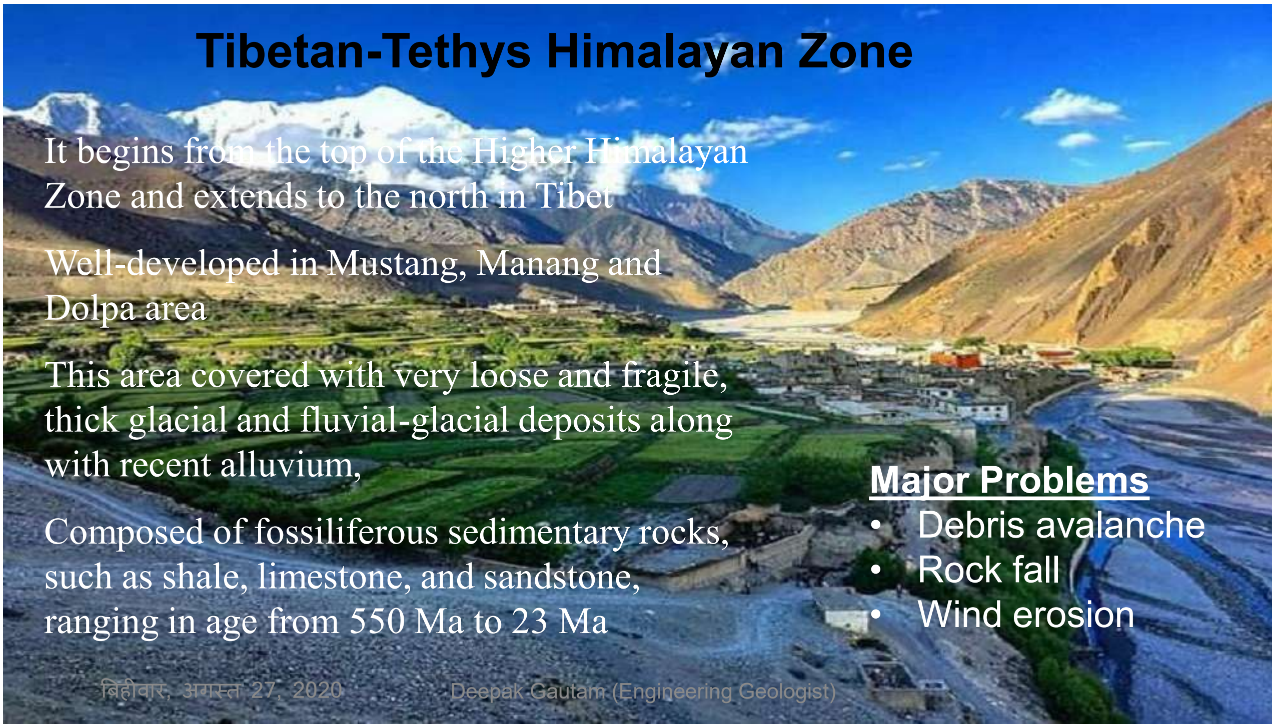
Main Central Thrust (MCT) at Myagdi

Higher Himalyan Zone

- Mainly consists of 10-12 km thick succession of high grade metamorphic rocks
- Lies between MCT and STDS
- Gneisses, schists, quartzites and marbles and granites in association with high-grade index minerals like kyanite, garnet etc.
- Has extremely high relief, steep topography, rocky cliff and outcrops with little soil cover terrain

Major problems of Higher Himalaya

- Mass movement
- Earthquake
- Wind erosion
- Rock fall
- weathering
- GLOF
- Snow avalanches



Tibetan-Tethys Himalayan Zone

It begins from the top of the Higher Himalayan Zone and extends to the north in Tibet

Well-developed in Mustang, Manang and Dolpa area

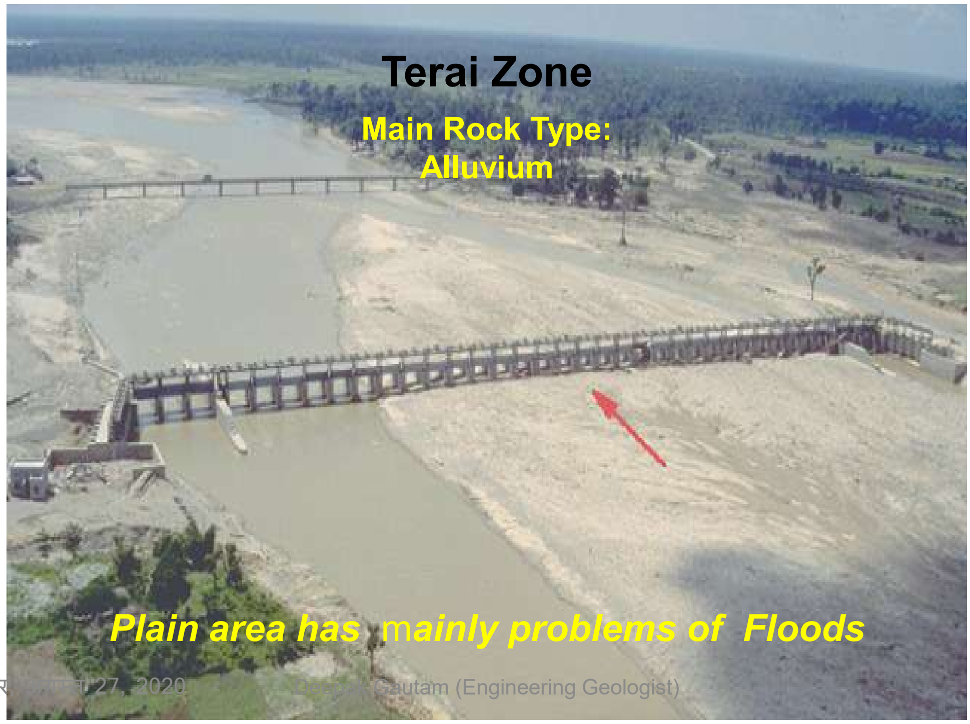
This area covered with very loose and fragile, thick glacial and fluvial-glacial deposits along with recent alluvium,

Composed of fossiliferous sedimentary rocks, such as shale, limestone, and sandstone, ranging in age from 550 Ma to 23 Ma

Major Problems

- Debris avalanche
- Rock fall
- Wind erosion

Engineering Geological Problems in Himalayas



Terai Vulnerable to Flood

Siwaliks Zone

Lesser Himlayan Zone
Main Rock Type:
Slate, Phyliite, Schist, Gneiss, Limestone, Dolomite, Quartzite
Old hard rock, thick soil formation, thick colluvium deposit in lower part of mountain slope, problems of large slope failures
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Higher Himalyan Zone
Main Rock Type:
Gneiss, Schist, Quartzite
Less soil formation, steep slopes, mainly rock slope failures
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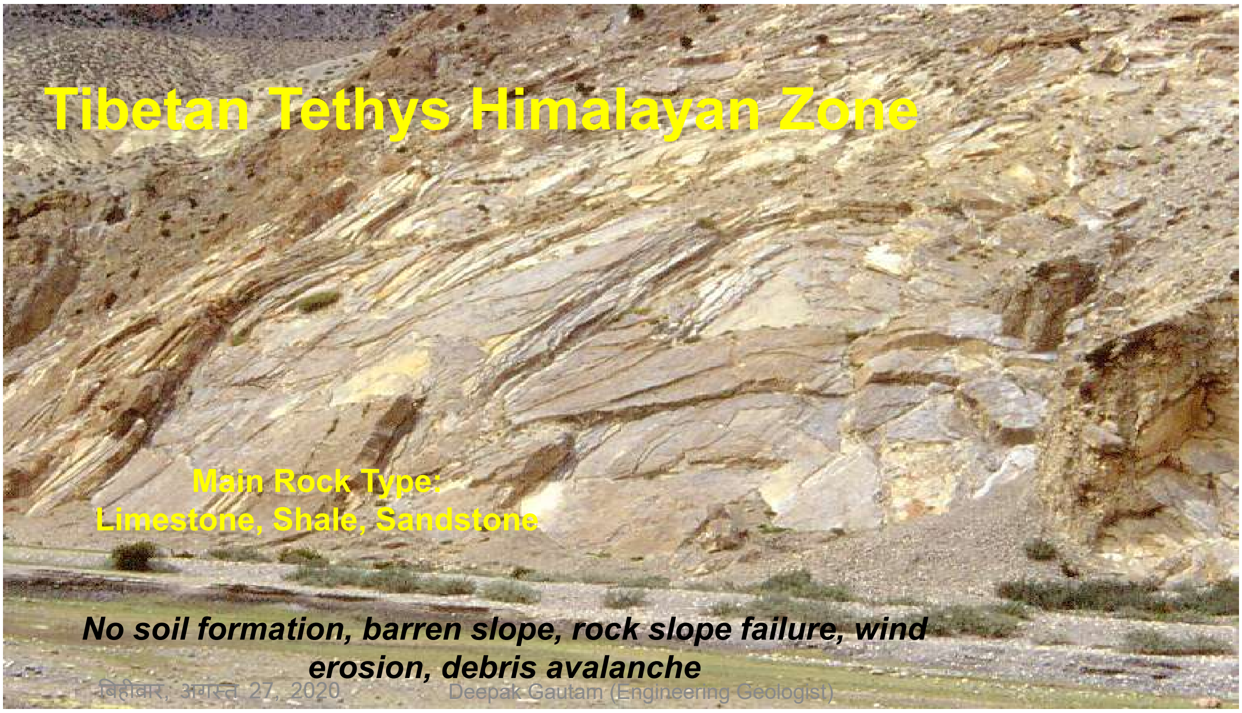


Why Himalayas are so vulnerable ????

- High relief (60-8848m): Slope failure,
- Active tectonics: Weak, unstable and permeable thrust zone
- Seismically active
- Mass movement
- Concentrated Precipitation (93% in summer, 37% in 24 hrs)

Hostile Natural Environment of Himalaya

River Cutting Down Quickly

Rocks Weathering Quickly

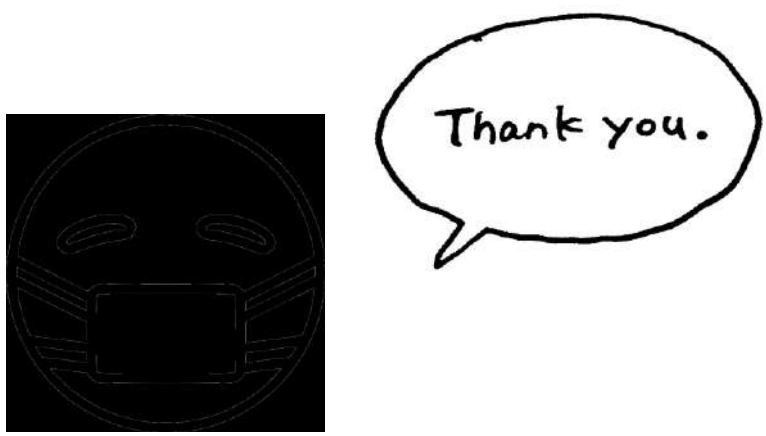
Mountains Still Rising

Slope Too Steep

Leads to

Degradation

(Mass Movement and Soil Erosion)



Hydrogeology

Prepared by:
Arishma Gadtaula
Engineering Geologist, M.Sc

Hydrogeology- Definition

- It is the branch of geology that deals with the study of occurrence, movement and quality of water beneath the ground surface.
- Groundwater/ subsurface water: The water that exists in the pore spaces and fractures in rocks and sediments beneath the earth surface.
- Sources of groundwater maybe precipitation, water bodies like stream,lakes etc. or irrigation.

Hydrological cycle

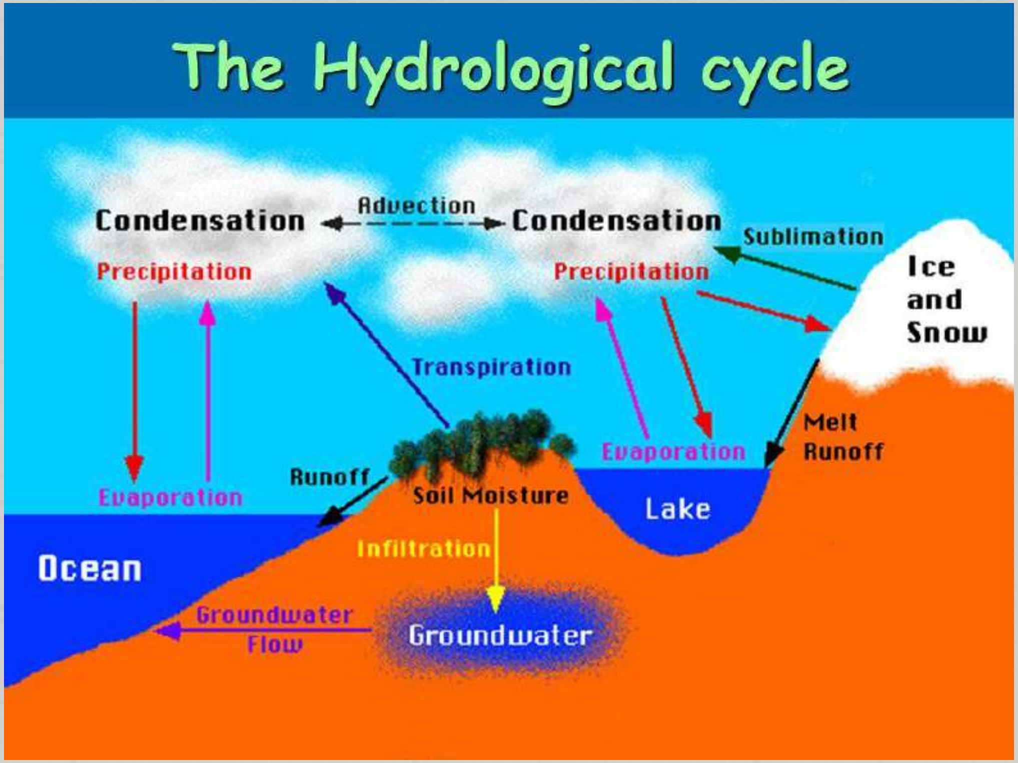


Figure 1: Hydrological Cycle

River channel Morphology

- River: A natural path defined by the flow of water is known as river. Rivers mostly originates from high hills or mountains. Small rivers in mountains or hills are called streams, rivulets or tributaries. When the river flows, the major geological action or the function carried by the river are erosion, transportation and deposition.

Figure 2 : Babai River

Geological action of river

- Erosion: The process of breaking down or wearing of rock due to geomorphic agents like moving water, glaciers melt and blowing wind is known as erosion. Erosion involves hydraulic action, abrasion and attrition.
- Transportation: The amount of sediment transported by stream is called load. Load may be of 3 types:
  (i) Dissolved load: Stream receiving underground water generally have dissolved load than water from surface run off, load in dissolved state is called dissolved load. Example: Calcium , sulphate, chloride, Mg, K.
  (ii) Suspended load: Load in suspension or in the form of floating bodies. Example: Fine particles of silt and clay.
  (iii) Bed load: Load apart from dissolved and suspension which are coarser in size. The bed load move slower than velocity of stream water, they move discontinuously by rolling or sliding. Example: Sand, gravel, pebble.
- Deposition: The loose materials transported downstream are deposited when the velocity of flowing water is reduced.

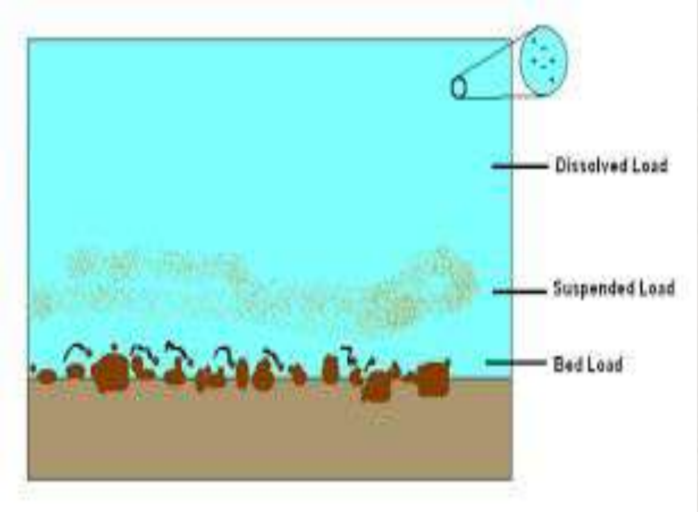


Figure 3: Types of Load

Types or Pattern of River Channels

Straight River	Meandering River	Braided River
• The river that follows straight path. • Originated at high or steep topography. • Gradient is high. • Velocity is high (Greatest in middle away from banks and bed of the channel . • High erosion (Mainly scouring than side cutting) and transportation capacity but low depositional capacity. • Mostly dominated at high hills or mountains.	• Latin word for Wandering • The river that follows zigzag path. • Originated at moderate topography • Moderate gradient and low velocity • Dominated by flood plain • Erosion and deposition occurs simultaneously • Channel shifted • Creates flood plain and oxbow lakes	• Bifurcated into several branches and may convert into single • Originates at very low relief • Low gradient and low velocity • Depositional rate is very high • Channel is shifted • Dominated with channel bars.

