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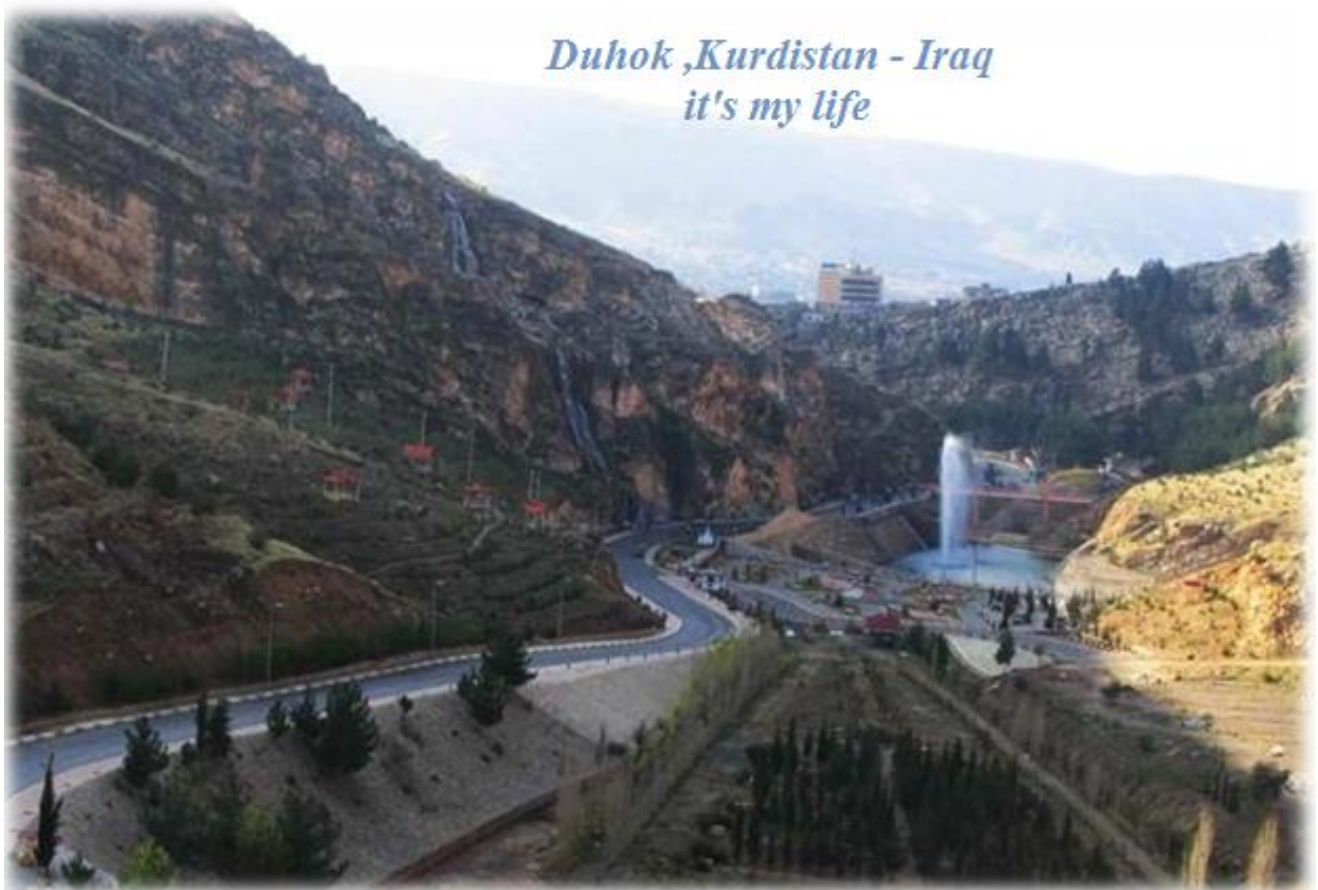
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# *Engineering Geology* *and* *Tunnels Engineering*

*Collected by*

*Ing. Jaafar MOHAMMED*

*2014 - 2015*



*Duhok ,Kurdistan - Iraq*  
*it's my life*

I wrote this simple textbook since I was at the second semester of my doctoral study in Czech Republic at the University of VŠB-Technical University of Ostrava, and through my research by preparing to my study I got this idea that I write this small textbook for civil Engineering student, because I thought that this work will be easier for them by searching information and save time as well as help them in the field.

Respective thanks to all the researchers and authors who I relied on their knowledge in my textbook and also, I thanks the Internet websites which I relied on , maybe I did not mention their names through texts but present in the references list .

It's my pleasure if there is any mistake in this textbook to contact me by e-mail

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*The aim of my work is make mix between Engineering Geology and Geotechnical Engineering , therefore, you can see there are two part ,first part is about Engineering Geology and the second is Geotechnical Engineering specialty Tunnelling .*

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## ***Abstract***

The foundation supporting a civil engineering structure is the most important element of the structure, and will have an effect on the quality, safety and construction costs of the project. Usually, the geotechnical properties of the foundations are determined through engineering geological surveys and ground investigations, prior to construction and will, in some cases, guide the planning and design.

Geology, one of the core science disciplines with physics, chemistry, and biology, is the search for knowledge about the Earth, how it formed, evolved, and how it works. Geology is often presented in the broader context of Geosciences; a grouping of disciplines specifically looking for knowledge about the interaction between Earth processes, Environment and Societies.

Structural Geology aims to characterise deformation structures (geometry), to characterize flow paths followed by particles during deformation (kinematics), and to infer the direction and magnitude of the forces involved in driving deformation (dynamics). A field-based discipline, structural geology operates at scales ranging from 100 microns to 100 meters (i.e. grain to outcrop). [1]

In the tunnel construction, a ground investigation such as surface geological survey, boring investigation, seismic prospecting refraction method, electrical exploration, etc. are carried out prior to construction, and the results are summarized in the geological profile. However, most of these investigations were conducted from surface, and several assumptions were made in the interpretation of the ground profile.

## ***Introduction***

Geology is the study of the Earth, it embraces knowledge of geological materials (characteristically soils and rocks) and the processes that formed them and that currently transform them. Engineering geology is the application of the science of geology to the technology of ground engineering. The subject requires a comprehensive knowledge of geology, as well as an understanding of engineering properties and behaviour of the geological materials. The practice involves site investigation and site characterization specific to the needs of the engineering project. In outline, the investigation should cover the area of terrain that is affected by the project, and any adjacent terrain from which geological processes could affect the project.

Engineering geology provides the link between geology and engineering through the formation of geological models which can be used to identify geological hazards and uncertainty, plan effective ground investigations, and define blocks of ground and geological structures in an engineering context to facilitate geotechnical risk assessment and design.

The geotechnical engineer plays a key role in most civil engineering projects as most structures are built on or in the ground. Geotechnical engineers assess the properties and behaviour of soil and rock formations. In order to ensure safety, long term stability and quality control in modern tunneling operations, the acquisition of geotechnical information about encountered rock conditions and detailed installed support information is required.

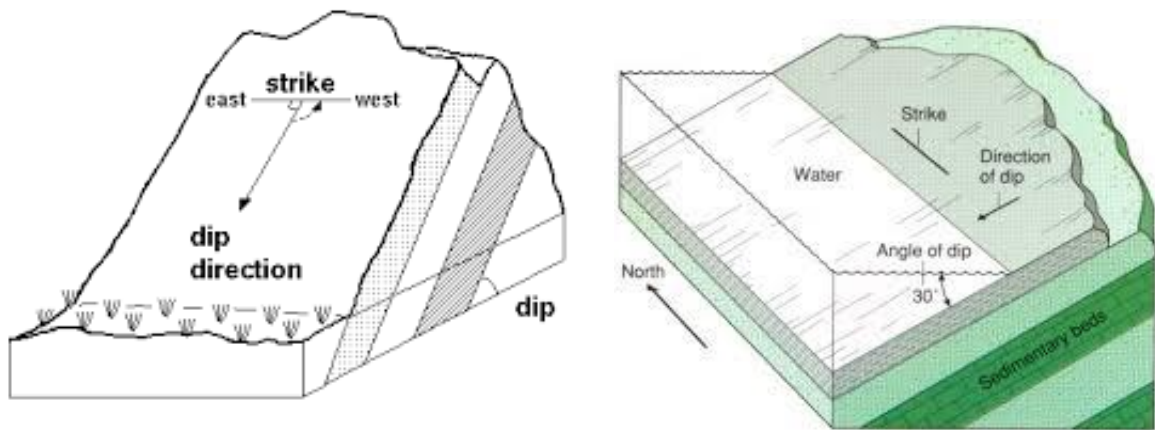
There are many rock mass classification schemes which are frequently used for different purposes such as estimation of strength and deformability of rock masses, stability assessment of rock slopes, tunneling and underground mining operations etc. Constructing tunnels have always challenged engineers, from the early basic drill and blast tunnels to modern TBM tunnels that are more like a gigantic tunnel factory.

### **When constructing tunnels you always follow some basic steps**

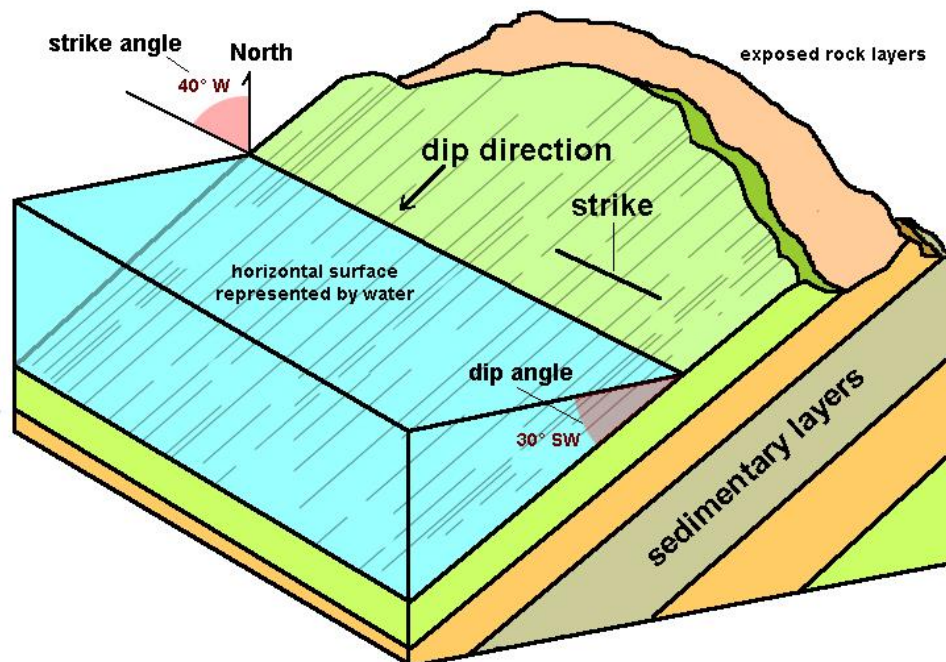
1. Ground investigation,
2. Excavation and
3. Support and maintenance.

As all scientists, structural geologists follow research strategies that call upon concepts such as: fact, hypothesis, model, theory, and law. A good understanding of these terms is essential to all scientists.

A **fact** is a bit of truth. For a structural geologist a “fact” could be the dip direction of a bedding plane. Having measured that north is to the left on the photo on the right, then it is a fact that the dip direction of the bedding is to the south.[1]



*Figure.1 – Dip direction*



*Figure.2 – Describing orientation of geologic features with strike and dip*

A **hypothesis** is an assumed fact. It is a short statement one makes to go further into reasoning. For instance, assuming that the bottom right photo contains the stretching lineation (hypothesis), then one can infer that the sense of shear deduced from the tilling of K-feldspars in this orthogenesis is top to the right. [1]

A **model** is a self-consistent framework providing a coherent explanation for the observed facts. A model combines as many facts as possible and as little hypotheses as possible. A good model allows making verifiable predictions. A model is proven wrong if key predictions are not verified. It can be iteratively strengthened via minor modifications to account for both the facts and the predictions.

A **theory** is a very robust model which accounts for a large number of independent facts; and who are numerous predictions have been verified over a long period of time.

A **law** is a simple, fundamental concept that is always verified by experiments and that underpin our understanding of the world. For instance, the law of gravity and the laws of thermodynamics underpin our understanding of Physics and Chemistry. [1]

## Part 1

# Geological Engineering

*In engineering geology basic knowledge is required of the following:*

- |                             |  |
|-----------------------------|--|
| I. Soil mechanics           | IV. Concrete and road-stone technology |
| II. Hydrology               | V. Mining technology                   |
| III. Foundation engineering | VI. Seismology                         |

## *Rocks and Minerals*

- I. A **mineral** is solid inorganic material of the Earth that has both a known chemical composition and a crystalline structure that is unique to that mineral.  
**Mineral Characteristics** [natural , inorganic ,solid , definite composition and crystal structure ]
- II. A **rock** is a solid aggregate of one or more minerals that have been cohesively brought together by a rock-forming process.



*Figure.3- Rocks vs Minerals*

## *Geologic Classification of Materials*

### **Bedrock**

Bedrock is a general term that includes any of the generally indurated or crystalline materials that make up the Earth's crust. Individual stratigraphic units or units significant to engineering geology within bedrock may include poorly or non-indurated materials such as beds, lenses, or intercalations.



*Figure. 4- Bedrock*

## Surficial Deposits

Surficial geology is the study of loose, unconsolidated material overlying the bedrock foundation. These layers were deposited, rearranged and eroded by glaciers, fluctuating sea level, streams, landslides, and bulldozers. While bedrock geologists tend to think in time-frames of millions of years, the surficial story is usually faster paced, taking place over millennia and mere centuries.

**They occur as two major classes:**

- Transported deposits generally derived from bedrock materials by water, wind, ice, gravity, and man's intervention and
- Residual deposits formed in place as a result of weathering processes. Surficial deposits may be stratified or unstratified such as soil profiles, basin fill, alluvial or fluvial deposits, landslides, or talus.



*Figure. 5- Surface Deposits can eventually become stuck together forming what is called conglomerate*

## Lination

**Lination** – a fabric element in which one dimension is considerably longer than the other two. Tectonic linear structures include elongated physical objects – stained mineral aggregates, **conglomerate pebbles** – lines of intersection between two sets of planar structures, and geometrically defined linear features such as fold hinge lines and crenulation axes.



*Figure. 6 - lination on a bedding plane*



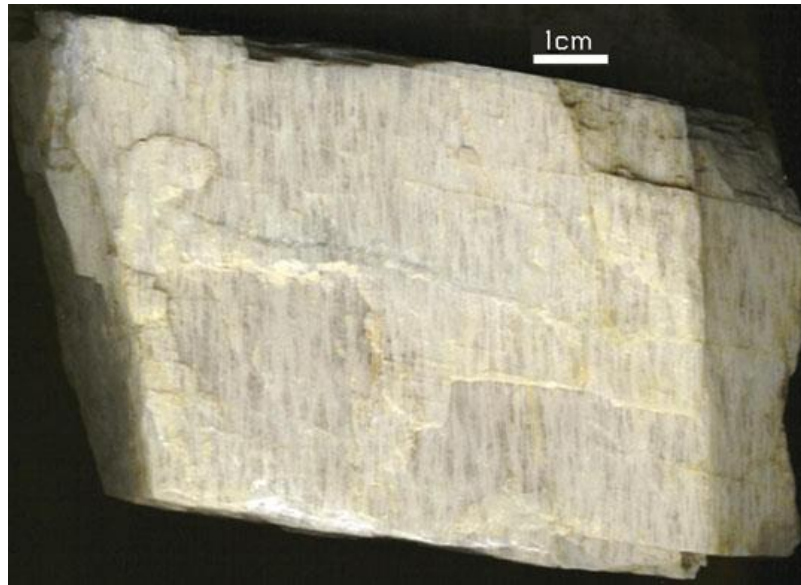
*Figure.7- Crenulation lineation*

### ***Types of lineation***

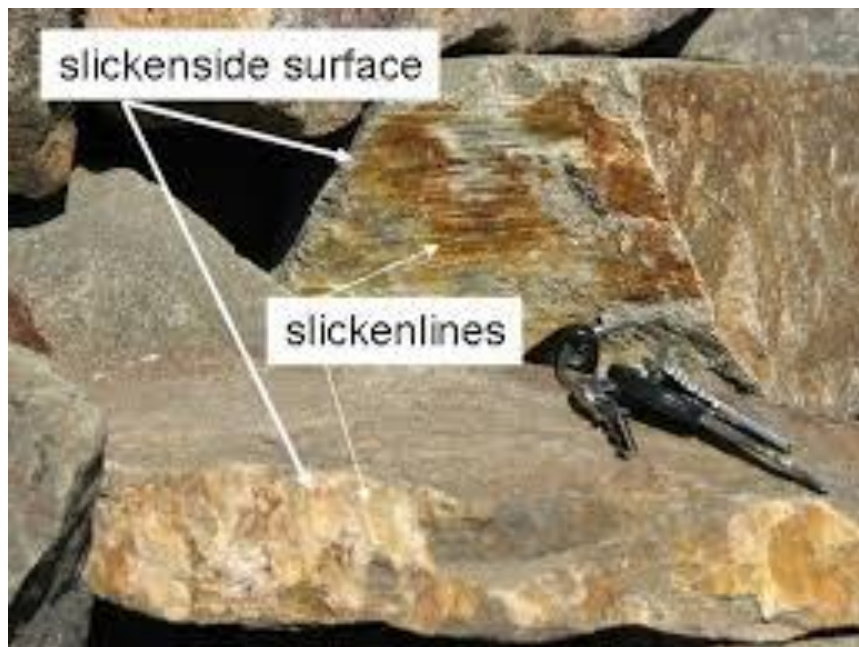
1. Penetrative lineations which build up a linear fabric or L-fabric
2. Surface lineations – restricted to a surface (e.g. slickenlines)
3. Geometric lineations – fold axes and intersection lineations



*Figure.8- Primary fabric*



*Figure.9- Perthite fabric in feldspar. Image from wikipedia commons*



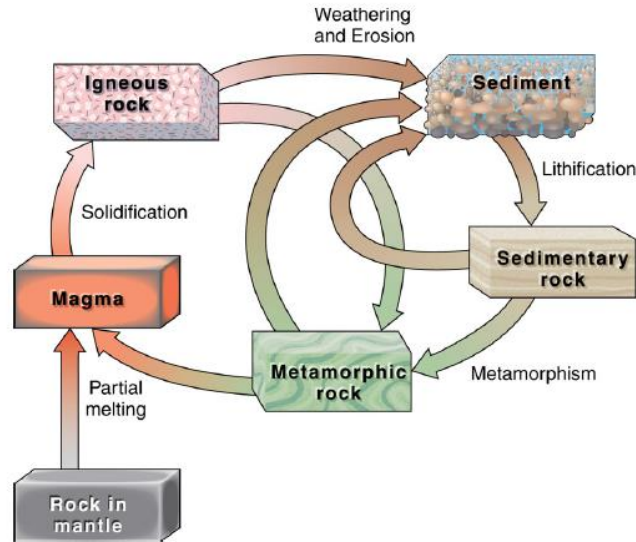
*Figure.10- slickenlines*

### ***Rock Types and Stratigraphy***

**Most rocks are an aggregate of one or more minerals, and a few rocks are composed of non-mineral matter.** According to their origin, rocks are divided into three groups, namely, the igneous, metamorphic and sedimentary rocks.

#### ***Major Rock Types***

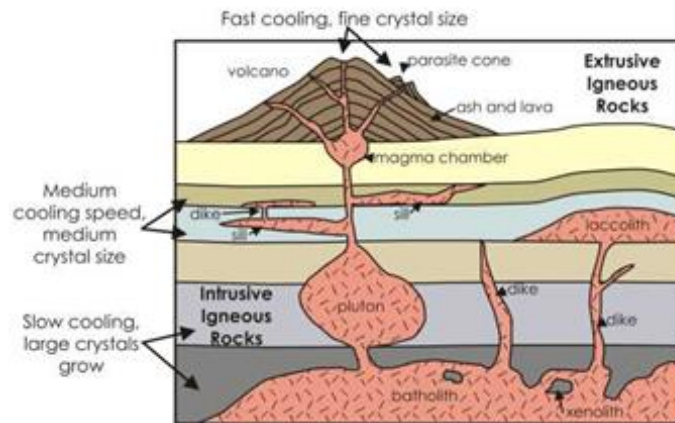
1. Igneous rocks are formed by the cooling of molten magma or lava near, at, or below the Earth's surface.
2. Sedimentary rocks are formed by the lithification of inorganic and organic sediments deposited at or near the Earth's surface.
3. Metamorphic rocks are formed when preexisting rocks are transformed into new rocks by heat and pressure below the Earth's surface.



**Figure.11- The rock cycle**

➤ **Igneous Rocks**

Igneous rocks are formed when hot molten rock material called magma solidifies. Magmas are developed when melting occurs either within or beneath the Earth’s crust, that is, in the upper mantle. Igneous rocks may be divided into intrusive and extrusive types, according to their mode of occurrence.



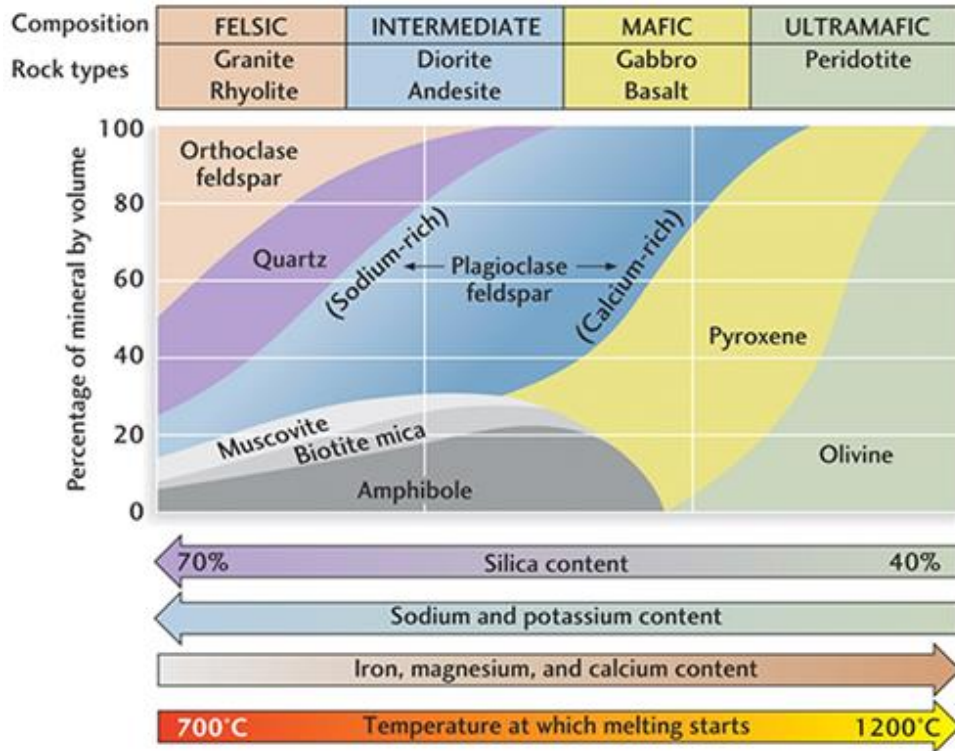
**Figure.12 - Igneous Rocks**

**The Classification of Igneous Rocks into Suites**

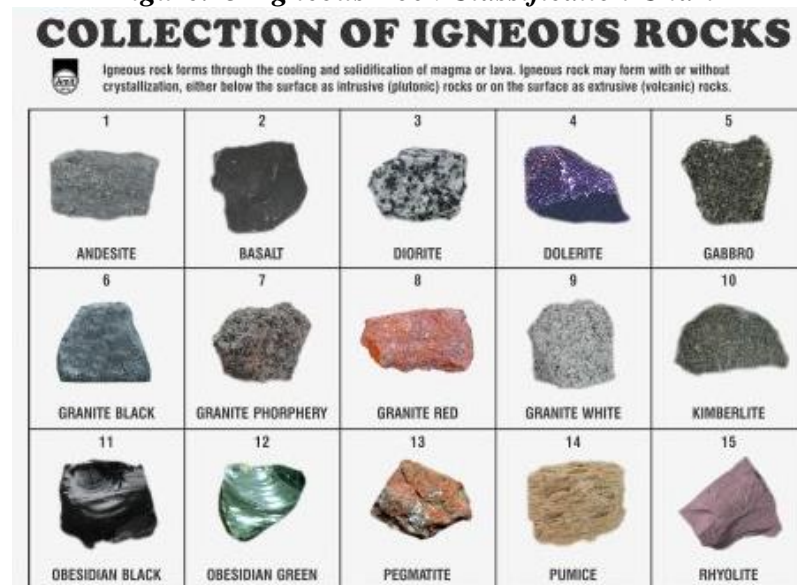
Igneous rocks are classified on several different criteria, including color, mineral composition, and chemistry. An igneous suite is a chemical classification. There are four major suites summarized in the table below.

**Table.1- classification of Igneous**

	FRACTIONATION		SEQUENCE	
	Komatiite Suite	Tholeiite Suite	Calcalkaline Suite	Alkaline Suite
Silica Saturation	Over Saturated	Over Saturated	Over Saturated 56-61%	Under Saturated <51%
Iron Enrichment	Low Fe: High Mg, Ni, Cr	Iron Enriched	Not Iron Enriched	Iron Poor
Alkali index CaNa/K ratio	> 1	> 1	1	< 1
Typical Rocks	Peridotite Basalt Andesite	Basalt	Diorite Monzonite Plagiogranite Rhyolites	Alkali basalt Alkali granite Syenite Sodalites
Tectonic Location	Archaean rifting sites	Rifting sites	Subduction zones; volcanic arcs	Many situations: rifts, hotspots volcanic arcs



**Figure.13- Igneous Rock Classification Chart**



**Figure.14- Collection of Igneous Rocks**

## ➤ Metamorphism and Metamorphic Rocks

Metamorphic rocks are derived from pre-existing rock types and have undergone mineralogical, textural and structural changes. These changes have been brought about by changes that have taken place in the physical and chemical environments in which the rocks existed. The changing conditions of temperature and/or pressure are the primary agents causing metamorphic reactions in rocks.

Metamorphic reactions are influenced by the presence of fluids or gases in the pores of the rocks concerned. For instance, due to the low conductivity of rocks, pore fluids may act as a medium of heat transfer. Not only does water act as an agent of transfer in metamorphism, but it also acts as a catalyst in many chemical reactions.

