Geologic Investigations For D.P.R. of Water Resources Projects

SCOPE

TOPOGRAPHY of Basin and Reservoir;
. Regional Geology;
. GEOLOGY of basin and reservoir;
. Local Geology of particular component of project
. Seismicity;
. Depth of overburden;

. Typical geological features for foundation;
.exploration;
. Case studies

Water Resources Projects

basis of mode of occurrence of WATER RESOURCE projects are divided into

TWO

- **Surface Water Resource**
- Under ground water resource

Surface Water resources Projects

They are grouped into **TWO** on the basis their position

Under ground Projects

Over ground projects

Under ground Projects

Important components

Tunnels

Shafts

Power houses

Over ground structures

Dams -

Important components

Main dam

Spillway

Tail channel

Canals

Canal crossing bridges, etc.

AND

Along the canal, where sufficient falls MICRO-HYDAL projects are considered.

Classification of Water Resource Projects

1) Cost of the project

2) Irrigable land

i) Major

ii) Medium

iii) Minor

iv) Micro

However,

magnitude of the geologic difficulty is dependent on magnitude of geologic defect & not on the category of project

there are several examples of functional failures of minor / medium dams in Konkan region of Maharashtra in the absence appropriate geological investigations

Methods
of Geologic Investigations

⬇

1) Surface

2) Sub-surface

Objectives & Importance of the Geological Investigations

In initial phase, Feasibility of the site is based on cost effective aspect…in which

⬇

geology of site and availability of construction material are considered..

In case of "extremely adverse geological features" where it is not cost-effective ➡ the site is rejected

Geologic Report for DPR

1) Surface geo studies

- Traverse geological mapping of the project area – fold, fault, attitude of stratum, etc.
- Satellite data of the project area is studied for identifying the geologic structure on regional scale.

2) Sub-Surface geo studies

- Geo logging of bore holes
- Generation of geo – Maps and Sections
- Geomechanic rock mass classification

Contents of Report

Materials and methods
Inferences
Conclusions
Suggestions / recommendations

Surface Investigations

- **Previous data including literature review plus Geo investigations done for other projects in vicinity**
- **Field reconnaissance survey where-in geologic factors like mineral resource available in project area are considered.**
- **Generation of surface geologic maps, sections, etc.**
- **Terrain analyses – morphotectonics and its influence on project.**
- **Geological Map should depict – strike and dip directions, fault, folds, anticline, syncline, fractures, shear zones, rock types, etc.**

Report should cover

rock types,
weathering status of rock mass
physical and petrologic properties,
mineral composition,
hardness,
engineering properties,
permeability,
influence of geology on engineering structure ,
problems likely to occur during construction period,
preventive measures,
further investigations - if needed.

Sub-surface Investigations

1. **Drilling – most reliable method**

2. **Test pitting, trenching - reliable method : but for limited depth**

if not satisfied with above for deep seated structures

3. **Geophysical methods**

For detail studies

↓

Sampling

Laboratory testing

Field testing

Topography of Basin and Reservoir

- Topography is a detailed map of the surface features of land. It includes the mountains, hills, creeks, slopes, water bodies, drainage pattern etc.

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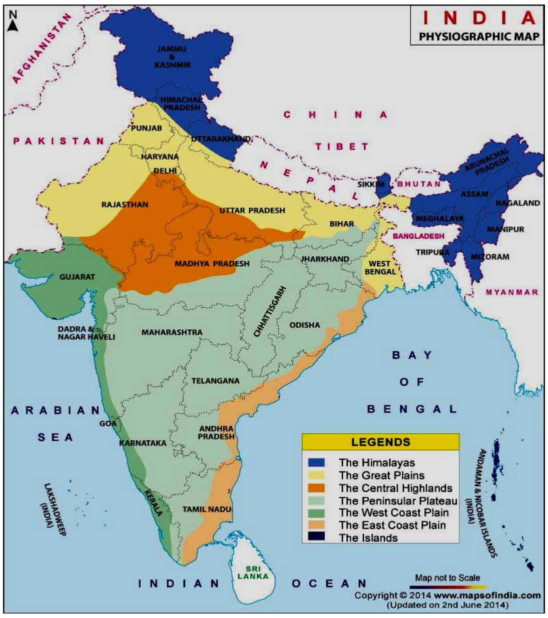
Topographic features reflect Geology with its structural characteristics like .. Faults, folds, shears, etc.