Features developed by river

- Point-bar and Ox-bow lake(Fig 5): It is a feature developed in meandering river. In meandering river, the meanders grow by eroding it's outer bank and depositing sediments at the inner bank. Such moon shaped sediments deposited in the inner bank is called ***Point-bar***. During this process, the sharpness of river bends increases and the neck of meander becomes narrow and narrow. Finally, a stage comes when due to intense erosion, the two banks meet each other. Then during high floods, the river may follow a straight path leaving behind a curved stagnant water body called an ***oxbow lake.***

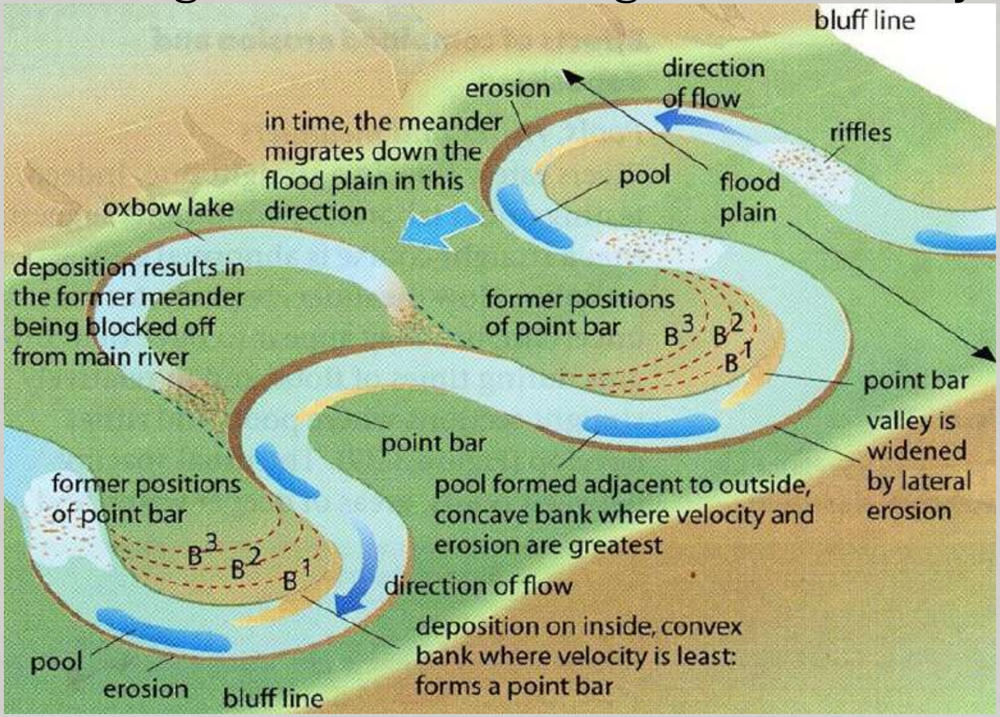


Figure 5: Point-bar and Ox-bow lake

- Alluvial fan(Fig 6): An alluvial fan is a fan or cone-shaped deposit of sediment crossed and built up by the streams. The material constituting a fan includes coarse boulders and pebbles at its head to finer material down it's slope.
- Flood plain(fig 7): These are areas of low and relatively flat land bordering the channel on one or both the sides, at bank level. These areas are readily submerged under water during flooding, when the river water overtops the banks of the channel and rises above the channel at low water.
- Deltas(fig 8): When a river enters a lake or sea it's velocity is checked rapidly and the process of deposition is accelerated. The coarser and heavier material is laid down first and the finer and lighter material is carried further out. Thus, the load brought by the river gets deposited at its mouth, which give rise to delta. These deposits are triangular in outline and resemble the Greek letter Δ (delta).

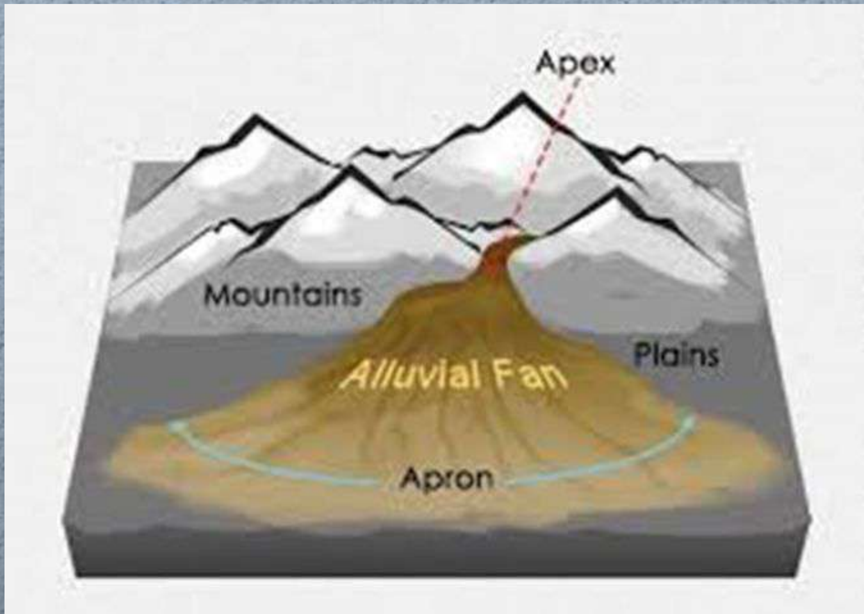


Figure 6 : Alluvial fan

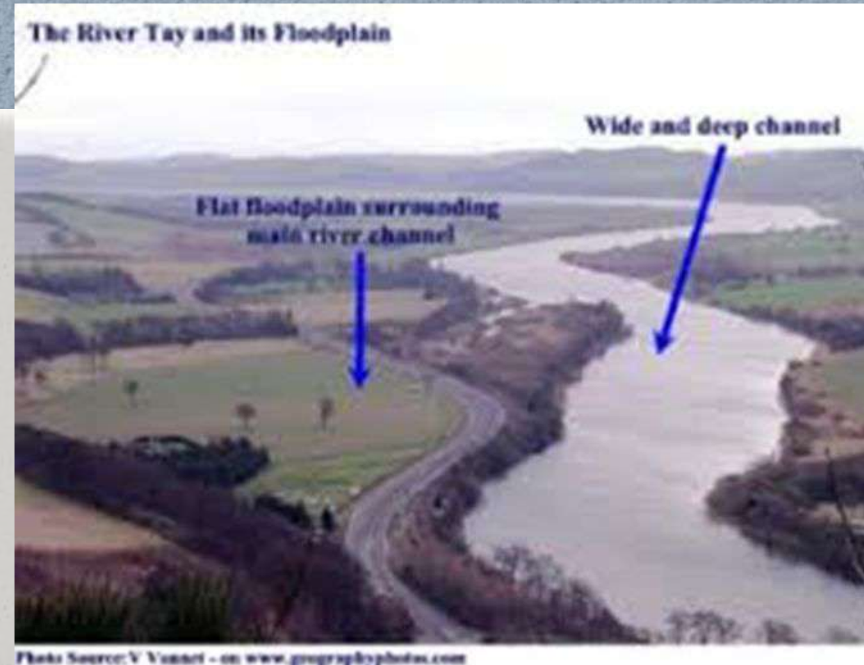


Figure 7: Flood plain

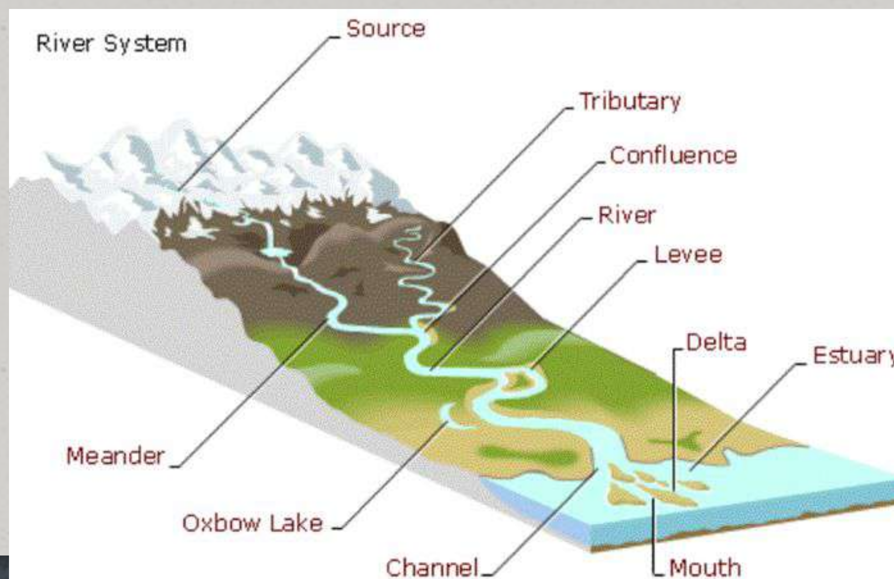


Figure 8: Delta

Occurrence of subsurface water

- Based on mode of occurrence, subsurface water is classified into two zones. They are:

(a) Zone of aeration/ Vadose zone: Water unsaturated zone consisting of air and water, water can't be extracted.

(b) Zone of saturation: Groundwater extraction zone, fully saturated.

Water table separates zone of aeration and zone of saturation.

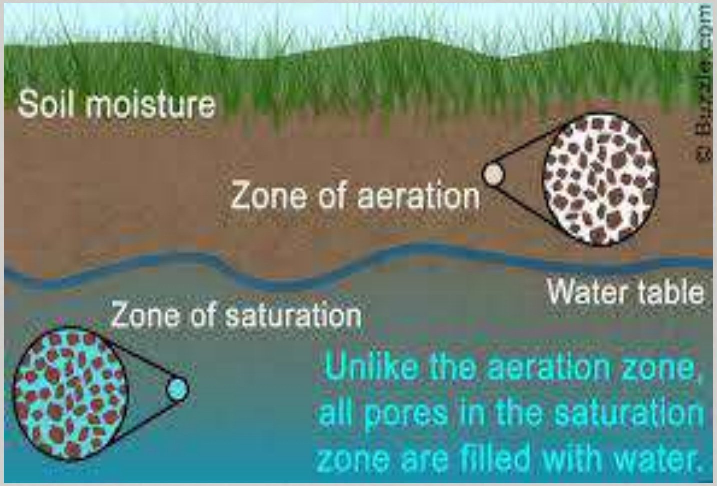


Figure 9: Different zone of subsurface water

Factors controlling occurrence and movement of Groundwater

- Climate
- Topography
- Porosity
- Permeability
- Hydraulic Gradient
- Hydraulic Conductivity

- Porosity: Porosity or void fraction is a measure of the void (i.e. "empty") spaces in a material, and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%.The larger the pore space or the greater their number, the higher the porosity and the larger the water holding capacity. It is denoted by ρ.

Mathematically,

ρ= Volume of voids (v)/ Total volume (V) * 100

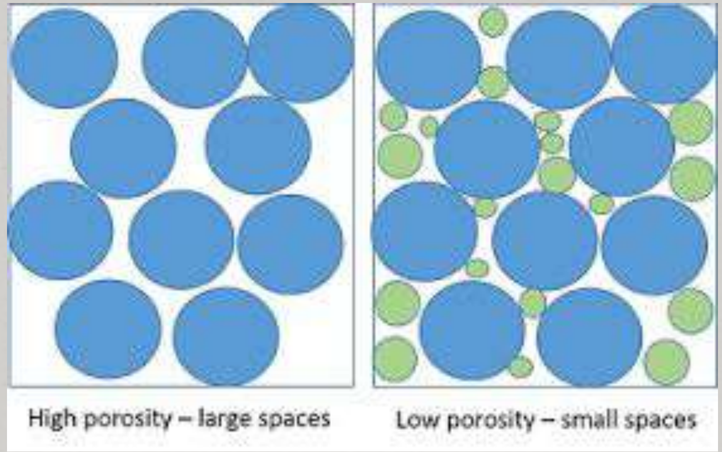


Figure 10: Porosity

Porosity values in different sediments/ rock

Rock/ Sediment	Porosity (%)
Sandstone	5-15
Shale	1-10
Limestone/ Dolomite	5-15
Sand/ Gravel	24-55
Clay	34-60
Silt	34-61

- Permeability:

The capacity of a rock to transmit a fluid. It varies with the fluid's viscosity, hydrostatic pressure, the size of openings, and particularly the degree to which the openings are interconnected. High permeability rocks are conglomerate, sandstone, basalt, limestone etc. Low permeability rocks are shale, unfractured granite, quartzite, gneiss etc.

Grain shape, grain packing, and cementation affect permeability.

- Hydraulic gradient:

Water flows from high to low fluid potential or head. Hydraulic head is used to determine the hydraulic gradient.

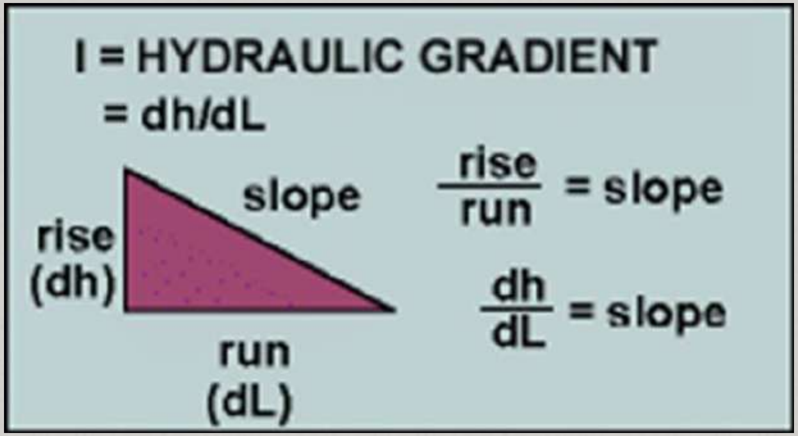
Hydraulic head = the driving force that moves groundwater. The hydraulic head combines fluid pressure and gradient.

Hydraulic gradient for an unconfined aquifer = approximately the slope of the water table.

It is also defined as head difference between the two points divided by its length.

Hydraulic gradient

(I)= h1-h2/L



- Hydraulic Conductivity

Movement of groundwater depends on rock and sediment properties and the groundwater’s flow potential. Porosity and permeability are important components of hydraulic conductivity.

HYDRAULIC CONDUCTIVITY = K (or P)

units = length/time (m/day)

Ability of a particular material to allow water to pass through it.

The definition of hydraulic conductivity (denoted "K" or "P" in hydrology formulas) is the rate at which water moves through material. Internal friction and the various paths water takes are factors affecting hydraulic conductivity. Hydraulic conductivity is generally expressed in meters per day.

WELL SORTED Coarse (sand-gravel) | **POORLY SORTED** Coarse - Fine | **WELL SORTED** Fine (silt-clay)

Permeability and Hydraulic Conductivity

High ⟷ **Low**

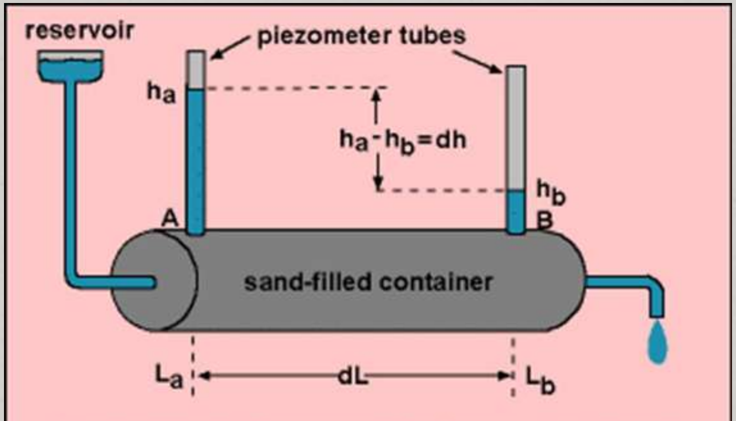
Sorting of material affects groundwater movement. Poorly sorted (well graded) material is less porous than well-sorted material.

Porosity and hydraulic conductivity of selected earth minerals (Keller, 2000)

Material	Porosity (%)	Hydraulic Conductivity (m/day)
Unconsolidated		
Clay	45	0.041
Sand	35	32.8
Gravel	25	205.0
Gravel and sand	20	82.0
Rock		
Sandstone	15	28.7
Dense limestone or shale	5	0.041
Granite	1	0.0041

Groundwater Movement -- Darcy's Law

- Q = KIA -- Henry Darcy, 1856, studied water flowing through porous material. His equation describes groundwater flow.
- Darcy's experiment:
  - Water is applied under pressure through end A, flows through the pipe, and discharges at end B.
  - Water pressure is measured using piezometer tubes.
  - Hydraulic head = dh (change in height between A and B)
  - Flow length = dL (distance between the two tubes)
  - Hydraulic gradient (I) = dh / dL



Horizontal pipe demonstrating Darcy's experiment

- The velocity of groundwater is based on hydraulic conductivity (K), as well as the hydraulic head (I).
- The equation to describe the relations between subsurface materials and the movement of water through them is

$$Q = KIA$$

Q = Discharge = volumetric flow rate, volume of water flowing through an aquifer per unit time (m3/day)

A = Area through which the groundwater is flowing, cross-sectional area of flow (aquifer width x thickness, in m2)

- Rearrange the equation to Q/A = KI, known as the flux (v), which is an apparent velocity

Aquifers

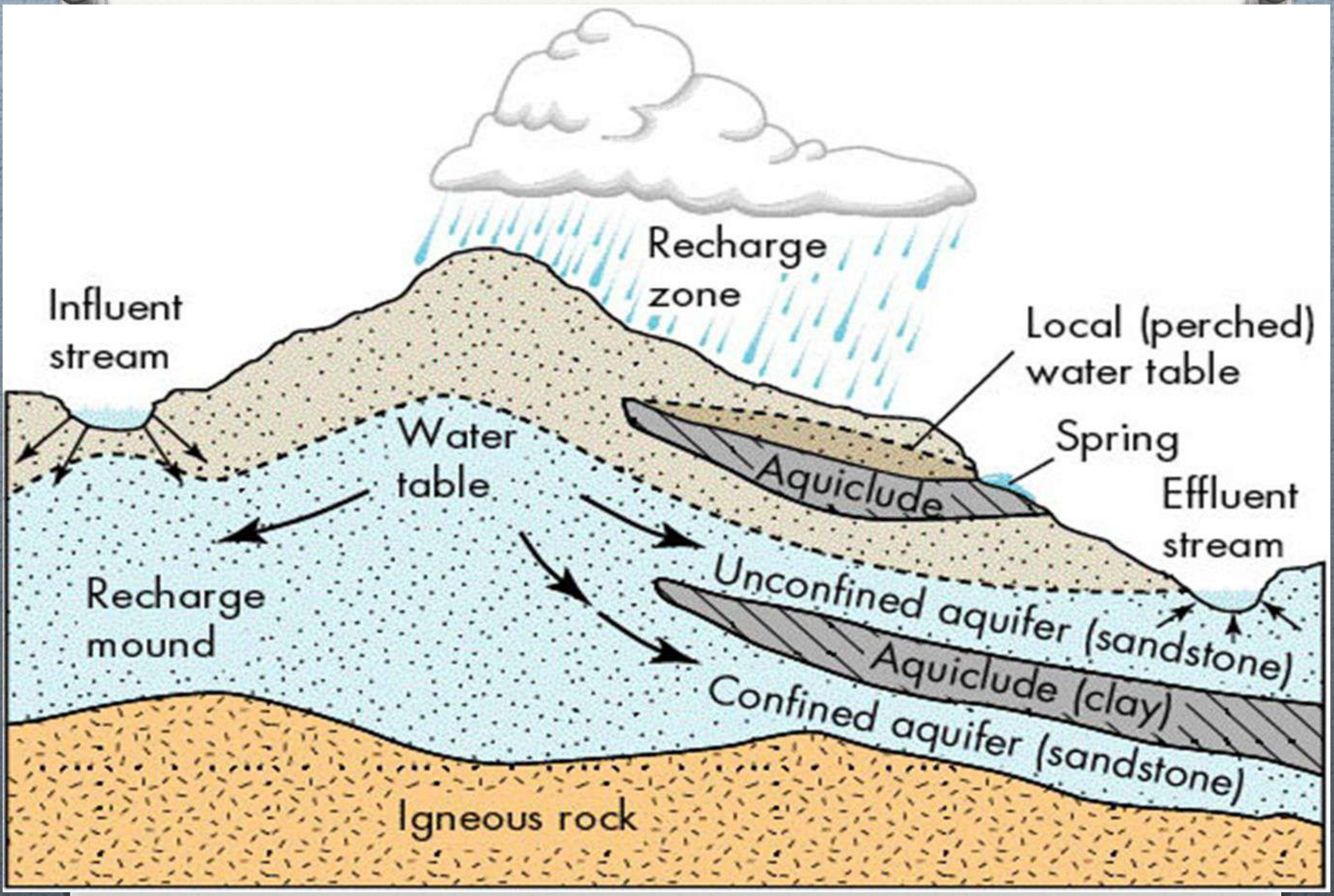
- An aquifer is a formation that allows water to be accessible at a usable rate. Aquifers are permeable layers such as sand, gravel, and fractured rock.
- Aquifers can be sand, gravel, and fractured rock. To be an aquifer, the stored water must be accessible at a usable rate.
- Synonyms: Groundwater reservoir, water bearing formation.