Two major types of metamorphism may be distinguished on the basis of geological setting. One type is of local extent, whereas the other extends over a large area. The first type refers to thermal or contact metamorphism, and the latter refers to regional metamorphism. Another type of metamorphism is dynamic metamorphism, which is brought about by increasing stress. However, some geologists have argued that this is not a metamorphic process since it brings about deformation rather than transformation.



Figure.15- Metamorphic Rocks

TEXTURE	GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT	MICA QUARTZ FELDSPAR AMPHIBOLE GARNET PYROXENE	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	Slate	
				Foliation surfaces shiny from microscopic mica crystals	Phyllite	
	Platy mica crystals visible from metamorphism of clay or feldspars			Schist		
	High-grade metamorphism; mineral types segregated into bands			Gneiss		
NONFOLIATED	Fine	Carbon	Regional	Metamorphism of bituminous coal	Anthracite coal	
	Fine	Various minerals	Contact (heat)	Various rocks changed by heat from nearby magma/lava	Hornfels	
	Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	Quartzite	
		Calcite and/or dolomite		Metamorphism of limestone or dolostone	Marble	
Coarse	Various minerals		Pebbles may be distorted or stretched	Metaconglomerate		

Figure.16- Scheme of Metamorphic Rocks

➤ **Sedimentary Rocks**

**Sedimentary rocks are created from sediments.** The sedimentary rocks form an outer skin on the Earth's crust, covering three-quarters of the continental areas and most of the sea floor.

Most sedimentary rocks are of secondary origin, in that they consist of detrital material derived by the breakdown of pre-existing rocks. However, certain sedimentary rocks are the products of chemical or biochemical precipitation whereas others are of organic origin. Thus, the sedimentary rocks can be divided into two principal groups, namely, the clastic (detrital) or exogenetic, and the non-clastic or endogenetic types. Nevertheless, one factor that all sedimentary rocks have in common is that they are deposited, and this gives rise to their most noteworthy characteristic, that is, they are bedded or stratified.



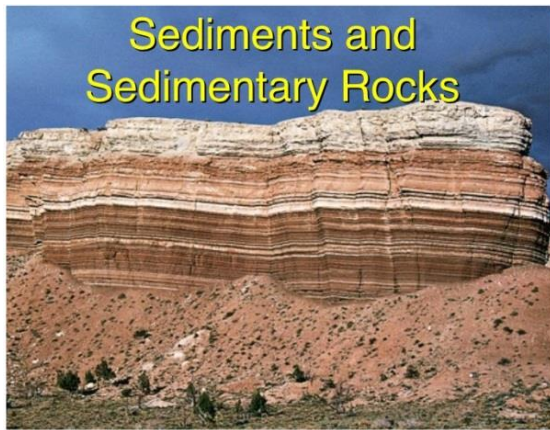
**Figure.17- Example of Clastic Sedimentary Rocks [Conglomerate and Because]**



**Figure.18- Example of Clastic Sedimentary Rocks [1-Shale, 2- Siltstone, 3- Sandstone]**



**Figure.19-Examples of Chemical Sedimentary Rocks - Evaporates [1-Gypsum, 2- Halite]**



## Sediments and Sedimentary Rocks



Figure.20- Sediments and Sdimentary Rocks

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

Figure.21- Scheme of Sediments Rocks

### Characteristics of Sedimentary Rocks

- I. Deposited at the earth's surface by wind, water, glacier ice, or biochemical processes
- II. Typically deposited in strata (layers) under cool surface conditions. This is in contrast to stratified volcanic rock (tuff), which has a hot origin.

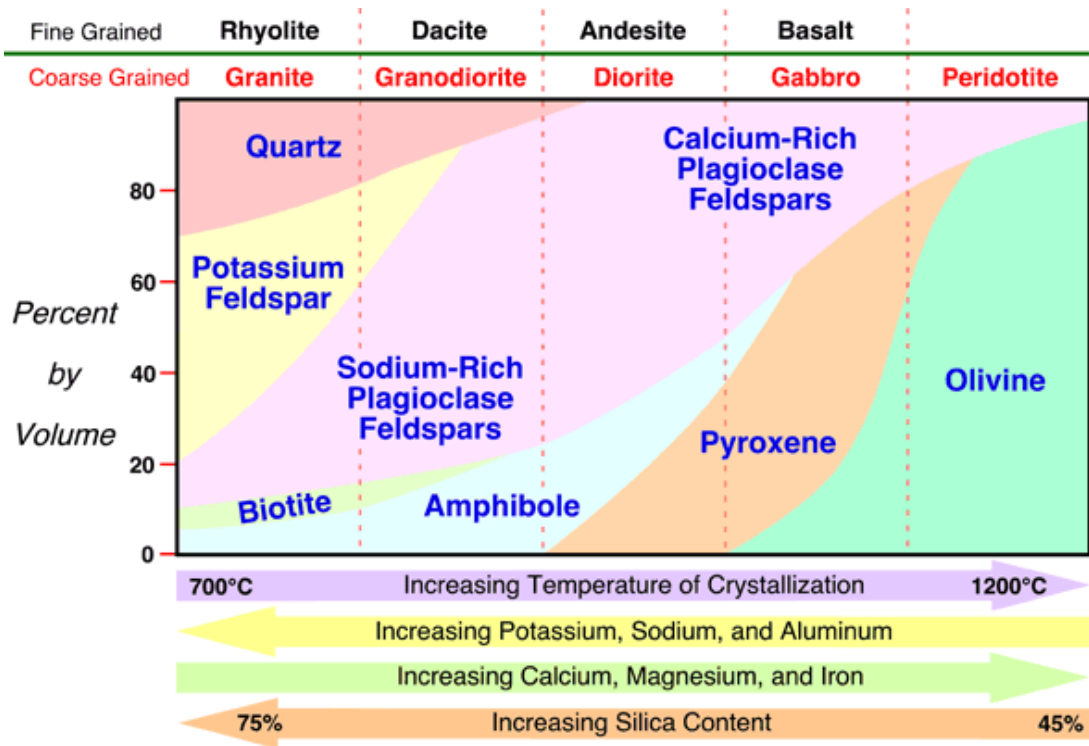


Figure.22- The classification of igneous rocks. This graphic model describes the difference between nine common igneous rocks based on texture of mineral grains, temperature of crystallization, relative amounts of typical rock forming elements, and relative proportions of silica and some common minerals.[ <http://www.physicalgeography.net/fundamentals/10e.html> ]

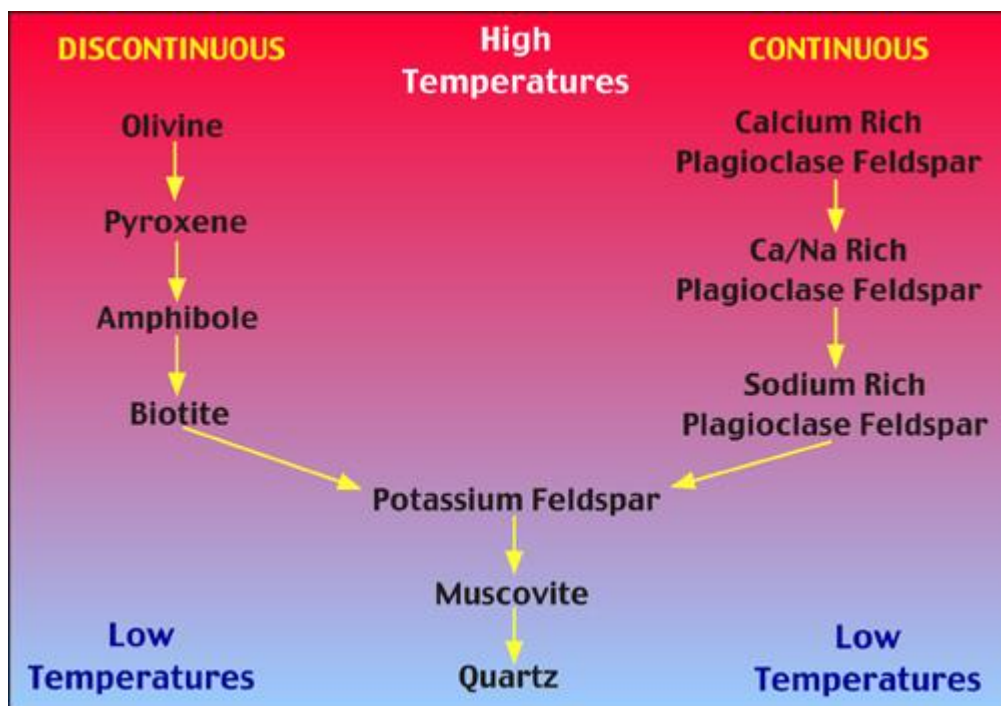


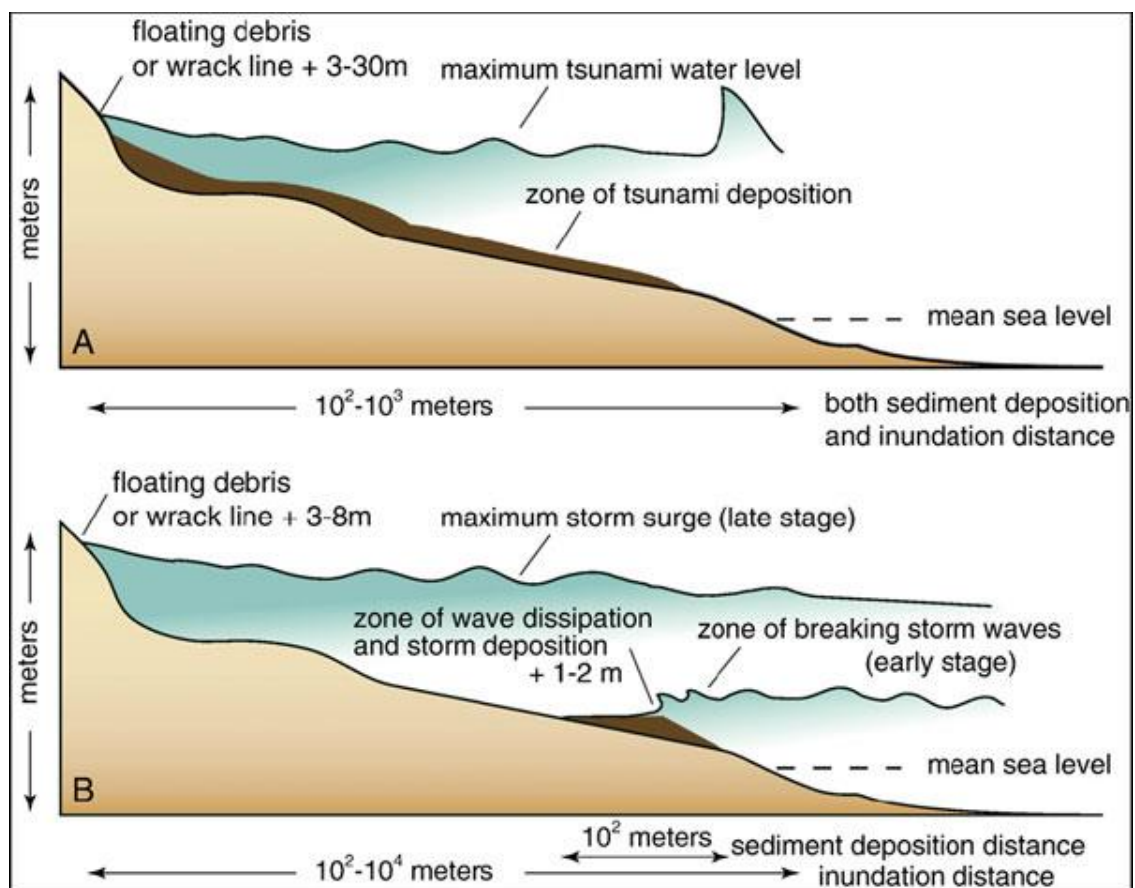
Figure .23- Bowen reaction series.[ <http://www.physicalgeography.net/fundamentals/10e.html> ]

### Three Major Types of Sediments

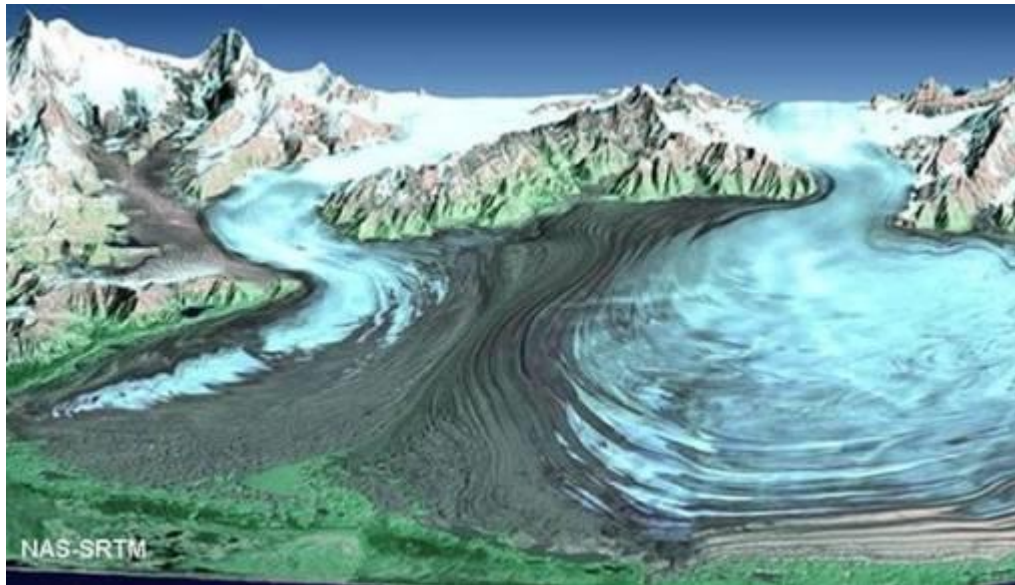
- Clastic sediments are physically deposited particles derived from weathered rocks. Clastic are transported by wind, moving water, glaciers, and/or gravity. Clastic are deposited when the transport energy is not sufficient to move the particles. As transport energy diminishes, the larger particles are deposited first.
- Chemical and biochemical sediments include minerals carried in solution in water, such as calcite and halite. Dissolved ions are precipitated from solution by biological activity, chemical change, or evaporation.
- Organic sedimentary rocks such as coal and some limestone are which form from the accumulation of plant or animal debris. Pictures and brief descriptions of some common sedimentary rock types are shown below.

### Transport of Sediments

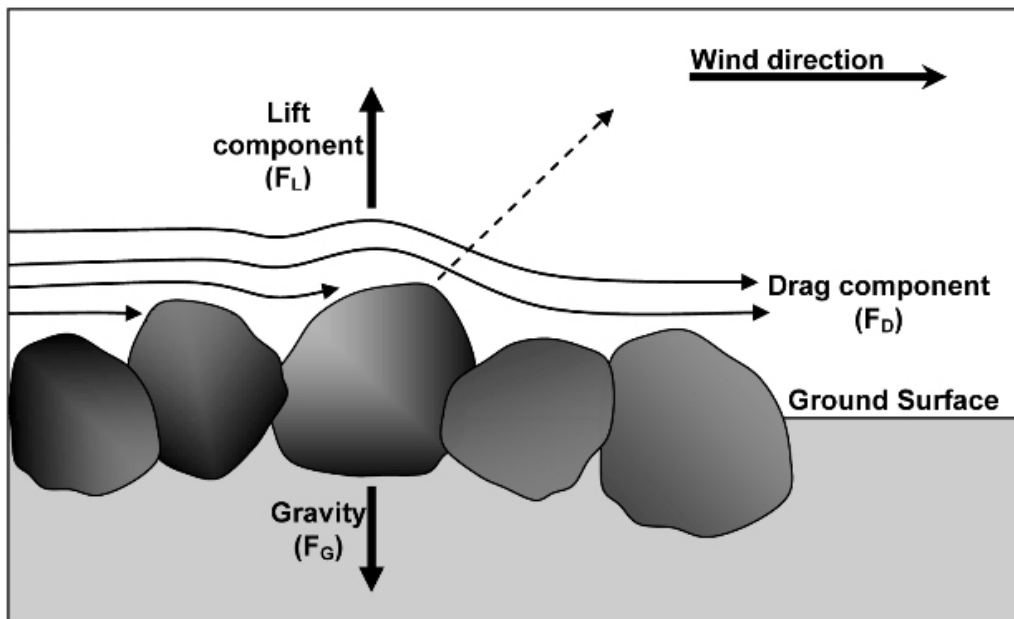
1. Water: rivers dump 25 billion tons of sediments into the ocean each year
2. Ice: glaciers slowly moving downhill drag great quantities of sediments
3. Air: air currents move material (but in far smaller quantities than water or ice)



**Figure.24- Comparison of typical inundation distances, sediment-transport distances, and maximum water levels (indicated by height of wrack line) for deposition by tsunamis (A) and coastal storms (B).** [ <http://soundwaves.usgs.gov/2007/11/> ]



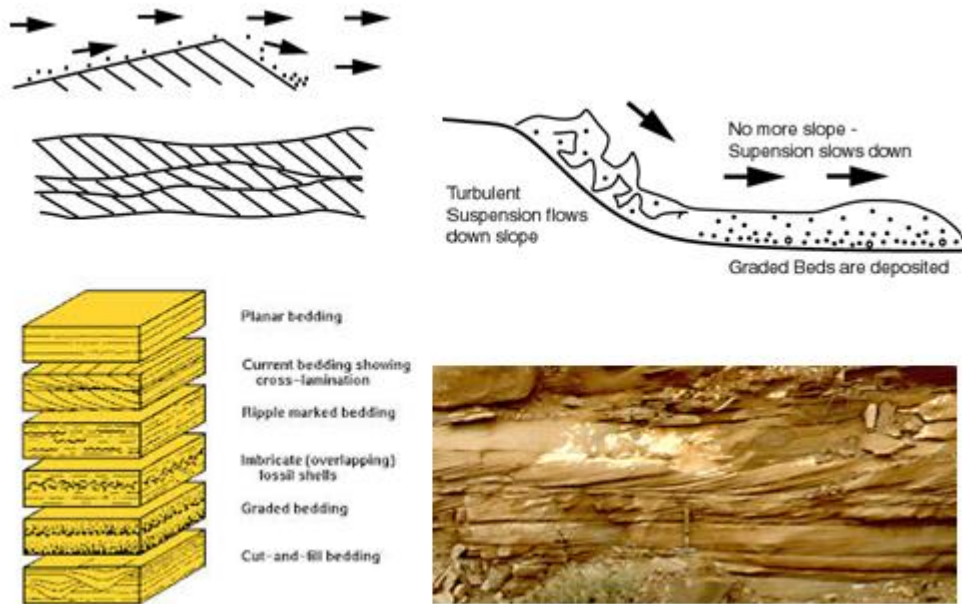
**Figure.25- Glaciers transport rock material frozen into the ice. When the ice melts, it deposits this material, often forming mounds called moraines at the sides and end of the glacier.**  
 [ <http://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle/page3605.html> ]



**Figure.26- Forces operating in the process of sand sized sediment entrainment.**  
 [ <http://www.nature.com/scitable/knowledge/library/coastal-dunes-aeolian-transport-88264671> ]

### ***Bedding and Sedimentary Structures***

Sedimentary rocks are characterized by their stratification, and bedding planes are frequently the dominant discontinuity in sedimentary rock masses. As such, their spacing and character (are they irregular, waved or straight, tight or open, rough or smooth) are of particular importance to the engineer. An individual bed may be regarded as a thickness of sediment of the same composition that was deposited under the same conditions. Lamination, on the other hand, refers to a bed of sedimentary rock that exhibits thin layers or lamina, usually a few millimeters in thickness. The lamina may be the result of minor fluctuations in the velocity of the transporting medium or the supply of material, both of which produce alternating thin layers of slightly different grain size.



**Figure 27 - Sedimentary Structure**

Clastic Sedimentary Rocks			
Texture (grain size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (rounded fragments)	Conglomerate
		Gravel (angular fragments)	Breccia
Medium (1/16 to 2 mm)		Sand	Sandstone
Fine (1/16 to 1/256 mm)		Mud	Siltstone
Very Fine (less than 1/256)		Mud	Shale

**Figure 28 - Clastic Sedimentary Rocks**

Chemical Sedimentary Rocks			
Composition	Texture (grain size)	Rock Name	
Calcite	Fine to coarse crystalline	Crystalline Limestone	
		Travertine	
	Shells and cemented shell fragments	Coquina	Biochemical Limestone
	Shells and shell fragments cemented with calcite cement	Fossiliferous Limestone	
Microscopic shells and clay	Chalk		
Quartz	Very fine crystalline	Chert (light color) Flint (dark color)	
Gypsum	Fine to coarse crystalline	Rock Gypsum	
Halite	Fine to coarse crystalline	Rock Salt	
Altered plant fragments	Fine-grained organic matter	Bituminous Coal	

**Figure 29 - Chemical Sedimentary Rocks**

## *Classification of Sedimentary Rocks*

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



*Figure.30 – Limestone*

- 2- **Breccia** is a clastic sedimentary rock that is composed of large (over two millimeter diameter) angular fragments. The spaces between the large fragments can be filled with a matrix of smaller particles or a mineral cement which binds the rock together. The specimen shown above is about two inches (five centimeters) across.



*Figure.31 – Breccia*

- 3- **Chert** is a microcrystalline or cryptocrystalline sedimentary rock material composed of silicon dioxide (SiO<sub>2</sub>). It occurs as nodules and concretionary masses and less frequently as a layered deposit. It breaks with a conchoidal fracture, often producing very sharp edges. Early people took advantage of how chert breaks and used it to fashion cutting tools and weapons. The specimen shown above is about two inches (five centimeters) across.



*Figure.32 – Chert*

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



**Figure.33 – Oil Shale**

- 5- **Coal** is an organic sedimentary rock that forms mainly from plant debris. The plant debris usually accumulates in a swamp environment. Coal is combustible and is often mined for use as a fuel. The specimen shown above is about two inches (five centimeters) across.



**Figure.34- Coal**

- 6- **Rock Salt** is a chemical sedimentary rock that forms from the evaporation of ocean or saline lake waters. It is also known by the mineral name "halite". It is rarely found at Earth's surface, except in areas of very arid climate. It is often mined for use in the chemical industry or for use as a winter highway treatment. Some halite is processed for use as a seasoning for food. The specimen shown above is about two inches (five centimeters) across.



**Figure.35 – Rock Salt**

- 7- **Conglomerate** is a clastic sedimentary rock that contains large (greater than two millimeters in diameter) rounded particles. The space between the pebbles is generally filled with smaller particles and/or a chemical cement that binds the rock together. The specimen shown above is about two inches (five centimeters) across.



**Figure.36 – Conglomerate**

- 8- **Sandstone** is a clastic sedimentary rock made up mainly of sand-size (1/16 to 2 millimeter diameter) weathering debris. Environments where large amounts of sand can accumulate include beaches, deserts, flood plains and deltas. The specimen shown above is about two inches (five centimeters) across.



**Figure.37– Sandstone**

- 9- **Dolomite** (also known as "dolostone" and "dolomite rock") is a chemical sedimentary rock that is very similar to limestone. It is thought to form when limestone or lime mud is modified by magnesium-rich groundwater. The specimen shown above is about four inches (ten centimeters) across.



**Figure.38 - Dolomite**

10- **Shale** is a clastic sedimentary rock that is made up of clay-size (less than 1/256 millimeter in diameter) weathering debris. It typically breaks into thin flat pieces. The specimen shown above is about two inches (five centimeters) across.



**Figure.39 – Shale**

11- **Flint** ,Flint is a hard, tough chemical or biochemical sedimentary rock that breaks with a conchoidal fracture. It is a form of microcrystalline quartz that is typically called “chert” by geologists. It often forms as nodules in sedimentary rocks such as chalk and marine limestones.



**Figure.40 – Flint**

12- **Siltstone** is a clastic sedimentary rock that forms from silt-size (between 1/256 and 1/16 millimeter diameter) weathering debris. The specimen shown above is about two inches (five centimeters) across.



**Figure.41 – Silstone**

13- **Iron Ore** is a chemical sedimentary rock that forms when iron and oxygen (and sometimes other substances) combine in solution and deposit as a sediment. Hematite (shown above) is the most common sedimentary iron ore mineral. The specimen shown above is about two inches (five centimeters) across.

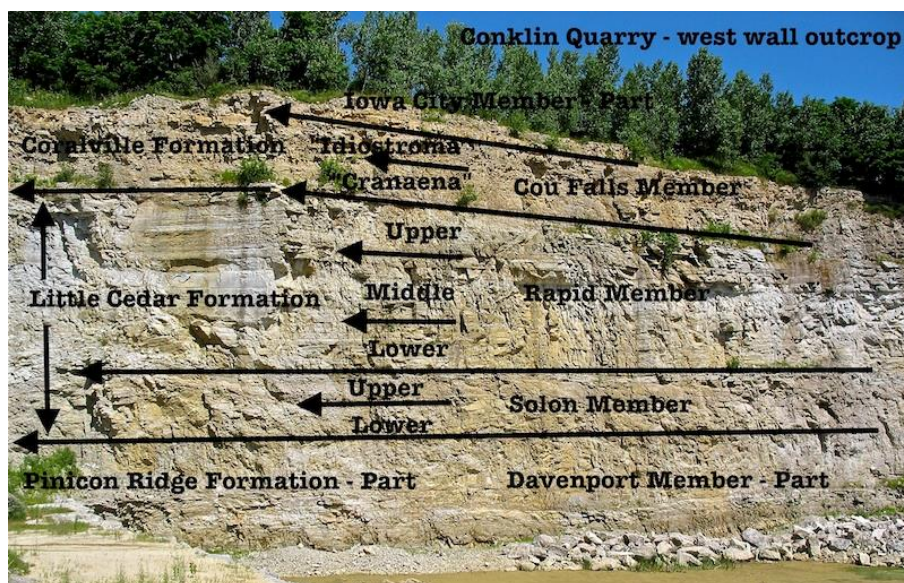


*Figure.42 – Iron Ore*

### ***Stratigraphy and Stratification***

Stratigraphy is the branch of geology that deals with the study and interpretation of stratified rocks, and with the identification, description, sequence, both vertical and horizontal, mapping and correlation of stratigraphic rock units. As such, it begins with the discrimination and description of stratigraphical units such as formations. This is necessary so that the complexities present in every stratigraphical section may be simplified and organized.