7 Topographic divisions of India



Topographic and Geomorphic features together give clues

regarding geologic features like

1) valleys → faults, fractures, shear zones

2) rolling topography → folds

3) linear mountain/ ridges → dykes

Geomorphology

- **Scientific discipline that describes and classifies the Earth's topographic features.**

Features indicate

- ***characters of the surface rocks and climatic variations, and include the developmental stage of landforms in geologic time period***

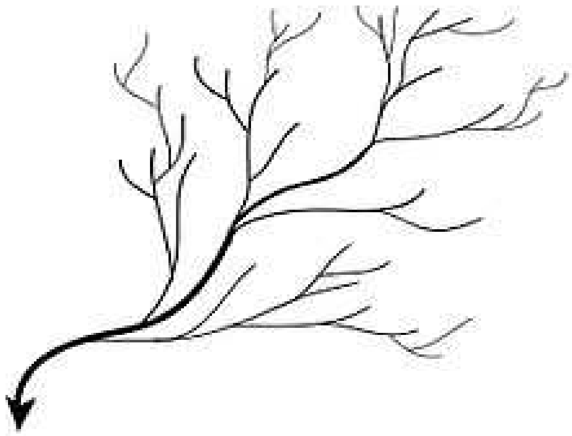
BECAUSE

earth face is always in the process of changes

Drainage Pattern is a BASIC FACTOR of geomorphology

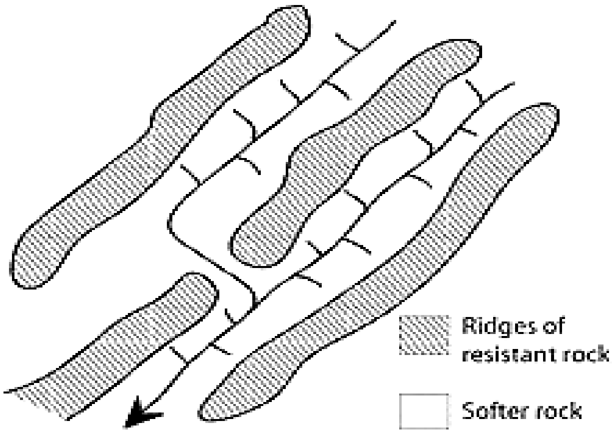
Major 6 patterns

Dendritic drainage pattern



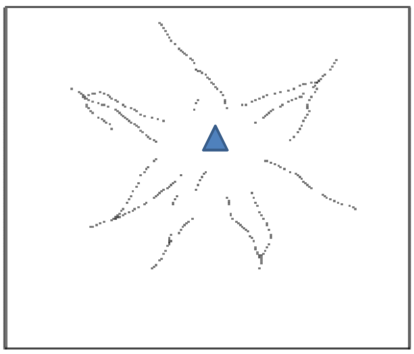
Dendritic drainage pattern developed in Himalaya

Trellis drainage is generally developed in **folded** mountains

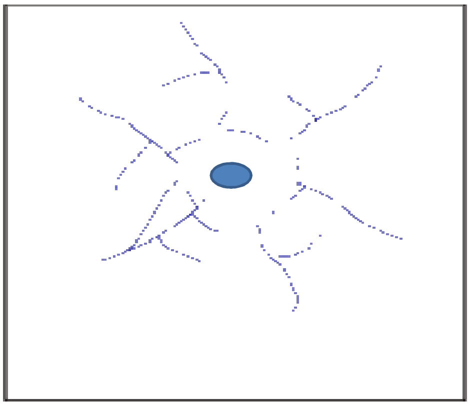


Radial drainage pattern

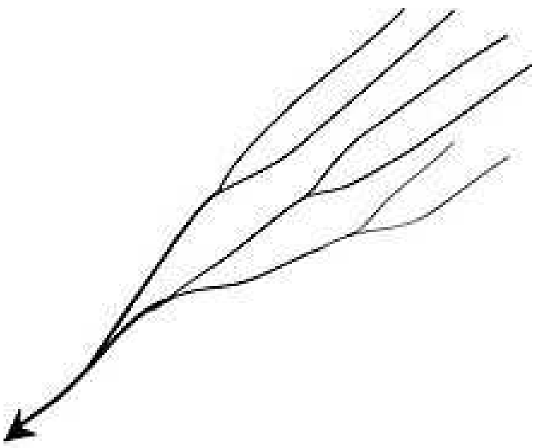
streams radiate outwards from a central **high land**



Annular drainage pattern is best seen in BASIN in central portion



PARALLEL drainage pattern



IMPLICATIONS OF GEO-TOPOGRAPHIC FEATURES

1) The soft rock beds are potential zones of the landslides, this endanger the civil structures.

2) Due to lithologic anisotropy of the alternate competent and incompetent rock mass types such as sandstones and shales, may pose problem of DIFFERENTIAL SETTLEMENT.