Types of Confining bed

- An impermeable or less permeable layer that stops or retards the movement of groundwater into and out of it is called confining bed. They are of three types:
- Aquiclude- It is an impermeable layer which doesn't transmit water at all. Although the formation is capable of absorbing water slowly. Clay soils, shales, and non-fractured, weakly porous igneous and metamorphic rocks are examples of aquiclude.
- Aquifuge- It is a geological formation that can neither absorb nor transmit water. Example: granite.
- Aquitard: It is a geological formation that is permeable enough to transmit the water in significant quantities for large area and long period. Example: sandy clay

Types of Aquifer

- Confined aquifers have non-permeable layers, above and below the aquifer zone, referred to as aquitards or aquicludes. These layers restrict water movement. Clay soils, shales, and non-fractured, weakly porous igneous and metamorphic rocks are examples of aquitards.
- Sometimes a lens of non-permeable material will be found within more permeable material. Water percolating through the unsaturated zone will be intercepted by this layer and will accumulate on top of the lens. This water is a perched aquifer.
- An unconfined aquifer has no confining layers that retard vertical water movement.



Recharge
zone
Influent
stream
Local (perched)
water table
Water
table
Spring
Aquiclude
Effluent
stream
Recharge
mound
Unconfined aquifer (sandstone)
Aquiclude (clay)
Confined aquifer (sandstone)
Igneous rock

Geological Factors for Formation of Different Hydrogeological Conditions

- Coarse sediments like sand, gravels, pebbles may store water within their pores.
- Presence of excessively jointed and fractured rocks may signify presence of water bodies.
- Porous rocks like sandstone, limestone, etc.
- Presence of geological structures like fault, fold.

Aquifer System of Nepal (Terai, Hills and Mountains)

Terai	Hills	Mountain
Loose unconsolidated sediments (Alluvial deposit comprising of coarse sediments such as sand, gravels, pebbles, cobbles and boulders.	Percolation of water in hilly areas is usually associated with highly fractured and jointed rock mass, porous rock deposits like sandstone, limestone,etc.	Aquifer fomed due to primary porosity and secondary porosity. Caves, caverns and solution channels in Limestone and dolomites.

- In the Hills and Mountains Region GW occurs in:
  – Unconsolidated sedimentary deposits deposits in.

• The Tectonic Valleys, e.g. Kathmandu, Dang, Deukhuri, Hetauda Hetauda, Udaipur Udaipur and others

• River Terraces (Tars)

- Fractured rocks in the Hills and Mountains.

• In the hill slopes, GW is stored for short time period
only. It is di h discharged it no the streams and rivers in
the forms of springs, and hot-water springs in some places.

- • In the mountain valleys,
- GW is stored for longer periods periods, and can be developed developed for beneficial beneficial uses

Assignment

- What is the significance of Darcy's law in groundwater movement?
- Differentiate between confined and unconfined aquifer.

Rock mass classification

Introduction

During the feasibility and preliminary design stages of a project, when very little detailed information is available on the rock mass and its stress and hydrologic characteristics, the use of a rock mass classification scheme can be of considerable benefit. At its simplest, this may involve using the classification scheme as a check-list to ensure that all relevant information has been considered. At the other end of the spectrum, one or more rock mass classification schemes can be used to build up a picture of the composition and characteristics of a rock mass to provide initial estimates of support requirements, and to provide estimates of the strength and deformation properties of the rock mass.

It is important to understand the limitations of rock mass classification schemes (Palmstrom and Broch, 2006) and that their use does not (and cannot) replace some of the more elaborate design procedures. However, the use of these design procedures requires access to relatively detailed information on in situ stresses, rock mass properties and planned excavation sequence, none of which may be available at an early stage in the project. As this information becomes available, the use of the rock mass classification schemes should be updated and used in conjunction with site specific analyses.

Engineering rock mass classification

Rock mass classification schemes have been developing for over 100 years since Ritter (1879) attempted to formalise an empirical approach to tunnel design, in particular for determining support requirements. While the classification schemes are appropriate for their original application, especially if used within the bounds of the case histories from which they were developed, considerable caution must be exercised in applying rock mass classifications to other rock engineering problems.

Summaries of some important classification systems are presented in this chapter, and although every attempt has been made to present all of the pertinent data from the original texts, there are numerous notes and comments which cannot be included. The interested reader should make every effort to read the cited references for a full appreciation of the use, applicability and limitations of each system.

Most of the multi-parameter classification schemes (Wickham et al (1972) Bieniawski (1973, 1989) and Barton et al (1974)) were developed from civil engineering case histories in which all of the components of the engineering geological character of the rock mass were included. In underground hard rock mining, however, especially at deep levels, rock mass weathering and the influence of water usually are not significant and may be ignored. Different classification systems place different emphases on the various parameters, and it is recommended that at least two methods be used at any site during the early stages of a project.

Terzaghi's rock mass classification

The earliest reference to the use of rock mass classification for the design of tunnel support is in a paper by Terzaghi (1946) in which the rock loads, carried by steel sets, are estimated on the basis of a descriptive classification. While no useful purpose would be served by including details of Terzaghi's classification in this discussion on the design of support, it is interesting to examine the rock mass descriptions included in his original paper, because he draws attention to those characteristics that dominate rock mass behaviour, particularly in situations where gravity constitutes the dominant driving force. The clear and concise definitions and the practical comments included in these descriptions are good examples of the type of engineering geology information, which is most useful for engineering design.

Terzaghi's descriptions (quoted directly from his paper) are:

- *Intact* rock contains neither joints nor hair cracks. Hence, if it breaks, it breaks across sound rock. On account of the injury to the rock due to blasting, spalls may drop off the roof several hours or days after blasting. This is known as a *spalling* condition. Hard, intact rock may also be encountered in the *popping* condition involving the spontaneous and violent detachment of rock slabs from the sides or roof.
- *Stratified* rock consists of individual strata with little or no resistance against separation along the boundaries between the strata. The strata may or may not be weakened by transverse joints. In such rock the spalling condition is quite common.
- *Moderately jointed* rock contains joints and hair cracks, but the blocks between joints are locally grown together or so intimately interlocked that vertical walls do not require lateral support. In rocks of this type, both spalling and popping conditions may be encountered.
- *Blocky and seamy* rock consists of chemically intact or almost intact rock fragments which are entirely separated from each other and imperfectly interlocked. In such rock, vertical walls may require lateral support.
- *Crushed* but chemically intact rock has the character of crusher run. If most or all of the fragments are as small as fine sand grains and no recementation has taken place, crushed rock below the water table exhibits the properties of a water-bearing sand.
- *Squeezing* rock slowly advances into the tunnel without perceptible volume increase. A prerequisite for squeeze is a high percentage of microscopic and sub-microscopic particles of micaceous minerals or clay minerals with a low swelling capacity.
- *Swelling* rock advances into the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks that contain clay minerals such as montmorillonite, with a high swelling capacity.

Classifications involving stand-up time

Lauffer (1958) proposed that the stand-up time for an unsupported span is related to the quality of the rock mass in which the span is excavated. In a tunnel, the unsupported span is defined as the span of the tunnel or the distance between the face and the nearest support, if this is greater than the tunnel span. Lauffer's original classification has since been modified by a number of authors, notably Pacher et al (1974), and now forms part of the general tunnelling approach known as the New Austrian Tunnelling Method.

The significance of the stand-up time concept is that an increase in the span of the tunnel leads to a significant reduction in the time available for the installation of support. For example, a small pilot tunnel may be successfully constructed with minimal support, while a larger span tunnel in the same rock mass may not be stable without the immediate installation of substantial support.

The New Austrian Tunnelling Method includes a number of techniques for safe tunnelling in rock conditions in which the stand-up time is limited before failure occurs. These techniques include the use of smaller headings and benching or the use of multiple drifts to form a reinforced ring inside which the bulk of the tunnel can be excavated. These techniques are applicable in soft rocks such as shales, phyllites and mudstones in which the squeezing and swelling problems, described by Terzaghi (see previous section), are likely to occur. The techniques are also applicable when tunnelling in excessively broken rock, but great care should be taken in attempting to apply these techniques to excavations in hard rocks in which different failure mechanisms occur.

In designing support for hard rock excavations it is prudent to assume that the stability of the rock mass surrounding the excavation is not time-dependent. Hence, if a structurally defined wedge is exposed in the roof of an excavation, it will fall as soon as the rock supporting it is removed. This can occur at the time of the blast or during the subsequent scaling operation. If it is required to keep such a wedge in place, or to enhance the margin of safety, it is essential that the support be installed as early as possible, preferably before the rock supporting the full wedge is removed. On the other hand, in a highly stressed rock, failure will generally be induced by some change in the stress field surrounding the excavation. The failure may occur gradually and manifest itself as spalling or slabbing or it may occur suddenly in the form of a rock burst. In either case, the support design must take into account the change in the stress field rather than the ‘stand-up’ time of the excavation.

Rock quality designation index (RQD)

The Rock Quality Designation index (*RQD*) was developed by Deere (Deere et al 1967) to provide a quantitative estimate of rock mass quality from drill core logs. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core. The core should be at least NW size (54.7 mm or 2.15 inches in diameter) and should be drilled with a double-tube core barrel. The correct procedures for measurement of the length of core pieces and the calculation of *RQD* are summarised in Figure 1.

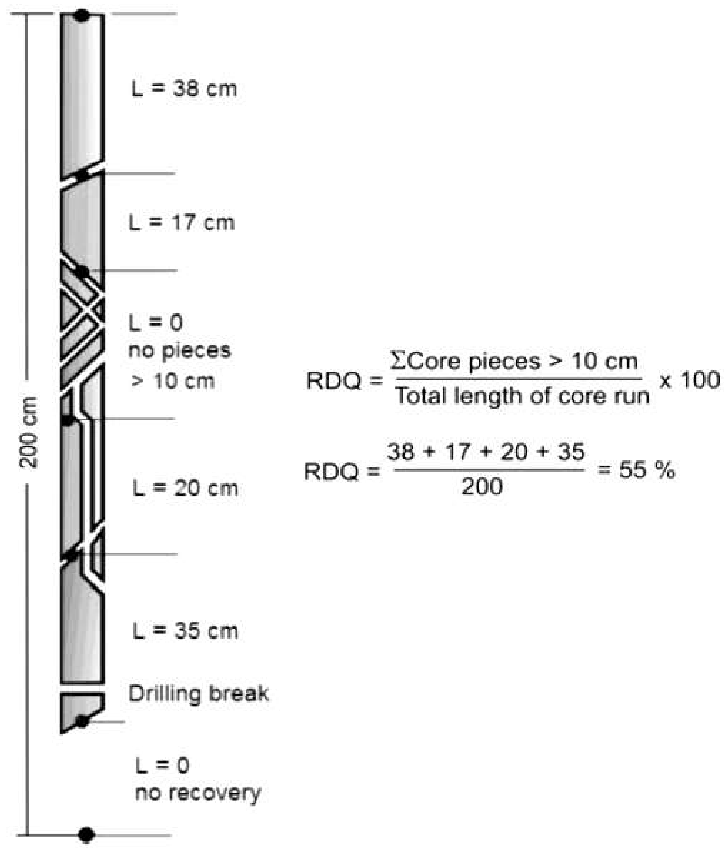


Figure 1: Procedure for measurement and calculation of *RQD* (After Deere, 1989).

Palmström (1982) suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the *RQD* may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is:

$$RQD = 115 - 3.3\, J_v \qquad (1)$$

where J_v is the sum of the number of joints per unit length for all joint (discontinuity) sets known as the volumetric joint count.

RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation. The use of the volumetric joint count can be quite useful in reducing this directional dependence.

RQD is intended to represent the rock mass quality in situ. When using diamond drill core, care must be taken to ensure that fractures, which have been caused by handling or the drilling process, are identified and ignored when determining the value of *RQD*.

When using Palmström's relationship for exposure mapping, blast induced fractures should not be included when estimating J_v.

Deere's *RQD* was widely used, particularly in North America, after its introduction. Cording and Deere (1972), Merritt (1972) and Deere and Deere (1988) attempted to relate *RQD* to Terzaghi's rock load factors and to rockbolt requirements in tunnels. In the context of this discussion, the most important use of *RQD* is as a component of the *RMR* and *Q* rock mass classifications covered later in this chapter.

Rock Structure Rating (RSR)

Wickham et al (1972) described a quantitative method for describing the quality of a rock mass and for selecting appropriate support on the basis of their Rock Structure Rating (*RSR*) classification. Most of the case histories, used in the development of this system, were for relatively small tunnels supported by means of steel sets, although historically this system was the first to make reference to shotcrete support. In spite of this limitation, it is worth examining the *RSR* system in some detail since it demonstrates the logic involved in developing a quasi-quantitative rock mass classification system.

The significance of the *RSR* system, in the context of this discussion, is that it introduced the concept of rating each of the components listed below to arrive at a numerical value of $RSR = A + B + C$.

1. *Parameter A, Geology:* General appraisal of geological structure on the basis of:
    a. Rock type origin (igneous, metamorphic, sedimentary).
    b. Rock hardness (hard, medium, soft, decomposed).
    c. Geologic structure (massive, slightly faulted/folded, moderately faulted/folded, intensely faulted/folded).
2. *Parameter B, Geometry*: Effect of discontinuity pattern with respect to the direction of the tunnel drive on the basis of:
    a. Joint spacing.
    b. Joint orientation (strike and dip).
    c. Direction of tunnel drive.
3. *Parameter C*: Effect of groundwater inflow and joint condition on the basis of:
    a. Overall rock mass quality on the basis of A and B combined.
    b. Joint condition (good, fair, poor).
    c. Amount of water inflow (in gallons per minute per 1000 feet of tunnel).

Note that the *RSR* classification used Imperial units and that these units have been retained in this discussion.

Three tables from Wickham et al's 1972 paper are reproduced in Tables 1, 2 and 3. These tables can be used to evaluate the rating of each of these parameters to arrive at the *RSR* value (maximum *RSR* = 100).

Table 1: Rock Structure Rating: Parameter A: General area geology

	Basic Rock Type				Geological Structure			
	Hard	Medium	Soft	Decomposed	Massive	Slightly Folded or Faulted	Moderately Folded or Faulted	Intensively Folded or Faulted
Igneous	1	2	3	4				
Metamorphic	1	2	3	4				
Sedimentary	2	3	4	4				
Type 1					30	22	15	9
Type 2					27	20	13	8
Type 3					24	18	12	7
Type 4					19	15	10	6

Table 2: Rock Structure Rating: Parameter *B*: Joint pattern, direction of drive

	Strike ⊥ to Axis					Strike || to Axis		
	Direction of Drive					Direction of Drive		
	Both	With Dip		Against Dip		Either direction		
	Dip of Prominent Joints [a]					Dip of Prominent Joints		
Average joint spacing	Flat	Dipping	Vertical	Dipping	Vertical	Flat	Dipping	Vertical
1. Very closely jointed, < 2 in	9	11	13	10	12	9	9	7
2. Closely jointed, 2-6 in	13	16	19	15	17	14	14	11
3. Moderately jointed, 6-12 in	23	24	28	19	22	23	23	19
4. Moderate to blocky, 1-2 ft	30	32	36	25	28	30	28	24
5. Blocky to massive, 2-4 ft	36	38	40	33	35	36	24	28
6. Massive, > 4 ft	40	43	45	37	40	40	38	34

Table 3: Rock Structure Rating: Parameter *C*: Groundwater, joint condition

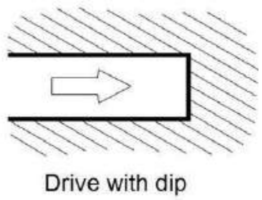
	Sum of Parameters $A + B$					
	13 - 44			45 - 75		
Anticipated water inflow gpm/1000 ft of tunnel	Joint Condition [b]					
	Good	Fair	Poor	Good	Fair	Poor
None	22	18	12	25	22	18
Slight, < 200 gpm	19	15	9	23	19	14
Moderate, 200-1000 gpm	15	22	7	21	16	12
Heavy, > 1000 gp	10	8	6	18	14	10

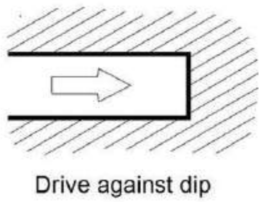
[a] Dip: flat: 0-20°; dipping: 20-50°; and vertical: 50-90°

[b] Joint condition: good = tight or cemented; fair = slightly weathered or altered; poor = severely weathered, altered or open

For example, a hard metamorphic rock which is slightly folded or faulted has a rating of *A* = 22 (from Table 1). The rock mass is moderately jointed, with joints striking perpendicular to the tunnel axis which is being driven east-west, and dipping at between 20° and 50°.

Table 2 gives the rating for *B* = 24 for driving with dip (defined below).





The value of *A* + *B* = 46 and this means that, for joints of fair condition (slightly weathered and altered) and a moderate water inflow of between 200 and 1,000 gallons per minute, Table 3 gives the rating for *C* = 16. Hence, the final value of the rock structure rating *RSR* = *A* + *B* + *C* = 62.

A typical set of prediction curves for a 24 foot diameter tunnel are given in Figure 2 which shows that, for the *RSR* value of 62 derived above, the predicted support would be 2 inches of shotcrete and 1 inch diameter rockbolts spaced at 5 foot centres. As indicated in the figure, steel sets would be spaced at more than 7 feet apart and would not be considered a practical solution for the support of this tunnel.