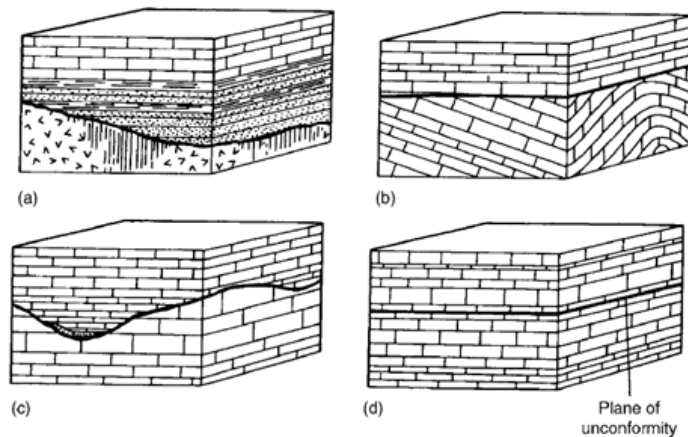
The changes that occur during deposition are responsible for stratification, that is, the layering that characterizes sedimentary rocks. A simple interruption of deposition ordinarily does not produce stratification. The most obvious change that gives rise to stratification is in the composition of the material being deposited. Even minor changes in the type of material may lead to distinct stratification, especially if they affect the colour of the rocks concerned. Changes in grain size may also cause notable layering, and changes in other textural characteristics may help distinguish one bed from another, as may variations in the degree of consolidation or cementation.



*Figure.43- Above is a view of the Middle Devonian strata exposed in the west wall of the River Products In Conklin Quarry. Unit contacts are approximate.*

## Unconformities

An unconformity normally means that uplift and erosion have taken place, resulting in some previously formed strata being removed. The beds above and below the surface of unconformity are described as unconformable. The structural relationship between unconformable units allows four types of unconformity to be distinguished. In Figure 28-a, stratified rocks rest upon igneous or metamorphic rocks. This type of feature has been referred to as a nonconformity (it also has been called a heterolithic unconformity). An angular unconformity is shown in Figure 28-b, where an angular discordance separates the two units of stratified rocks.



**Figure. 44- Types of unconformities: (a) nonconformity or heterolithic unconformity, (b) angular unconformity, (c) disconformity and (d) paraconformity.**

The lowest bed in the upper sequence of strata usually rests on beds of differing ages. This is referred to as overstep. In a disconformity, as illustrated in Figure 28-c, the beds lie parallel both above and below the unconformable surface, but the contact between the two units concerned is an uneven surface of erosion. When deposition is interrupted for a significant period but there is no apparent erosion of sediments or tilting or folding, then subsequently formed beds are deposited parallel to those already existing. In such a case, the interruption in sedimentation may be demonstrable only by the incompleteness of the fossil sequence.

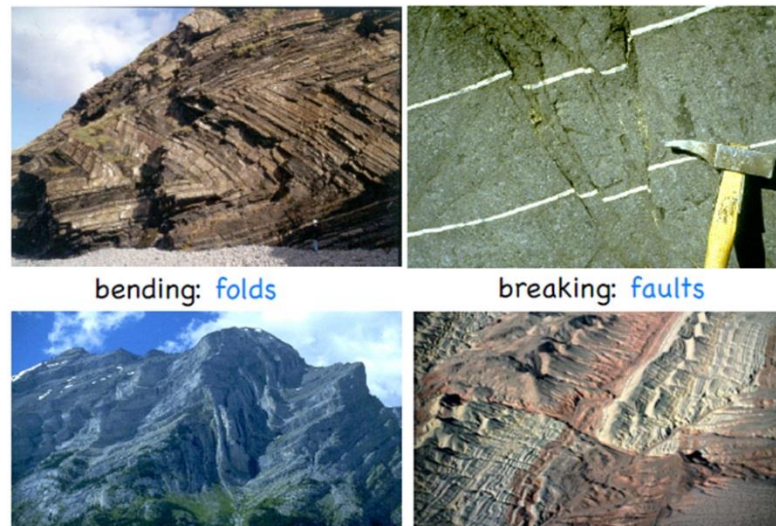
## Types of Unconformities

Types of Unconformities		
Type	Example	Description
Nonconformity		Unstratified igneous or metamorphic rock may be uplifted to Earth's surface by crustal movements. Once the rock is exposed, it erodes. Sediments may then be deposited on the eroded surface. The boundary between the new sedimentary rock and the igneous or metamorphic rock is a <i>nonconformity</i> . The boundary represents an unknown period of time during which the older rock was eroded.
Angular unconformity		An <i>angular unconformity</i> forms when rock deposited in horizontal layers is folded or tilted and then eroded. When erosion stops, a new horizontal layer is deposited on top of a tilted layer. When the bedding planes of the older rock layers are not parallel to those of the younger rock layers deposited above them, an angular unconformity results.
Disconformity		Sometimes, layers of sediments are uplifted without folding or tilting and are eroded. Eventually, the area subsides and deposition resumes. The layers on either side of the boundary are nearly horizontal. Although the rock layers look as if they were deposited continuously, a large time gap exists where the upper and lower layers meet. This gap is known as a <i>disconformity</i> .

## Geological Structures

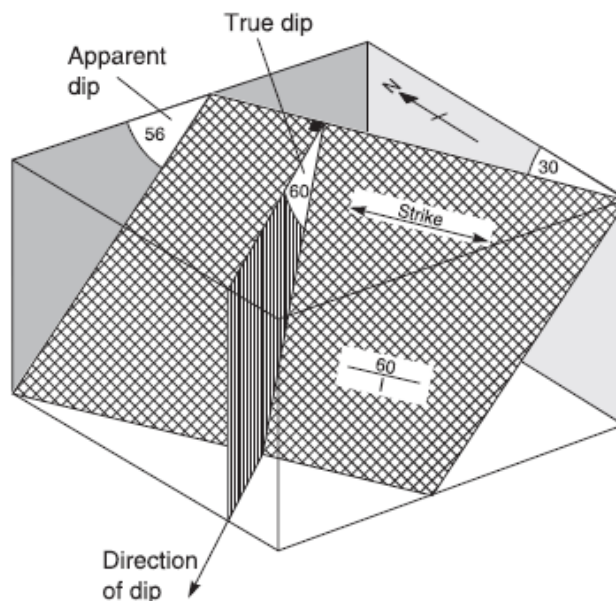
The two most important features that are produced when strata are deformed by earth movements are folds and faults, that is, the rocks are buckled or fractured, respectively.

A fold is produced when a more or less planar surface is deformed to give a wavy surface. On the other hand, a fault represents a surface of discontinuity along which the strata on either side have been displaced relative to each other. Dynamically produced patterns and arrangements of rock or sediment that result from forces acting within the Earth; Structural geology is study of shapes, arrangements and relationships among rocks and stresses that deform them.



**Figure.45- Bending or Breaking of rocks yield different structures**

There are two important directions associated with inclined strata, namely, dip and strike. True dip gives the maximum angle at which a bed of rock is inclined and should always be distinguished from apparent dip. The latter is a dip of lesser magnitude whose direction can run anywhere between that of true dip and strike. Strike is the trend of inclined strata and is orientated at right angles to the true dip, it has no inclination. Folds are wave-like in shape and vary enormously in size. Simple folds are divided into two types, that is, anticlines and synclines.



**Figure.46- Illustration of dip and strike: orientation of cross-hatched plane can be expressed as strike 330°, dip 60°.**

## *Structural Geology and Tectonics combines two aspects*

### **1. Description and analysis of 3D structures and microstructures.**

Structural geologists are concerned with features resulting from deformation. These include fractures, faults, folds, bounding, shear zones, cleavages (also known as schistosity), foliations and lineations. From the analysis of these structures, they aim at understanding finite strain (i.e., the ultimate product of long, sometimes Polyphase deformation histories), and incremental strain (i.e., the small increments of deformation, the accumulation of which leads to the finite strain). [1]

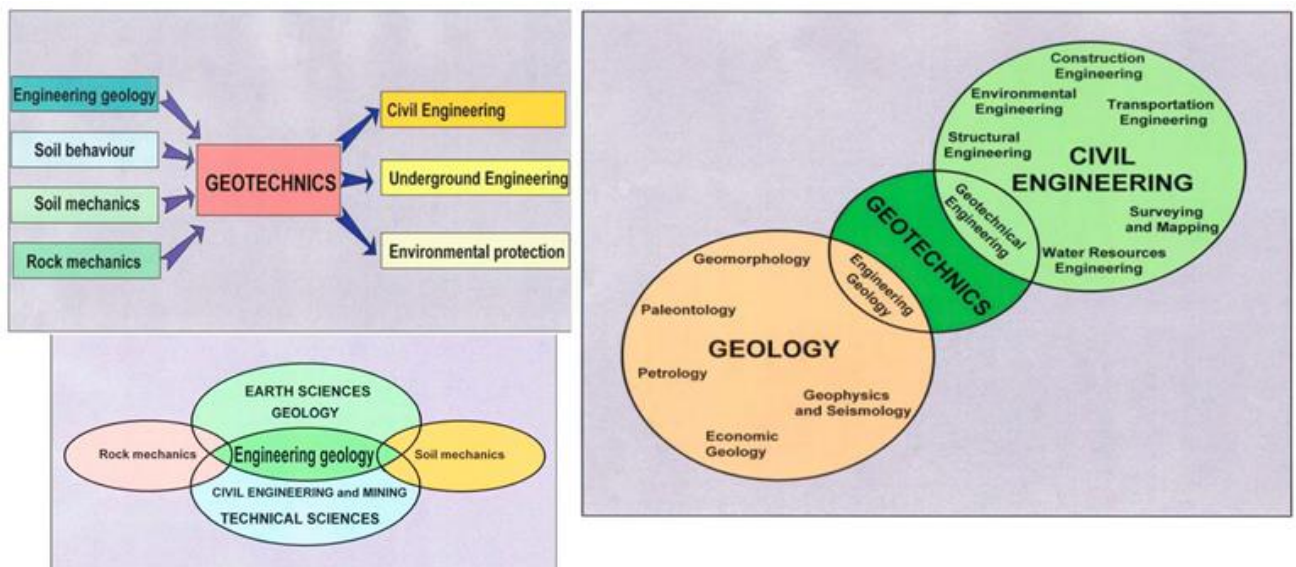
They are interested to understand “strain fields” by mapping deformation features such as foliations and stretching lineations that tell us the orientation of the principal shortening direction and principal lengthening direction respectively.

In the case of faults and shear zones, they are interested to understand their kinematics (i.e., the relative sense of motion of the blocks they separate), and the magnitude of the displacement involved. They are interested to infer the direction of maximum and minimum stress directions from small deformation features such as centimeter-scale extensional fractures and associated stylolitic joints.[1]

### **2. Design of tectonic models (Tectonics).**

The purpose of these models is to explain the deformation history that led to the observed 3D strain fields. Tectonic models incorporate a broad range of data from other disciplines. No matter how tectonics design these models, tectonic models should always be: [1]

1. **Physically valid:** They must obey the law of physics, sounds trivial but not easy to meet this requirement without computational modelling.
2. **Testable:** They must provide testable predictions (structural, sedimentological, petrological, geochemical, geophysical ...) that can be verified.
3. **Robust:** They must explain a large number of unrelated facts,
4. **Lean:** Hypotheses should be kept at a minimum compared to the number of fact models explain.



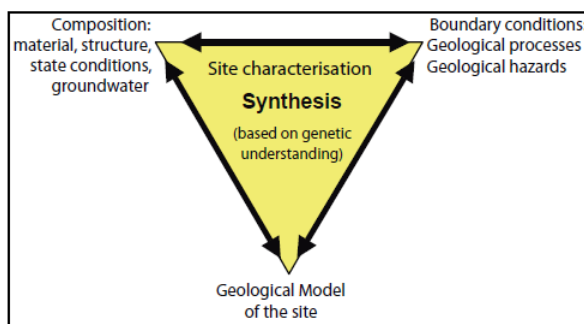
*Figur.47- Relation between Engineering Geology and Geotechnical [2]*

**Table.2- Important events in the early development of the fields of engineering geology and geotechnics [2]**

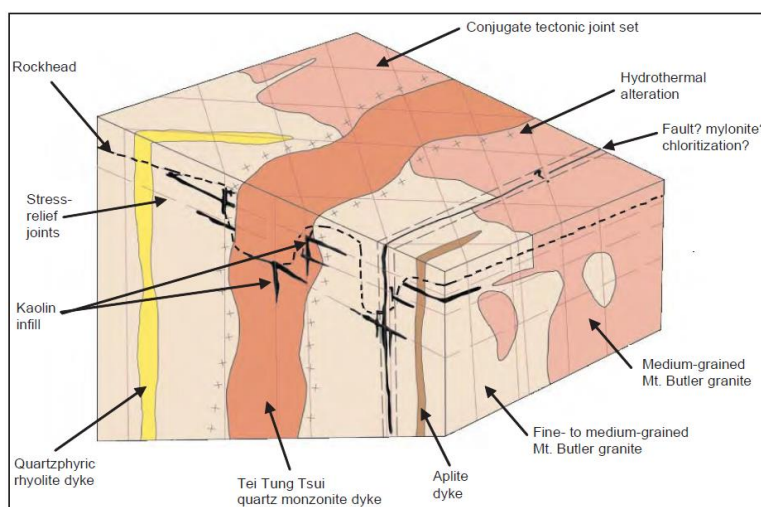
Important events in history	
Engineering geology	Geotechnics
<b>1888</b> – Engineering Geology Division was established at the Geological Society of America in the United States	<b>Until 1936</b> – Geotechnics was organized by several national committees (Sweden, France)
<b>1964</b> – International Association of Engineering Geology (IAEG) was set up during the 22nd International Geological Congress in New Delhi	<b>1936</b> – First International Conference on Soil Mechanics and Foundation Engineering (ICSMFE) in Harvard
<b>1970</b> – First International Congress IAEG in Paris	<b>1953</b> – International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) had become firmly established during the third ICSMFE in Switzerland

The output of engineering geological practice primarily consists of the geological model and advice to engineers and others involved with the project regarding development of the ground and design models. The amount of engineering geological input required for a particular civil engineering project varies depending on geological factors such as rock type, superficial deposits, geological structure and weathering as well as engineering considerations such as the type of scheme and the construction method adopted.

Engineering geological practice is primarily concerned with the determination of geological and hydrogeological conditions to facilitate ground engineering with respect to the recognition and management of geotechnical risk.



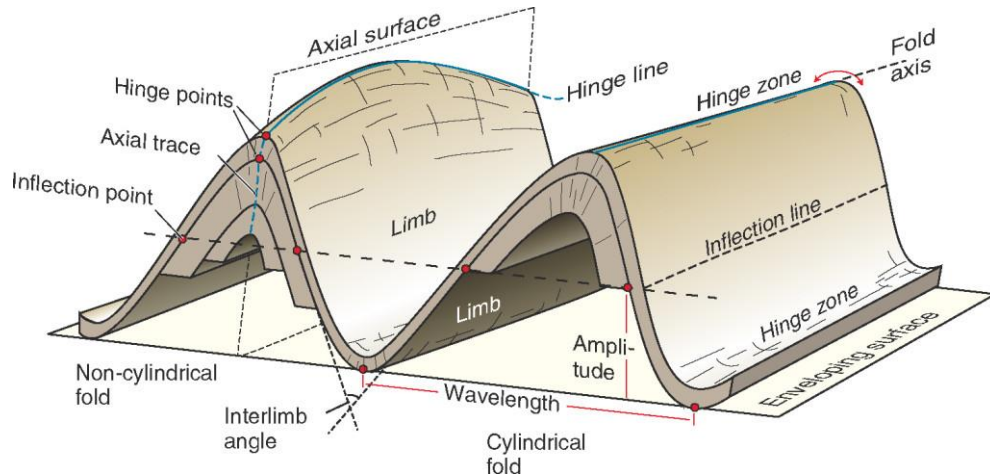
**Figur.48- Main elements of the geological model (Bock, 2006)**



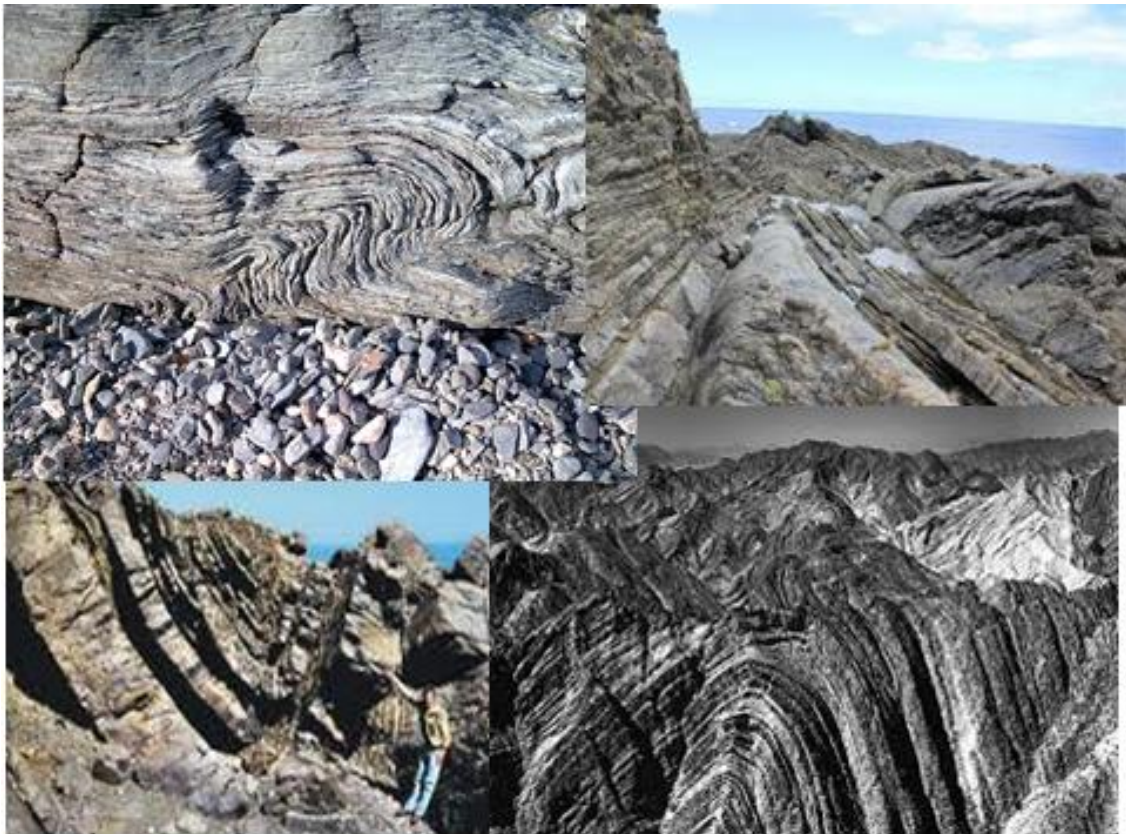
**Figure.49- Example of a geological model based on a desk study (Parry et al., 2004b)**

## *Anatomy of Folds*

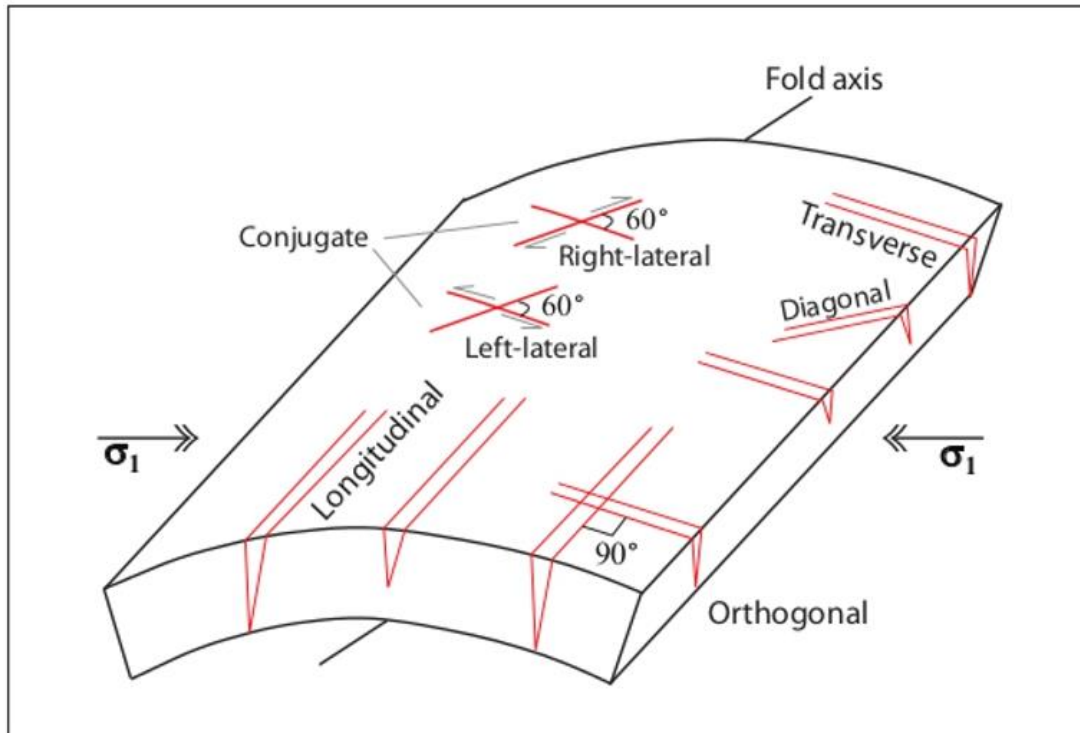
In order to extract scientifically valuable data, folds are best observed perpendicular to their axial surface. Therefore is impotent to orient yourself so you can observe both limbs of the fold. The hinge points are the end points of the hinge line, which connects two limbs that are oriented with dips usually opposite to each other. Each limb, either side to the hinge line may one or several different geological layers. However, usually the thickness varies in nature. The area with the maximum curvature of a fold is known as the hinge zone.



**Figure. 50- Anatomy of Folds**



**Figure.51- Type of Folds**



**Figure. 52-** A geometric classification of fractures into longitudinal, transverse (cross), conjugate, diagonal (oblique), and orthogonal fractures developed on a fold structure. These field-based concepts were formulated by geologists in the first half of the 20th century. Modified from Singhal and Gupta, *Applied Hydrogeology of Fractured Rocks* (2010).

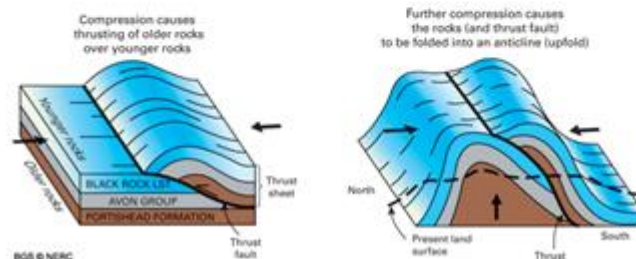
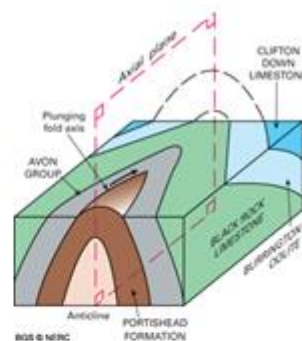


**Figure.53-** These are folds in Cretaceous strata exposed at Ernst Tinaja in Big Bend National Park. They show the disharmonic geometry and maintenance of bedding-perpendicular thickness that characterize a parallel fold style.



**Figure.54- These are deformed Cretaceous strata from Ernst Tinaja in Big Bend National Park. Note how the thicker limestone layer is brittlely faulted. However, as the fault is traced down into the underlying thinner bedded strata is disappears in a complex of small folds. This is not accidental. The folding and faulting are linked, and this is an example of a tri-shear zone, where slip concentrated on one surface or zone gets distributed over an area.**

**Block diagram to illustrate the concentric pattern of older rocks surrounded by younger rocks that has been produced by erosion of the Mendip periclinal.**

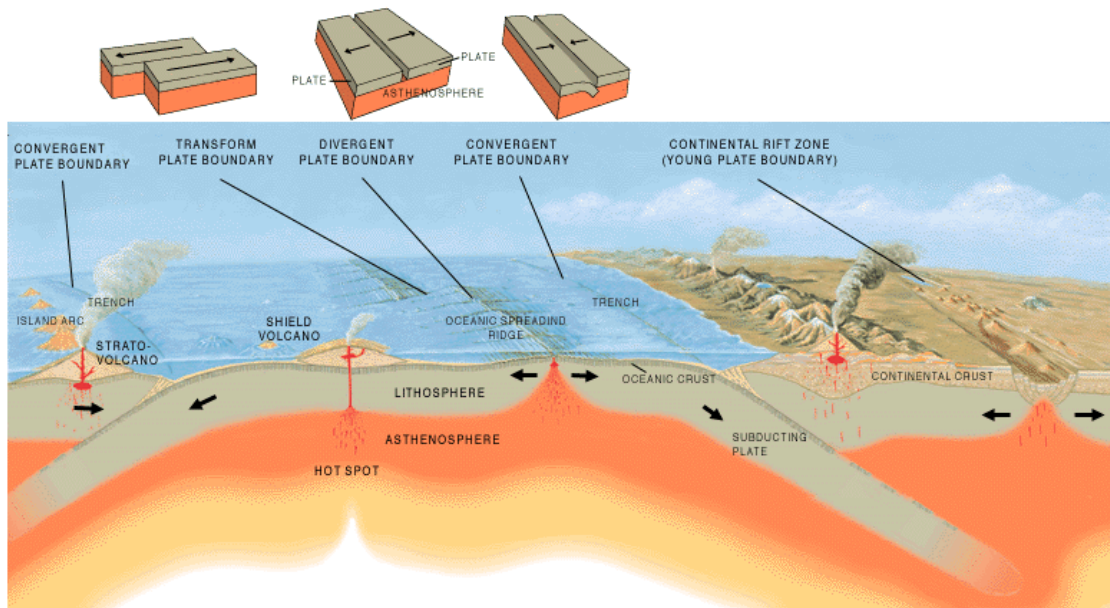


**Figure.55- Cartoon to show how thrust faults can move older rocks on top of younger rocks**

## **Faults**

Faults are fractures in crustal strata along which rocks have been displaced. The amount of displacement may vary from only a few tens of millimeters to several hundred kilometers. In many faults, the fracture is a clean break; in others, the displacement is not restricted to a simple fracture, but is developed throughout a fault zone. The dip and strike of a fault plane can be described in the same way as those of a bedding plane. The angle of hade is the angle enclosed between the fault plane and the vertical. The hanging wall of a fault refers to the upper rock surface along which displacement has occurred, whereas the foot wall is the term given to that below. The vertical shift along a fault plane is called the throw, and the term heave refers to the horizontal displacement.