For preventing differential settlement

↓

reinforcement /raft foundation, grouting, etc. need to be considered

Panoramic view of the western face of Sahyadri mountain

HORIZONTAL DISPOSITION OF DECCAN TRAP FLOWS

This topography offers large number sites for storage tanks
but
canal network is not cost-effective due to landslides and rugged topography

Himalaya is Geologically recent mountain

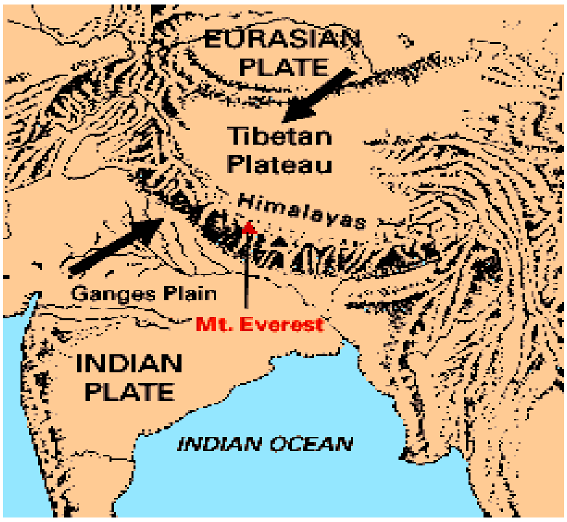
- in Geologic past there was Sea named

↓

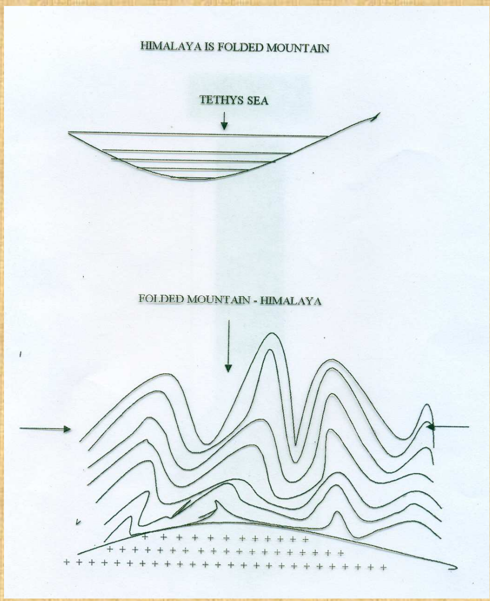
TETHYS

"Geosyncline (basin like structure)"

Himalaya Mountain ranges



Mountain Building Activity



Topographic Divisions of Himalaya

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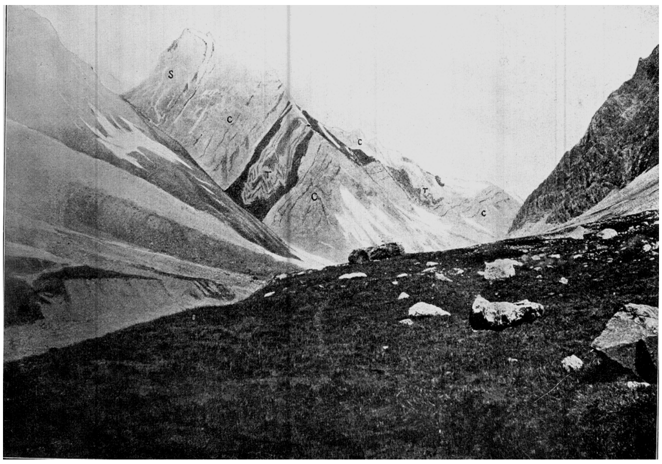
Three Divisions

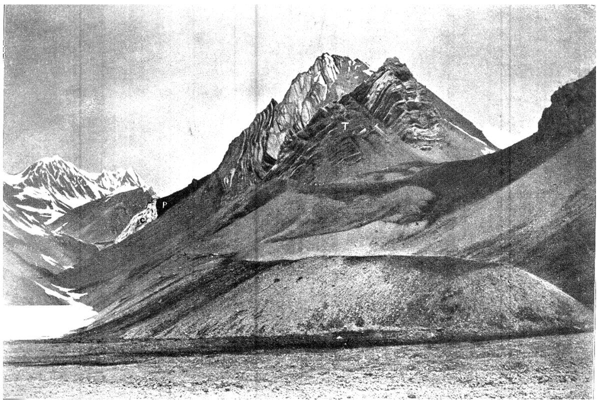
1) **Sub-Himalaya or Outer Himalaya**
2) **Lesser Himalaya or Middle Himalaya**
3) **Greater Himalaya or Inner Himalaya**

Folded mountain of Himalaya

Folded mountain of Himalaya



Folded mountain of Himalaya



1 - Division–wise
Geologic Peculiarities of the Himalaya

Sr. No.	Division	Rock types	Structure
1.	Sub-Himalaya or Outer Himalaya	Sandstones, siltstones, shales, Boulder, Conglomerate	Broad synclines and anticlines, reverse faults, ↓ main boundary fault separates Siwaliks and early tertiary and older beds.