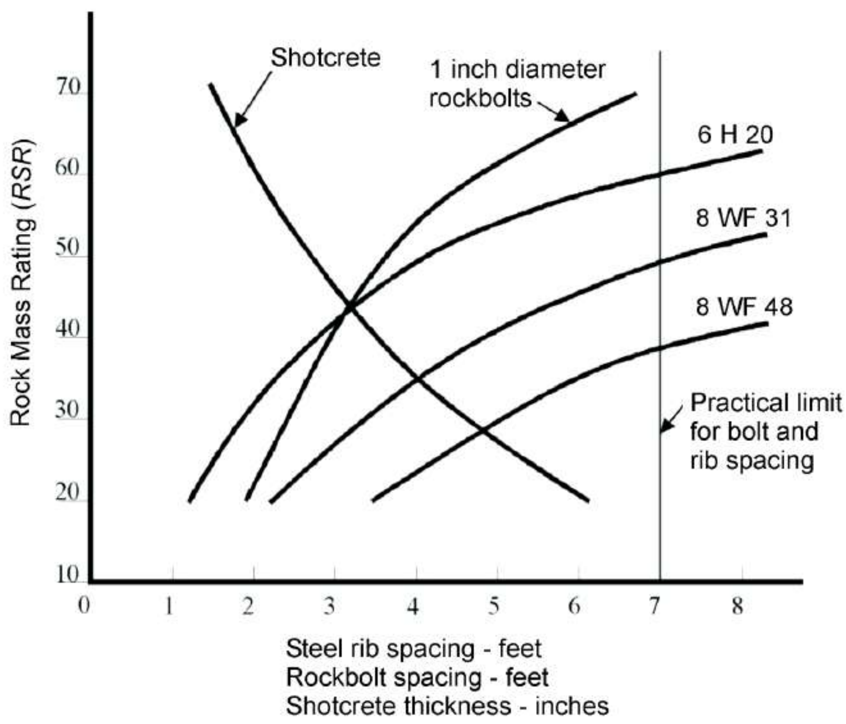


Figure 2: *RSR* support estimates for a 24 ft. (7.3 m) diameter circular tunnel. Note that rockbolts and shotcrete are generally used together. (After Wickham et al 1972).

For the same size tunnel in a rock mass with *RSR* = 30, the support could be provided by 8 WF 31 steel sets (8 inch deep wide flange I section weighing 31 lb per foot) spaced 3 feet apart, or by 5 inches of shotcrete and 1 inch diameter rockbolts spaced at 2.5 feet centres. In this case it is probable that the steel set solution would be cheaper and more effective than the use of rockbolts and shotcrete.

Although the *RSR* classification system is not widely used today, Wickham et al's work played a significant role in the development of the classification schemes discussed in the remaining sections of this chapter.

Geomechanics Classification

Bieniawski (1976) published the details of a rock mass classification called the Geomechanics Classification or the Rock Mass Rating (*RMR*) system. Over the years, this system has been successively refined as more case records have been examined and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. The discussion which follows is based upon the 1989 version of the classification (Bieniawski, 1989). Both this version and the 1976 version deal with estimating the strength of rock masses. The following six parameters are used to classify a rock mass using the *RMR* system:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (*RQD*).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities.

In applying this classification system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions.

The Rock Mass Rating system is presented in Table 4, giving the ratings for each of the six parameters listed above. These ratings are summed to give a value of *RMR*. The following example illustrates the use of these tables to arrive at an *RMR* value.

A tunnel is to be driven through slightly weathered granite with a dominant joint set dipping at 60^{o} against the direction of the drive. Index testing and logging of diamond drilled core give typical Point-load strength index values of 8 MPa and average *RQD* values of 70%. The slightly rough and slightly weathered joints with a separation of < 1 mm, are spaced at 300 mm. Tunnelling conditions are anticipated to be wet.

Table 4: Rock Mass Rating System (After Bieniawski 1989).

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.

** Modified after Wickham et al (1972).

The *RMR* value for the example under consideration is determined as follows:

Table	*Item*	*Value*	*Rating*
4: A.1	Point load index	8 MPa	12
4: A.2	*RQD*	70%	13
4: A.3	Spacing of discontinuities	300 mm	10
4: E.4	Condition of discontinuities	Note 1	22
4: A.5	Groundwater	Wet	7
4: B	Adjustment for joint orientation	Note 2	-5
		Total	59

Note 1. For slightly rough and altered discontinuity surfaces with a separation of < 1 mm, Table 4.A.4 gives a rating of 25. When more detailed information is available, Table 4.E can be used to obtain a more refined rating. Hence, in this case, the rating is the sum of: 4 (1-3 m discontinuity length), 4 (separation 0.1-1.0 mm), 3 (slightly rough), 6 (no infilling) and 5 (slightly weathered) = 22.

Note 2. Table 4.F gives a description of 'Fair' for the conditions assumed where the tunnel is to be driven against the dip of a set of joints dipping at 60^{o}. Using this description for 'Tunnels and Mines' in Table 4.B gives an adjustment rating of -5.

Bieniawski (1989) published a set of guidelines for the selection of support in tunnels in rock for which the value of *RMR* has been determined. These guidelines are reproduced in Table 4. Note that these guidelines have been published for a 10 m span horseshoe shaped tunnel, constructed using drill and blast methods, in a rock mass subjected to a vertical stress < 25 MPa (equivalent to a depth below surface of <900 m).

For the case considered earlier, with *RMR* = 59, Table 4 suggests that a tunnel could be excavated by top heading and bench, with a 1.5 to 3 m advance in the top heading. Support should be installed after each blast and the support should be placed at a maximum distance of 10 m from the face. Systematic rock bolting, using 4 m long 20 mm diameter fully grouted bolts spaced at 1.5 to 2 m in the crown and walls, is recommended. Wire mesh, with 50 to 100 mm of shotcrete for the crown and 30 mm of shotcrete for the walls, is recommended.

The value of *RMR* of 59 indicates that the rock mass is on the boundary between the 'Fair rock' and 'Good rock' categories. In the initial stages of design and construction, it is advisable to utilise the support suggested for fair rock. If the construction is progressing well with no stability problems, and the support is performing very well, then it should be possible to gradually reduce the support requirements to those indicated for a good rock mass. In addition, if the excavation is required to be stable for a short amount of time, then it is advisable to try the less expensive and extensive support suggested for good rock. However, if the rock mass surrounding the excavation is expected to undergo large mining induced stress changes, then more substantial support appropriate for fair rock should be installed. This example indicates that a great deal of judgement is needed in the application of rock mass classification to support design.

Table 5: Guidelines for excavation and support of 10 m span rock tunnels in accordance with the *RMR* system (After Bieniawski 1989).

Rock mass class	Excavation	Rock bolts (20 mm diameter, fully grouted)	Shotcrete	Steel sets
I - Very good rock *RMR*: 81-100	Full face, 3 m advance.	Generally no support required except spot bolting.		
II - Good rock *RMR*: 61-80	Full face , 1-1.5 m advance. Complete support 20 m from face.	Locally, bolts in crown 3 m long, spaced 2.5 m with occasional wire mesh.	50 mm in crown where required.	None.
III - Fair rock *RMR*: 41-60	Top heading and bench 1.5-3 m advance in top heading. Commence support after each blast. Complete support 10 m from face.	Systematic bolts 4 m long, spaced 1.5 - 2 m in crown and walls with wire mesh in crown.	50-100 mm in crown and 30 mm in sides.	None.
IV - Poor rock *RMR*: 21-40	Top heading and bench 1.0-1.5 m advance in top heading. Install support concurrently with excavation, 10 m from face.	Systematic bolts 4-5 m long, spaced 1-1.5 m in crown and walls with wire mesh.	100-150 mm in crown and 100 mm in sides.	Light to medium ribs spaced 1.5 m where required.
V – Very poor rock *RMR*: < 20	Multiple drifts 0.5-1.5 m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting.	Systematic bolts 5-6 m long, spaced 1-1.5 m in crown and walls with wire mesh. Bolt invert.	150-200 mm in crown, 150 mm in sides, and 50 mm on face.	Medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if required. Close invert.

It should be noted that Table 5 has not had a major revision since 1973. In many mining and civil engineering applications, steel fibre reinforced shotcrete may be considered in place of wire mesh and shotcrete.

Modifications to *RMR* for mining

Bieniawski's Rock Mass Rating (*RMR*) system was originally based upon case histories drawn from civil engineering. Consequently, the mining industry tended to regard the classification as somewhat conservative and several modifications have been proposed in order to make the classification more relevant to mining applications. A comprehensive summary of these modifications was compiled by Bieniawski (1989).

Laubscher (1977, 1984), Laubscher and Taylor (1976) and Laubscher and Page (1990) have described a Modified Rock Mass Rating system for mining. This MRMR system takes the basic *RMR* value, as defined by Bieniawski, and adjusts it to account for in situ and induced stresses, stress changes and the effects of blasting and weathering. A set of support recommendations is associated with the resulting *MRMR* value. In using Laubscher's *MRMR* system it should be borne in mind that many of the case histories upon which it is based are derived from caving operations. Originally, block caving in asbestos mines in Africa formed the basis for the modifications but, subsequently, other case histories from around the world have been added to the database.

Cummings et al (1982) and Kendorski et al (1983) have also modified Bieniawski's RMR classification to produce the *MBR* (modified basic *RMR*) system for mining. This system was developed for block caving operations in the USA. It involves the use of different ratings for the original parameters used to determine the value of *RMR* and the subsequent adjustment of the resulting *MBR* value to allow for blast damage, induced stresses, structural features, distance from the cave front and size of the caving block. Support recommendations are presented for isolated or development drifts as well as for the final support of intersections and drifts.

Rock Tunnelling Quality Index, *Q*

On the basis of an evaluation of a large number of case histories of underground excavations, Barton et al (1974) of the Norwegian Geotechnical Institute proposed a Tunnelling Quality Index (Q) for the determination of rock mass characteristics and tunnel support requirements. The numerical value of the index Q varies on a logarithmic scale from 0.001 to a maximum of 1,000 and is defined by:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \tag{2}$$

where *RQD* is the Rock Quality Designation
J_n is the joint set number
J_r is the joint roughness number
J_a is the joint alteration number
J_w is the joint water reduction factor
SRF is the stress reduction factor

In explaining the meaning of the parameters used to determine the value of Q, Barton et al (1974) offer the following comments:

> *The first quotient* (RQD/J_n), representing the structure of the rock mass, is a crude measure of the block or particle size, with the two extreme values (100/0.5 and 10/20) differing by a factor of 400. If the quotient is interpreted in units of centimetres, the extreme 'particle sizes' of 200 to 0.5 cm are seen to be crude but fairly realistic approximations. Probably the largest blocks should be several times this size and the smallest fragments less than half the size. (Clay particles are of course excluded).
>
> The second quotient (J_r/J_a) represents the roughness and frictional characteristics of the joint walls or filling materials. This quotient is weighted in favour of rough, unaltered joints in direct contact. It is to be expected that such surfaces will be close to peak strength, that they will dilate strongly when sheared, and they will therefore be especially favourable to tunnel stability.
>
> When rock joints have thin clay mineral coatings and fillings, the strength is reduced significantly. Nevertheless, rock wall contact after small shear displacements have occurred may be a very important factor for preserving the excavation from ultimate failure.

Where no rock wall contact exists, the conditions are extremely unfavourable to tunnel stability. The 'friction angles' (given in Table 6) are a little below the residual strength values for most clays, and are possibly down-graded by the fact that these clay bands or fillings may tend to consolidate during shear, at least if normal consolidation or if softening and swelling has occurred. The swelling pressure of montmorillonite may also be a factor here.

The third quotient (J_w/SRF) consists of two stress parameters. *SRF* is a measure of: 1) loosening load in the case of an excavation through shear zones and clay bearing rock, 2) rock stress in competent rock, and 3) squeezing loads in plastic incompetent rocks. It can be regarded as a total stress parameter. The parameter J_w is a measure of water pressure, which has an adverse effect on the shear strength of joints due to a reduction in effective normal stress. Water may, in addition, cause softening and possible out-wash in the case of clay-filled joints. It has proved impossible to combine these two parameters in terms of inter-block effective stress, because paradoxically a high value of effective normal stress may sometimes signify less stable conditions than a low value, despite the higher shear strength. The quotient (J_w/SRF) is a complicated empirical factor describing the 'active stress'.

It appears that the rock tunnelling quality *Q* can now be considered to be a function of only three parameters which are crude measures of:

1. Block size	(*RQD/Jn*)
2. Inter-block shear strength	(*Jr/ Ja*)
3. Active stress	(*Jw/SRF*)

Undoubtedly, there are several other parameters which could be added to improve the accuracy of the classification system. One of these would be the joint orientation. Although many case records include the necessary information on structural orientation in relation to excavation axis, it was not found to be the important general parameter that might be expected. Part of the reason for this may be that the orientations of many types of excavations can be, and normally are, adjusted to avoid the maximum effect of unfavourably oriented major joints. However, this choice is not available in the case of tunnels, and more than half the case records were in this category. The parameters *Jn*, *Jr* and *Ja* appear to play a more important role than orientation, because the number of joint sets determines the degree of freedom for block movement (if any), and the frictional and dilational characteristics can vary more than the down-dip gravitational component of unfavourably oriented joints. If joint orientations had been included the classification would have been less general, and its essential simplicity lost.

Table 6 (After Barton et al 1974) gives the classification of individual parameters used to obtain the Tunnelling Quality Index *Q* for a rock mass.

The use of Table 6 is illustrated in the following example. A 15 m span crusher chamber for an underground mine is to be excavated in a norite at a depth of 2,100 m below surface. The rock mass contains two sets of joints controlling stability. These joints are undulating, rough and unweathered with very minor surface staining. *RQD* values range from 85% to

95% and laboratory tests on core samples of intact rock give an average uniaxial compressive strength of 170 MPa. The principal stress directions are approximately vertical and horizontal and the magnitude of the horizontal principal stress is approximately 1.5 times that of the vertical principal stress. The rock mass is locally damp but there is no evidence of flowing water.

The numerical value of *RQD* is used directly in the calculation of *Q* and, for this rock mass, an average value of 90 will be used. Table 6.2 shows that, for two joint sets, the joint set number, $Jn = 4$. For rough or irregular joints which are undulating, Table 6.3 gives a joint roughness number of $Jr = 3$. Table 6.4 gives the joint alteration number, $Ja = 1.0$, for unaltered joint walls with surface staining only. Table 6.5 shows that, for an excavation with minor inflow, the joint water reduction factor, $Jw = 1.0$. For a depth below surface of 2,100 m the overburden stress will be approximately 57 MPa and, in this case, the major principal stress $\sigma_1 = 85$ MPa. Since the uniaxial compressive strength of the norite is approximately 170 MPa, this gives a ratio of $\sigma_c/\sigma_1 = 2$. Table 6.6 shows that, for competent rock with rock stress problems, this value of σ_c/σ_1 can be expected to produce heavy rock burst conditions and that the value of *SRF* should lie between 10 and 20. A value of $SRF = 15$ will be assumed for this calculation. Using these values gives:

In relating the value of the index *Q* to the stability and support requirements of underground excavations, Barton et al (1974) defined an additional parameter which they called the Equivalent Dimension, *De*, of the excavation. This dimension is obtained by dividing the span, diameter or wall height of the excavation by a quantity called the Excavation Support Ratio, *ESR*. Hence:

The value of *ESR* is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. Barton et al (1974) suggest the following values:

Excavation category		*ESR*
A	Temporary mine openings.	3-5
B	Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drifts and headings for large excavations.	1.6
C	Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels.	1.3
D	Power stations, major road and railway tunnels, civil defence chambers, portal intersections.	1.0
E	Underground nuclear power stations, railway stations, sports and public facilities, factories.	0.8

Table 6: Classification of individual parameters used in the Tunnelling Quality Index *Q*

DESCRIPTION	VALUE	NOTES	
1. ROCK QUALITY DESIGNATION	***RQD***		
A. Very poor	0 - 25	1. Where *RQD* is reported or measured as ≤ 10 (including 0),	
B. Poor	25 - 50	a nominal value of 10 is used to evaluate *Q*.	
C. Fair	50 - 75		
D. Good	75 - 90	2. *RQD* intervals of 5, i.e. 100, 95, 90 etc. are sufficiently	
E. Excellent	90 - 100	accurate.	
2. JOINT SET NUMBER	J_n		
A. Massive, no or few joints	0.5 - 1.0		
B. One joint set	2		
C. One joint set plus random	3		
D. Two joint sets	4		
E. Two joint sets plus random	6		
F. Three joint sets	9	1. For intersections use ($3.0 \times J_n$)	
G. Three joint sets plus random	12		
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15	2. For portals use ($2.0 \times J_n$)	
J. Crushed rock, earthlike	20		
3. JOINT ROUGHNESS NUMBER	J_r		
a. Rock wall contact			
b. Rock wall contact before 10 cm shear			
A. Discontinuous joints	4		
B. Rough and irregular, undulating	3		
C. Smooth undulating	2		
D. Slickensided undulating	1.5	1. Add 1.0 if the mean spacing of the relevant joint set is	
E. Rough or irregular, planar	1.5	greater than 3 m.	
F. Smooth, planar	1.0		
G. Slickensided, planar	0.5	2. J_r = 0.5 can be used for planar, slickensided joints having	
c. No rock wall contact when sheared		lineations, provided that the lineations are oriented for	
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)	minimum strength.	
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)		
4. JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
a. Rock wall contact			
A. Tightly healed, hard, non-softening, impermeable filling	0.75		1. Values of ϕr, the residual friction angle, are intended as an approximate guide
B. Unaltered joint walls, surface staining only	1.0	25 - 35	to the mineralogical properties of the
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0	25 - 30	alteration products, if present.
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0	20 - 25	
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0	8 - 16	

Table 6: (cont'd.) Classification of individual parameters used in the Tunnelling Quality Index *Q* (After Barton et al 1974).

4, JOINT ALTERATION NUMBER	J_a	ϕr degrees (approx.)	
b. Rock wall contact before 10 cm shear			
F. Sandy particles, clay-free, disintegrating rock etc.	4.0	25 - 30	
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0	16 - 24	
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0	12 - 16	
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0	6 - 12	
c. No rock wall contact when sheared			
K. Zones or bands of disintegrated or crushed	6.0		
L. rock and clay (see G, H and J for clay	8.0		
M. conditions)	8.0 - 12.0	6 - 24	
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0		
O. Thick continuous zones or bands of clay	10.0 - 13.0		
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0		
5. JOINT WATER REDUCTION	J_w	approx. water pressure (kgf/cm^2)	
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0	< 1.0	
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66	1.0 - 2.5	
C. Large inflow or high pressure in competent rock with unfilled joints	0.5	2.5 - 10.0	1. Factors C to F are crude estimates; increase J_w if drainage installed.
D. Large inflow or high pressure	0.33	2.5 - 10.0	
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1	> 10	2. Special problems caused by ice formation are not considered.
F. Exceptionally high inflow or pressure	0.1 - 0.05	> 10	
6. STRESS REDUCTION FACTOR		***SRF***	
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)		10.0	1. Reduce these values of *SRF* by 25 - 50% but only if the relevant shear zones influence do not intersect the excavation
B. Single weakness zones containing clay, or chemically dis- tegrated rock (excavation depth < 50 m)		5.0	
C. Single weakness zones containing clay, or chemically dis- tegrated rock (excavation depth > 50 m)		2.5	
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)		7.5	
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)		5.0	
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)		2.5	
G. Loose open joints, heavily jointed or 'sugar cube', (any depth)		5.0	

Table 6: (cont'd.) Classification of individual parameters in the Tunnelling Quality Index Q (After Barton et al 1974).