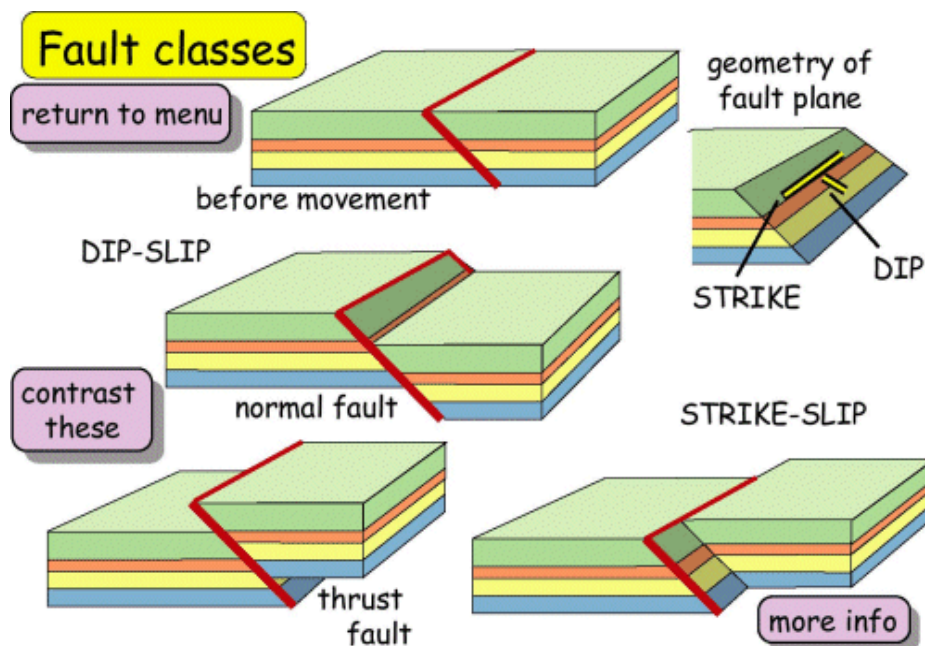
Where the displacement along a fault has been vertical, then the terms downthrow and upthrow refer to the relative movement of strata on opposite sides of the fault plane.



**Figure.56- Faults**

The “normal fault” is generated by the traction with vertical motion with respect to the “fault plane”, which typically has an angle of 60° from the horizontal plane, and as we have seen, generates a “hanging wall” and a “foot wall” where rocks on one side of the fault sink over rocks from the other side of the fault.

The “reverse fault” is generated by compression. It has horizontal movements where the upper block (hanging wall) is located above the lower block (footwall). It occurs in areas where the rocks are compressed against each other so that the rocky crust area occupies less space, creating an exposed area of the fault called “outbound.” The “strike-slip fault” or “transform fault” has a predominant horizontal component and a small vertical component. The rock block from one side moves to one direction, while the opposite block is moving in an opposite direction. It is identified due to the discontinuity of a field.



**Figure.57-Falts Classes**

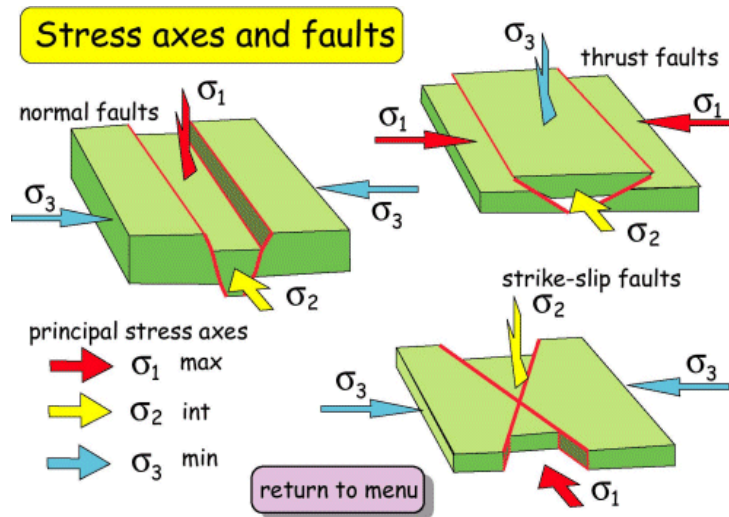


Figure.58- Stress axes and Falts

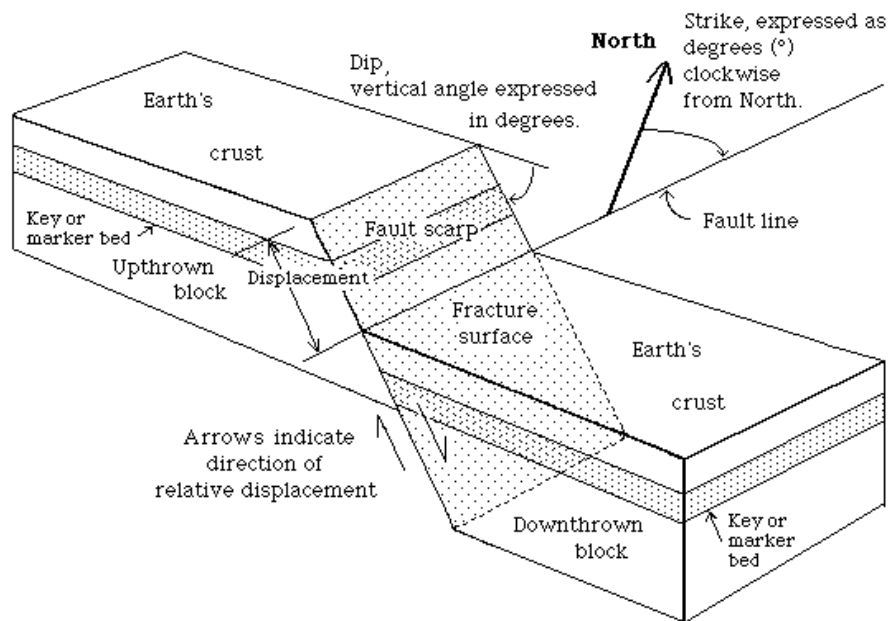


Figure.59- In a geological fault there can be identified the following components: “fault plane”, “fault blocks”, “guidance or orientation”, “dip”, “displacement” and “triangular facets”

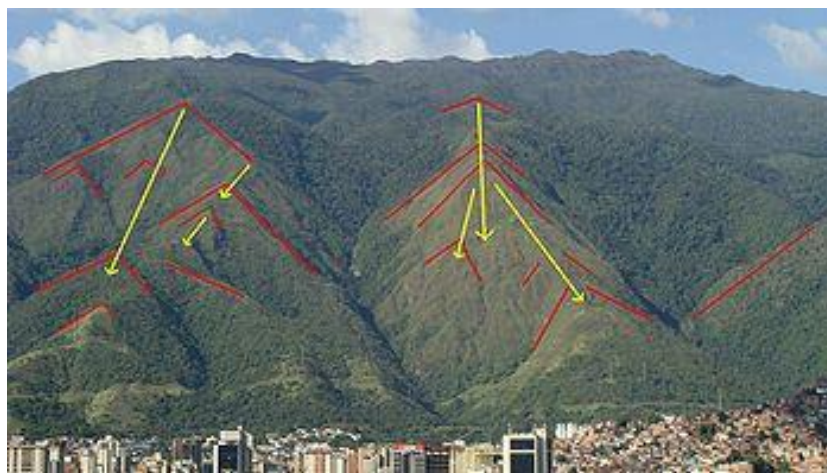


Figure.60- Faults are classified into three types by the direction in which their blocks move

## ***Faults and weakness zones***

In Norway, serious instability in underground excavations has rarely been experienced, and when such serious stability problems have been experienced most of them have been related to faults and weakness zones. Possible stability problems associated with weakness zones are (Nilsen & Dahl 1994):

1. Cave-in at the working face during tunneling.
2. Instability at the working face.
3. Water inflows into the tunnel.
4. Swelling of smectite, especially when smectite occurs in combination with other problem- minerals like calcite (solvable) and chlorite (low friction).
5. Cave-in after completion

Face instability is often encountered in weakness zones due to heavily fractured and low-strength properties of rocks. Such instabilities may develop very quickly. If not sufficiently supported the result may be cave-in at the working face. In worst case a cave-ins may propagate several tens of meters above tunnel level. Cave-in has also been found to occur after completion of tunnel projects, often several years later. If not sufficiently supported, a weakness zone may cause serious instability and fall-out. In brittle fault zones with open joints, major water inflows into the tunnel may cause serious problems for the excavation works. Swelling clay is also common in weakness zones.

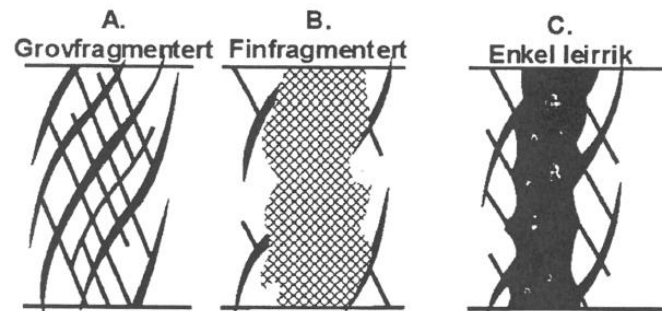


***Figure .61- Image from rock fall in the Hanekleiv tunnel. The rock fall was caused by a weakness zone containing swelling clay (Picture in courtesy of Statens Vegvesen).***

***Faults may be classified according to type of rocks they are formed in:***

- Faults in hard and brittle rocks like granite and gneiss.
- Faults in weak and more ductile rocks like phyllite.

Rocks will respond different to applied stresses depending on the rock's strength and elasticity. Faults in rock types that are hard and brittle, like granite, will often result in a wide zone with crushed and coarse material (figure below). Faults in ductile rocks like phyllite will often be characterized as a thinner zone containing ne grained material (Nilsen & Dahl 1994).



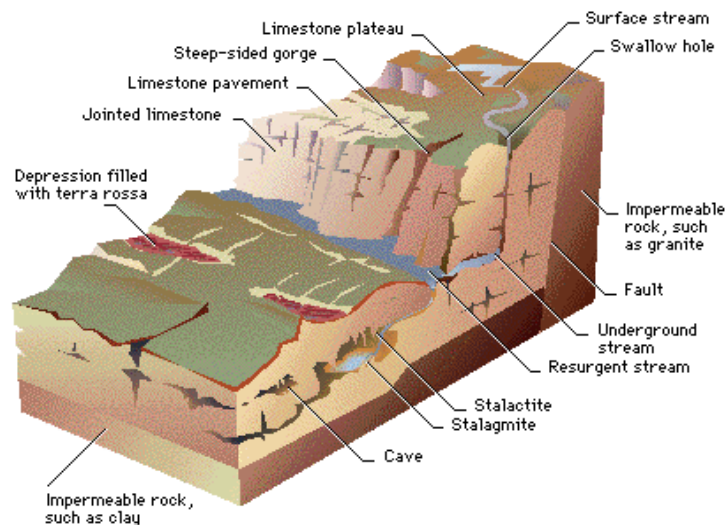
***Figure.62- Classification of crushed zones; (A) coarsely fragmented, (B) finely fragmented and (C) containing clay (Nilsen & Broch 2009).***

Faults and weakness zones will most likely create a need for additional rock support. The amount of extra support is dependent of the characteristics of the fault and the surrounding rock, like thickness of the fractured zone, the amount of jointing and crushing, types of minerals present and cohesion. The high water inflows often associated with weakness zones must be sealed and tightened with for example injection grouting.

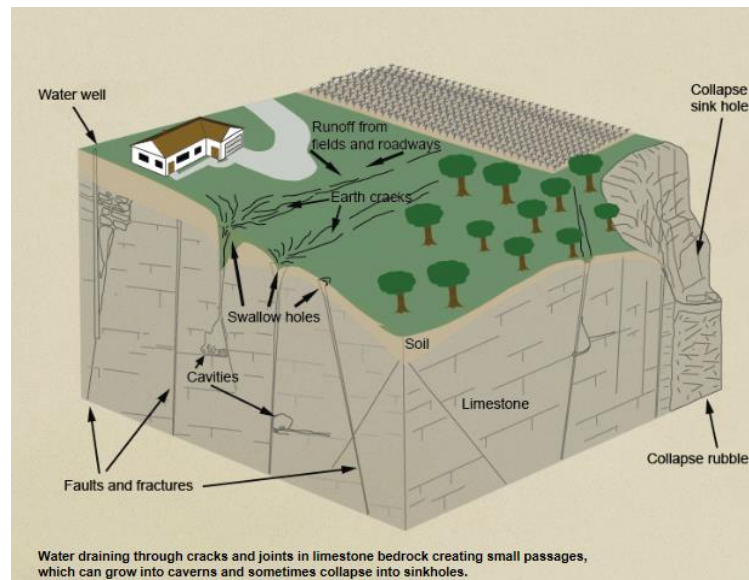
***Aquifer materials***

Both consolidated and unconsolidated geological materials are important as aquifers. Of the consolidated materials (i.e. bedrock), sedimentary rocks are the most important because they tend to have the highest porosities and permeability's.

Sedimentary rock formations are exposed over approximately 70% of the earth's land surface. These sedimentary formations are typically hundreds to thousands of meters thick, and they are underlain by the igneous and metamorphic rocks that make up the rest of the crust.



***Figure.63- Aquifer materials***



***Figure.64- Water draining through cracks and joints in limestone bedrock creating small passages, which can grow into caverns and sometimes collapse into sinkholes***

Suites of karst landforms in limestone and related carbonate rocks evolve through progressive denudation of the land surface, while underground denudation is simultaneously enlarging cave conduits so that ever larger proportions of the drainage can pass underground. Both surface and underground denudation is largely by dissolution of the carbonate, at rates dependent on the flow and chemical aggressiveness of the water. Both these factors are dependent on climate.

If solution continues, its rate slackens and it eventually ceases when saturation is reached. Therefore, solution is greatest when the bicarbonate saturation is low. This occurs when water is circulating so that fresh supplies with low bicarbonate saturation are made available continually.

Water flows are largely a consequence of rainfall input (though they can be increased locally by supplies of allogenic water draining off adjacent outcrops of non-karstic rocks).

### ***Rock properties***

From the perspective of hydrogeology the important characteristics of rocks are how much open space they have, how well connected those open spaces are, how strong the rocks are, and how soluble they are.

Sedimentary rocks are formed close to the surface of the earth at relatively low temperatures and pressures. Clastic sedimentary rocks are comprised of weathered and transported fragments of other rocks and minerals. Depending on the degree of sorting and rounding of those fragments, and the extent to which they are cemented together, clastic sedimentary rocks can be quite porous. Some clastic sedimentary rocks are also relatively soft and weak, and are easily susceptible to fracturing. Most sedimentary rocks also have some bedding features that can enhance porosity.

### ***Porosity***

The empty spaces in between the crystals or fragments that make up a rock represent porosity that can hold water. Porosity is a measure of how much water a body of rock can hold, expressed as a percentage of the rock's volume. The spaces between the grains or crystals of a rock are referred to as intergranular porosity. Fractures in a rock also represent porosity, and this is known as fracture porosity. For most naturally occurring media the porosity is between (0.10 to 0.40) although on occasion values outside this range have been observed.

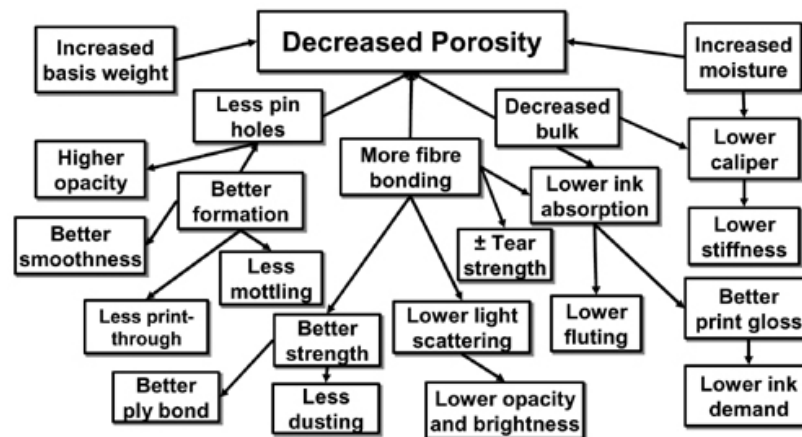


## Reservoir rock & Source Rock Types: Classification

**Reservoir rock:** A permeable subsurface rock that contains petroleum. Must be both porous and permeable

**Source rock:** A sedimentary rock in which petroleum forms.

- Reservoir rocks are dominantly sedimentary (sandstones and carbonates); however, highly fractured igneous and metamorphic rocks have been known to produce hydrocarbons, albeit on a much smaller scale
- Source rocks are widely agreed to be sedimentary
- The three sedimentary rock types most frequently encountered in oil fields are shales, sandstones, and carbonates
- Each of these rock types has a characteristic composition and texture that is a direct result of depositional environment and post-depositional (diagenetic) processes (i.e., cementation, etc.)
- Understanding reservoir rock properties and their associated characteristics is crucial in developing a prospect



*Figure.65- Total paper quality control with porosity measurement. Better formation can increase or decrease porosity depending on how formation is improved. Combined online measurement of formation and porosity gives the best possibilities to improve paper quality and to reduce variations*

## Description, Properties and Behaviour of Soils and Rocks

*The terms classification and description have the following meanings*

**Classification:** the identity of the material itself, i.e. what its composition and intrinsic properties are.

**Description:** the in-situ properties of the material, i.e. what it is like in its undisturbed state.

Classification systems used in soil mechanics, such as the Casagrande system, refer primarily to the material itself; they make only passing reference to the state in which the material exists in the ground.

Descriptive systems used in logging core, investigation pits etc, enable accurate accounts to be given of the state of the material in-situ. In some situations, for example where borrow sources are being investigated, or when only disturbed samples are available, then classification of the material itself is possible (and relevant), but description of its undisturbed state is not possible (or relevant).

A distinction between these two aspects is therefore made when describing a soil.

## Soil Groups

The framework for the classification and description of soil is provided in the following sections. For engineering purposes soil is grouped as shown in Table below.

**Table.3- Soil Froups**

COARSE SOILS (granular soils or non-cohesive soils)		FINE SOILS (cohesive soils)		OTHER SOIL
Gravel	Sand	Silt	Clay	Organic Soils

### Gravel and Sand

Gravel and sand comprise rock fragments of various sizes and shapes that may be either rock fragments or single minerals. In some cases there may be only a narrow range of particle sizes present, in which case the material is described as ‘uniform’. In other cases a broad range of particle sizes may be present and the material is described as ‘well graded’

### Silt

Silt is intermediate between clay and fine sand. Silt is less plastic and more permeable than clay, and displays ‘dilatant’ and ‘quick’ behaviour. Quick behaviour refers to the tendency of silt to liquefy when shaken or vibrated, and dilatancy refers to the tendency to undergo volume increase when deformed. A simple test of patting a saturated soil sample in the hand can be undertaken to assess these properties and distinguish silt from clay.

### Clay

Clay consists of very small particles and exhibits the properties of ‘cohesion’ and ‘plasticity’, which are not found in sand or gravel. Cohesion refers to the fact that the material sticks together, while plasticity is the property that allows the material to be deformed without volume change or rebound, and without cracking or crumbling.




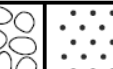





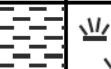

### Organic Soil

Organic soil is distinguished in Table above, as a category different from coarse or fine soils, but should only be identified as such if the organic content is high and the material no longer behaves like a silt or clay. Soils containing small to moderate amounts of organic material still retain the properties of silts or clays and should be described within those categories.

### Behaviour

Soil behaviour always depends to some extent on grain size and this forms a starting point for the engineering classification of soils. On this basis soils are categorized as in Table below.

**Table.4- Grain Size Criteria**

TYPE	COARSE									FINE		ORGANIC
	Boulders	Cobbles	Gravel			Sand			Silt	Clay	Organic Soil	
			coarse	medium	fine	coarse	medium	fine				
Size Range (mm)	200	60	20	6	2	0.6	0.2	0.06	0.002	Refer to Section 2.3.5		
Graphic Symbol												

The properties of a coarse soil are closely related to particle size. For this reason, particle size is the sole criterion used in classifying coarse soils.

However, there is no clear relationship between properties and particle size in a fine soil; this is because the properties are influenced by both the size and composition of particles. For this reason, other methods, including physical manipulation of the soil (for visual description), and Atterberg Limit tests (for laboratory classification) are used to describe and classify them. In most cases a soil consists of particle sizes spread over more than one category.

Gravels and sands are the two principal types of coarse-grained soils and, in this classification, both are subdivided into five subgroups on the basis of grading.

**Table.5- Symbols used in the Casagrande soil classification**

Main soil type		Prefix
Coarse-grained soils	Gravel	G
	Sand	S
Fine-grained soils	Silt	M
	Clay	C
	Organic silts and clays	O
Fibrous soils	Peat	Pt
Subdivisions		Suffix
For coarse-grained soils	Well graded, with little or no fines	W
	Well graded with suitable clay binder	C
	Uniformly graded with little or no fines	U
	Poorly graded with little or no fines	P
	Poorly graded with appreciable fines or well graded with excess fines	F
For fine-grained soils	Low compressibility (plasticity)	L
	Medium compressibility (plasticity)	I
	High compressibility (plasticity)	H

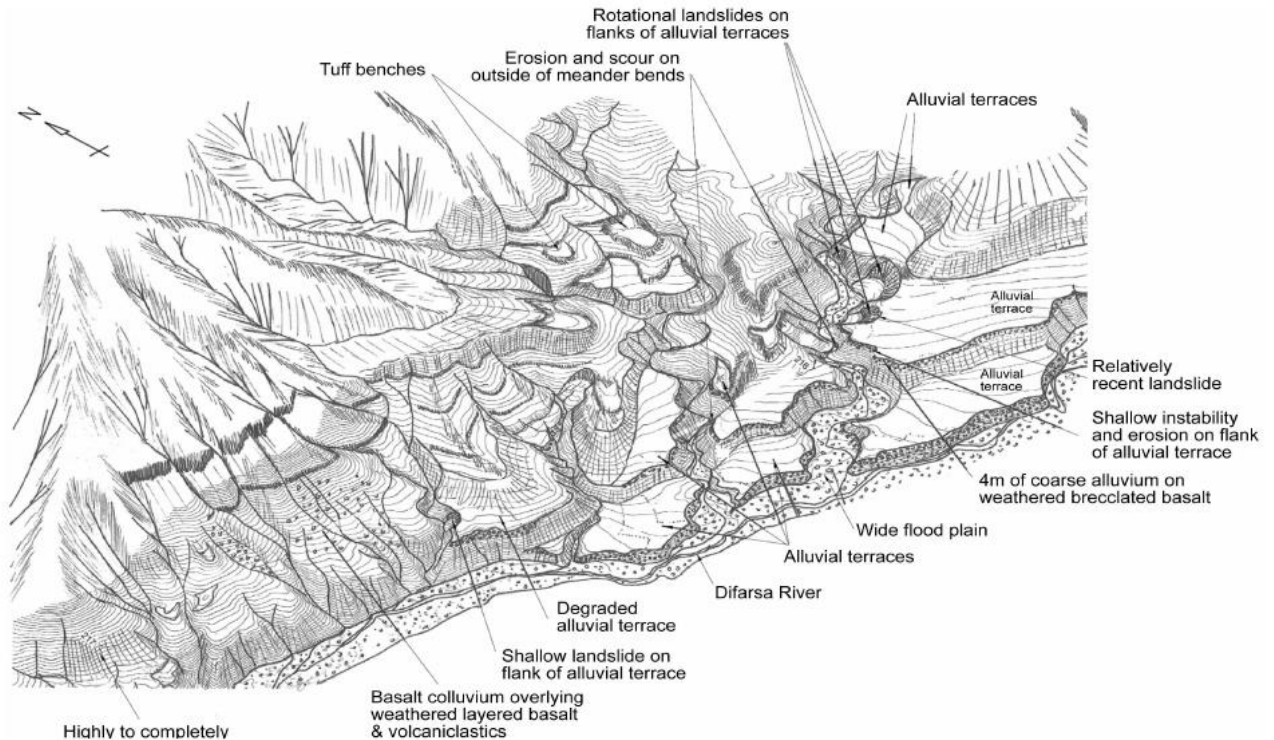
**Table.6- Unified soil classification . Coarse soils. More than half of the material is larger than No.200 sieve size**

Field identification procedures (excluding particles larger than 76 mm and basing fractions on estimated weights)			Group symbols*	Typical names
Gravels. More than half of coarse fraction is larger than No. 7 sieve size	Clean gravels (little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (appreciable amount of fines)	Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
		Non-plastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures
Sands. More than half of coarse fraction is smaller than No. 7 sieve size†	Clean sands (little or no fines)	Plastic fines (for identification procedures, see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
		Wide range in grain sizes and substantial amounts of all intermediate particle sizes	SW	Well-graded sands, gravelly sands, little or no fines
	Sands with fines (appreciable amount of fines)	Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines
		Non-plastic fines (for identification procedures, see ML below)	SM	Silty sands, poorly graded sand-silt mixtures
		Plastic fines (for identification procedures, see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures

## ***Geologic Mapping & Documentation***

Geologic mapping is defined as the examination of natural and manmade exposures of rock or unconsolidated materials, the systematic recording of geologic data from these exposures, and the analysis and interpretation of these data in two- or three-dimensional format (maps, cross sections, and perspective [block] diagrams). **The maps and cross sections generated from these data:**

- I. Serve as a record of the location of factual data;
- II. Present a graphic picture of the conceptual model of the study area based on the available factual data; and
- III. Serve as tools for solving three-dimensional problems related to the design, construction, and/or maintenance of engineered structures or site characterization.



***Figure.66- Typical Illustration of Field Mapping for Route Selection and Preliminary Design***

### ***An engineering geologist engaged in geologic mapping is responsible for:***

1. Recognizing the key geologic conditions in a study area that will or could significantly affect hazardous and toxic waste sites or a proposed or existing structure;
2. Integrating all the available, pertinent geologic data into a rational, interpretive, three-dimensional conceptual model of the study area and presenting this conceptual model to design and construction engineers, other geologists, hydrologists, site managers, and contractors in a form that can be understood.