2 - Division–wise
Geologic Peculiarities of Himalaya

Sr. No.	Division	Rock types	Structure
2	Lesser Himalaya or Middle Himalaya	Un-fossiliferous sediments – e.g. shales, slates, phyllites, limestones, Quartzites and acid & basic injections with low grade metamorphism	Highly folded and faulted.

3 - Division–wise
Geologic Peculiarities of Himalaya

Sr. No.	Division	Rock types	Structure
3	Greater Himalaya or Inner Himalaya	Schists, granites, granulites, crystalline limestone, and abundant plutonic injections.	Massive bands of rock with relatively widely spaced joints, Monotonous uniformity of rock facies where thermal metamorphism seen

Distribution of Geologic formations, India

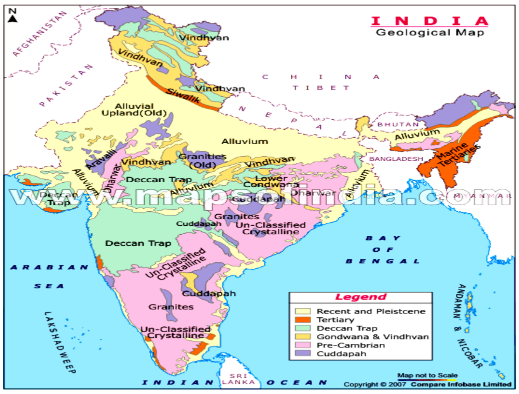
Recent and Pleistocene – Banks of river courses and sea shore

Tertiaries – Shelfs and Siwalik

Deccan Traps – Maharashtra

Gondawana and Vindhyan – Caddapah, Arawali and Mahanadi, and J & K

Pre-Cambrians – Southern Peninsula including Orissa and adjoining states

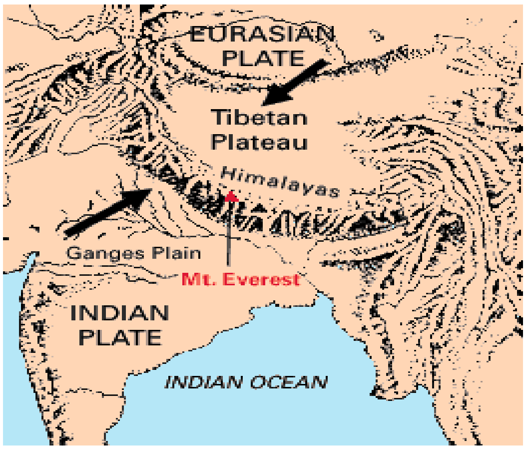


Geologic succession

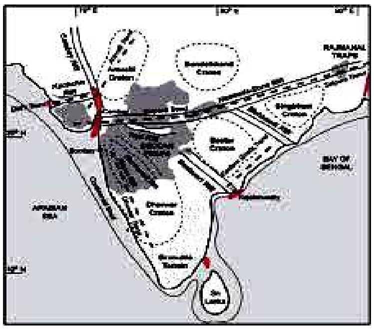
Age	Group	Formation	Lithology
Quaternary to Recent	Older and newer alluvial plains	Ramgarh Formation Bauras Formation Hirdepur Formation Baneta Formation Surajkund Formation Dhansi Formation Palikavar Formation	Calcareous sand, silt, clay, gravel and conglomerate
Cretaceous to Palaeogene	Deccan trap	Traps	Basaltic lava flows
Upper Permian to Upper Jurassic	Gondwana	Jabalpur Formation Bagra Formation Denwa Formation Panchmari Formation Bijori Formation Motur Formation Barakar Formation Talchir Formation	Boulder beds, sandstone, shale, clay, and minor proportion of coal
Proterozoics	Vindhyan	Bhander, Rewa and Kaimur	Shale, sandstone, limestone and quartzite
Palaeo-Proterozoic	Mahakoshal group	--------------------------	Quartzite, phyllite and dolomite
Precambrians	Achaeans	Basement	Metamorphic, granites