DESCRIPTION	VALUE			NOTES
6. STRESS REDUCTION FACTOR			***SRF***	
b. Competent rock, rock stress problems				
	σ_c/σ_1	$\sigma_t\sigma_1$		2. For strongly anisotropic virgin stress field (if measured): when $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to $0.8\sigma_c$ and σ_t to $0.8\sigma_t$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to $0.6\sigma_c$ and $0.6\sigma_t$, where σ_c = unconfined compressive strength, and σ_t = tensile strength (point load) and σ_1 and σ_3 are the major and minor principal stresses.
H. Low stress, near surface	> 200	> 13	2.5	
J. Medium stress	200 - 10	13 - 0.66	1.0	
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2	
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10	
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20	3. Few case records available where depth of crown below surface is less than span width. Suggest *SRF* increase from 2.5 to 5 for such cases (see H).
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure				
N. Mild squeezing rock pressure			5 - 10	
O. Heavy squeezing rock pressure			10 - 20	
d. Swelling rock, chemical swelling activity depending on presence of water				
P. Mild swelling rock pressure			5 - 10	
R. Heavy swelling rock pressure			10 - 15	

ADDITIONAL NOTES ON THE USE OF THESE TABLES

When making estimates of the rock mass Quality (Q), the following guidelines should be followed in addition to the notes listed in the tables:

1. When borehole core is unavailable, *RQD* can be estimated from the number of joints per unit volume, in which the number of joints per metre for each joint set are added. A simple relationship can be used to convert this number to *RQD* for the case of clay free rock masses: $RQD = 115 - 3.3\, J_v$ (approx.), where J_v = total number of joints per m^3 ($0 < RQD < 100$ for $35 > J_v > 4.5$).
2. The parameter J_n representing the number of joint sets will often be affected by foliation, schistosity, slaty cleavage or bedding etc. If strongly developed, these parallel 'joints' should obviously be counted as a complete joint set. However, if there are few 'joints' visible, or if only occasional breaks in the core are due to these features, then it will be more appropriate to count them as 'random' joints when evaluating J_n.
3. The parameters J_r and J_a (representing shear strength) should be relevant to the weakest significant joint set or clay filled discontinuity in the given zone. However, if the joint set or discontinuity with the minimum value of J_r/J_a is favourably oriented for stability, then a second, less favourably oriented joint set or discontinuity may sometimes be more significant, and its higher value of J_r/J_a should be used when evaluating Q. The value of J_r/J_a should in fact relate to the surface most likely to allow failure to initiate.
4. When a rock mass contains clay, the factor *SRF* appropriate to loosening loads should be evaluated. In such cases the strength of the intact rock is of little interest. However, when jointing is minimal and clay is completely absent, the strength of the intact rock may become the weakest link, and the stability will then depend on the ratio rock-stress/rock-strength. A strongly anisotropic stress field is unfavourable for stability and is roughly accounted for as in note 2 in the table for stress reduction factor evaluation.
5. The compressive and tensile strengths (σ_c and σ_t) of the intact rock should be evaluated in the saturated condition if this is appropriate to the present and future in situ conditions. A very conservative estimate of the strength should be made for those rocks that deteriorate when exposed to moist or saturated conditions.

The crusher station discussed earlier falls into the category of permanent mine openings and is assigned an excavation support ratio *ESR* = 1.6. Hence, for an excavation span of 15 m, the equivalent dimension, *De* = 15/1.6 = 9.4.

The equivalent dimension, *De*, plotted against the value of *Q*, is used to define a number of support categories in a chart published in the original paper by Barton et al (1974). This chart has recently been updated by Grimstad and Barton (1993) to reflect the increasing use of steel fibre reinforced shotcrete in underground excavation support. Figure 3 is reproduced from this updated chart.

From Figure 3, a value of *De* of 9.4 and a value of *Q* of 4.5 places this crusher excavation in category (4) which requires a pattern of rockbolts (spaced at 2.3 m) and 40 to 50 mm of unreinforced shotcrete.

Because of the mild to heavy rock burst conditions which are anticipated, it may be prudent to destress the rock in the walls of this crusher chamber. This is achieved by using relatively heavy production blasting to excavate the chamber and omitting the smooth blasting usually used to trim the final walls of an excavation such as an underground powerhouse at shallower depth. Caution is recommended in the use of destress blasting and, for critical applications, it may be advisable to seek the advice of a blasting specialist before embarking on this course of action.

Løset (1992) suggests that, for rocks with $4 < Q < 30$, blasting damage will result in the creation of new 'joints' with a consequent local reduction in the value of *Q* for the rock surrounding the excavation. He suggests that this can be accounted for by reducing the *RQD* value for the blast damaged zone.

Assuming that the *RQD* value for the destressed rock around the crusher chamber drops to 50 %, the resulting value of *Q* = 2.9. From Figure 3, this value of *Q*, for an equivalent dimension, *De* of 9.4, places the excavation just inside category (5) which requires rockbolts, at approximately 2 m spacing, and a 50 mm thick layer of steel fibre reinforced shotcrete.

Barton et al (1980) provide additional information on rockbolt length, maximum unsupported spans and roof support pressures to supplement the support recommendations published in the original 1974 paper.

The length L of rockbolts can be estimated from the excavation width B and the Excavation Support Ratio ESR:

$$L = 2 + \frac{0.15B}{ESR} \tag{3}$$

The maximum unsupported span can be estimated from:

$$\textit{Maximum span (unsupported)} = 2\,ESR\;Q^{0.4} \tag{4}$$

Based upon analyses of case records, Grimstad and Barton (1993) suggest that the relationship between the value of Q and the permanent roof support pressure P_{roof} is estimated from:

$$P_{roof} = \frac{2\sqrt{Jn}\, Q^{-\frac{1}{3}}}{3Jr} \tag{5}$$

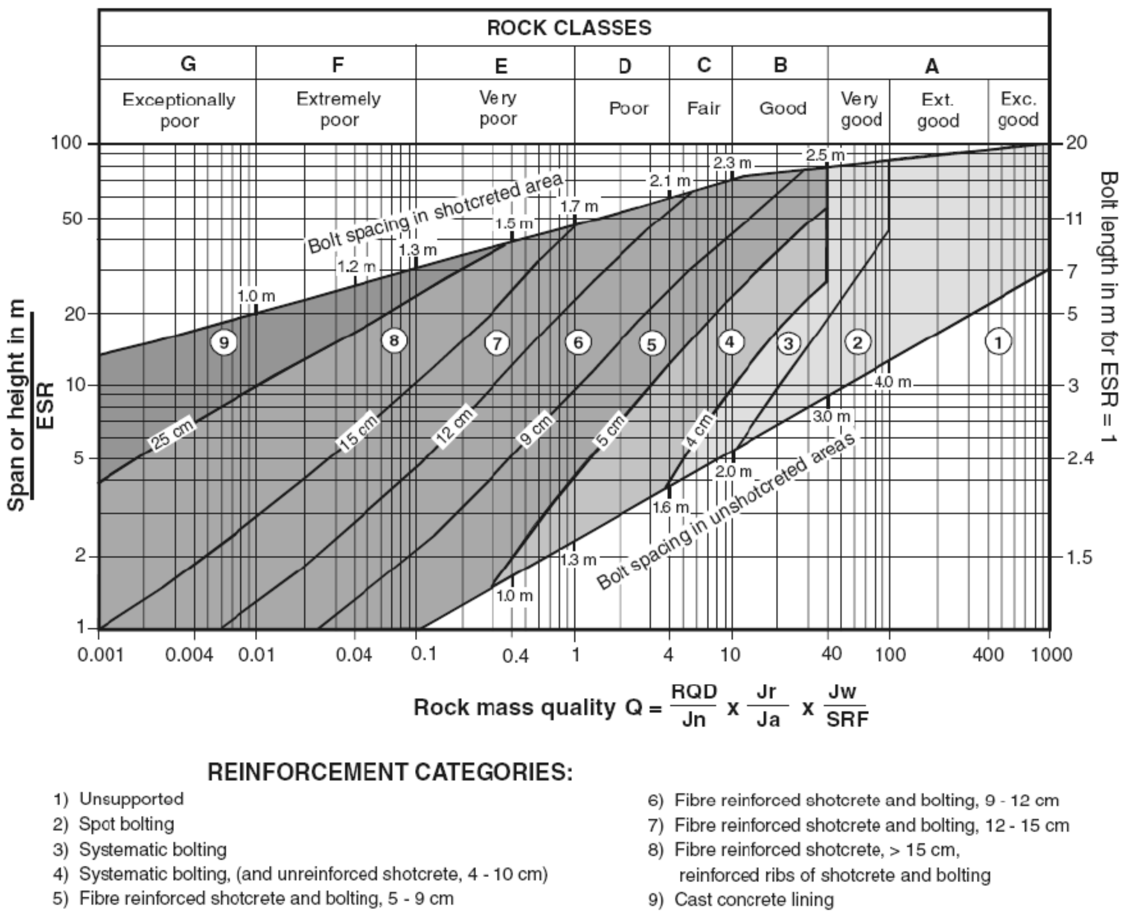


Figure 3: Estimated support categories based on the tunnelling quality index Q (After Grimstad and Barton, 1993, reproduced from Palmstrom and Broch, 2006).

Using rock mass classification systems

The two most widely used rock mass classifications are Bieniawski's *RMR* (1976, 1989) and Barton et al's *Q* (1974). Both methods incorporate geological, geometric and design/engineering parameters in arriving at a quantitative value of their rock mass quality. The similarities between *RMR* and *Q* stem from the use of identical, or very similar, parameters in calculating the final rock mass quality rating. The differences between the systems lie in the different weightings given to similar parameters and in the use of distinct parameters in one or the other scheme.

RMR uses compressive strength directly while *Q* only considers strength as it relates to in situ stress in competent rock. Both schemes deal with the geology and geometry of the rock mass, but in slightly different ways. Both consider groundwater, and both include some component of rock material strength. Some estimate of orientation can be incorporated into *Q* using a guideline presented by Barton et al (1974): 'the parameters *Jr* and *Ja* should ... relate to the surface most likely to allow failure to initiate.' The greatest difference between the two systems is the lack of a stress parameter in the *RMR* system.

When using either of these methods, two approaches can be taken. One is to evaluate the rock mass specifically for the parameters included in the classification methods; the other is to accurately characterise the rock mass and then attribute parameter ratings at a later time. The latter method is recommended since it gives a full and complete description of the rock mass which can easily be translated into either classification index. If rating values alone had been recorded during mapping, it would be almost impossible to carry out verification studies.

In many cases, it is appropriate to give a range of values to each parameter in a rock mass classification and to evaluate the significance of the final result. An example of this approach is given in Figure 4 which is reproduced from field notes prepared by Dr. N. Barton on a project. In this particular case, the rock mass is dry and is subjected to 'medium' stress conditions (Table 6.6.K) and hence *Jw* = 1.0 and SRF = 1.0. Histograms showing the variations in *RQD*, *Jn*, *Jr* and *Ja*, along the exploration adit mapped, are presented in this figure. The average value of $Q = 8.9$ and the approximate range of *Q* is $1.7 < Q < 20$. The average value of *Q* can be used in choosing a basic support system while the range gives an indication of the possible adjustments which will be required to meet different conditions encountered during construction.

A further example of this approach is given in a paper by Barton et al (1992) concerned with the design of a 62 m span underground sports hall in jointed gneiss. Histograms of all the input parameters for the *Q* system are presented and analysed in order to determine the weighted average value of *Q*.

Carter (1992) has adopted a similar approach, but extended his analysis to include the derivation of a probability distribution function and the calculation of a probability of failure in a discussion on the stability of surface crown pillars in abandoned metal mines.

Throughout this chapter it has been suggested that the user of a rock mass classification scheme should check that the latest version is being used. It is also worth repeating that the use of two rock mass classification schemes side by side is advisable.

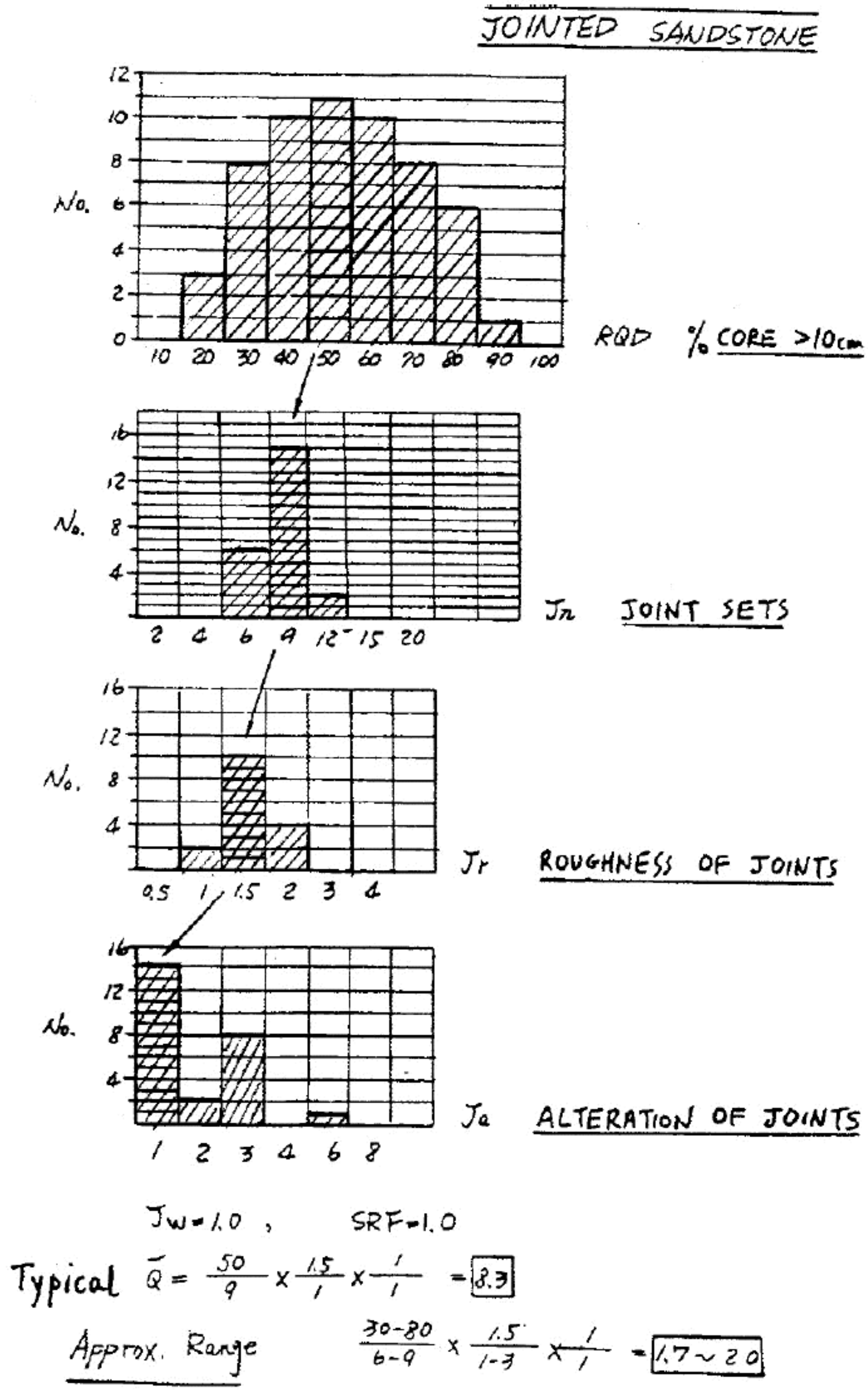


Figure 4: Histograms showing variations in *RQD*, *Jn*, *Jr* and *Ja* for a dry jointed sandstone under 'medium' stress conditions, reproduced from field notes prepared by Dr. N. Barton.

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Chapter 5

Prepared by: Arishma Gadtaula

Hazard- Introduction

- Hazard is defined as a dangerous phenomenon, substance, human activity or condition that may cause loss of life, loss of livelihoods and services, social and economic disruption, or environmental damage.
- According to Varne’s, ”Hazard is defined as the probability of occurrence of the potentially damaging phenomenon within a specific period of time within a given area”.

Hazards- Types

Geological:

These are naturally occurring or man made geological conditions resulting in loss of life and property. They may occur slowly or suddenly.

Climatic:

These are hazards resulting due to change in atmospheric patterns and conditions. They are generally caused by wind velocity, precipitation, temperature,humidity,etc.

Environmental:

Any single or combination of toxic agents in the environment resulting due to human activities or natural process impacting the health of people are environmental hazards.

Industrial:

Hazards created due to industrial process. Example: explosions, fire,nuclear reaction,etc.

Effects of Hazards

Primary: Example: landslide

Secondary: Example: Disruption of sewer system as a result of earthquakes

Tertiary: Long term effects

Example: Loss of habitat by flood

Factors determining the severity of hazards

Duration	Magnitude	Predictability
Regularity	Frequency	Spatial concentration
Areal extent	Number of hazards	

Vulnerability to Hazards and Disasters

- It is the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, gender and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management.

Risk

- Risk is the combination of the probability of an event and its negative consequences. In technical settings the emphasis is usually placed on the consequences, in terms of “potential losses” for some particular cause, place and period.
- Risk= hazard* Exposure

Vulnerability

- Vulnerability refers the way a hazard or disaster will affect human life and property. Vulnerability to a given hazard depends upon following factors:
- Proximity to a possible hazardous event
- Population density in the area proximal to the event
- Scientific understanding of the hazard
- Public education and awareness of the hazard
- Existence or non-existence of early-warning systems and lines of communication
- Availability and readiness of emergency infrastructure
- Construction styles and building codes
- Cultural factors that influence public response to warnings

Factors of Geological Hazards

- Lithology of an area
- Ground water condition
- Rainfall
- Geotechnical propertiess of soil
- Weathering of rock
- Natural slope
- Vegetation or land cover
- Climate change
- Erosion by streams, glaciers, etc.

Most common geological factors causing hazards in Nepal

- Fragile and steep topography
- Geological diversity
- Geological structures
- Active tectonics of Himalaya
- Groundwater condition
- Degree of weathering
- Unplanned urbanization
- Improper construction activities

Major geological Hazards: Flood

- Nepal is the second highest country at risk of floods in South Asia (UNDP, 2009). Regular flooding,
- Predominantly in the monsoon season, results in significant loss of life, property, and livelihoods.
- Flood refers to the unusual rise in water level in rivers/ streams which submerges the land that is usually dry.

Causes of Flood

- Heavy Rainfall
- Overflowing rivers
- Broken dams
- Urban drainage basins
- High tides and Tsunamis
- Channels with steep sides
- Lack of vegetation
- Melting of snow and ice

Impacts of Flood

Does flooding have any positive impact?