The engineering geologist needs to realize that geologic mapping for site characterization is a dynamic process of gathering, evaluating, and revising geologic data and that the significance of these data, both to the structure and to further exploration, must be continually assessed. The initial exploration program for a structure is always based on incomplete data and must be modified continuously as the site geology becomes better understood. The key to understanding the site geology is through interpretive geologic drawings such as geologic maps, cross sections, isopachs, and contour maps of surfaces. These working drawings, periodically revised and re-interpreted as new data become available, are continuously used to assess the effects of the site geology and to

delineate areas where additional exploration is needed. These drawings are used in designs, specifications, and modeling and maintained in the technical record of the project.

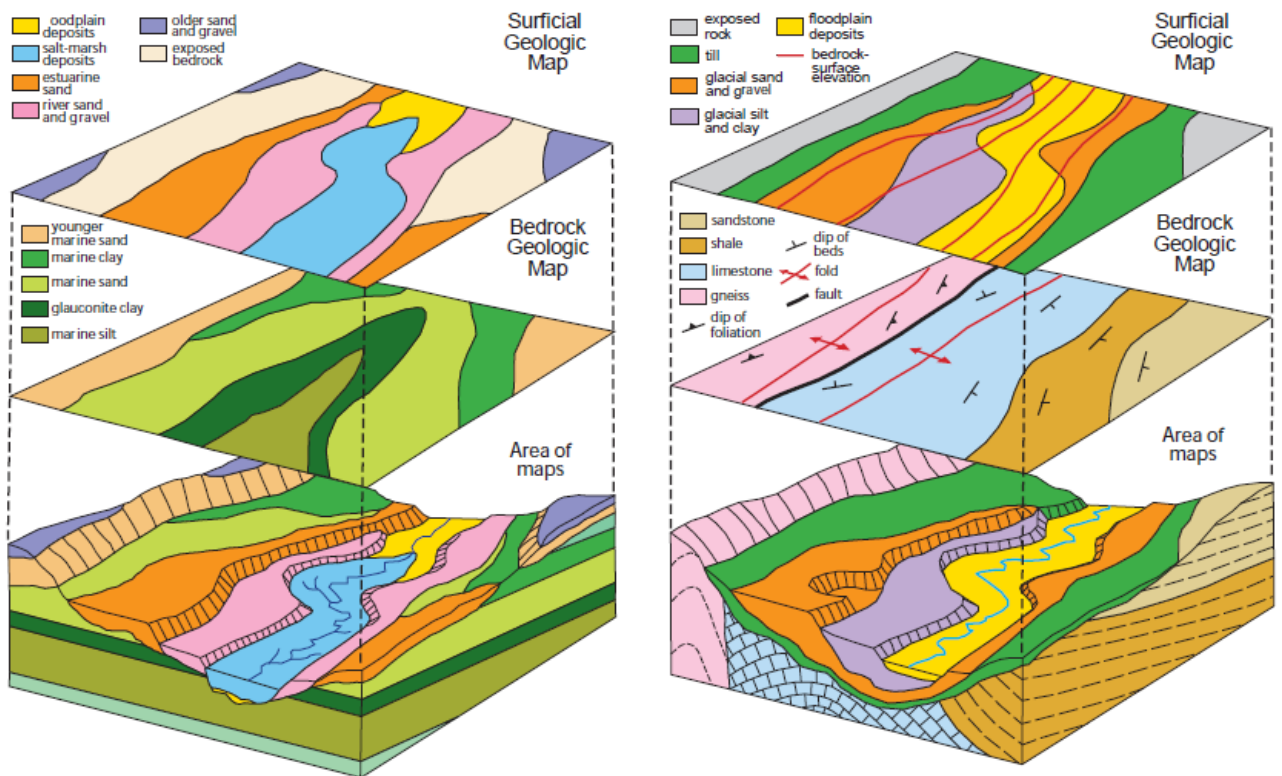


Figure.67- Block diagrams illustrating bedrock and surficial geologic maps in the Coastal plain (left) and northern New Jersey(right)

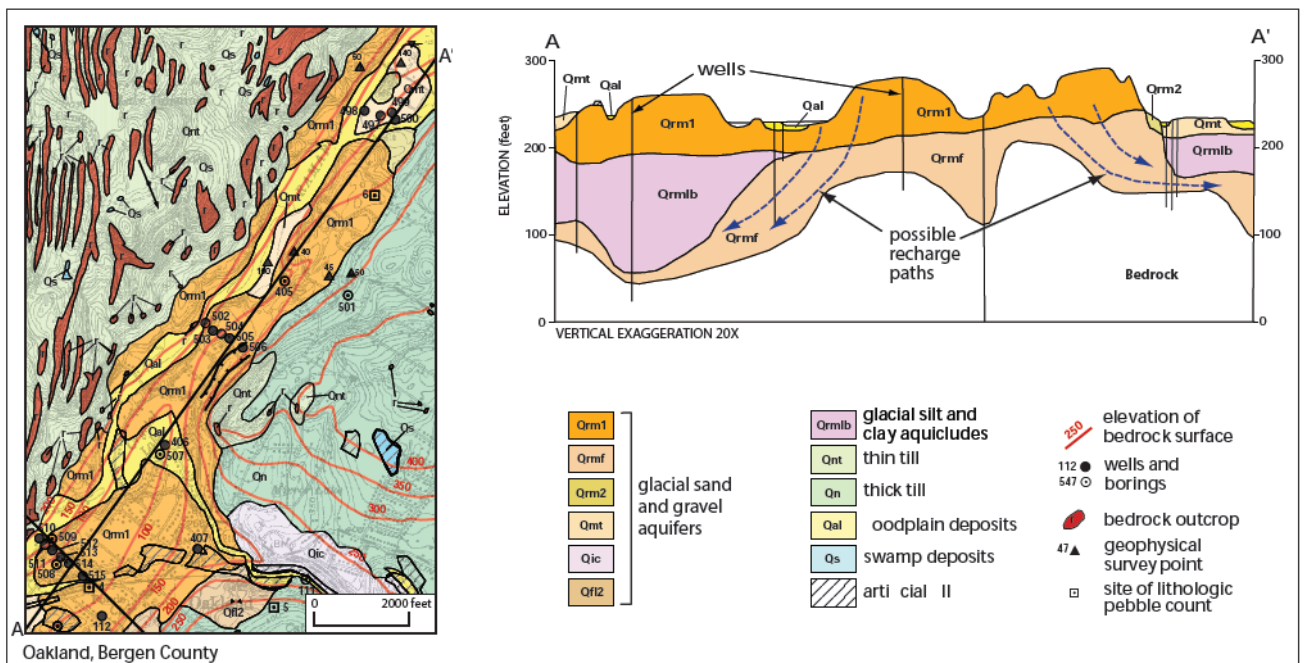


Figure.68- Map and cross section of a glacial valley-fill aquifer in the Ramapo River valley. From N.J.Geological survey open file Map OFM62..

## ***Development of a Study Plan***

Prior to mapping any project, a study plan must be developed. Depending on the complexity of the site geology, the nature of the engineered structure, and the level of previous studies, the study plan may be preliminary or comprehensive. Although elements of the plan may be modified, expanded, or deleted as geologic data become available, the primary purpose of the study plan—coordination among all geologists and engineers working on the project—should be retained. Early study plan development and agreement to this plan by those involved in the project are necessary to prevent the collection of unneeded, possibly costly data and ensure needed data are available at the correct time in the analysis, design, and construction process.

## ***Scope of Study***

The purpose and scope of the mapping project are strongly influenced by the primary engineering and geologic considerations, the level of previous studies, and overall job schedules. The purpose and scope are formulated jointly by the geologists and engineers on the project. Time of year and critical dates for needed information also will have a great impact on the pace of data collection and the personnel needed to handle a mapping project. Discussion of these factors prior to initiating the mapping program is essential so that only necessary data are obtained and the work can be completed on schedule. Items to consider when defining the scope of a mapping program are:

1. Study limits.—Set general regional and site study limits based on engineering and geologic needs.
2. Critical features and properties.—Determine the critical geologic features and physical properties of site materials that will need to be defined and discuss the difficulties in collecting data on these features.
3. Schedules.—Determine schedules under which the work will be performed and define key data due dates. Prioritize work to be done. The time of year the mapping is to be performed, the type of mapping required, available personnel and their skills, the availability of support personnel such as drill crews and surveyors, and budget constraints will influence the work schedule and must be carefully evaluated.
4. Extent of previous studies.—Collect and study all available geologic literature for the study area. The extent and adequacy of previous studies helps to define the types of mapping required and how data will be collected, i.e., based on analyses, design, or construction needs.
5. Photography.—Aerial and terrestrial photography should be considered for any project. As a minimum, aerial photographs of the site should be reviewed. Aerial photographs reveal features that are difficult to recognize from the ground or at small scales. Extensive use of terrestrial or aerial photography will require a different approach to the mapping program. Define areas where terrestrial photogrammetry could aid mapping progress. Terrestrial photography of various types is an integral part of the final study record.

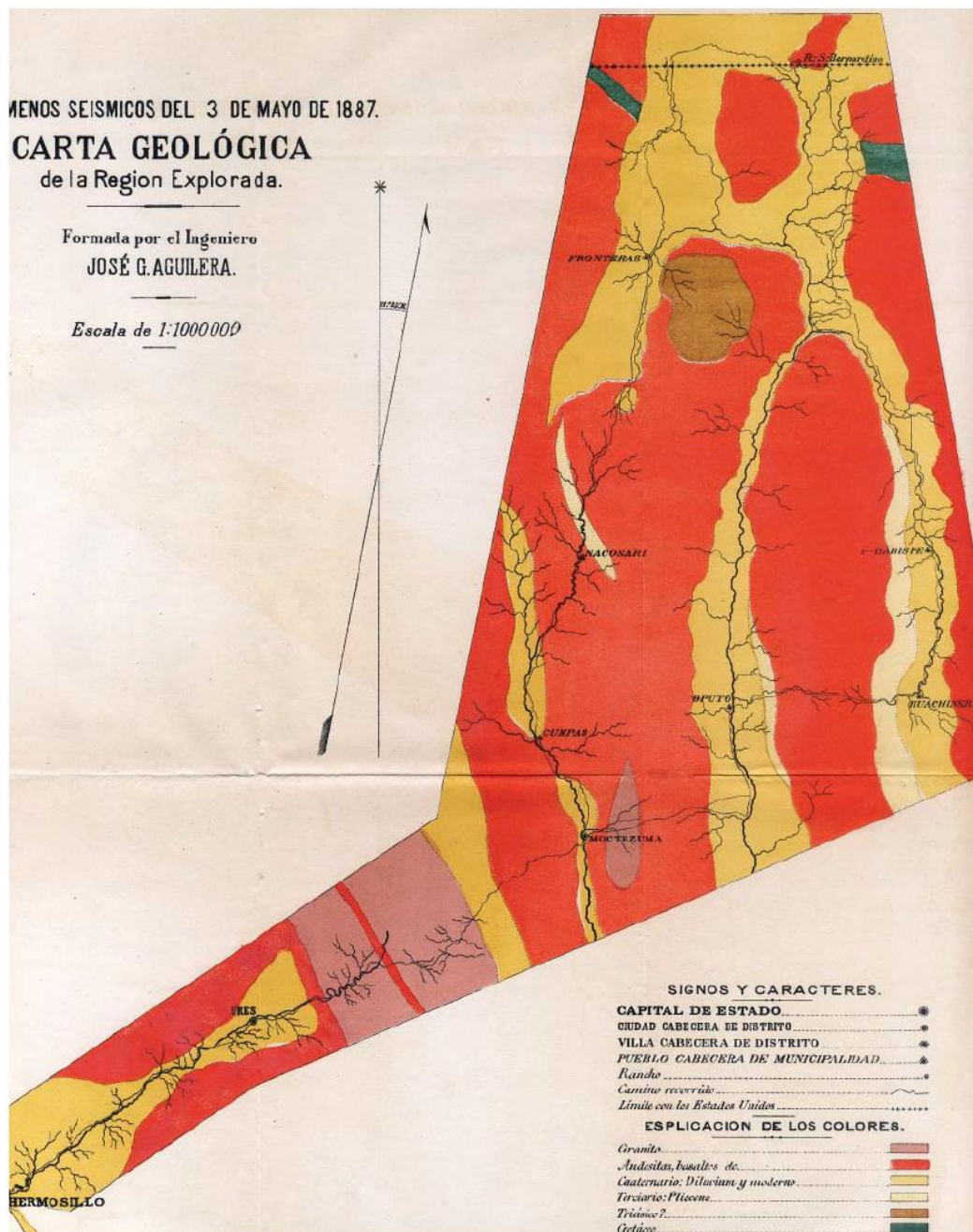
## ***Map Type***

Define the types of mapping required and how data are to be collected, including special equipment needed for data collection. The types of mapping required depend on the study purpose or the type of structure or site that is to be built or rehabilitated, structure size, the phase of study (planning through operation and maintenance), and the specific design needs.

## ***Scales and Controls***

Define the required scales for design or construction needs. Although finished maps can be enlarged or reduced photographically or by Computer-Aided Drafting Design (CADD)-generated drawings to any desired scale, in most cases map text and symbols will have to be redone for legibility. Selection of an adequate map scale at the beginning of a mapping project will save time and energy as well as

help ensure that the types of data needed can be portrayed adequately on the final drawings. Suggested map scales for various types of investigations are listed under specific mapping techniques.



**Figure.69- Excerpt from the geologic map of northeastern Sonora by José G. Aguilera (1888). The original map scale is 1: 1,000,000. The reproduction is reduced to a scale of ~1: 1,500,000. The map employs six cartographic units and shows Aguilera's itinerary.**

## Weathering

1. **Weathering:** changes that take place in a rock exposed at the earth's surface
2. **Mechanical Weathering:** breaking larger pieces into smaller pieces (clastic), with no change of chemical composition
3. **Chemical Weathering:** original minerals partially dissolve and new minerals form that are more stable at the lower temperature and pressure, and moister environment at the earth's surface.

## ***Mechanical Weathering***

Mechanical weathering consists chiefly of extensive fracturing of rocks without any relation to the chemical changes which may be occurring simultaneously. Several of the physical processes which produce mechanical weathering are described below.

### ➤ **Freezing of Water**

Most water systems in rocks are open to the atmosphere, but preliminary freezing on the surface encloses the system. When water freezes it expands nearly one-tenth its volume, creating great pressures (up to  $4000 \pm \text{lb/in}^2$ ) in enclosed spaces. This expansion of the ice fractures the rock and breaks it into smaller particles.

### ➤ **Temperature Changes**

Daily and seasonal temperature changes cause differential expansion and contraction in rocks which result in spalling or exfoliation. This type of weathering is most noticeable in moist, cold climates and results from a combination of frost action, chemical decomposition, and temperature expansion and contraction.

### ➤ **Action of Plants**

Trees and plants have an amazing capacity to grow in the joints of rock masses. The wedging action caused by root growth hastens the disintegration process near the earth's surface.

## ***Miscellaneous Mechanical Agents***

There are many other methods by which mechanical weathering is accomplished. Animals, by their burrowing activities, can accelerate disintegration. Crustal movements, such as faulting and folding, create much damage in a short time. Gravity causes rock slides and avalanches which break up large rock masses. Ice (in the form of glaciers) has disintegrated and transported enormous quantities of rock.

## ***End Producte of Weathering***

Materials produced by mechanical weathering tend to be of angular shape. These particles are composed of the same material as the parent rock. Chemical processes act to change the chemical composition of the parent rock. Materials produced chemically will have a greater volume but a lower specific gravity than that of the original material. The products of both types of weathering include materials moved in solution or colloidal suspension, and residual substances. The former usually are transported from the scene of activity to become sediments. The residual products remain after the soluble constituents have been leached. The chief residual product is clay. Oxides of iron and aluminum are also residual products of weathering and usually are formed, but not exclusively, in tropical climates. Other end products are minerals such as quartz, zircon, and rutile, which are not appreciably soluble under ordinary conditions of weathering. It is important for engineers to be able to recognize weathered rock and to appreciate the limitations it may place on construction. In general, weathered rock will be softer, less dense, and will have more voids than the original material. The greater the decay, the greater will be the potential water and clay content. Weathered material may become highly unstable.

## ***Energy of Environment***

- I. **High-energy** environments can carry both large and small particles. Typically the conditions are catastrophic (landslide, flood).
- II. **Low-energy** environments (lake, Deep Ocean) can carry only small particles.



## **Part 2**

### ***Geotechnical Engineering -Tunnelling***

For civil engineering, ground models need to be prepared that are simplified representations of a site and that should incorporate all the important elements relevant to design and construction. The models are generally developed from a preliminary 3D interpretation of the geology based on desk study and surface mapping and then refined by further study of environmental factors such as earthquake hazard and hydrogeology. Models will be improved by ground investigation and testing and finally presented as a design model specifically tuned to the project.

One of the key features of many ground models is differentiating between upper, soil-like materials, and underlying rock, with the separating boundary being called rockhead or, sometimes, 'engineering rockhead'. Care must be taken in using this term because it has various definitions and connotations and is sometimes used in an over-simplistic way for what is a complex situation.

The tunnel engineering geology and deformation control is one key of the basis for the tunnel engineering construction and operation management and safety technology security. However, it is becoming one of the bottleneck problems for underground tunnel construction project information to be solved accurately and fast to assess the stability of surrounding rock because of the special environment in the tunnel construction and acquiring the deformation information of surrounding rock. The geotechnical engineer plays a key role in most civil engineering projects as most structures are built on or in the ground. Geotechnical engineers assess the properties and behaviour of soil and rock formations.

***Geotechnical engineering is a collective term for the more individual disciplines of:***

- Soil mechanics
- Foundation engineering
- Engineering geology and hydrology
- Environmental science
- Rock mechanics
- Rock engineering
- Other related disciplines to civil engineering design and construction.

The geotechnical engineer may, for example, assess the materials to be used for the stability of dams, roads, channels, tunnels and airport runways.

The importance of geology in the planning of tunnels is stressed, as is the significance of the vast uncertainty and risk that exist in underground projects. When Tunnel project is situated in complex geological setting and offers heterogeneous ground conditions. Therefore comprehensive geological, hydrogeological and geotechnical ground investigation was designed and implemented. The investigation included all kind of state-of the art investigation methods comprising field work, in-situ testing as well as laboratory analyses. A flexible approach in investigation strategies allowed for appropriate investigation of sections with complex geological architecture .

### ***Tunnel Form***

**Two forms of tunnel were considered:**

1. Cut and Cover Construction
2. Tunnelling through Bedrock

Cut and Cover construction would be appropriate where the road alignment is at a relatively shallow depth of up to about 15 m, leading to only a small cover over the tunnel. Tunnelling is suitable where the depth of the road alignment is over 30 m, giving a cover of over 20 m. This assumes a tunnel

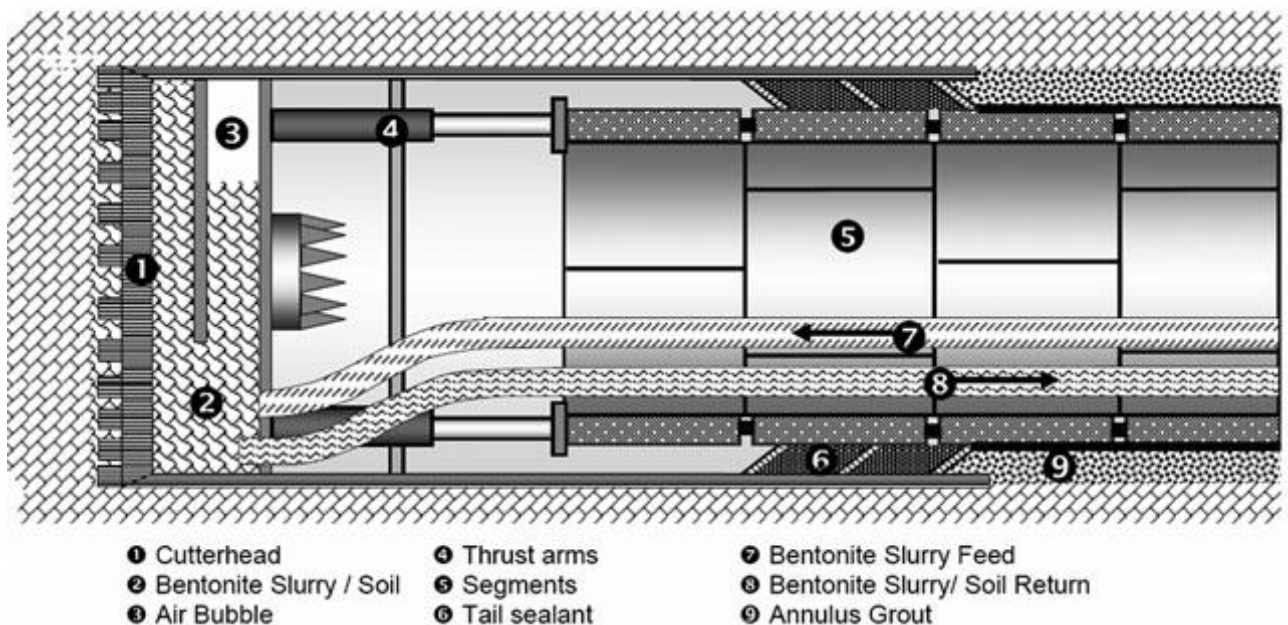
width of about 15 m and height of about 10 m. Between 15 m and 30 m, tunnelling can still be considered but would require greater support measures.

A combination of cut and cover construction form at either end near the tunnel portals and tunnelling methods in the middle section where the tunnel is at greater depth were considered to be appropriate. Ideally, an investigation of a construction site should yield precise, three-dimensional locations of rock and soil units, locations and extent of fractures, quantitative appraisals of the physical and chemical properties of the rock and soil units, and appraisal of the materials in and near fractures or other rock or soil discontinuities. Estimates should be made of amounts and distribution of ground water or noxious gases, of rock or ground-water temperatures, and of the possibilities of seismic activity. Such data will permit adequate, economical engineering planning and design and will be of great practical value during construction. In actual practice, exact prediction of all the geologic conditions that will be encountered during construction almost never is realized, and the geologist should be given the opportunity to study and interpret for the engineer the geologic features revealed during construction and not anticipated in kind or degree during the site investigation.

### ***Soft soil tunneling***

Tunnels in soft soil are often constructed as bored tunnels, when the use of cut and cover tunnel techniques is not possible or too costly an option. Bored tunnelling techniques cover both tunnels constructed by the use of a **Tunnel Boring Machine (TBM)** and tunnels constructed by hand tools and machines, using an observational approach with temporary support of the excavation. The latter is often called **Sprayed Concrete Lined (SCL)** tunnels.

Two typical TBM types are the **Earth Pressure Balance (EPB)** machine and the slurry machine. During construction, the former is able to counterbalance the ground and water pressures in front of the TBM by the use of one or two screws between the cutterhead and the conveyer belt. The latter uses a technique where bentonite slurry is pumped into the cutterhead and mixed with the excavated material. The mixed slurry is then pumped out of the tunnel where the bentonite and the excavated material are separated again. This system also provides stability in front of the TBM during tunnel construction.



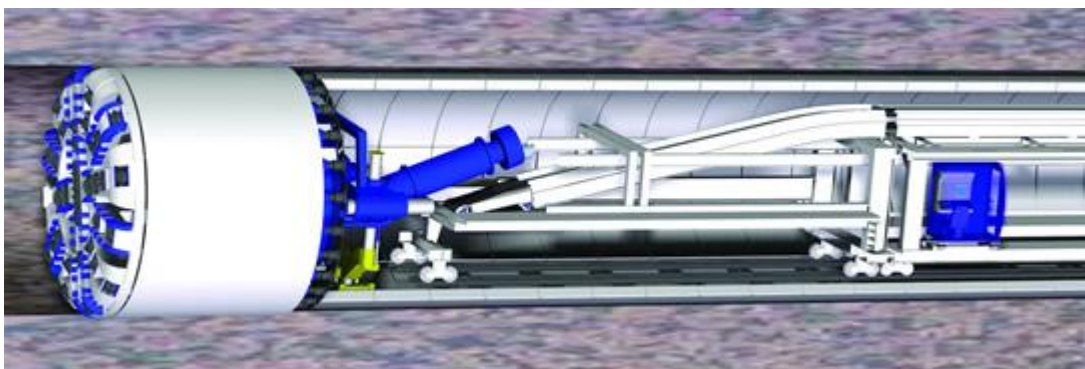
***Figure. 70– TBM***



***Figure.71 - The construction of Crossrail's first permanent sprayed concrete lined (SCL) tunnels on the project is now underway at Blomfield Street in the City of London.***

Tunnels constructed by a TBM are typically circular and used in soft ground for long tunnels. TBM tunnels are used both in urban and non-urban areas in soft soil and in a sub-aqueous environment. Compared to SCL tunnels, TBM bored tunnels can be constructed in less competent ground and where water pressures are high or impossible to drain. TBM bored tunnels are typically lined with a prefabricated segmental concrete lining.

SCL bored tunnels are often used for construction of non-circular tunnels or shorter tunnels in relative competent ground conditions, where the ground can be drained during construction. The SCL cross-section can be excavated in sections to suit the actual conditions, and excavations are temporarily lined with a primary lining consisting of shotcrete. The permanent secondary internal lining is built as an in-situ cast concrete lining.



***Figure.72 - Earth Pressure Balance Machine***

### ***Risk management of tunnels***

Risk management is essential in tunnel design and construction. There is a potential for major accidents in tunnels both while the tunnels are being constructed and during operation of the completed tunnel. The major accidents which have occurred in recent years merely emphasise this. Thus, it is important that systematic risk management is implemented in tunnel projects in order to ensure an adequate level of safety in a cost-efficient way.

The safety concept is a description of the main features of tunnel design and operation to be implemented to ensure adequate safety during operation of the completed tunnel. The concept should

be developed early in the design process to serve as the basis for initial project approval and for the detailed design.