Seismic Activities

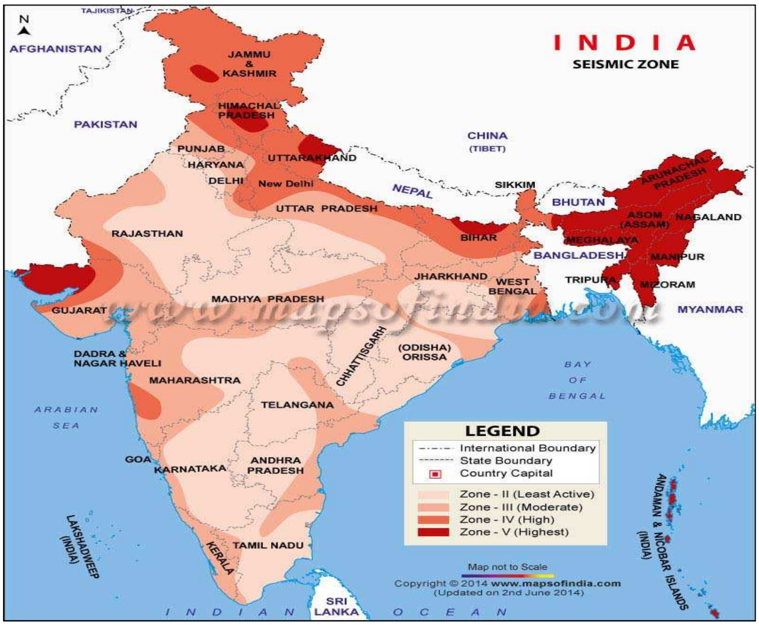
Seismic activity in Indian Continent is associated with Plate tectonics



Seismic activity in Southern Plateau of India is associated
Major Sub-crustal lineaments



Seismic zones of India most active to least active



Reservoir Induced Seismicity

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In India – Koyana Dam has been considered

But

I do not agree to

Geological Investigations must have objective of
Reservoir Competency

Effective water storage is the purpose of construction of Dam

but

This is hampered sometimes due to leakages through the pervious rock at foundation or at its periphery

adverse geologic features

↓

faults, fractures, shear zones, pervious stratum, etc.

Two Methods of Geologic Investigations

1. Surface Geologic investigation

2. Sub-surface geologic explorations

Surface Geologic investigations (mapping)

Carried out by

- Taking Traverses in the area
- Collection of geologic data
  like ….

Rock type

Attitude of bed (like strike and dip directions)

Geologic structures like faults, folds, fractures, shear zones, dykes, sills, etc.

Major ADVRESE geologic features to be investigated for civil engineering structures

↓

Shear Zones

Weak Joints

Faults

Solution Cavities

Weathered Zones

Buried Channels

Geologic features and probable problems on structure….

↓

Horizontal stratification are – safe

- Inclined stratification in d/s direction ---
  - stability problem

Folds – merits based on inclination and perviousness of strata
d/s dipping pervious strata - prone to leakages

Faults – leakages, stability, settlement

Shear zones / fractures- leakages, stability, settlement

Sub-Surface Geologic Investigations

1 - Rock core drilling

Rock-core samples are obtained by drilling with special drills into the rock mass with a hollow steel tube

The rock-cores obtained are studied by different techniques and equipment depending on the type of data desired.

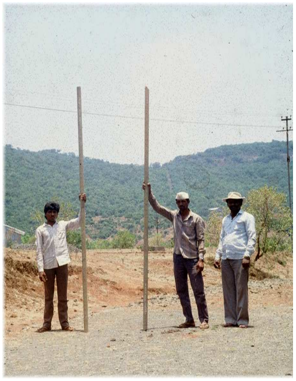
Some of the Drill types

- Auger drilling
- Cable tool drilling
- Diamond core drilling
- Hydraulic rotary drilling
- Sonic (vibratory) drilling, etc.

Rock drilling

Rock core diamond drill bits

Classical example of more than 3 m long core samples of columnar compact basalt drilled with diamond bit



GEOLOGS

GEOLOGS FOR MATR-23

Project: Geotechnical Investigation for Malad, Vesova Transfer Tunnels, Land Based Portion of Erangal Outfall — Diameter of Hole: NX

Borehole no: MATR -23 — Depth of bh (m): 40.00

Co-ordinates — Ground RL (m): 27.124

f- fresh joints lined with chlorophaeite / black glassy material, ch-chlorophaeite, bg- black glass, m - multiple joints, i- inclined joint (about 45 degrees), h - horizontal, b - mechanically broken, v- vertical joint, LAB - speciment sent for testing, (very small core pieces - *)

Core Dril Run (m)		Lithologic description of cores from geotechnical point of view	Piece No.	Length of Piece (cm)	Structural Features		Core Recovery (%)	Rock Quality Designation (%)	RQD	Jn	Jr	Ja	Jw	SRF	Q	Strength	RQD	**Jspa** Spacing of Disconinuity	**Jond** Condition of joints	**Jw** Water Condition	**Jadj** Adjustment for Joint Orientation	RMR
From	To				Description of Discontinuities	Number of discontinuities / approx. orientation (degrees)																
1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
3.15	4.00		1	5			49	0														
			2	4																		
			3	2																		
			4	8																		
			5	4																		
			6	5																		
			7	5																		
			8	9																		
4.00	5.50		9	68			97	87														
			10	30																		
			11	7																		
			12	9																		
			13	14																		
			14	18																		