Positive Impacts

Recharges Groundwater

Shapes the land structures

Deposits valuable nutrients in the soil

Cleansing of banks as well as river beds

Helps in maintaining floodplain biodiversity

Negative Impacts

Loss of life and property

Damage to bridges, sewerage systems, roadways and canals

Contamination of water resources

Risk of epidemics

Damage to crops and cultivable land

Unwanted deposition

Wetland formation

Flood control

Afforestation

Bioengineering

Construction of leeves, dams, reservoirs.

Structural Control on Geo-Hazards

- The hazards resulted due to the geological features and processes that present severe threats to humans, property and environment.
- Example: Earthquake, flood, landslide, erosion, etc.
- ***What are the structures that control geo-hazards?***

Engineering Protection Structures

For earthquake protection

For landslide protection

For erosion protection

Rock fall protection

Flood protection

Geological hazards in soil mass

- Soil erosion
- Debris flow
- Mudflow
- Earth flow
- Creep
- Lateral spreads
- Solifluction
- Slump

Geological hazard in rock mass

- Rock fall
- Rock topple
- Rock slide
- Rock avalanche

Engineering Evaluation of geological hazard and Risk problem, Specific Hazard Mapping and Mitigation Measures

- Hazard assessment is defined as, "The process of studying the nature "The process of studying the nature of natural /manmade hazards determining its essential features (degree of severity, duration, extent of the impact, area) and their relationship".
- The hazards are preliminarily recognized and the nature of the hazard is identified with the characterization of how severe the hazard is, and what are the areas and categories which is affected by the hazard along with determination of the impact that the hazard has created on socio-economic aspects.
- The hazard assessment approach may be qualitative, quantitative, probabilistic or deterministic.

Framework for hazard assessment

1. Identifying hazardous processes occurred in the past
2. Determining the the severity of the physical effects of past hazardous processes (magnitude)
3. Determining the frequency of occurrence of hazardous process
4. Deducing the likely effects of a process of a given magnitude if it were to occur now
5. Making all this information available in a form useful to planners and public officials responsible for making decisions in event of a disaster.

- ***Geological hazards can be assessed by :***

❖ Preparation of geological map

❖ Study of the historical hazard events.

❖ Preparation of hazard map

❖ Calculation of risk

❖ Public awareness and capacity building program

Hazard map

- Map giving information about the areas that are affected or are to be affected by a particular hazard.
- It helps in providing information about the risk and vulnerability to the hazard which helps in preventing loss of life and property.
- It provides a measure for the government or local level for prioritization to the specific hazard.

Geological hazard evaluation and mitigation

- Geological hazards are evaluated by engineering geologists who are educated and skilled in interpretation of geomorphology, interaction between earth and structures present and in hazard mitigation.
- An engineering geologist provides recommendations and necessary designs to mitigate hazards.
- Proper training on hazard mitigation also helps the local community to identify major hazards for further mitigation.

Mitigation for geological hazards

- Relocation
- Construction of engineering structures like dams, leeves, gabbion wall,etc.
- Protection of shorelines and streams by engineering structures
- The strength of soil or rock may be improved by mixing other aggregates
- Additional mitigation may include construction of mega structures like deep foundations, tunnels surface and sub surface drain,etc.
- Proper building code adoption in hazard prone areas.

Risk Assessment

- It involves assessment of hazard along with the study on socio-economic aspects.
- Risk assessment involves;

  Hazard assessment preliminarily,

  Location of elements at risk subjected to hazards

  Potential exposure to the physical effects of a hazardous situation

  Vulnerability of an area when subjected to hazard.
- Risk assessment helps the decision makers to compare and evaluate possible or probable hazards, set priorities on mitigation measures and where to focus for study.

Chapter 6: Measurement, Analysis and Interpretation of Structural Geological Data

DATE: 2019/7/1

Prepared by: Arishma Gadtaula

Rock mass: Introduction, Properties, Classification Systems

- Rock is intersected by discontinuities known as rock mass.
- Rock mass is heterogenous in nature due to variation in rock type, discontinuities and the degree of weathering.
- The strenght of rock mass depends upon the discontinuities rather than the intact rock strength.
- Rock mass = Intact rock+ Discontinuities
- The rock where discontinuities are not present is called Intact rock.
- Intact rock has their own mineralogy, texture, degree of weathering, cementation and rock type.

Difference between Intact rock and Rock mass

Properties

- Properties of rock may be studied depending upon whether it’s a rock mass or intact rock.

6.1.2.1 Properties of intact rock

(i) Rock strength:

Strength of an intact rock is a quantitative engineering property.

Rock experiences different stresses namely tensile, compressive and shear.

Compressive strength is the most widely used stress for engineering applications.

No.	Description	UCS (Mpa)	Example
R1	***Very Weak Rock-*** crumbles under sharp blows with geological pick point and can be cut with pocket knife.	1- 25	Chalk, rock salt
R2	***Moderately Weak Rock-*** shallow cuts or scarping with pocket knife with difficulty, pick point indents deeply with firm blow	25-50	Coal, schist, siltstone
R3	***Moderately Strong Rock-*** Knife cannot/ can be used to scratch or peel surface, shallow indentation under firm blow from pick point.	50-100	Marble, gneiss
R4	***Strong Rock-*** hand sample breaks with one firm blow from hammer end of geological pick.	100-200	Gabbro, Basalt
R5	***Very Strong Rock-*** requires many blows from geological pick to break intact sample.	>200	Quartzite, granite

(ii) Weathering Grade

- Weathering grade of rock significantly influences the engineering properties of rock. Degree of weathering depends upon various factors such as size, orientation, of discontinuities and groundwater movement.

Weathering description	Grade No.	Rock material description
Fresh	I	No visible changes of weathering.
Slightly weathered	II	Slight changes in color; slight weakening.
Moderately weathered	III	Changes in color; considerable weakened but cannot be broken by hand.
Highly weathered	IV	Considerable weakened; larges pieces can be broken by hand.
Completely weathered	V	Considerably weakened; disintegrate in water; original texture apparent.
Residual soil	VI	Soil derived by in-situ weathering but having lost retaining original texture and fabric.

6.1.2.2 Properties of Discontinuities

Rocks are involved in construction and design of structures and are to be studied during excavation in tunnels, dams, mines, etc.

The strength and stability of the rocks are of prime importance which depends upon the rock mass discontinuity properties.

Rock mass show heterogeneity and anisotropism due to varying rock type, presence of discontinuities and differing degrees of weathering.

These discontinuities in rock masses are observed in statistically heterogeneous region. So, for further investigation of discontinuity, statistically heterogeneous region is identified initially.

Such regions are identified with single rock type, sediment deposition, and same no. of joint sets with similar orientation. Proper investigation of the rock mass discontinuity properties is essential to collect useful information about the rock.

The essential rock mass discontinuity properties that are to be identified are as follows:

- Orientation:

The dip amount and dip direction of the discontinuity should be measured. The modes of failure, i.e. daylight, wedge and plane failure condition is controlled by the orientation

- Spacing:

The perpendicular distance between two adjacent discontinuities is spacing. The rock mass strength, excavation operation methods and support system is highly influenced by spacing.

- Persistence:

This represents the continuity till where the discontinuity mass spreads. It helps to define the potential volume of the failure mass.

- Aperture :

Aperture relates to the outlet present within the discontinuity. The outlet may either be empty or filled with materials. The joint with aperture filled up by infill material is open.

- Surface characteristics:

The surface characteristics define whether the joint or bedding surface is smooth or rough. Based on the scale of observation, the joint roughness can be distinguished in large scale or small scale. Depending upon whether the surface is stepped undulated, slickensided, smooth, and planar or rough, the surface characteristics of rock mass discontinuity is estimated.

- Water flow condition:

The water flow condition of the rock mass discontinuity is essential for proper rock mass strength estimation. Following conditions rule the water flow situation during site investigation:

a)Dry b) Wet c) Seepage d) Dripping e) Flow

Rock mass Classification System

Rock mass classification system ensures to improve the quality of site investigation by providing quantitative information for design purpose.

It is also used to determine the strength of rock and help to determine the support condition required for rock to provide desired strength and leads to successful completion of an engineering project.

Different rock mass classification systems are:

1. Terzaghi rock mass classification
2. Rock Quality Designation Index (RQD)
3. Bieniawski's Geomechanics classification
4. Rock Tunneling Quality Index (Q-value)

6.1.3.1 Terzaghi rock mass classification

This is the first organized system was proposed by Dr. Karl Terzaghi. This system was mainly qualitative and used for rock tunnel design and construction projects.

Type	Rock characteristics
Intact rock	Rock with no joints
Stratified rock	Rock with little strength along bedding surface
Moderately jointed rock	Rock mass jointed but cemented
Blocky and seamy rock	Jointed rock mass without any cementing of joints
Crushed rock	Rock that has been reduced to sand size particles without any chemical weathering.
Squeezing rock	Rock containing considerable amount of clay
Swelling rock	Rock that squeezes primarily from mineral swelling.

6.1.3.2 Rock Quality Designation (RQD)

RQD was introduced by Deere to determine the quantitative estimate of rock mass quality from drill core log. RQD is given by:

$$RQD = \frac{\text{Sum of Length of core pieces} > 10\text{ cm}}{\text{Total length of core run}} * 100\%$$

Sometimes, the drilling may be inaccessible in such cases RQD can be determined by the following relation suggested by Palmstorm:

RQD= 115- 3.3 Jv

Where Jv= sum of number of joints per unit volume

From the value obtained for RQD, Rock mass is classified according to the table shown below:

RQD value (%)	Rock mass quality
<25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

Bieniawski's Geomechanics Classification (RMR)

Rock Mass Rating (RMR) system is a geomechanical classification system of rocks developed by Bieniawski in 1973. This system provides the quantitative information about the rocks. The RMR system utilizes the following parameters to determine the quantitative basis for rock mass:

i) Uniaxial Compressive Strength of Intact Rock Material,

ii) Rock Quality Designation, RQD,

iii) Joint or discontinuity spacing,

iv) Joint condition,

v) Groundwater condition and

vi) Joint orientation.

The parameters considered during RMR are strength of intact rock material, drill core quality (Rock Quality Designation), spacing of discontinuities and groundwater condition.

Class No.	Rating	Rock Quality
I	100-81	Very good rock
II	80-61	Good rock
III	60-41	Fair rock
IV	40-21	Poor rock
V	<21	Very poor rock

6.1.3.4 Rock Tunneling Quality Index (Q-value)

Barton et.al (1974) at the Norwegian Geotechnical Institute (NGI) originally proposed The Q- system of rock mass classification based on the 200 case histories of tunnels (Singh and Goel, 1991). The rock mass quality ‘Q’ value was described as:

$$Q = [RQD/ Jn] \; [Jr / Ja] \; [Jw /SRF]$$

Where,

RQD= Deere’s Rock Quality Designation,= 115- 3.3 Jv

Jn= Joint set number,

Jr= Joint roughness number for critically oriented joint set,

Ja = Joint alteration number for critically oriented joint set,

Jw= Joint water reduction factor,

SRF = Stress Reduction Factor to consider in situ stresses,

Jv= Volumetric Joint Count.

The main aim of Q-System is to create preliminary empirical design of support system for tunnels and caverns.

The numerical value of Q varies on a logarithmic (base 10) scale from 0.001 to 1000 .

RQD/ Jn = measure of block size , Jr/Ja = inter block strength Jw/ SRF = active stress at site

Based on Q- value, rock mass is classified in various groups as:

Q- value range	Rock mass quality
0.001- 0.01	Exceptionally poor
0.01-0.1	Extremely poor
0.1- 1.0	Very poor
1.0-4	Poor
4-10	Fair
10-40	Good
40-100	Very good
100-400	Extremely good
400- 1000	Exceptionally good

THANK YOU FOR YOUR ATTENTION!

HYDROGEOLOGY

Introduction

- Hydrology: Hydrology is the branch of science that basically deals with everything related to water. It includes the study of its origin, occurrence, movement, its transport from the atmosphere to the earth and vice versa, its forms and other hydrological phenomena that take place.

Hydro	+	Logos	=	Hydrology
(Water)		(science)		

Branches

- **Chemical hydrology** is the study of the chemical characteristics of water.
- **Ecohydrology** is the study of interactions between organisms and the hydrologic cycle.
- **Hydrogeology** is the study of the presence and movement of groundwater.

Hydroinformatics is the adaptation of information technology to hydrology and water resources applications.
Hydrometeorology is the study of the transfer of water and energy between land and water body surfaces and the lower atmosphere.
Isotope hydrology is the study of the isotopic signatures of water.

Surface hydrology is the study of hydrologic processes that operate at or near Earth's surface.
Drainage basin management covers water storage, in the form of reservoirs, and floods protection.
Water quality includes the chemistry of water in rivers and lakes, both of pollutants and natural solutes.

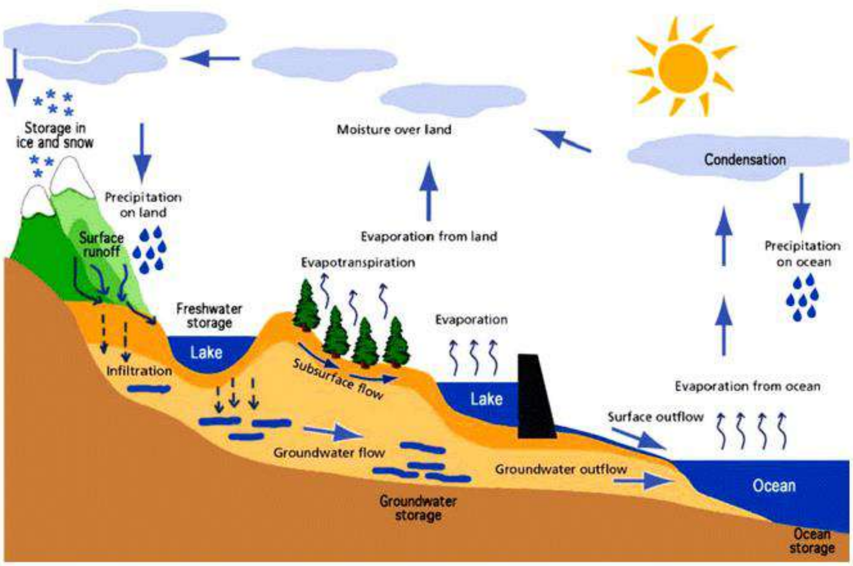
HYDROGEOLOGY

The branch of geology that deals with the study of occurrence, movement and quality of water beneath the earth surface is called hydrogeology

HYDROLOGICAL CYCLE

Water occurs naturally in different forms such as in rives, lakes, and ocean, and transforms from one state to another in a closed loop within earth mass and atmosphere. This loop is called hydrological cycle.

HYDROLOGICAL CYCLE



WATER BUDGET

- **The distribution of global water in different forms is called the water budget.**

	Area (x 10^6 km^2)	Volume (x 10^3 km^2)	Proportion (%)
Oceans	360	1370323	93.93
Groundwater - total	-	64000	4.39
Polar ice glaciers	16	24000	1.65
Lakes	510	230	0.016
Rivers		1.2	0.0001
Soil moisture	-	75	0.05
Atmospheric water	-	14	0.001

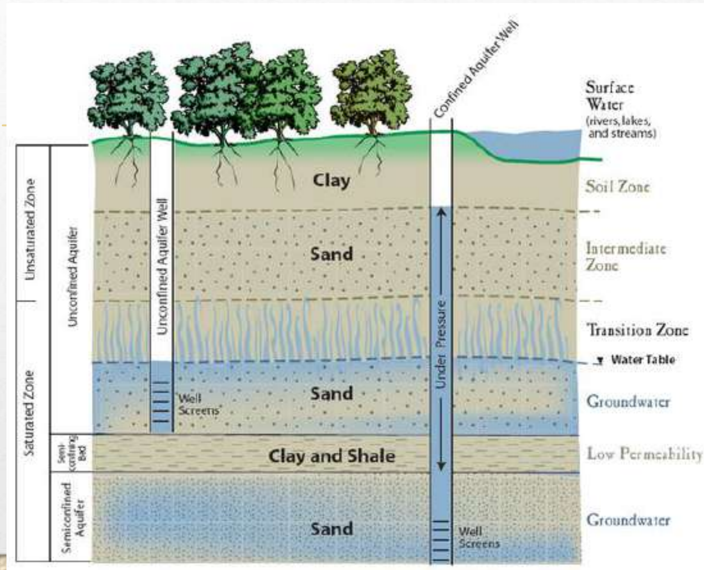
GROUNDWATER

- Rainfall and melted snow usually discharge as runoff through surface water courses, and some part infiltrates into the soil and bedrock. The water moves more or less vertically downwards under gravity through soil.
- **Groundwater** is water located beneath the earth's surface in soil pore spaces and joints and fractures of rocks or Groundwater is the water found underground in the cracks and spaces in soil, sand and rock.
- *It is stored in and moves slowly through geologic formations of soil, sand and rocks called **aquifers**.*
- The infiltration of precipitation is **called recharge**. The area from where the rainfall and/or melted snow infiltrated into subsurface, is called **recharge zone.**

GROUNDWATER ZONATION

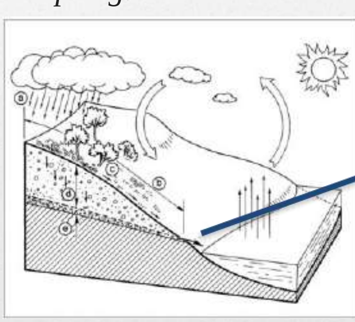
- **There are three distinct zones below the ground surface:**
  1. **Saturated or Phreatic Zone –** It is the zone where pores and fissures are never completely filled, but through which water migrates. Some water is stored in pore spaces.
  2. **Zone of intermittent saturation –** It is an intermediate zone which extends from the highest level reached by the upper surface of the saturated zone to the lowest level to which it falls in drought.
  3. **Unsaturated or Vadose zone –** In this zone, pores and fissures are permanently filled with water. The saturated zone extends to a depth of several hundred meters below ground level. The movement of water is too slow in this zone.

GROUNDWATER ZONATION



Major sources of Ground water

- **Spring:** A spring is the natural outflow of groundwater through rock fracture, rock pores, joints or faults at a region where the water table intersect the ground surface. *When groundwater makes its way to the earth's surface and emerges as small water holes or wet spots, this feature is referred to as a spring.*



Types of spring

- It classified into two categories:
- a) Gravity Spring

The Spring that result from gravitational forces

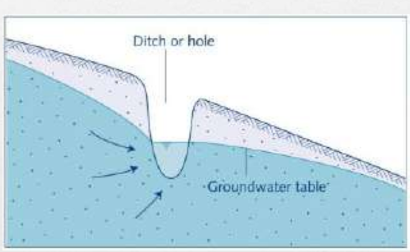
- Depression Springs
- Contact springs
- Artesian Spring
- Karst Spring

Gravity Spring

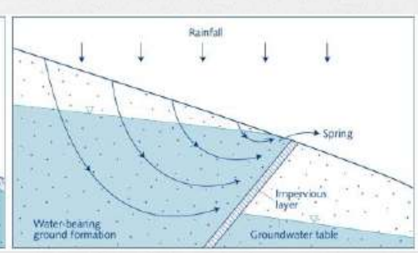
•Gravity springs occur either if the ground surface dips below the water table ('depression subtype') or if an outcrop of impervious soil prevents the downward flow of the water ('overflow subtype').