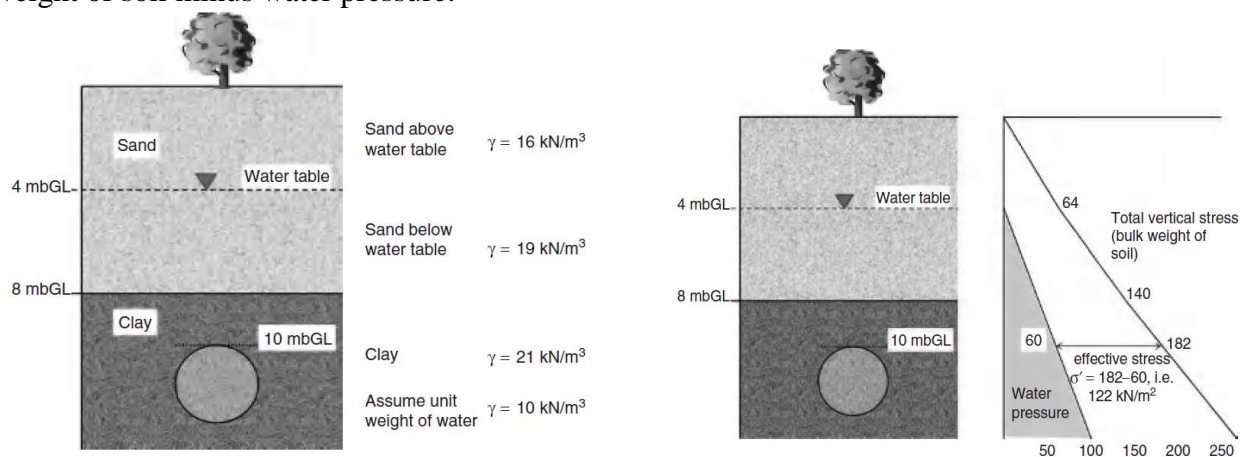
An overall risk assessment should be carried out in order to identify all types of risk during operation of the tunnel. For significant hazards detailed risk assessments should be carried out as a basis for the design decisions. This may include simulations of fire development and smoke spread as well as simulations of evacuation scenarios. An overall risk assessment should be carried out in order to identify all types of risk during the construction of the tunnel. Design and construction methods should be re-evaluated for significant hazards, and risk mitigations should be considered in order to reduce risks to an acceptable level.

## Loads

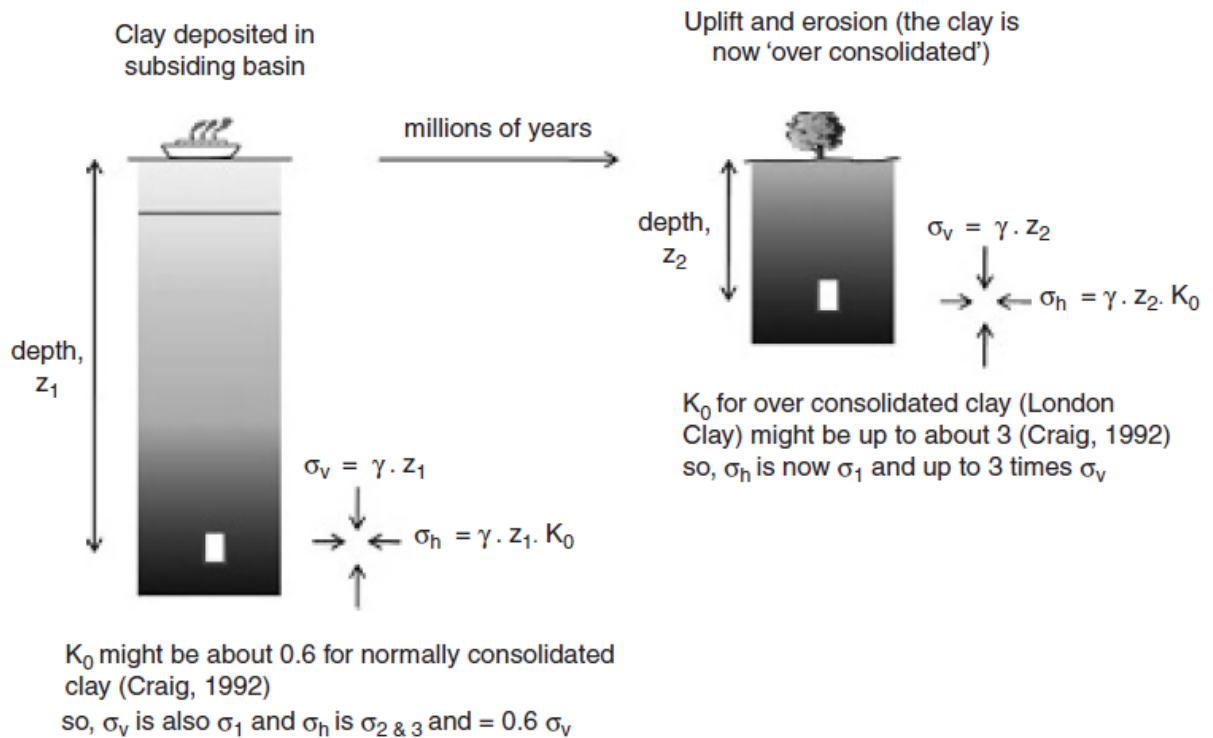
Most civil engineering projects involve either loading the ground, say from the weight of a new building, or unloading because of excavation of a slope or in a tunnel. Load changes can be permanent or temporary, static (due to weight) or dynamic (due to blasting, for example). A further important consideration for most geotechnical problems is the self weight of the ground and other in situ stresses.

## Natural stress conditions

At any point in the Earth's crust, the stresses can be resolved into three orthogonal directions. These are termed the maximum, intermediate and minimum principal stresses and depicted  $\sigma_1$ ,  $\sigma_2$  and  $\sigma_3$ , respectively. By definition, the planes to which the principal stresses are normal are called principal planes and the shear stresses on these planes are zero. An important point regarding rock engineering is that all unsupported excavation surfaces are principal stress planes because there are no shear stresses acting on them (Hudson, 1989). One of the principal stresses will always be perpendicular to the Earth's surface (Anderson, 1951) and is generally vertical. For projects close to the Earth's surface, such as cut slopes or foundations, natural stresses include self weight, weight of included water and buoyancy effects below the water table, which reduces the total stress to an effective stress (weight of soil minus water pressure).



**Figure.73 –Example: Soil profile with tunnel to be constructed with crown at 10mbGL, and show Total and effective stresses (vertical) .by Steve Hencher**



**Figure.74 - Stress conditions in overconsolidated soil. Uplift and erosion will result in a reduction in the vertical stress on the soil element but some residual horizontal stress may be retained from its burial history.** by Steve Hencher

### **Temporary and permanent works**

The engineer's design generally concerns the permanent works – the long-term stability and performance of the finished project. Performance is measured by criteria specific to a project, such as settlement, leakage, durability and long-term maintenance requirements. During construction, there will usually be other design considerations including stability of temporary excavations, disturbance to the groundwater conditions and water inflow to the works. Temporary work design is generally the responsibility of the contractor and his design engineers, perhaps checked by an independent checking engineer. The design of deep temporary excavations can be just as demanding as for permanent works. In tunnels, during construction there may be a need to stabilise the walls and possibly the working face using rapidly applied techniques, including shotcrete with mesh or steel fibres, steel arches or lattice girders and rock bolts (Hoek et al., 1995).

### **Options for construction**

Up to about a century ago, all tunnels in soil or rock were excavated by hand, using explosives where necessary to break up the rock in advance of mucking out. Nowadays, many are excavated using powerful machines. The main options generally adopted in modern tunnelling and typical support measures are set out in Table below.

**Table 7- Options for tunnelling (after Muir Wood, 2000).**

<i>Ground type</i>	<i>Excavation</i>	<i>Support</i>
Strong rock	Drill and blast or TBM	Nil or rockbolts
Weak rock	TBM or roadheader	Rockbolts, shotcrete, etc.
Squeezing rock	Roadheader	Variety depending on conditions
Overconsolidated clay	Open-face shielded TBM or roadheader	Segmental lining or shotcrete etc.
Weak clay, silty clay	EPB closed-face machine	Segmental lining
Sands, gravel	Closed-face slurry machine	Segmental lining

### ***Hard rock tunnelling***

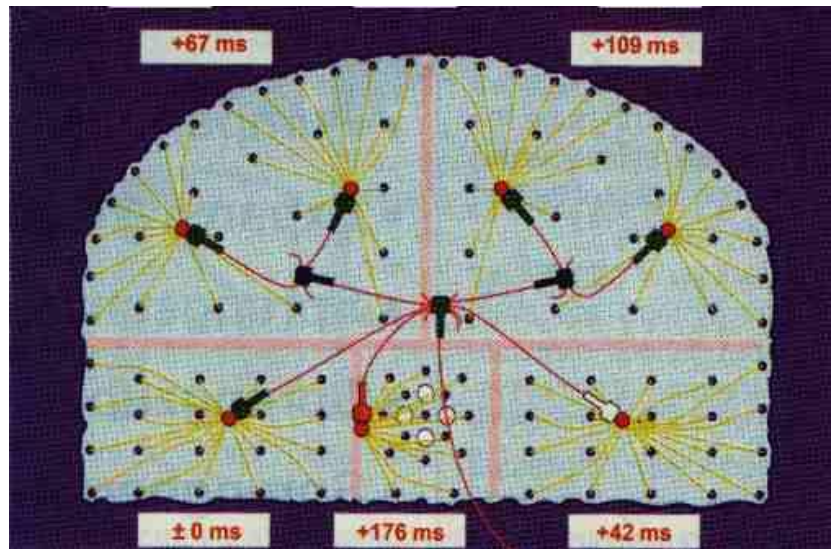
The main options are drill and blast, a roadheader excavating machine or to use a TBM that may be either open (without a protective shield) or shielded.

### ***Drill and blast/roadheaders***

Generally, drill and blast tunnels are more flexible than TBMs and allow difficult ground conditions to be understood and overcome, but they may be much more time consuming unless a number of access points can be found to allow operations to proceed from several faces at the same time. Holes are drilled in the face, and explosives placed in the holes. Issues of tunnel blast design are addressed by Zare & Bruland (2006). The holes are detonated sequentially to break to a free face over micro seconds. The aim is to break the rock to manageable size so it can be excavated (mucked out) readily with machines, without further blasting or hammering. Other aims may be to keep blast vibrations to a minimum and not cause damage or offence to nearby residents, and usually to keep as closely as possible to the excavation shape prescribed by the designers, i.e. minimising overbreak. Typical advances per round are 3 to 3.5m, sometimes up to 5m in very good rock conditions. Depending on the size of tunnel and ground conditions, the full face may be blasted in one round or may be taken out as a series of smaller headings – top, or side, that may be supported by sprayed concrete with steel mesh or steel/ carbon fibres, rock bolts, and/or steel arches or lattice girders, before the tunnel is advanced.



***Figure.75 - Vehicle with bore jumbos to drill shotholes for a later blast***

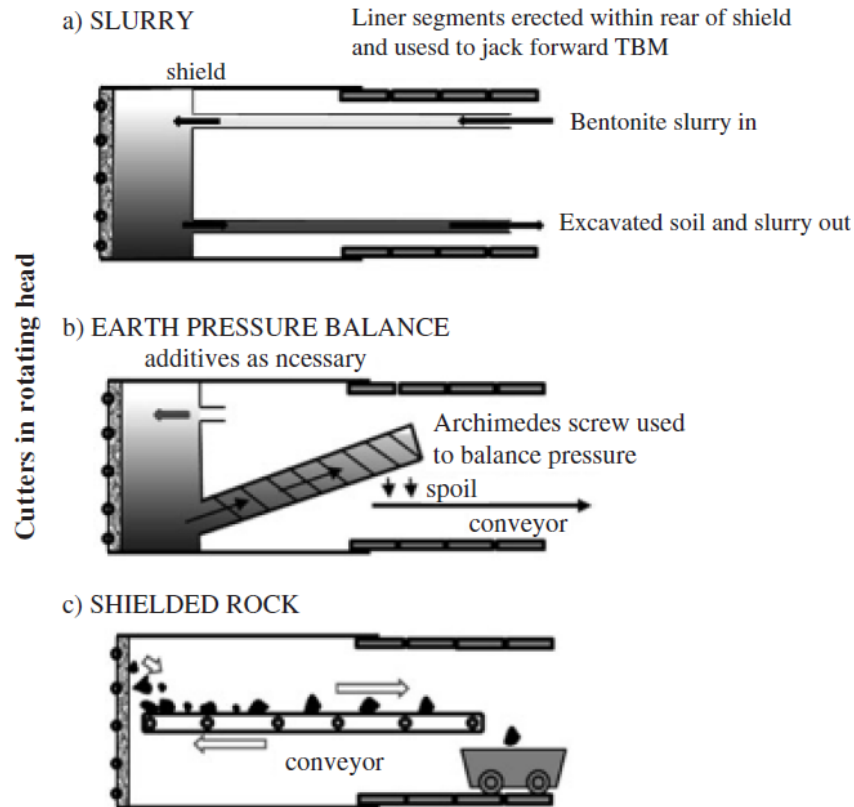


**Figure.76 - Example of an explosion scheme for drill and blast tunnelling.**

After blasting, and dust and gases have dissipated and safety checks made (e.g. for methane or radon), the broken rock is mucked out and it is the engineering geologist's task to examine and map the geological conditions exposed. The freshly blasted rock may well be unstable, and the geologist should not approach the face until the contractor has carried out all necessary scaling and/or rock support work to make the tunnel safe.

The design and use of modern hard rock TBMs is covered comprehensively by Maidl et al. (2008). In good rock with high RQD, open TBMs are sometimes used, but generally only for relatively small diameter tunnels. The tunnel advances by jacking forward against grippers that are extended laterally against the tunnel walls. Clearly, if the rock becomes poor quality then there may be problems with the grippers. There is also no way of preventing groundwater ingress other than by grouting, preferably in advance of the machine. In poorer-quality rock, generally, shielded TBMs are used. A single shield machine pushes against the liner, as for soil TBMs. In other set-ups there are two shields; the rear shield has grippers and provides the reaction against which the front shield can push forward. The cutter head has discs that rotate as the cutter head itself rotates. The thrust of the machine causes the rock to fail, mainly in tension. A major consideration is the lifetime of the cutting discs before they need to be replaced, as addressed by Maidl et al. (2008). options include freezing the ground and grouting the ground to stabilise it to allow the TBM to be withdrawn (NCE, 19 January 2011).

Where the materials to be excavated include strong and weaker material, this is known as mixed-face conditions. For stability, the major issue concerns relative mobility of the materials rather than just strength. A mixed face of strong boulders and hard clay presents problems in terms of rate of excavation, but generally not in terms of heading stability. However, a combination of strong, stable rock with a more mobile material, such as flowing, rapidly squeezing or fast ravelling material, provides conditions where the overall stability of the heading can be very difficult to control as well as difficult to excavate. Shirlaw et al. (2003) provide examples of major inflows resulting from the use of conventional rock tunnelling methods too close to the transition from rock-like to soil-like conditions. Ironically, this particular type of mixed-face condition has become even more problematic with the introduction of modern tunnelling technology.



**Figure.77 - Schematic diagrams of shielded TBMs. a) Slurry machine; bentonite slurry is pumped to plenum chamber and mixes with spoil cut at the face. Mixture is removed for separation and treatment before recycling. b) Principles of EPBM. Cut soil (with additives as necessary) is removed by a screw device with the pressures monitored and maintained. c) Single-shield rock TBM. Rock cut from the face is mucked out and TBM pushes forward against the liner erected to the rear of the shield. Other rock TBMs use grippers pushed against the walls of the tunnel and use this as the reaction force for advancing the TBM.**

**Table 8- Typical problems with TBM tunnels and possible mitigation measures.**

Problem	Mitigation
Ground too strong (intact strength and/or lack of discontinuities)	May need to pull TBM back and advance with drill and blast
Ground too weak and collapsing (should have been an earth balance or slurry machine perhaps)	Ground improvement might be necessary in advance of tunnel drive – grouting or freezing
Major faults	Collapse of ground and TBM gets stuck. May need to sink a shaft in front of machine and construct a tunnel back to and around the TBM to free it up. Ground treatment and possible hand construction through fault zone may be required to get the TBM going again
Weak ground and high <i>in situ</i> stresses leading to squeezing action on TBM	Can cause huge delays. Ground improvement to strengthen the ground and resist the squeezing pressures
Too much clay for slurry treatment	Can cause delay and necessitate installation of additional treatment plant – extra hydrocyclones, etc
Ground abrasive because of high silica content causing too much wear on teeth, leading to cost and delay	Cost may be prohibitive, necessitating a change of excavation method
Too much water and TBM electrics not protected	Drilling and grouting in advance of machine or possibly ground freezing or compressed air working. Possible change of method to drill and blast or employ different machine with suitable spec
Excess tunnel slurry pressure causes blowout at ground surface	Lower pressure
Pressure too low causes face collapse	Reverse of the above

## ***Tunnel support***

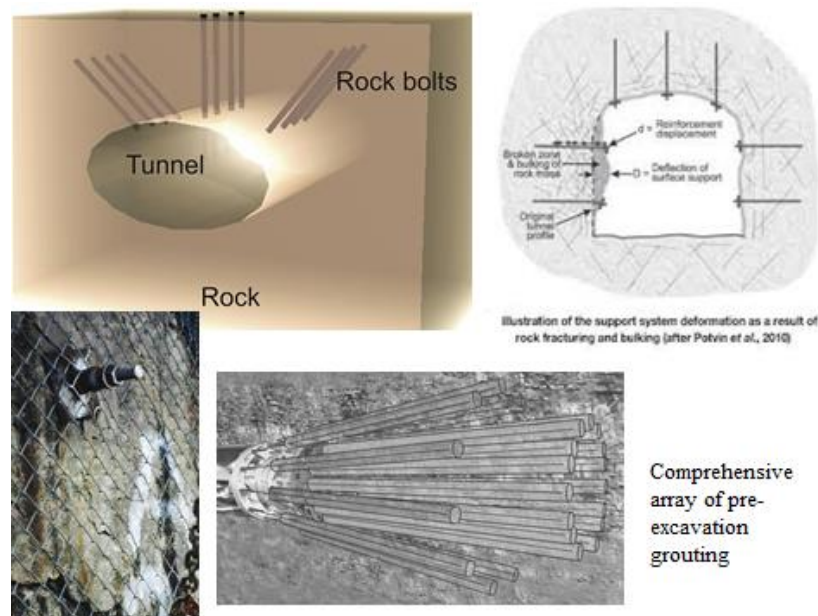
Rock tunnelling, in general, relies largely on the rock mass locking up as joints and interlocking blocks of rock interact and dilate during the process of convergence towards the excavation. Good-quality rock often forms a natural arch and no or little support is needed. However, in weaker ground, such as in fault zones, the rock mass cannot support itself, even with reinforcement, and requires artificial support in the form of steel arch ribs, typically encased in shotcrete. Optimising support requirements in weaker ground requires prediction of likely convergence rates, making observations as excavation is undertaken, i.e. observational methods, and then applying support such as rock bolts and/or shotcrete and/or steel arch ribs to control the movement and prevent excessive loosening (Powderham, 1994). In stronger, blocky rock masses, rock movement will be much less, and the purpose of the support is then to prevent loss of loose blocks and wedges, which would destabilise the arch and maybe lead to raveling failure.

## ***Rock tunnel support systems***

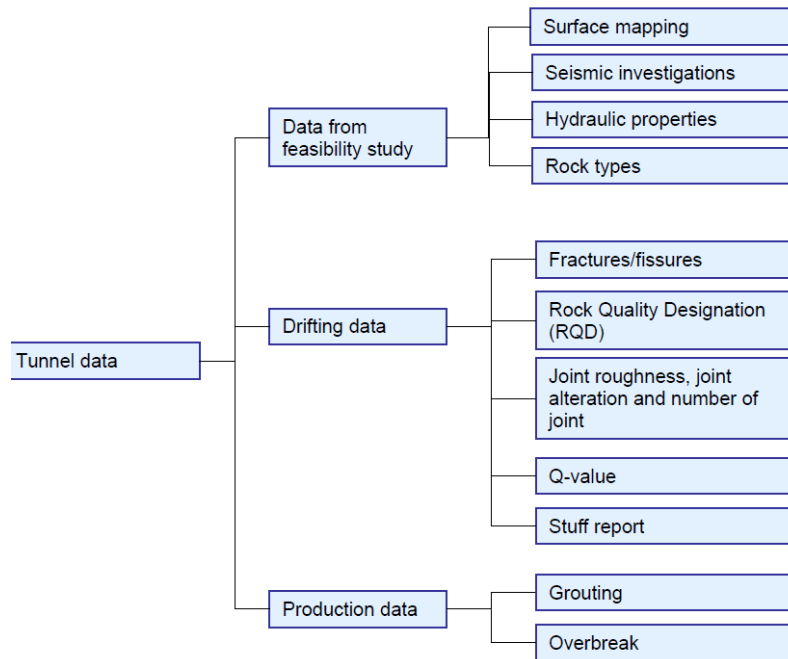
There are different support systems when building tunnels, passive support, active support, shotcrete and rockbolts or dowels are all types of support.

- Passive support is steel ribbed precast concrete segments that are used as liner on the inside of the tunnel, often used in TBM tunnels where the TBM places the segment.
- Active support is shotcrete and rockbolts together forming a self-supporting arch within the rock mass, often used to support rock mass over tunnel openings. It works better than passive support for all types of ground conditions except weak soils.
- Rockbolts or dowels are used as support in jointed rocks to secure loose bolts or reinforce the material where the stress level makes the excavation area collapse if not supported. Rockbolts are steel rods that either has an expansion shell in the end or is fixed with grouting.

**Rock grouting in tunnels is a way to prevent groundwater from leaking into tunnels.** Groundwater transports through joints in the rock mass and by filling these with grout, the rock mass is made impermeable. It is important to prevent groundwater level lowering since it affects wells and can also cause subsidence of structures situated above the underground opening. Grouting can be performed either before or after excavation. Pre-grouting is injected as a screen in front of the face.



***Figure.78- Rock tunnel support systems***



**Figure.79- Map tree over data chart for all tunnel projects**

### **Methods of calculating rock quality**

The degree of fracturing is estimated with Rock quality Designation (RQD), which is defined as the percentage obtained by dividing the summed lengths of all core pieces equal or greater than 100 mm by the total core length (Edelbro 2003). The rock quality expressed as RQD is presented in Table.8.

**Table.9- Rockquality according to the RQD-method**

<i>RQD</i>	<i>Rock Quality</i>
90 – 100	Very good
75 – 90	Good
50 – 75	Fair
25 – 50	Poor
0 – 25	Very poor

### **Tunnel squeezing**

When a tunnel opening is formed, the local stress regime is changed. The radial stress falls to zero and the tangential stresses increase to three times the in situ overburden load (neglecting the effects of any locked-in stress resulting from past tectonic action that has not been relieved). If the unconfined compressive strength of the rock is less than the increased tangential stress, a mode of failure will be initiated which is described as "squeezing rock". As elastic failure occurs, with consequent reduced load-bearing capacity of the ground, the load is transferred by internal shear to adjacent ground until an equilibrium condition is reached. If the ground develops brittle failure and is shed from the tunnel walls, then there will be no residual strength of the failed ground to share in the load redistribution. If the ground is sufficiently weak or the overburden load too great, the unrestrained tunnel may close completely. [5].



*Figure.80- Failure of a tunnel section due to very severe squeezing (background) and re-mined and re-supported tunnel (foreground) (Hoek & Marinos 2009).*



*Figure.81- The 1.5km deep Olmas Trans-Andean tunnel is being cut through sever squeezing ground*

### **The Squeezing Process**

The detailed mechanism of ground movement is complex and depends on the presence or absence of water and swelling minerals as well as on the physical properties of the ground. For the purposes of this discussion, however, the squeezing process may be described as follows.

### **Creep**

As a consequence of the reduced elastic modulus and the reduced strength of the rock additional radial movement of the tunnel walls occurs. In the zone outside the tunnel, the rock properties are substantially changed. In particular, both the elastic modulus and the unconfined compressive

strength decrease continuously (but not in a linear fashion) from their original values still existing in undisturbed rock toward the tunnel wall. The tunnel decreases in diameter as the weakened material creeps toward the tunnel boundary. The rate of movement is roughly proportional to the applied load. The movement is therefore time-dependent (after the initial elastic stress relief, which may be regarded as essentially instantaneous).

### **Modeling Rock Behavior**

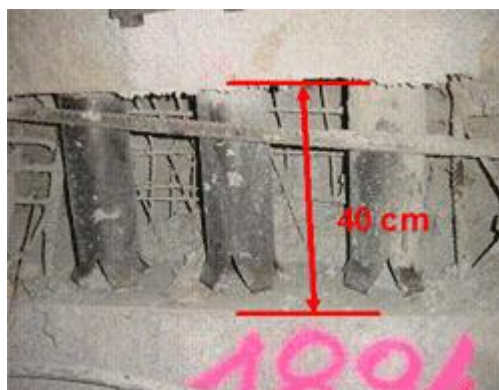
Because of the nature of the failure mode, elasto-plastic and visco-elasto-plastic mathematical models have been developed to describe the resulting movements and to evaluate the stress regimes for tunnels in rock. These models are not exact but correspond sufficiently well with experience to be useful. Unfortunately, for any given tunnel they depend on the use of information which can only be derived from experience in the specific tunnel involved. It has been noted from experimental work that the net load appearing at the tunnel surface varies with the tunnel diameter as a power function. The loading is also dependent on the rate of tunnel advance. It is therefore clear that when such conditions are encountered, the smallest tunnel diameter adequate for the purpose should be selected. Experience also shows that circular tunnels are easier to support than any other shape.

### **Monitoring**

Rate of squeeze and rock loads are somewhat dependent on tunnel size and rate of advance. It is essential in squeezing (or swelling) conditions--or even in blocky and seamy rock where joint closure may create problems--to establish a program of convergence point installations which will be routinely used to monitor the amount and rate of movement of the tunnel walls. This information collected over time and collated with the behavior of the tunnel support system will provide the information needed both to predict and to install the appropriate amount of support as tunneling progresses.

### **Yielding Supports**

One approach to squeezing rock is to go to a simple and workable system of yielding supports as illustrated in Figure 67. The number of yielding joints can be modified to provide the needs of the rock currently being excavated since all components are manufactured on site. Each joint permits up to 22 cm of closure. (See Figure 68) It has been found essential to shotcrete the gaps once the closure nears the limit allowed without the steel sections actually butting together. Failures have been common when this butting has been allowed to happen. It has also been found that allowing the invert to heave freely for twenty to thirty days before making an invert closure allows the total support system to resist all remaining loads with some reserve capacity for long term load increases. Other, more complicated yielding systems have been designed and used.