2 - Geophysical investigations

These methods are cheaper than rock core drilling

BUT

have several limitations about accuracy of results

Electric resistivity is fairly reliable for
estimating depth of over burden and buried channels

Important Methods of Geophysical Investigation Surveys

Electric Resistivity Surveys

Gravity meter

Electromagnetic

Radiometric

Seismic refraction

Seismic reflection

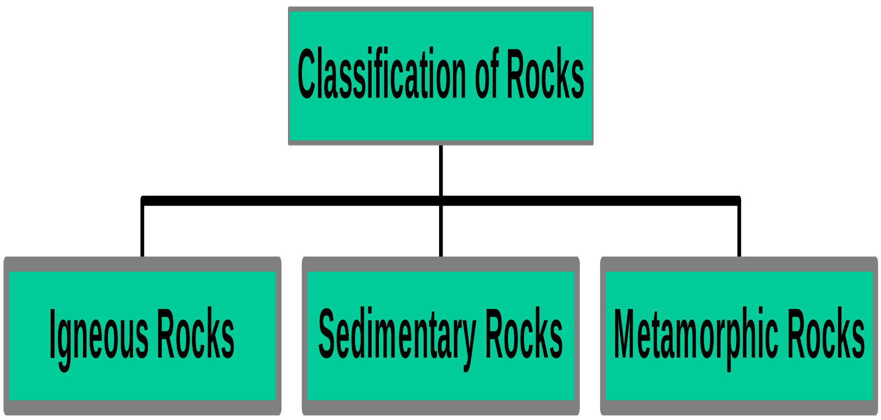
Over Burden / soft rock create

Major Problems like

1) Slope stability during heavy rains

2) Leakages

3) Settlement



Igneous Rocks

- Based on Position

1) Volcanic Rocks – deposited at earth surface due to volcanic activity
e.g. All types of basalt

2) Hypabassal rocks – formed beneath earth surface but at shallow depths – intrusion of Magma
e.g. Dyke, sills – dolerite

3) Plutonic Rocks – deep seated rocks
e.g. Granite

Metamorphic Rocks

The metamorphic rocks are derived from all types of rocks;

⇓

due to temp. and pressure acted upon them

⇓

product is dependent on
composition of original rock
and
degree metamorphism

e.g.
Gneisses
Amphibolites
Shiest, etc.

Sedimentary Rocks

↓

agent of transportation

water and wind

↓

Formed in lakes, sea, river banks, open ground.

e.g.

Sandstone
Shale
Limestone
Conglomerate, etc.

Geologic
Weak Features

↓

linear and planar features

↓

Fault,
shear zones,
dykes,
Fractures,
Bedding planes,
foliation (parallel), etc.

Dyke (dolerite) in Deccan Traps

Joints: 3 sets plus random

magma invaded into basalt rocks

FAULTS

↓

Generally linear and extending over long distances

Thickness few millimeters to some meters

Adjoining rock is highly fractured

Thrust Fault

Folds

Treatment to Weak features

Shear zones
Folds
faults

Conventionally carried out

Excavate weak portion and fill back with concrete

$d = 0.002\ bH + 5$ for $H > 150$ ft
$d = 0.3\ b + 5$ for $H < 150$ ft

where
H = height of the dam
b = width of the weak zone
d = depth of excavation weak zone for clay gouge $d > 0.1\ H$

For Underground excavations

Investigations in Different phases

1) Investigations
2) Engineering planning & design
3) construction phases

- Analysis of rock deformations;
- Evaluation of hardness of rock;
- Analysis of rock stability;
- Control of blasting procedures, etc.

In this context Engineering properties required

⬇

1. Rock mass classification
a. rock mass rating, b. tunneling quality index

2. Modulus of elasticity

3. Uniaxial compressive strength

4. Tri-axial compressive strength

5. Shearing along the plane of discontinuity

6. Durability test

7. In-situ stress pattern

8 . Structural features like fractures, faults, shear zones, dykes, etc.

Physical properties of rocks

⬇

principal rock type

colour

Crystalanity

mineralogy

porosity

hardness
compressive strength

unit weight (dry), etc.

Geotechnical Properties of Rocks

↓

– Mineralogical composition and texture;

– Planes of weakness;

– Degree of mineral alteration;

– Pore water content,

– Length of time and rate of changing stress that a rock experiences, etc.

Geotechnical properties more dependent

↓

structure and texture of rocks

e.g.