•The water flows more or less **horizontally** out of the ground.

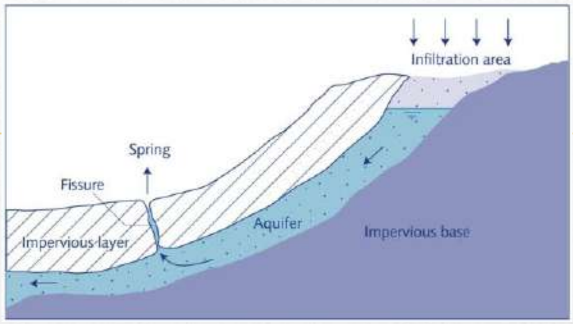
Depression Spring



Contact spring



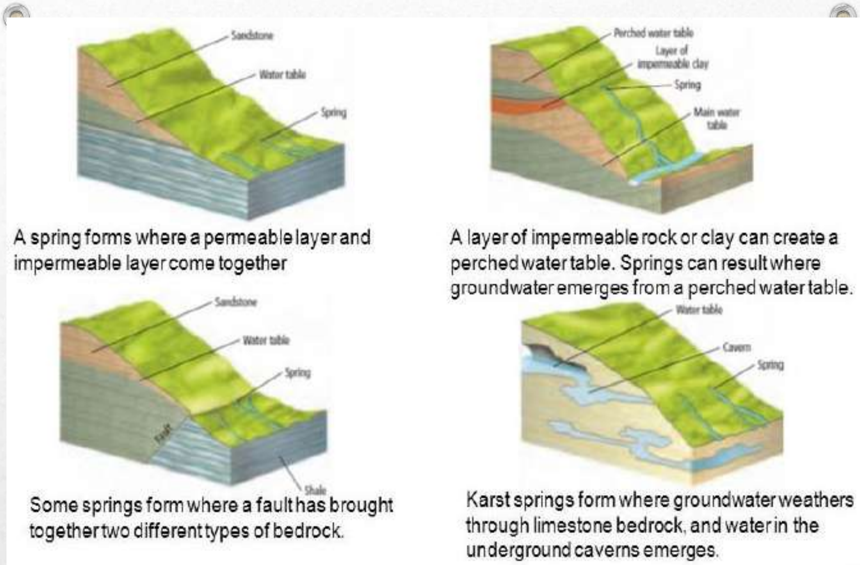
Artesian Springs



•Artesian springs occur when water is trapped between impervious layers and is forced to the surface under pressure.
•The water flows **vertically** out of the ground.

b) Non-gravity springs:

- Fracture Springs:
- Volcanic Springs



2. Well

- A well is an excavation or structure created in the ground by digging, driving, or drilling to access liquid resources, usually water. It is usually vertical. The wells can be dug into various types of rocks and the quqlity and quantity of water available depends on the various rock types. It can divided into two types
- a) open well
- b) Tube wells
- - Shallow tube well
- - Deepboring

AQUIFERS

- ***Aquifer:*** An aquifer is strata of rock or soil that holds groundwater from which groundwater can be extracted in significant quantity for economic purposes.
- ***Aquicludes:*** The geological formation that permits the storage of water but by virtue of its properties, is not capable of transmitting water in sufficient quantity is called an aquiclude. It is to be treated as practically impermeable layer. Example: Clay
- ***Aquifuge:*** The geological formation that neither permits the storage of water nor is capable of transmitting water is called aquifuge. It is made up of relatively impermeable materials. Example: solid granite.

AQUIFERS Cont.

***Water Table*:** The upper surface of groundwater observed below the ground surface is called water table.

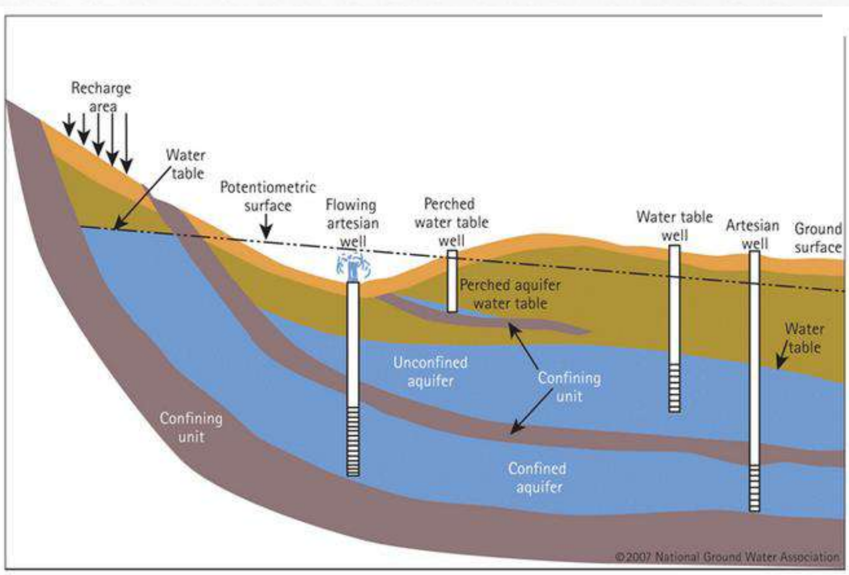
There are three distinct types of aquifers:

1. **Unconfined aquifer** – It is an open aquifer that extends up to ground surface and contains the water essentially at atmospheric pressure. The water table fluctuates seasonally that controls the volume of water in the aquifer.

AQUIFERS Cont.

2. **Confined aquifer** – It is a geological formation of rock or soil holding water, bounded above and below by impermeable layers such as clay. The pressure of groundwater in the confined aquifer is greater than atmospheric pressure. The confined aquifer is also called as pressure aquifer or artesian aquifer.
3. **Perched aquifer** – It is a local semi-confined aquifer. It is found within an unconfined aquifer lies over a impermeable layer, but open to the top part. The upper level of water in perched aquifer is greater than the water table.

AQUIFERS



Factors controlling the occurrence of groundwater

- The occurrence of groundwater depends upon various factors. They are listed below:
- a) **Climate:** Climate is one of the controlling the occurrence and movement of groundwater. It is found that 5mm rainfall in one hour facilitates more runoff and results in less filtration. However, a rainfall of about 5mm in 24 hours facilitates less runoff and more infiltration. In area where the climate is humid, more water is lost due to evaporation and transpiration and hence very less amount of water will infiltrate resulting in less amount of groundwater.

b) Topography:

The area with steep topography has more runoff of the precipitated water and results in less infiltration. The area with gentle topography facilitates more infiltration and less runoff and the area with horizontal land or depressed land there is negligible amount of runoff and almost all water infiltrates into the ground.

- **c) Hydraulic Gradient:**

The ratio of head difference between two points and the distance between two points is called hydraulic gradient.

Hydraulic gradient (I)= $\Delta l/L$

Where, Δl = head loss between two points

L = distance between two point

d) Hydraulic conductivity

- **Hydraulic conductivity is defined as the flow velocity per unit hydraulic gradient**

Typical Values of Aquifer Parameters

Aquifer Material	Porosity (%)	Typical Values for Hydraulic Conductivity ($m \cdot s^{-1}$)
Clay	55	2.3×10^{-9}
Loam	35	6.0×10^{-6}
Fine sand	45	2.9×10^{-5}
Medium sand	37	1.4×10^{-4}
Coarse sand	30	5.2×10^{-4}
Sand and gravel	20	6.0×10^{-4}
Gravel	25	3.1×10^{-3}
Slate	<5	9.2×10^{-10}
Granite	<1	1.2×10^{-10}
Sandstone	15	5.8×10^{-7}
Limestone	15	1.1×10^{-5}
Fractured rock	5	$1 \times 10^{-8}–1 \times 10^{-4}$

e) Hydraulic transmissivity:

- Transmissivity is most simply defined as the effective hydraulic conductivity of an aquifer or other water bearing unit multiplied by the thickness of that unit

f) Geological formations:

- Geological formation like aquifer, aquiclude and aquifuge alter the transmission of water

g) Vegetation cover

h) Porosity

In soil materials, there are spaces or gaps between the grains, which are called pores or voids. In rocks, the spaces are formed by fractures, joints, and bedding planes.

The porosity of soil or rock is defined as the ratio of volume of pores to the total volume of rock/soil material.

$$Porosity\ (\eta) = \frac{V_v}{V_t} \times 100\%$$

i) Primary porosity: It developed during the decomposition of sediments.

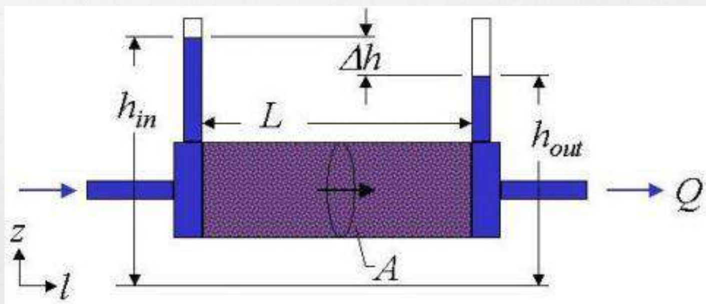
ii) Secondary porosity: It developed after formation of rock such as joints, cracks etc.

i) Permeability:

Permeability is a parameter that describes the ability of a rock/soil material to transmit water. The interconnection of pores determines the degree of permeability. So, highly porous materials may not always have high permeability. A geological formation needs highly permeable to be a good aquifer. For example, sand, gravel, sandstone, and fractured limestone are good aquifers. Clay, silt, and shale are not aquifers.

Darcy's Law

- A French engineer Henri Darcy, in 1856 formulated a relationship between the rate of flow of water through a porous medium to other parameters. It shows the volumetric flow rate is a function of the flow area, elevation, fluid pressure and a proportionality constant.



Darcy's law cont.

- Q = AK*Δh/L……………..(i)
- Where,
- Q = Volumetric flow rate (m3/s)
- A = flow area perpendicular to L (m2 or ft2)
- K = Hydraulic conductivity (m/s or ft/s)
- L = Flow path length (m or ft)
- h = Hydraulic head

The hydraulic head is the height that water would rise in a piezometer. Thus Δh is simply the difference in height of water in piezometer placed at the inlet and the outlet

Δh = h(in) – h(out)

Geological factors for formation of different hydrological conditions

- Coarse sediments such as sand, gravels, pebbles, cobbles and boulders inter pore spaces between such fractions
- Highly jointed and fractured rocks
- Highly porous rocks such as limestone, sandstone
- Deep seated thrusts and fault zones
- Permafrost in snow covered zones

Different types of aquifer system of Nepal

a) General hydrogeology of Nepal

i) No groundwater potential zone

ii) Highly productive zone

iii) Moderately productive aquifer

b) i) Mountain aquifer zone: Highly fractured and jointed rock mass, porous rock deposit (limestone, sandstone etc).

Permafrost zone (in high mountain zone as snow covered zone)

ii) Bhabar Zone: the aquifer that mostly consists of alluvial sediments deposits as outwash fan. It is considered as recharge zone of Terai region

iii) Terai aquifer zone: loose unconsolidated sediment alluviul deposit comprises of coarse sediments such as sand, gravel, pebbles, cobbles and boulders

Engineering Significance of Groundwater

Effects of Groundwater in engineering works, such as:

- Site selection
- Cost of project
- Durability and safety of structures

It plays prominent role in:

- Slope movement
- Volume changes by shrinkage and swelling
- Cause collapse of loose soils
- Erode the foundation of structures
- Changes in rock and soil properties
- Influence on subsurface excavation, tunnels

Engineering Significance of Groundwater

In engineering geological investigation, the following important information on subsurface water conditions should be evaluated:

- The distribution of sub-surface water
- Water content
- Direction and velocity of subsurface water flow
- Springs and seepages from individual water bearing horizons
- Depth to water table and its range of fluctuation
- Regions of confined water and piezometric levels
- Hydrochemical properties such as pH, salinity, corrosiveness
- Presence of bacterial or other pollutants

Engineering Significance of Groundwater

Subsurface water conditions are significant for three major aspects of civil engineering works:

1. Subsurface water may pose a problem to construction,
2. It may be an erosive agent that degrades the foundation of the structure,
3. Subsurface water may be critical to the functioning of the structure

Assignments

1. **What is an aquifer? Describe various types of acquifers.**
2. **Discuss on the engineering significance of subsurface water.**
3. **Write short notes on:**
   1. **Hydrological cycle**
   2. **Confined aquifer and Artesian wells**
   3. **Type of springs**

Site Investigation

•

Introduction

- For all civil engineering projects like reservoirs, dams, tunnels, roads, bridges, and buildings, a detailed knowledge about the project site is very necessary. It is essential to investigate the engineering properties of rock or soil at the site. *Site investigation is defined as the overall evaluation of specific site condition which is selected for construction of any civil engineering infrastructure.* The geological investigation of the project site is simply termed as *site investigation*.
- Main objectives of site investigation are to determine
  1. the lithology (rock / soil type) of the area,
  2. the geological structures of the area,
  3. the groundwater conditions in the region,
  4. the seismicity (seismic condition) of the region.

Phase of site investigation

There are mainly three phase of site investigation. They are described below:

a) Preliminary study:

b) Detail Investigation:

c) Implementation Phase

Method of Site Investigation

There are two broad types of investigations:

1. surface investigations

2. subsurface investigations

Surface investigations are carried out to obtain useful details regarding rock outcrops /soil on the surface and their possibilities of extending beneath the surface. These investigations also provide the knowledge about drainage pattern, hydrogeological distributions, land use patterns, soil type, and topographical features such as slope, relief, shape of slope, and morphology of landscapes.

Indirect surface investigation

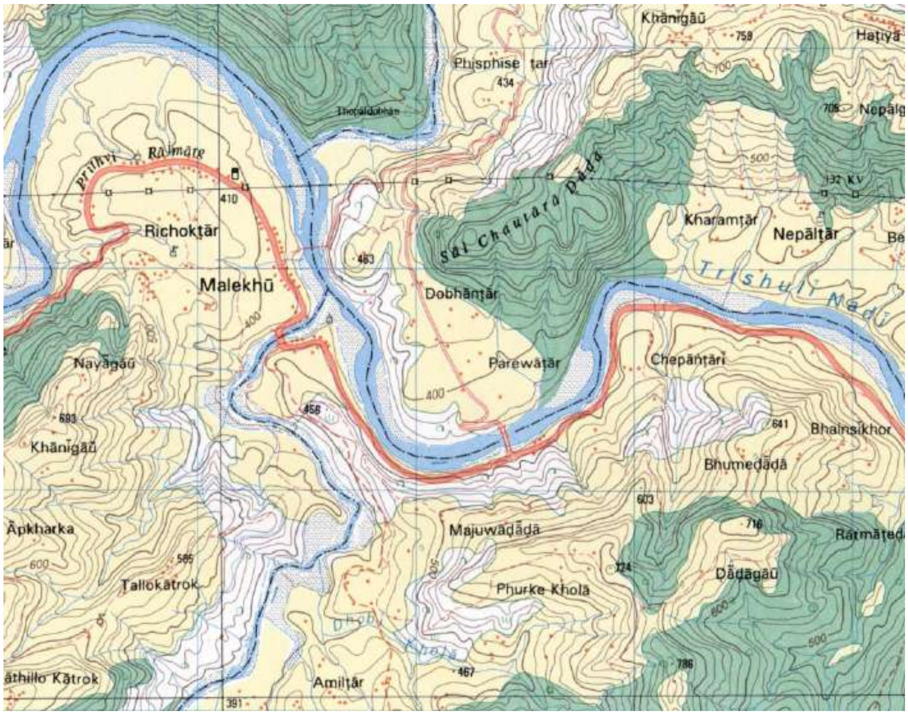
In this investigation preliminary idea can be obtained about any specific site by not visiting directly the site

- Review of previous literatures including geological maps if available.
- Topographical map analysis; slope, drainage networ k, existing structures
- Remote sensing; study and interpretation of aerial p hotography and satellite image using stereoscope

Method of Site Investigation

- **Topographic Map:**

Topographic map is an orthographic projection of three-dimensional expression of the topography or elevation relative to the mean sea level. The map basically comprises features to show elevation (contour lines), rivers and tributaries, land utilization, distribution of infrastructures, and political boundaries. Map scale, north pointing arrow, and legends used in map are also included with geographical as well as Cartesian coordinates. Topographic map gives basic surface morphological information, and also some clues about the geological structures and type of lithology. Landforms and drainage patterns in any area can be mapped with the help of topographic map of that region. Profiles can also be drawn from the topographic maps.



Method of Site Investigation

- **Satellite Imageries:**

These images are taken by satellites in a regular time interval from a specified height. The sensors assigned in the satellite send rays to land surface and receivers in the sensors receive the reflected rays at the same time.

Interpretation of satellite images are used in site investigation.

Method of Site Investigation

Direct surface investigation

It is investigation carried out by visiting the actual site. Information is collected and documented by observatio n measurement and interpretation.

Some data are to be collected in direct surface investig ation

- Type of rock or soil and major component
- Attitude of rock
- Thickness of soil and rock
- Weathering condition of rock
- Different properties of discontinuities
- Geological structure like bedding, foliation, joints, fau lts fold etc
- Slope stability factors, natural slope and landslide

Types of Investigation

- **Geological Map:**

A geological map depicts the distribution of rocks and soils on the surface from which the subsurface extension of rocks can be inferred. A geological section along a desired line is drawn on the geological map that shows the vertical distribution of rocks along the profile line. A geological map shows the distribution of lithology, geological structures and their orientations in symbol. The contact between two rock types is parallel to the strike line. Using the dip direction and dip amount given in the geological map, thickness of strata can also be calculated. Horizontal thickness of strata is just horizontal measurement of strata on map, vertical thickness is the elevation difference between the upper and lower boundaries of strata.