**Figure 82- Yielding Support in Squeezing Ground**

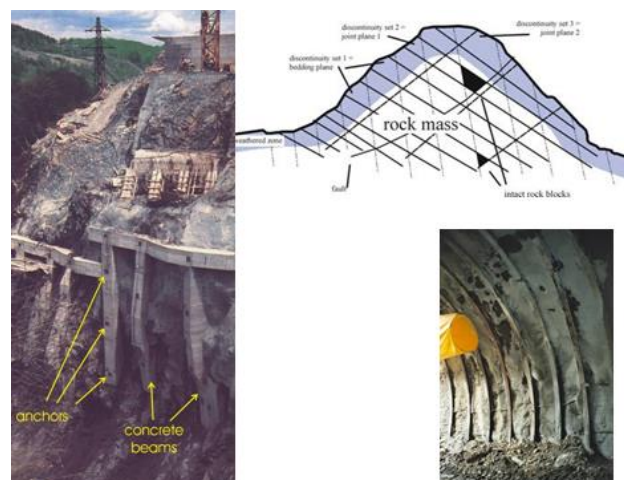


**Figure 83- Yielding Support Crushed to 20 cm (One-half) (ILF, 2008)**

In summary, the support system provides a relatively low initial support pressure and permits almost uniform stress relief for the rock in a controlled manner around the entire circumference of the tunnel while preventing the rock from ravelling. The shotcrete is not damaged by the convergence because of the yielding joints and so maintains its integrity, provided that timely closures are made. After allowing practically all of the stress relief required by the elasto-plastic stage of rock deformation, the support system is made rigid whence it can support a pressure of 3.8 MPa which is available to deal with long term creep pressure.

### ***Discontinuous rock mechanics***

Rock mechanics for engineering geology and civil engineering purposes is mostly governed by discontinuities in the rock mass. Discontinuities are planes of mechanical weakness, such as fractures, joints, faults, etc. The discontinuities make the behavior of a rock mass anisotropic and make calculations of strength and deformation highly complicated. The chemical and physical exposure of rocks to water and air at the surface of the earth reduce rocks to soil, a process normally denoted as weathering. Soil in various states of weathering may form layers or pockets that exist within rock masses or form the boundary of a rock mass. These soils often contain remnants of discontinuities which were originally present in the rock mass and hence cause an anisotropic behavior of soil masses. An engineering application, such as a tunnel, foundation or slope, in a rock mass is highly likely not only to be in rock but also in soil. Therefore the study of discontinuous rock mechanics is not complete without including discontinuous soil masses.



***Figure.84- Discontinuous rock***

The shear strength of a rock mass and its deformability are influenced very much by the discontinuity pattern, its geometry and how well it is developed. Observation of discontinuity spacing, whether in a field exposure or in a core stick, aids appraisal of rock mass structure. In sedimentary rocks, bedding planes are usually the dominant discontinuities, and the rock mass can be described as shown in Table 3. The same boundaries can be used to describe the spacing of joints (Anon, 1977a).

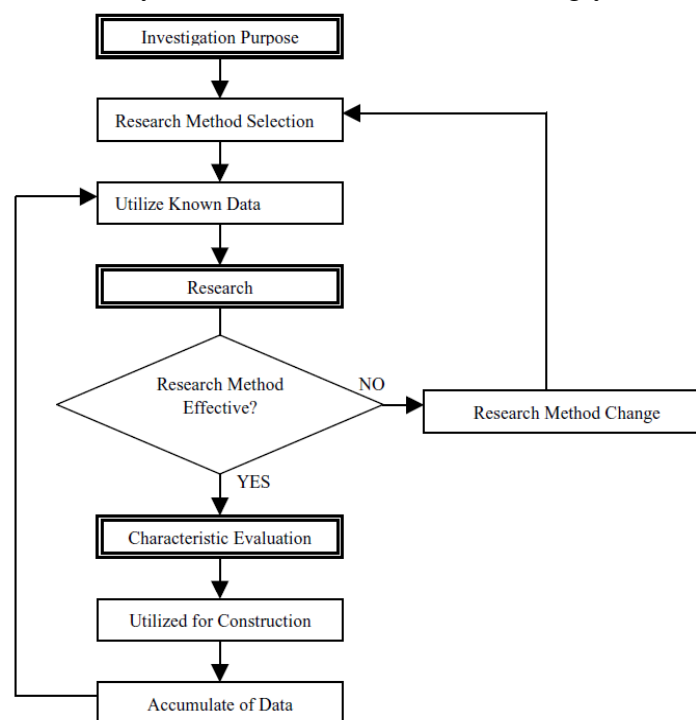
**Table 10-Description of bedding plane and joint spacing (after Anon, 1970a). With kind permission of the Geological Society**

Description of bedding plane spacing	Description of joint spacing	Limits of spacing
Very thickly bedded	Extremely wide	Over 2 m
Thickly bedded	Very wide	0.6–2 m
Medium bedded	Wide	0.2–0.6 m
Thinly bedded	Moderately wide	60 mm–0.2 m
Very thinly bedded	Moderately narrow	20–60 mm
Laminated	Narrow	6–20 mm
Thinly laminated	Very narrow	Under 6 mm

### ***Tunnelling Geological Information Evaluation Technique***

It is important to predict the likely geological conditions ahead of the tunnel face. Various techniques are available to assist in these kinds of predictions. When the survey results are being utilized, the accuracy and reliability of the investigations must be evaluated sufficiently, because the characteristics of these investigations may vary by investigation principle or by characteristics of the research objects. Generally, the geological properties of a tunnel are complex even though the ground conditions of adjacent tunnels may be alike. Therefore, evaluation of the ground investigation results should be performed for every tunnel.

Considering that the most important thing is the usability of the obtained geological information for tunnel construction, the ground investigation purpose should be established beforehand, and evaluation classification of the survey results should be done accordingly.



**Figure. 85- Flow chart for evaluation of the ground investigation results carried out under construction**

All geological structures supposed to be effective for quality and safety of the tunnel under construction, such as faults, fractured zones, water contained zones, large-scale cavities etc., became the researched survey object. And, the scale of fractured zone was supposed to be equivalent to the tunnel cross section as several metres width.

### ***Unexpected Events on Tunnel Constructions***

- 1. Defects in design,**
- 2. Irregularities in the applied method,**
- 3. Human errors,**
- 4. Negligence,**
- 5. Disregard of method or safety requirements**

**Unexpected events may take place anywhere**

- Preparatory measures need to be taken to prevent unexpected (undesirable) events
- The majority of such events, however, are due to foreseeable reasons
- Preparatory measures can be taken; at least the unfavorable impacts of a possible occurrence can be minimized

When projects go wrong because of ground conditions, it is sometimes because those adverse ground conditions were truly onerous and unpredictable but other times because of poor ground characterization and modelling. Furthermore, if and when things end up in litigation it is often clear that the problem has been exacerbated by the way the project was set up, managed and contracted (Muir Wood, 2000; Baynes, 2007). Quite often, good practice, which is set out in standards and the literature, is simply not followed because of lack of knowledge, experience or application in the engineering teams or for commercial reasons. Where unexpectedly difficult conditions are encountered during a project, for whatever reason, the consequences can be minimized provided the attitudes of the various parties are to work together to solve the issues.

### ***Ground risks***

First, it is worth considering where ground risks arise. Clayton (2001) divides them essentially into three: technical, contractual and managerial. Of the technical risks, these were split down by McMahon (1985) and Trenter (2003) in to:

1. The risk of encountering unknown geological conditions and
2. The risk of using incorrect design criteria.

If one examines failures in projects, however, often the causes are far more complex and it is the interaction of the various predisposing conditions at a site and other construction factors that caused the problems. Very often mismanagement is fundamental to why critical factors are missed, overlooked or not dealt with properly, as discussed for tunnels by Muir Wood (2000).

### ***Geology: material-scale factors***

Geotechnical hazards occur at a full range of scales from micro (mineralogy, friction) to macro (plate tectonics, typhoons). Material factors are at the scale of hand-held samples or pieces of core. It is the scale of most laboratory and in situ tests. Hazards at this scale are associated with the physical and chemical nature and properties of the various geological materials making up the site and used in construction, including their durability.

## ***Significant hazards and risks***

There are several key hazard areas that have the potential to cause harm associated with incidents in tunnels and underground structures:

1. The contents and use (traffic and machinery movement, electricity, water, hazardous materials and stored items, construction phase hazards, human behaviour)
2. Structure (collapse, underfoot conditions, restricted space/access and egress)
3. Complexity (disorientation, loss of communication, travel distances, difficulties associated with evacuation of public/casualties, difficulty determining and applying firefighting tactics, media and resources)
4. Physiological (temperature, humidity, fatigue, restricted space)
5. Environmental (heat, smoke and smoke travel, darkness, irrespirable atmosphere, oxygen deficiency, inundation, pollution, weather/wind conditions/ unexpected fire spread direction and intensity).

### ***Rehabilitation of Structural Elements***

Water infiltration is the most common cause of deterioration. However, deficiencies could be the result of substandard design or construction, or the result of unforeseen or changing geologic conditions in the ground that supports the tunnel. Another common reason for repairs is the fact that many tunnels have outlived their designed life expectancy and therefore the construction materials themselves are degrading. Due to the fact that there are different causes for the degradation, the method of repair could vary.

## ***Water Infiltration***

### ***1. Problem***

Since many tunnels are constructed deep in the ground and often below the groundwater table, controlling water infiltration is of great concern to tunnel owners. Consequently, water infiltration is the underlying cause of most deterioration of the tunnel structure and components. Water infiltration can occur in all types of tunnel construction. Even tunnels that are designed to be waterproof, such as immersed tube tunnels that are placed in a trench at the bottom of a body of water, can develop leaks due to inadequate connection/joint design, substandard construction, and deterioration of the waterproof lining due to chemical or biological agents in the water or from tears caused by tunnel settlement. Most tunnels are designed with the foreknowledge that water will exist in the ground, but it is prevented from entering the tunnel by providing drainage mechanisms around the exterior of the lining or embedded within the joints. As ground water flow patterns change over time and drains become clogged with sediment, the water is bound to find its way into the tunnel through joints or structural cracks.

Another scenario that may occur in a few urban settings is that the elevation of the ground water table may rise due to the accumulating effects of basements of surrounding buildings being made relatively waterproof and the city's water supply needs being met by reservoirs many km (miles) away instead of through groundwater extraction. This could cause a tunnel that was designed to be above the water table to experience hydrostatic forces that it is unable to resist and subsequently water infiltration becomes a problem.

As can be expected, nothing positive occurs when water infiltrates into a tunnel. The negative consequences can vary from minor surface corrosion of tunnel appurtenances to major deterioration of the structure and thus decreased load carrying capacity of the tunnel. Most tunnels have problems that fall somewhere in between. Below is a list of possible forms of tunnel degradation or safety risks that can result from water infiltration.

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 *all information is from* [<http://www.fhwa.dot.gov/bridge/tunnel/maintman04.cfm>]

## ***2. Consequences of Water Infiltration***

As can be expected, nothing positive occurs when water infiltrates into a tunnel. The negative consequences can vary from minor surface corrosion of tunnel appurtenances to major deterioration of the structure and thus decreased load carrying capacity of the tunnel. Most tunnels have problems that fall somewhere in between. Below is a list of possible forms of tunnel degradation or safety risks that can result from water infiltration.

1. Cement and sometimes aggregates of concrete liners are eroded causing the structure to be weakened.
2. Reinforcement steel with poor or inadequate cover corrodes and causes delamination and spalling of the concrete cover.
3. Bolts that connect segmental linings can corrode and fail.
4. Masonry units and mortar can be very susceptible to water deterioration and can swell or become brittle depending on chemicals in water.
5. Steel segmental liners or steel plates can experience section loss if exposed to both moisture and air.
6. Fine soil particles can be carried through cracks with the water, creating voids behind the liner, which can cause settlement of surrounding structures and/or cause eccentric loading on tunnel that can lead to unforeseen stresses. These fine particles can also clog drains in or behind the lining.
7. Fasteners of interior finishes or other appurtenances (fans, lights, etc.) can corrode and pose danger to a motorists or trains traveling through the tunnel.
8. Water may freeze on roadway and safety walks or form icicles from the tunnel crown, all of which endanger tunnel users.
9. Frozen drains can cause ground water to find or create a new location to enter the tunnel, which may be undesirable.
10. Road salts carried by vehicles into highway tunnels, along with the presence of infiltrated water, can increase deterioration of the structure, especially the invert.
11. Rate of corrosion for tunnel components of rail transit tunnels can be increased by the presence of stray current from electrified traction power systems.



***Figure.86- Ice formation at location of water infiltration in plenum area above ceiling slab***

### **3. Remediation Methods**

In general, there are three options that a tunnel owner must consider for remediation of a water infiltration problem. The three alternatives are: short term repairs, long term repairs or, as a last resort, reconstruct all or portions of the tunnel lining that is causing the problem using methods of waterproofing that incorporate newer technologies. It should be noted that the alternative classifications are given for descriptive purposes and that overlaps between them do exist.

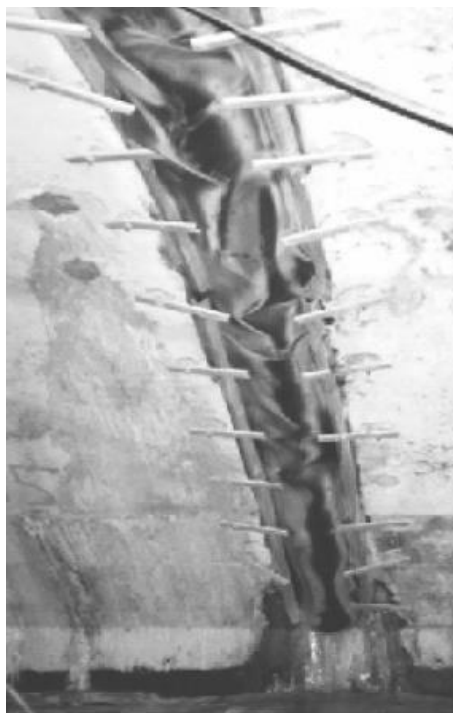
Since the first and second alternatives are the most common and usually most cost effective, a more detailed development of the current methods and some associated details will be given. The third option will not be discussed in as much detail as the first two but will include a brief discussion of some current technologies being used on new tunnel construction. To determine the most cost efficient method of repair for a particular situation, a specific cost analysis should be performed that considers the costs over the life of the tunnel.

#### **a) Short Term Repairs**

For certain situations, it might be necessary to redirect infiltrated water to the tunnel drainage system on a temporary basis until further investigation can be performed and a more long term solution implemented. It should be noted that certain tunnels, whether due to deficiencies in design or construction or a change in the ground water table, will not be able to stop the water infiltration completely without a total restoration or reconstruction of the tunnel lining or at least significant portions where water infiltration is a problem. Therefore, some tunnels may have to rely on a long term system that conveys the water rather than prevents the water from entering the tunnel.

##### **(1) Drainage Troughs**

If leaks are occurring in joints at the tunnel crown in a direction perpendicular to the tunnel length, then neoprene rubber sheets can be attached to the tunnel lining with aluminum channels. The sheets can be directed to channel the water to the side of the tunnel where it can flow into the tunnel drainage system. A similar method utilizing metal drainage troughs is sometimes used to redirect isolated areas of infiltration to the drainage system.



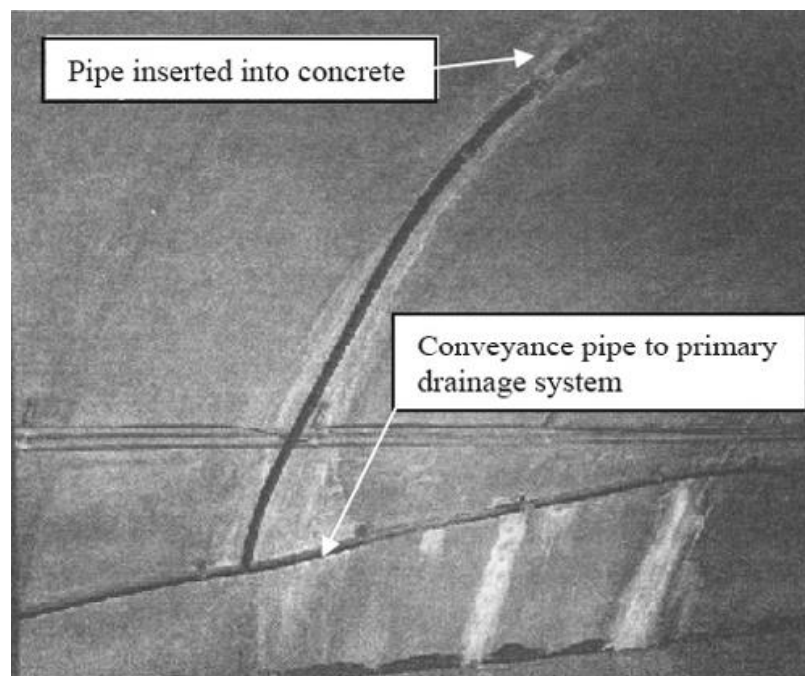
**Figure.87- Temporary drainage systems comprised of neoprene rubber troughs and 25 mm (1 in) aluminum channels.**



**Figure.88 - Temporary drainage systems comprised of neoprene rubber troughs and 25 mm (1 in) aluminum channels.**

## **(2) Plastic Pipe Network**

Another rather rudimentary method is to use plastic piping with one end inserted into the concrete at the main concentration of the leak. The piping can be hooked together in a network that conveys the water to the primary drainage system



**Figure.89- Temporary drainage system comprised of 50 mm (2 in) plastic pipe.**

## **b) Long Term Repairs**

Since water infiltration is an ongoing problem for tunnel owners, there have been a wide variety of methods and materials used to prevent the water from entering the tunnel and causing undesirable degradation. Multiple techniques have not performed favorably over the long term, but that does not necessarily mean that the method utilized was the problem. Many different factors are involved in determining which method should be used that is site specific in that the cause and volume of the water infiltration will help determine how to properly prevent it. One method might work very well for one tunnel but not another. Therefore, it is suggested that a detailed study be performed on major leaks to determine the source and amount of water leakage, and the cause and exact location of the leak. This, along with knowing the type and condition of the materials that make up the tunnel lining structure, will help determine how to address the problem. Also, the method of preparing the surface

and the procedure for installing the waterproofing system should be investigated to help determine which system should be used.

### **(1) Insulated Panels**

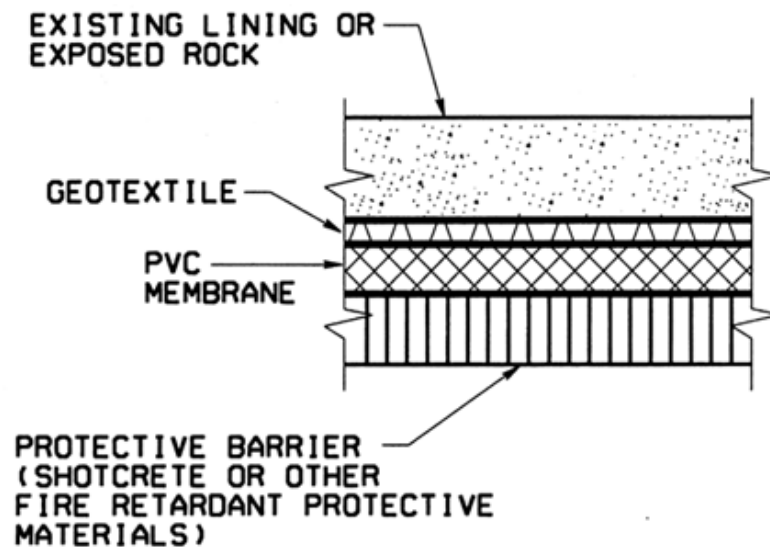
Insulated panels have been successfully used to line exposed rock tunnels to allow the water to flow behind the insulation down to the primary drainage system, while being insulated to prevent water from freezing. An example of this installation is a tunnel in the Pennsylvania Mountains that used two-inch-thick, 2.4 m by 9.6 m (8 ft by 32 ft) panels of Ethafoam insulation that was secured to the rock using 12 mm (½ in) diameter galvanized steel pins set into the rock on a .9 m (3 ft) square grid . It should be noted that use of this type of system would reduce the interior clearances within the tunnel.



*Figure.90- Insulated panels used as a waterproofing lining to keep infiltrating water from freezing. (Photo courtesy of Tunnels & Tunnelling International)*

### **(2) Waterproofing Membrane**

As an addition to the method given above, a continuous, flexible membrane can be used as the waterproofing layer that allows the water to flow towards the main tunnel drainage system. The specific process that has been effectively used involves placing a geotextile material against the existing tunnel interior, then a PVC waterproofing membrane, followed by a layer of material that will protect the membrane, such as shotcrete or other fire-retardant and protective materials. The term geotextile stands for a wide variety of materials which are normally synthetic and whose main purpose is to provide a drainage gallery outside the waterproofing membrane through which the infiltrating water can freely pass. This system requires a relatively smooth surface to attach the membrane to, without projections that could potentially puncture the membrane. It is suggested that mock-up trials be performed to ensure that the components of the system achieve adequate bond to each other, especially the application of a protective layer on the inside of the membrane. If shotcrete is used a minimum membrane thickness might be required as well as limiting the aggregate size in the shotcrete. If a fire retardant protective material is applied in sheets then the connection of this material through the membrane must be properly sealed to prevent water infiltration through this joint.



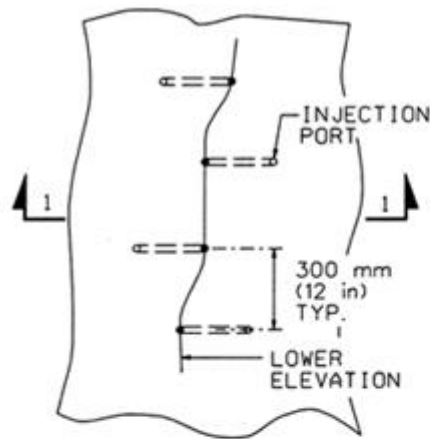
*Figure.91 Section of Membrane Waterproofing System*

### **(3) Crack/Joint Injection**

The most common method for preventing water infiltration in concrete linings is to inject the crack/joint with a particle or chemical grout. Particle grouts are very fine cementitious grouts that produce nonflexible fillers that prevent water from penetrating the crack/joint. Since these grouts are nonflexible, they are not recommended for any location that might experience structural movements in the future. Chemical grouts on the other hand can be highly flexible and also have low viscosities that enable them to be injected into very thin cracks. Chemical grouts are expensive, sometimes toxic or flammable and require a high degree of skill for proper application; therefore, an understanding of the chemical properties and their suitability for the desired application is essential.

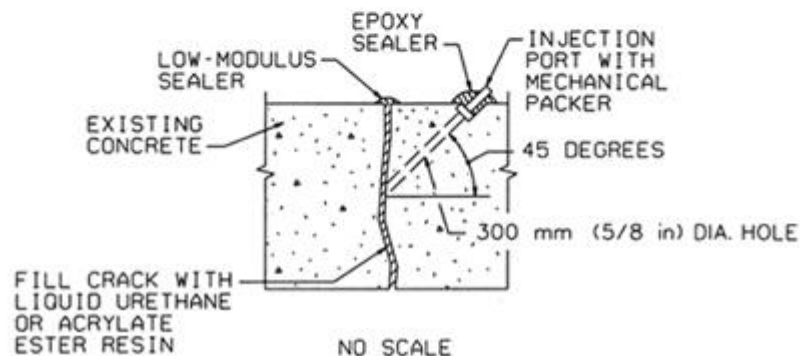
Even with the drawbacks of some chemical grouts, their performance in stopping water infiltration is significantly superior to particle grouts; therefore, they are used more frequently. It is important to note that if chemical grouts are allowed to dry out they may not be as effective. This could happen if the source of the water infiltration is diverted or the ground water elevation drops below the crack location. In the event of a dry crack.

Of the chemical grouts developed to date, the polyurethane, reactive grouts have performed the best for tunnel applications. This type of grout expands into a foam at the presence of water and subsequently seals off the crack, not allowing water to pass through. This foam is also moderately resistant to tensile forces; therefore it can expand when and if a crack/joint continues to open further. It has been found that when applying pressure to inject the grout that low pressure for an extended period is better than high pressure for a short period. The latter can result in further damage to the concrete.



#### NOTES

1. REMOVE LOOSE MATERIAL FROM CRACK.
2. DRILL 15 MM (5/8 IN) DIA. INJECTION PORTS AT 45 DEG. ANGLE TO CRACK. ALTERNATING SIDES.
3. INSTALL MECHANICAL PACKER IN INJECTION PORT.
4. SEAL SURFACE OF CRACK WITH LOW-MODULUS GEL IF CRACK IS ACTIVELY LEAKING.
5. FLUSH CRACK WITH CLEAN WATER.
6. INJECT LIQUID URETHANE OR ACRYLATE ESTER RESIN INTO LOWEST MECHANICAL PACKER WITH HAND OPERATED HYDRAULIC PUMP UNTIL GROUT CAN BE SEEN AT THE NEXT INJECTION PORT UP.
7. REPEAT PROCESS UNTIL ENTIRE CRACK IS INJECTED.
8. REGROUTING MAY BE PERFORMED FOR UP TO A WEEK AFTER INITIAL GROUTING.



**Figure.92- Leaking ceack repair detail**

In addition to polyurethane chemical grouts, acrylate esters are also being used to inject cracks. The esters have an advantage over the polyurethanes in that they form a gel upon reaction with the water and serve as a barrier to water penetrating a crack. The esters will also not dry out as can occur with polyurethane grouts as described earlier. For this reason, a site specific investigation will need to be conducted to determine which material is most cost-effective over the long term.

#### **(4) Soil/Rock Grouting (Back-Wall Grouting)**

As an alternative to injecting a crack/joint (which is generally successful for stopping the leak through the injected crack/joint, but can force the water along the path of least resistance towards another crack/joint), similar materials can be injected through the liner into the soil/rock beyond. The goal of this method is to provide a protective barrier on the outside of the tunnel lining either in specific crack/joint locations or over an entire segment of the tunnel. The material that is injected can form this protective barrier or the injected material can introduce cohesion into the soil, which makes the soil itself impermeable.