Mineral assemblage of
compact basalt, amygdaloidal basalt and volcanic breccia is same

But

Lab & field tests results
differ widely

↓

because of structures and textures are different

Texture – structure ⇨ ⇦ Geotechnical Properties of Rocks

Texture and structure influences

⇩

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

Further

Rock defects such as

Micro-fractures,

grain boundaries,

mineral cleavages,

twinning planes

AND

planar discontinuities influence the ultimate rock strength and may act as "surfaces of weakness"

where failure occurs

Geomechanic Rock Mass Classification

⇩

1) Rock mass rating (RMR)

2) Tunneling quality index (Q)

Engineering Classification Systems for Rock (cont.)

– Bieniawski's Geomechanics system - rock mass rating (RMR) which increases with rock quality (from 0-100).

It is based on five parameters namely,

Rock strength;

Drill core quality;

Groundwater conditions;

Joint and fracture spacing,

joint characteristics.

Adjustment for joint orientation

Tunneling quality index

RQD - Rock Quality designation

Jn - joint set number

Jr - joint roughness number

Ja - joint alteration number

Jw - joint water reduction factor

SRF - stress reduction factor

Dyke (dolerite), Joints: 3setsplus random

Important Engineering Properties of Rocks

Porosity-

Identifies the relative proportions of solids & voids;

Density-

a mineralogical constituents parameter;

Permeability-

the relative interconnection of pores;

Durability-

tendency for eventual breakdown of components or structures with degradation of rock quality, and

Strength-

existing competency of the rock fabric binding components.

Permeability

Dense rocks like granite, basalt, schist and crystalline limestone possess

very low permeability in lab-specimens,

but

Field tests can show significant permeability due to open joints and fractures.

Strength- by point load test

Point Load Test of Broch and Franklin (1972)

Irregular rock or core samples are placed between

hardened steel cones and loaded until failure

by development of tensile cracks parallel to the axis of loading

Engineering Properties of the rocks of the Himalayan Rock

similar rock types exhibit variations in properties

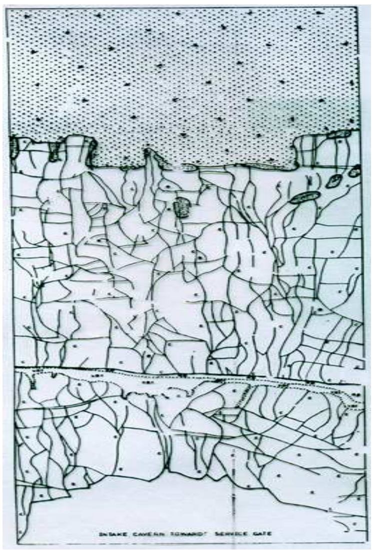
Rock Type	Crushing Strength Dry (Kg/cm²)	Crushing Strength Wet (Kg/cm²)	Poisson's Ratio	Modulus of Elasticity (Field Tests) 10^5 kg/cm²	PROJECT
Sandstone (Lower Siwalik)	513 - 1069	-	0.67 – 0.2	0.5 – 1.6	Bhakra Dam Site
Siltstone (Lower Siwalik))	595 – 948	-	0.30 - 0.35	0.19 – 1.4	Bhakra Dam Site
Sandstone (Lower Siwalik)	53 – 551	10 – 400	-	-	Thein Dam
Sandstone (Lower Siwalik)	351 – 1125	211 – 773	0.103 – 0.225	0.08 – 0.22	Kodri P.H. Yamuna Hydel Project.
Sandstone (Middle Siwalik)	68 – 258	17 – 44	0.15 – 0.25	0.08 – 0.59	Ramganga Dam Project U.P.
Sandstone (Middle Siwalik)	128 – 421	33 – 121	0.06 – 0.12	0.37 – 0.4	Ramganga Dam Project U.P.
Sandrock (Upper Siwalik)	19 – 247	0 – 121	0.34 – 0.38	0.21 – 0.86	Beas Dam Project, Punjab.
Sandrock (Upper Siwalik)	89 – 123	-	0.29 – 0.36	0.42 – 1.01	Beas Dam Project, Punjab.