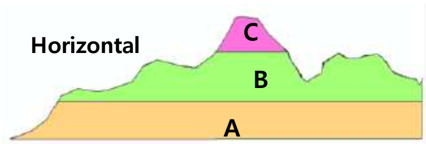
Geological Maps

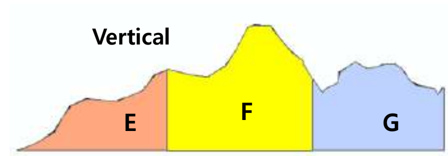
- Thematic maps that depict the distribution of different rock types with geological structures and order of superposition

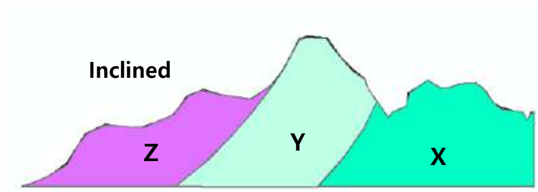
A geological map gives information on:

- Positional attitude of bedrocks
  - Horizontal
  - Vertical
  - Inclined (Dipping with some angle)
- Geological structures
  - Folds
  - Faults

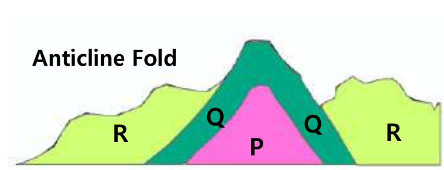
Position of Bedrocks

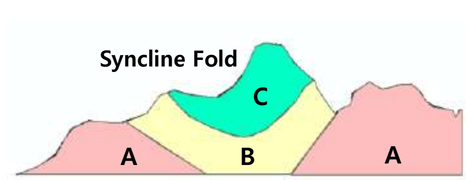






Geological Structures

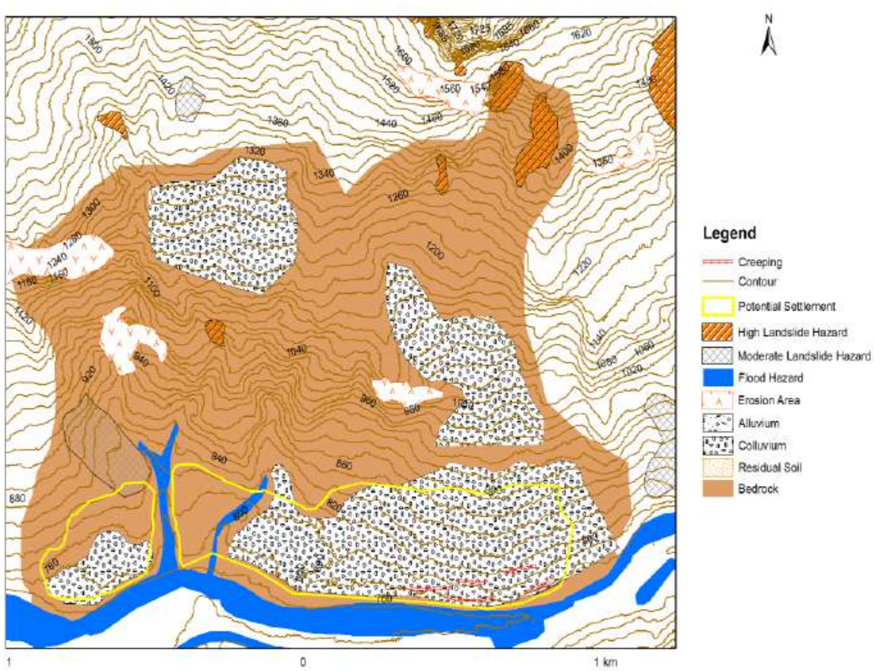




Method of Site Investigation

- **Engineering Geological Map:**

Engineering geological map comprises engineering geomorphic units, condition of bedrock and soil, distribution of mass movement activities, and hydrological features. The main purpose of this map is to deliver the information that is essential to engineering purposes such as construction of infrastructures. Engineering geological map is also based on the topographic map of the region and includes information from both geological map and topographic map. Information from aerial photographs and satellite images can also be incorporated to make it more reliable. Generally, engineering geological maps are prepared along road sides and other engineering project sites.



Method of Site Investigation

Subsurface investigations can be accomplished in two ways: *direct subsurface explorations*, and *indirect subsurface investigations*.

Direct Methods:

In the direct methods, the examination of rocks or soil materials is carried out by digging wells, trial pits, adits, shafts, drill holes, and exploratory tunnels. In the direct method, the rock or soil specimen is taken and further examined at the site or in the laboratory.

1. **Borehole logs – A borehole is made to find the subsurface structures and lithology at a site. The materials in the order found in borehole are called lithologs or simply logs. These logs give the actual scenario of subsurface composition.**

- **Auger boring**
- **Wash boring**
- **Core boring**

Method of Site Investigation

2. **Drilling: This exploration to find the nature of soil, geological structure, engineering properties of rock, porosity, permeability and water table.**

RQD – The quality of rocks is influenced by presence of discontinuities such as joints and fractures. If the rocks have no discontinuities, they are of good quality. Rock Quality Designation (RQD) is a measurement about how much percentage of discontinuities are present in a drilled rock core. It is computed as the ratio of sum of all continuous solid rock (if more than 10cm long) to the total length of core. It is rated as:

- **Poor (25 – 50%)**
- **Fair (50 – 75%)**
- **Good (75 – 90%)**
- **Excellent (90 – 100%)**

Method of Site Investigation

<u>Indirect Methods</u>:

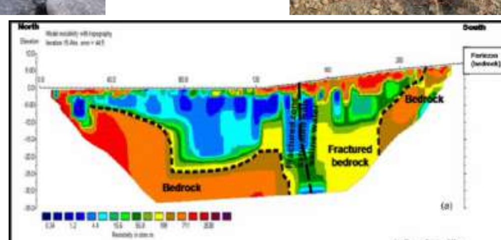
1.Geophysical Investigations –

Geophysical tools are very useful in the subsurface investigation. It uses physical tools such as electric current and seismic waves to find the properties of rock and soil. After interpretation by geophysicist, the subsurface mapping is done. Geophysical methods are relatively cheaper than borehole digging. They take shorter time too. There are some geophysical tools widely used in the subsurface investigations:

- **Electrical Methods – Different mineral composition of rocks and grain size and material of soil with or without presence of groundwater shows different resistivity when electrical current is passed through the materials. The uniformity and differences in the electrical properties are used to identify the rock and soil materials.**

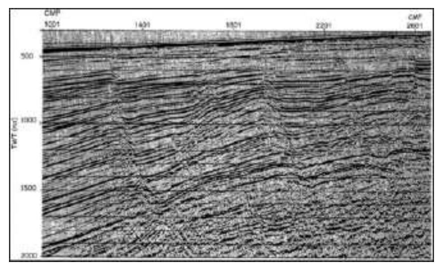
Method of Site Investigation

Electrical Resistivity Tomography (ERT), Vertical Electrical Sounding (VES) are most common electrical methods to study subsurface geology. The ERT gives an image of profile in 2-D that is later interpreted by geophysicist. VES is 1-D, and generally used in identifying aquifer materials.



Types of Investigation

- **Seismic Methods – Likewise electric properties, the rock and soil materials show different seismic properties. When artificially generated seismic waves are passed through the material, the waves reflect with different angles from the boundary surface of two distinct materials. Similarly, some waves refract with different angles on these boundaries. The materials can be identified after interpretation of such results.**



Method of Site Investigation

- **Gravitational Methods – Earth itself has a gravitational property. Rock and soil materials also have their own gravitational properties. In the analysis, it is assumed that the earth is ideally homogeneous in nature. The gravity value observed in the particular material is compared with the ideal gravity value. This difference is gravity is called a gravity anomaly. Gravimeter is used to measure the gravity anomaly and the values are interpreted to identify the materials such as salt domes, metallic ore bodies, etc.**

- **Magnetic Methods – It is one of the oldest geophysical methods used in exploration of subsurface earth. Earth is a magnet itself with definite magnetic field. The magnetic intensity can be measured in any part of the earth. Since, the earth is not really homogeneous, the observed value of magnetic intensity differs from the theoretical value. The difference is called magnetic anomaly. Highly magnetic rock bodies or metallic ore bodies can be distinguished from less magnetic and non-metallic masses using this method. This method is generally used in prospecting for magnetic ore bodies and for oil exploration.**

Geological criteria for physical infrastructures

- **Waste disposal site**
- **Infrastructure developments**
  - **Roads**
  - **Tunnels**
  - **Bridges**
  - **Foundations**
- **Dams and reservoirs**

Geologic Criteria for Waste Disposal site

Following parameters must be considered carefully for the investigation of waste disposal site:

- **Topographic features / terrain morphology**
- **Rainfall pattern in the locality**
- **Nature of surface water flow on the site**
- **Rock /Soil characteristics at site**
- **Nature of ground water flow and water table**
- **Type of wastes and volume to dispose per day**
- **Distance from residents and waster sources**
- **Distance to travel to dispose wastes**

Geologic Criteria for Waste Disposal site

- Topographic features / terrain morphology
  - Depression or isolated basin should be preferred
  - Highland or steep sloped (> 20^{o}) terrain is not suitable
- Rainfall pattern in the locality
  - Low rainfall zone is preferred as possible
- Nature of surface water flow on the site
  - Surface water should not flow through the selected site
- Distance from residents and waster sources
  - Disposal site must be far from residential area (~1 km)
  - Distance from water sources must be more than 500 m

Geologic Criteria for Waste Disposal site

- Rock /Soil characteristics at site
  - Intact rock with less discontinuities and fractures are preferred
  - Good aquifer rocks with karst structures should be avoided
  - Rock above and below the site should be stable in terms of slope
  - Impermeable soil, such as clay is good
  - Gravel, sand, and coarse grained alluviums should be avoided
  - Site with high groundwater level are not suitable
  - Liquefaction potential sites should be avoided
  - Seismically inactive sites should be chosen

Geologic Criteria for Road

- **In hilly and mountainous terrain with bedrock**
  - **The road alignment should avoid the active geological structures such as fault, thrust, and axis of folds**
  - **Hard and less discontinuous rocks are more suitable**
  - **Inclination of bedding and discontinuities should favor the slope of terrain to reduce the slope instability**
  - **Rocks with high strength and less weathering and erosion characteristics are more suitable**
  - **Rocks with karst and caverns should be avoided as possible**
  - **Presence of old landslides and other mass movements should be considered**
  - **Active landslides and creep zones should be avoided**

Geologic Criteria for Road

- **In hilly and mountainous terrain with soil**
  - If the soil is colluvium, the slope gradient with more than 25^{o} is not suitable
  - The thick soil cover on sloped terrain is not suitable because it is prone to erosion and slope failure
  - Residual soil is indicator of high weathering, so the characteristic of clay minerals present in that soil should be considered
  - Bearing capacity of soil must be high
  - Groundwater, seepage, and springs must be managed

Geologic Criteria for Road

- **In plain area with soil**
  - Well-graded soil is more suitable (containing equal proportion of all sizes of soil)
  - Naturally compacted soil with high load bearing capacity is suitable
  - Silt and sand area with high ground water level are prone to liquefaction. These sites should be avoided as possible
  - The surface drain must be well and the road must be raised to avoid inundation
  - The site with majority of coarse-grained soil is not more suitable
  - The road should not be barrier for surface water

Geologic Criteria for Tunnel

- Attitude of rock
- Strength of rock
- Effect of water on rock
- Number of joints
- Orientation of bedrock should be perpendicular to tunnel axis
- Ground water flow and seepage should be protected
- Geological structures such as fault, thrust, and fold axis should be avoided
- Cost

Geologic Criteria for Bridge

- Study of drainage and catchment area of the stream/river is necessary
- Local as well as regional rainfall pattern and maximum 24-hours prec ipitation is required before designing bridge
- Maximum /peak discharge of the river at the proposed bridge site is n ecessary
- Abutments must be founded in hard rocks with high strength in hilly terrain
- The stability analysis of the abutment sites are necessary
- Abutments should avoid Landslides or deep gully erosion
- The straight segment of river is good for bridge site
- If there is soil, the soil must have high bearing capacity and free of li quefaction at the foundation of abutment and piers
- Environment impact

Geologic Criteria for Foundations/ Building

- Soil and rock characteristics
- Depth of foundation depends on the height and scale of infrastructure to be founded
- Coarse soil is preferable than Fine Grained soil
- Hard and less jointed rock more suitable
- Silt and clay soils with high groundwater table is not appropriate for foun dation of large infrastructures
- Soil with high Load bearing capacity is preferable
- High strength and low plasticity soil is good for foundations
- Groundwater condition
- Topographical criteria
- Geological structure
- Natural hazard criteria

Geologic Criteria for Dam and Reservoirs

- Dam site should chosen at narrow channel
- Rocks associated with dam site must be of good quality, without dis continuities and fractures
- Rock weathering degree must be less
- Geological structure should be avoided; fault, thrust, and fold
- River with wide valley and narrow at a place is good for dam and reservoir construction
- Technically strong , impermeable and stable site
- Construction materials should not be far from the construction site
- Catchment area
- Environment impact
- Groundwater condition
- Siltation Problems

Study of Reserve Estimation of Construction Materials

Construction Materials

Construction materials include all the rock and soil originated materials used in engineering works such as stones of building facing, protective blanketing materials o earth dam, aggregates of runways, and concrete. The size, shape, and quality of materials are chosen and determined on the specific purpose of works and designs.

The construction materials are quarried from naturally occurring sites of rock mass. Before excavation, quarries are explored for the quality and economically sufficient amount. Various surveys and inspections are carried out to find the quarry sites. The natural deposit materials in sufficient amount and desired quality that can be minable is called *reserve*.

Types of Reserves

There are three types of reserves:

1. **Proved or measured reserves – Estimation of reserve is based on sufficient data, so that it will not vary in tonnage and grade during mining.**
2. **Probable or indicated reserves – These reserves have lesser degree of assurance and based on limited data of sampling. In case of uniform deposits, these estimations may not vary with the actual measured reserves.**
3. **Possible or inferred reserves – These reserves show only possibility of deposits that are inferred with lack of data but with some experiences to related works.**

Types of Reserves

Reserve Estimation Methods

To estimate the reserves of construction materials, following four methods are broadly on practice:

1. **Cross-section Method**
2. **Isopach Method**
3. **Extended Area Method**
4. **Block Method**

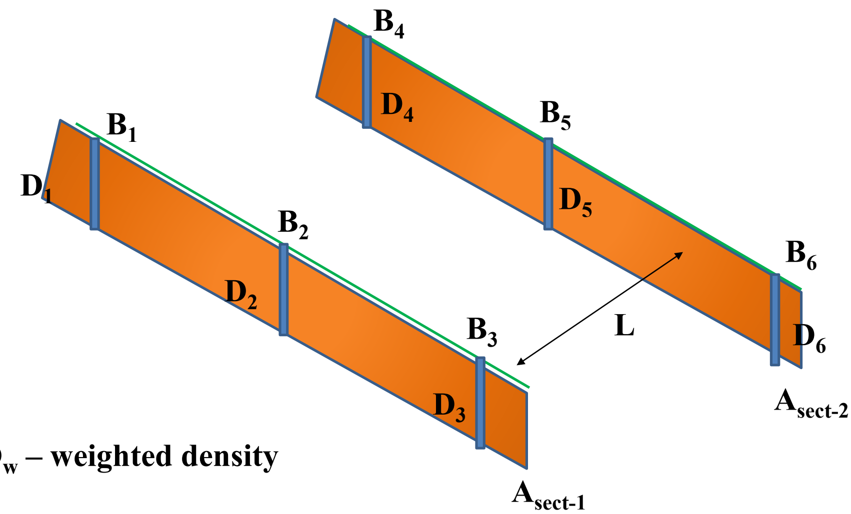
Cross-section Method

In this method, cross-sectional profiles are drawn along different alignments with the help of boreholes to find the actual thickness of desired rock strata. The densities of the strata are also calculated for all locations, and a weighted density is calculated. For example, if we are going to estimate the limestone reserve, are area of limestone in each section is calculated using grid method. Weighted density of limestone strata in each section is also calculated as

$$D_w = \frac{1}{n}\sum_{i=1}^{n} D_i$$

where, D_i = density measured at i^{th} borehole

Cross-section Method



D_w – weighted density

Cross-section Method

Volume of strata between two parallel sections is calculated as:

$V = \{[A_{sect\text{-}1} + A_{sect\text{-}2}]/2\} \text{ x } L$

where, *A* is area and *L* is distance between two sections

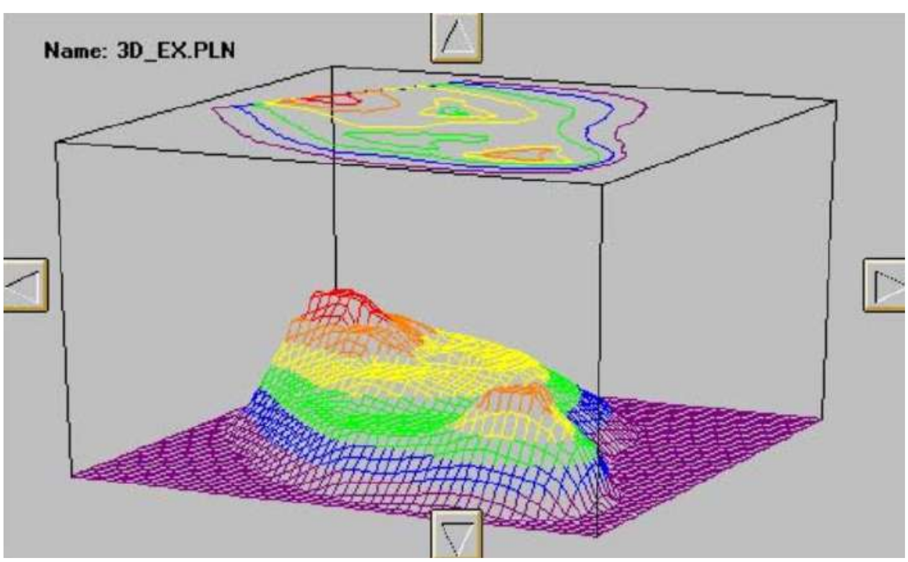
Finally, the actual reserve is estimated as:

$Q = V$ **x Average of weighted densities**

Isopach Method

This method is used to calculate area and thickness of horizontal beds of sediments such as sand and gravel beds directly measuring areal extent of the deposit from the map using a grid method. Densities of the samples are determined from the samples taken using pits, trenches, or bore holes. If the deposit lies beneath the other strata, the area is calculated by adding the area of overlying strata and the area of areal exposure. Then, volume is calculated using the area and average thickness. Once, if the density volume are available, the reserve can be estimated.

Isopach Method



Extended Area Method

This method is suitable where the exploratory pits or boreholes are in grid. Each pit or borehole is considered at center of grid so that each borehole covers equal area. If the pits are dug in an interval of 100 m, the area covered by one pit is calculated as 50 x 50 m^2. Then, the total area is calculated as

A = area of one pit x no. of pits

Weighted density is calculated from the field measurements for each pits. Then, volume is calculated using the area and average thickness.

The reserve is calculated same as previous method :

$Q = V \times D_w$

Block Method

In this method, few blocks are defined depending on thickness and properties of material. The thickness of each block is calculated from the exploratory openings such as pits and bore holes. Area of each block is calculated by triangular method. Then, volume is calculated for each block. Weighted density for each block is calculated by taking the densities of materials from the corresponding boreholes. Reserve of each block is calculated at first, and finally the individual reserves are summed up to get the total reserve at the area.

Assignment-11

1. What is reserve? Discuss the different types of reserve estimation techniques.