Peculiar rock mass types

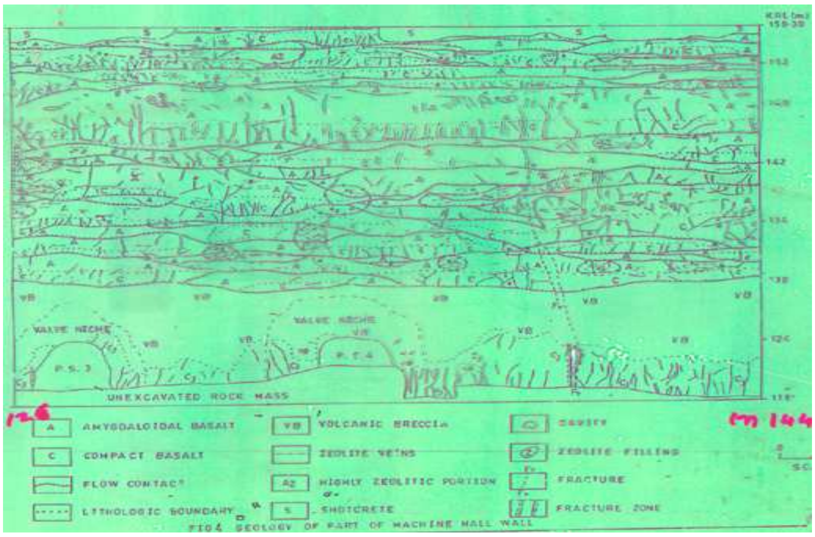
Deccan Trap Basalt

Exposed red bole and volcanic breccia

"AA" type of Deccan Trap flow - Variation in structural features with depth



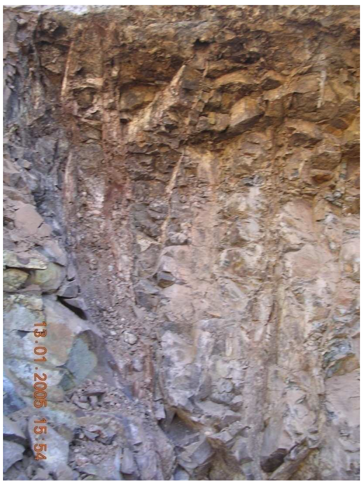
Horizontal thin "pahoehoe" and "aa" flows of basalt



Cavity in a flow of Deccan Trap Basalt
(about 3x1.5m size)

Fracture zone in Deccan Trap Basalt

Fracture zone in Deccan Trap Basalt



Sedimentary rock –
Shale inter-bedded with grits

Vindhyan Quartzitic sandstone near Udaipur
Shear zone – disintegrated rock material

Debris of Black shale

Almost un-jointed Granite of California

Sculptures in Massive (un-jointed) Granite mount Black hills of South Dakota

Exposure of Schist

moderate angle of dip and planes of foliations

Schist showing foliations

Schists – micro- folded soft and hard mineral layers

Augean gneiss near Gangotri

Failures of Water Resources Projects due to Geology

» **Partial**

or

» **Complete**

MAJOR CAUSES OF DAM FAILURES

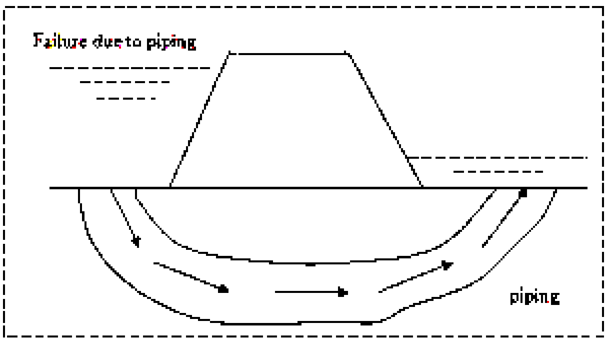
OVERTOPPING

PIPING & SEEPAGE

FOUNDATION – weak soft rock foundations settlement, slides

OTHERS

Dam failure due to Piping



Buried river channel at Khakrapara MI tank near Dhule, Maharashtra

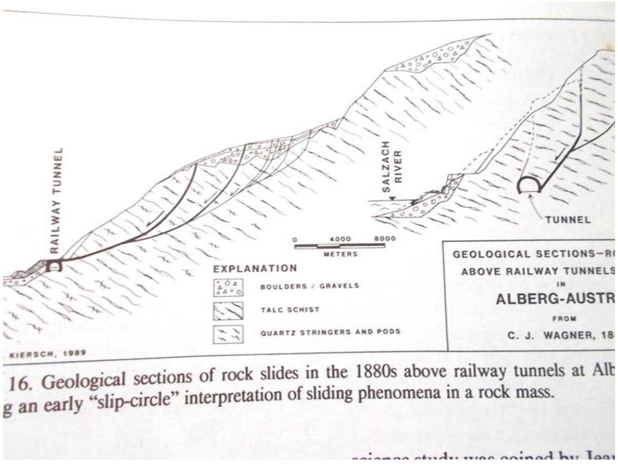
Khparkheda Dam – leakages below foundation
Loose conglomerate when reservoir is totally dry – buried river channel

Waste weir / Spill way

There are several examples of weak foundations of side spill ways causing erosion and leakages though the foundation rocks more particularly in case of Minor Irrigation Tanks

Dam failure - spillway

Slope stability - Landslides along slip circle in soft stratum (overburden)



Landslide at Ghatghr Pump Storage Scheme

Diversion of river by 180 degree and Silting of Reservoir

Practically NO engineering structure can be rejected on the basis of adverse geologic environ

but

It should be cost-effective

QUALITY CONSCIOUS FETCHES SUCCESS

Thank you !