The procedure for this method consists of drilling holes perpendicular to and through the liner on a predetermined pattern (based on ground conditions and amount of water present), and installing mechanical injection packers. Then, a grout is injected into the soil/rock and maintained at a constant pressure for a prescribed amount of time to allow the grout to penetrate small cracks in the soil/rock. There are different grouts that are available and a site-specific investigation is necessary to determine which one is best suited for the particular conditions. Some of the available grouts are:

- Microfine cement grouts
- Polyurethane chemical grouts
- Acrylate ester resin chemical grouts

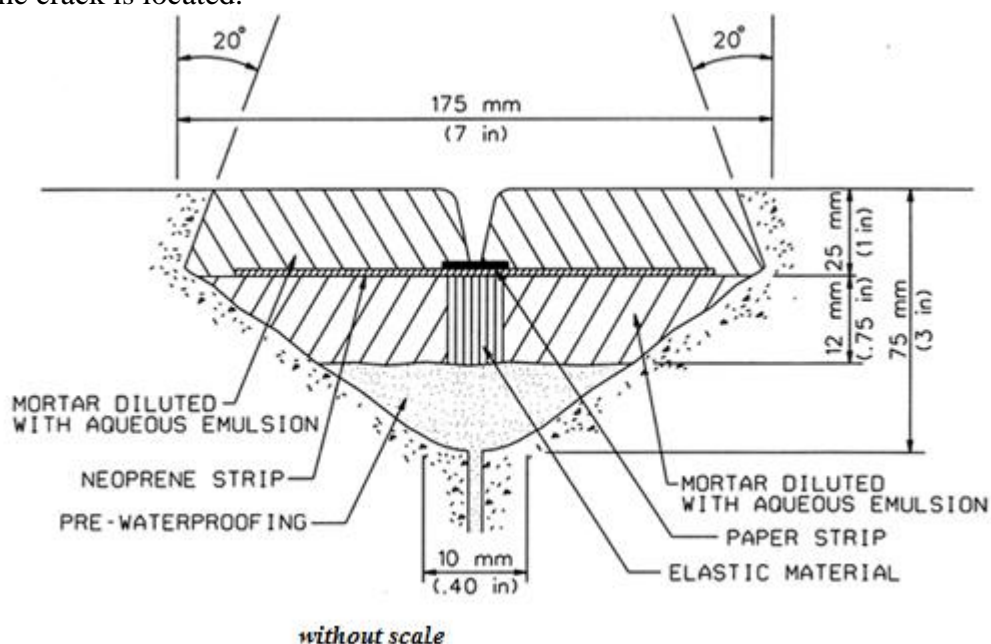
- Acrylamide-based chemical grouts (highly toxic).

Typically the chemical grouts are more expensive; therefore, the cement grouts can be used for areas where voids exist behind the liner and large volumes of grout are required.

In the case of a steel or cast iron liner, the existing grout plug holes should be used as the location for the new grout placement, since the liner would not have been designed to handle additional holes being drilled through it.

### (5) Crack/Joint Repair

If water infiltration through cracks/joints in concrete linings cannot be stopped by injecting the crack/joint as described previously because of excessive movement which surpasses the tensile strength of the grout material used, then another approach is to convert a crack into a joint that allows differential movement of the concrete, and add waterproofing components to the existing joints. Figure 4.7 portrays a method of routing out the crack or joint to a specific depth and then properly sealing off the water infiltration with successive layers of different impervious materials. The finished product will look and behave like a joint in that it will allow for some differential movement and will be watertight. As with the other repair techniques, a registered professional engineer should review and approve the application of this method to the specific site location. This is especially true for this method due to the possible weakening of the structural capacity of the lining depending on where and what direction the crack is located.



**Figure 93- Repair of a concrete joint or crack by inclusion of a neoprene strip**

### c) Reconstruction and New Construction

If the tunnel degradation has advanced to a point where repairing numerous localized areas of the liner becomes cost prohibitive, it may be necessary to reconstruct larger areas using different techniques. This could include shotcrete or pumping plasticized concrete within a form liner. There are several relatively new technologies that are being used for new tunnel construction that can also be incorporated into reconstruction procedures, with some modifications. These methods generally attempt to prohibit the water from infiltrating the final liner and thus entering into the tunnel space. This is accomplished by collecting the water and draining it away either within the liner or on the exterior of the tunnel. The latter method is less common because the drains can become clogged with fine soil particles. In addition, using an exterior drainage system in a tunnel below the ground water

elevation is normally not effective over the long term because of the ability for water to penetrate very small cracks that develop between drains.

There are various detailed techniques that will only be explained briefly, although many of these are complex in nature. Furthermore, should an extensive repair be needed, it is recommended that a specialized consultant be obtained to develop possible solutions that are specific to the tunnel in question.

### **(1) Shotcrete Applications**

The use of shotcrete in tunnel construction has greatly increased since the advent of the Sequential Excavation Method (SEM) and the improvement of the shotcrete materials and application processes used. A few of the general material classifications for shotcrete are cementitious, latex/acrylic-modified, or two-component epoxy. Shotcrete can also be used in tunnel rehabilitation in various forms. One method is to simply coat the entire interior of the tunnel walls and ceiling with a mix design that makes the cured shotcrete relatively impervious to water. This method has some drawbacks that include decreasing the tunnel clearances and trapping the moisture inside the original liner. Trapped moisture can lead to deterioration due to chemical reactions between the water and the liner material, especially in masonry.

Another more in-depth procedure is to remove all or portions of the existing liner, replace it with a structural layer of shotcrete, then place a geotextile layer and waterproofing membrane (either sheet membrane or sprayable polymer membrane), and finally provide a protective, non-structural finish liner of shotcrete on the inside that initially adheres to the waterproofing membrane during curing. As mentioned previously, the membrane thickness and shotcrete aggregate size may have restrictions placed on them in order to ensure that the membrane is not damaged during the shotcreting procedure. It is possible to place another geotextile layer or other protective material on the inside of the membrane, but attachment of this layer is difficult since the attachment mechanism has to puncture the membrane. The thickness of this liner is dependent on the tunnel size and shape and the amount of water infiltration that is expected. It is recommended that a detailed site investigation be performed to determine if this final lining will need to resist any hydrostatic loadings. This method allows water that penetrates the initial liner to be directed down the tunnel along the waterproofing membrane to the primary tunnel drainage system. The existing liner can be removed with traditional demolition techniques or, depending on the depth of removal desired,



***Figure.94- Laser controlled cutter for removing portions of existing tunnel liner. (Photo courtesy of Tunnels & Tunnelling North America)***

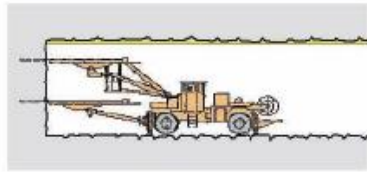
## **(2) Joint Control**

It is not often that there is an opportunity to completely reconstruct a joint in an existing tunnel. However, when there is a complete tunnel reconstruction or new tunnel construction, the joints can be fitted with a new system that allows the joint to be initially injected with chemical or particle grouts and to be reinjected at any future time that the joint might begin to leak due to settlement of the structure. Also, products exist that can be inserted at anticipated crack locations that actually facilitate crack development at that location. Once the crack occurs, the product can be injected with a chemical or particle grout to stop water infiltration.

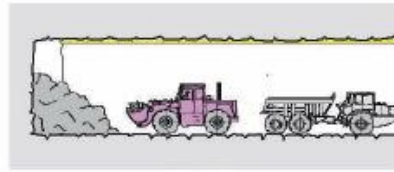
## **(3) Concrete Design**

One of the most effective methods of preventing water infiltration in reconstruction or new construction is to properly design the concrete or shotcrete mix to approach impermeability and to not be as susceptible to cracking. This is primarily done by ensuring adequate reinforcement and limiting the water/cement ratio to 0.45. Other considerations include the use of water reducing and shrinkage reducing admixtures. Another admixture that is increasing in usage is a waterproofing additive. This admixture reacts with the fresh concrete to produce crystalline formations throughout the cured concrete that resist the penetration of water.

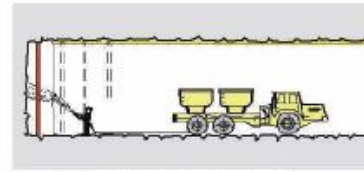
*Appendix :Collection Images*



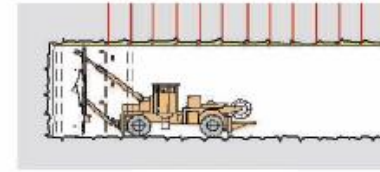
Excavating



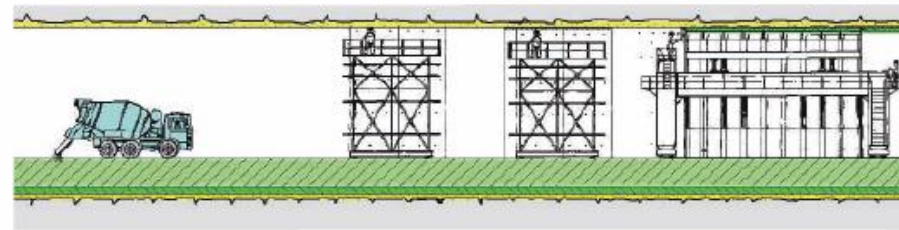
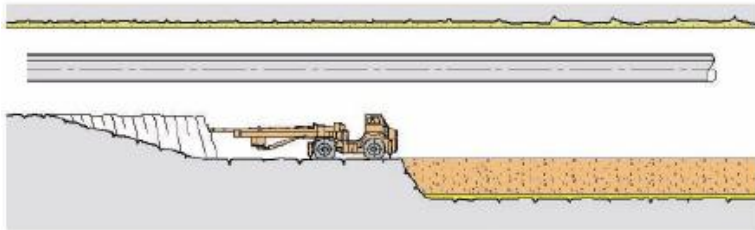
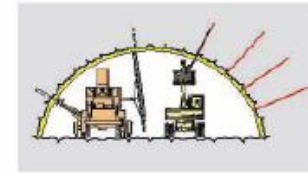
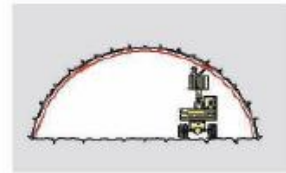
Mucking



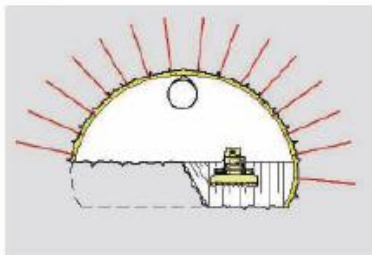
Installing Lattice Girders



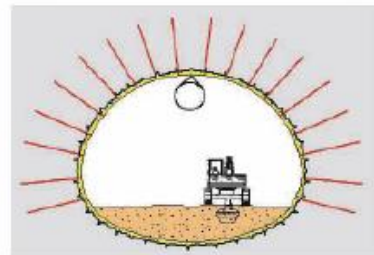
Rockbolting



Waterproofing    Reinforcement    Formwork



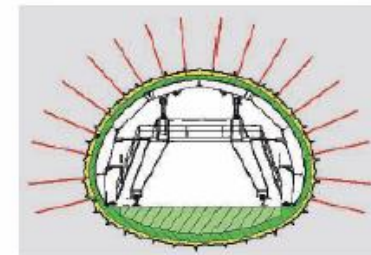
Bench Excavation



Invert Excavation  
Shotcrete Arch in invert



Invert Concreting



Final Lining CIP Concrete

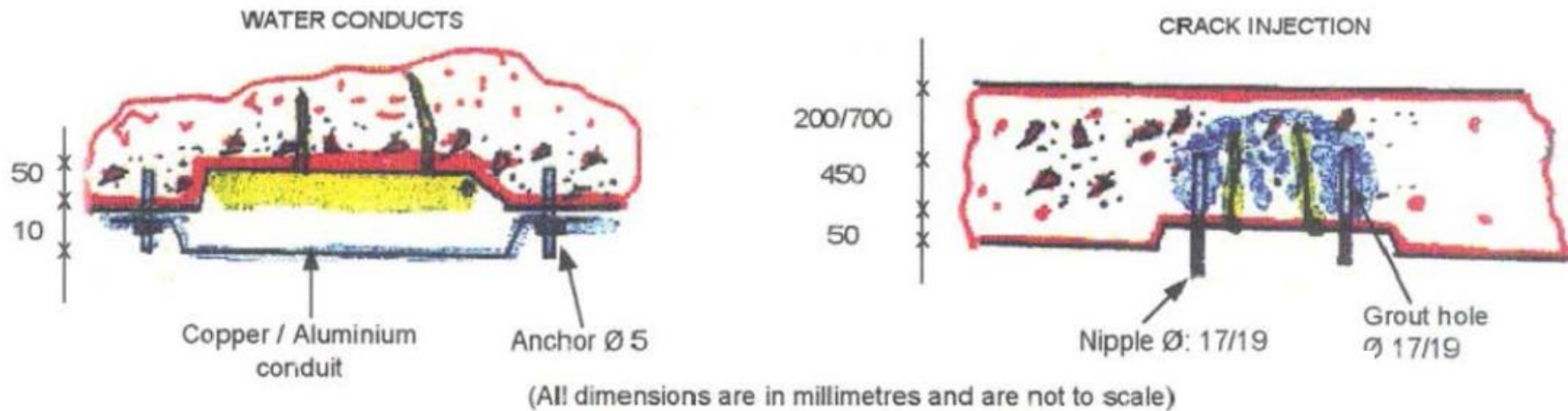
*Graphic showing a New Austrian Tunneling Method construction sequence*



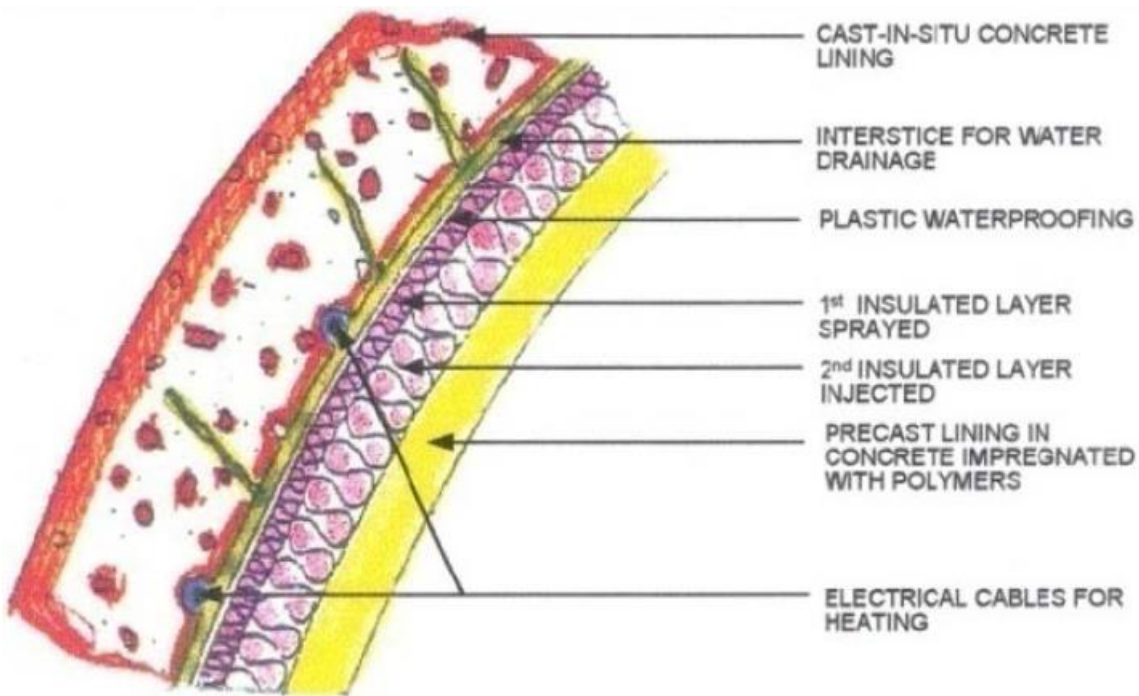
***TUNNEL OPERATIONS, MAINTENANCE, INSPECTION AND EVALUATION (TOMIE) MANUAL***



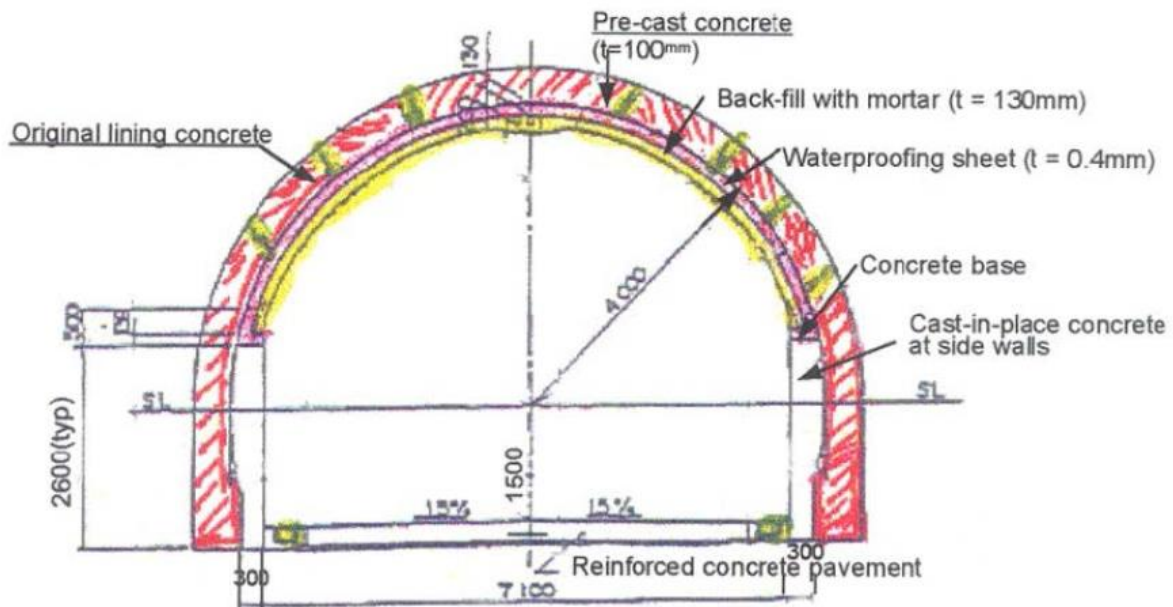
**Temporary Drainage Systems Comprised of Neoprene Rubber Troughs and 25 mm (1") Aluminum Channels (FHWA, 2005)**



**Copper/Aluminum Conduit along with Crack Injection Used to Convey Water Penetrating a Concrete Liner (Russell, 2001)**



***Leakage Control on the Interior Face of an Existing Concrete Tunnel using a Space for Water Drainage, Electrical Heating Cables, Plastic Waterproofing, Sprayed Insulating Layer, and an Interior Precast Liner (Russell, 2001)***



***Sealing of Leakage Water on the Interior Concrete Face by Placing a Waterproofing Sheet and a Protective Reinforced Mortar Layer (Russell, 2001)***



***Insulated Panels under Waterproofing Membrane in Air Plenum Region above Roadway have Dislodged in an Isolated Location (NCHRP, 2010)***



***Underside of Waterproofing Membrane in Air Plenum Slab. Note that Heat Welded Attachments on the Underside of the White Membrane Receive the Insulation Panels' Anchors without Penetrating the Membrane (NCHRP, 2010)***



*Leakage at a Construction Joint through the Cementitious Coating that was Applied on the Underside of the Tunnel Arch in a Pennsylvania Tunnel (NCHRP, 2010)*



*Leak Injection, Tuscarora Tunnel PA Turnpike*



*Using Shotcrete to Make Overhead Ceiling Repairs in Liberty Tunnel-Pittsburgh, PA (NCHRP, 2010)*



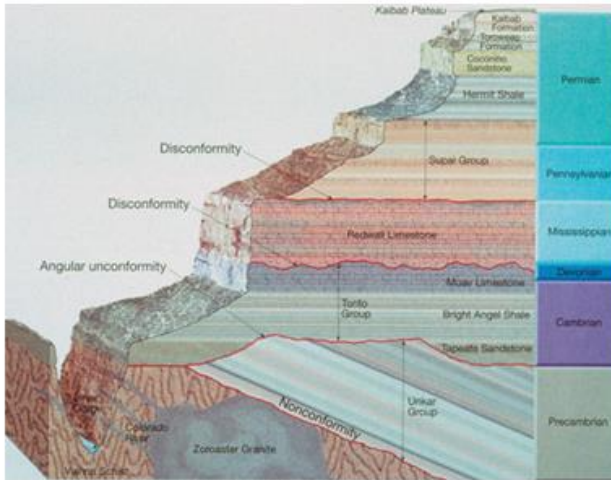
*Reinforcing Steel for Repair, Sumner Tunnel- Boston, MA*



***Rock Tunnel with Shotcrete Wall Repair and Arch Liner (I-75 Lima, Ohio) (2009, FHWA)***

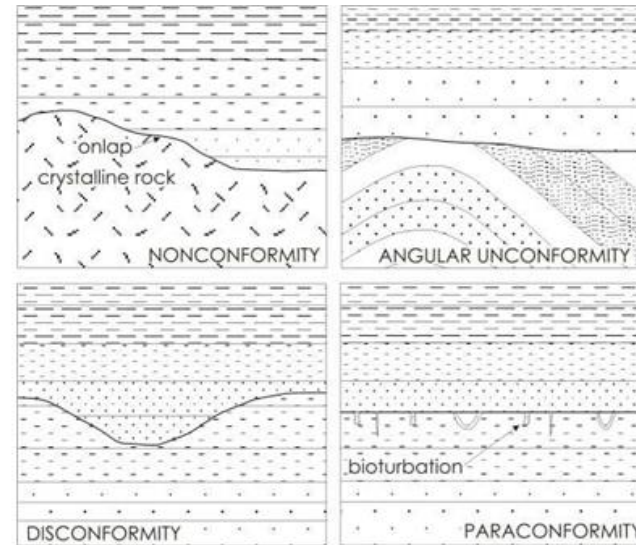


***Rock Bolts (Dowels) Supporting Liner, I-75 Lima, Ohio Underpass (2009, FHWA)***

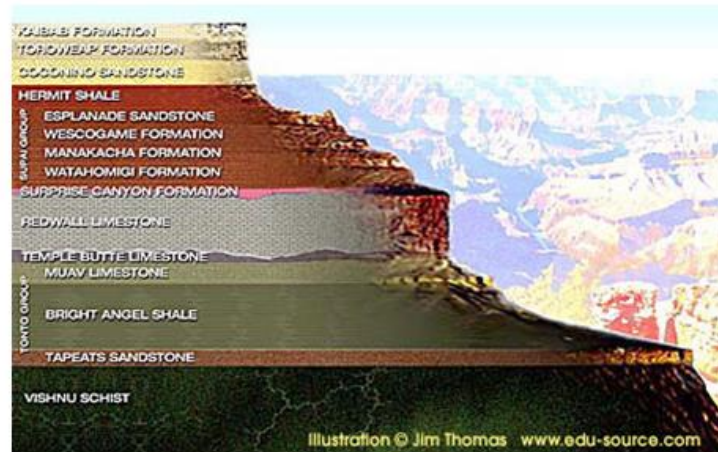


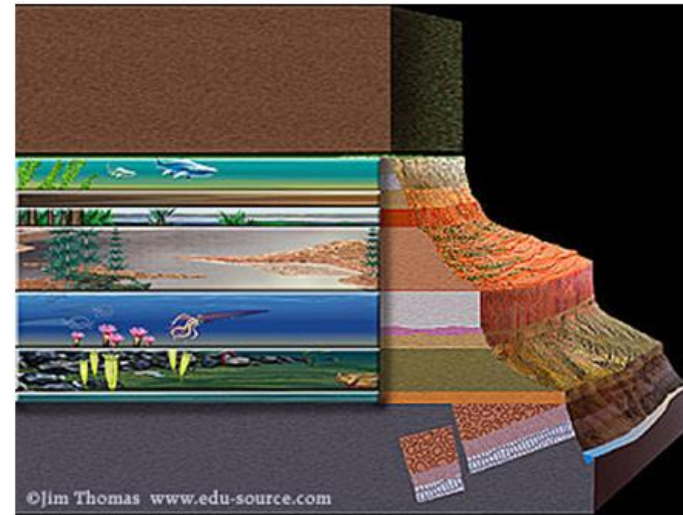
University of Iowa Department of Geoscience

*Unconformities within the stratigraphic succession comprising the wall rocks of the Grand Canyon, Arizona.*










*Types of Unconformities*






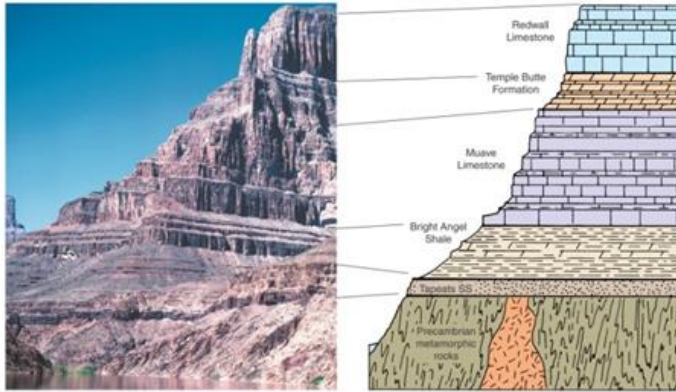
IGNEOUS ROCKS	
<p><b>PUMICE</b>            Environment of formation = extrusive (volcanic)            Texture = Glassy, vesicular            Grain size = non-crystalline            Color = light            Density = low            Composition = felsic</p>	
<p><b>VESICULAR BASALT</b>            Environment of formation = extrusive (volcanic)            Texture = Glassy, vesicular            Grain size = non-crystalline            Color = dark            Density = medium            Composition = mafic</p>	

<p><b>GRANITE</b>  Environment of formation = intrusive (plutonic)  Texture = coarse  Grain size = 1 mm to 10mm  Color = light  Density = low  Composition = felsic</p>		<p><b>SCORIA</b>  Environment of formation = extrusive (volcanic)  Texture = Glassy, vesicular  Grain size = non-crystalline  Color = dark  Density = medium  Composition = mafic</p>	
<p><b>DIORITE</b>  Environment of formation = intrusive (plutonic)  Texture = coarse  Grain size = 1 mm to 10mm  Color = medium  Density = medium  Composition = medium</p>		<p><b>RHYOLITE</b>  Environment of formation = extrusive (volcanic)  Texture = fine  Grain size = less than 1 mm  Color = light  Density = low  Composition = felsic</p>	
<p><b>ANDESITE</b>  Environment of formation = extrusive (volcanic)  Texture = fine  Grain size = less than 1 mm  Color = light  Density = medium  Composition = intermediate</p>		<p><b>GABBRO</b>  Environment of formation = intrusive (plutonic)  Texture = coarse  Grain size = 1 mm to 10mm  Color = dark  Density = high  Composition = mafic</p>	
<p><b>BASALT</b>  Environment of formation = extrusive (volcanic)  Texture = fine  Grain size = less than 1 mm  Color = dark  Density = high  Composition = mafic</p>		<p><b>PERIDOTITE</b>  Environment of formation = intrusive (plutonic)  Texture = coarse  Grain size = 1 mm to 10mm  Color = dark  Density = high  Composition = ultramafic</p>	

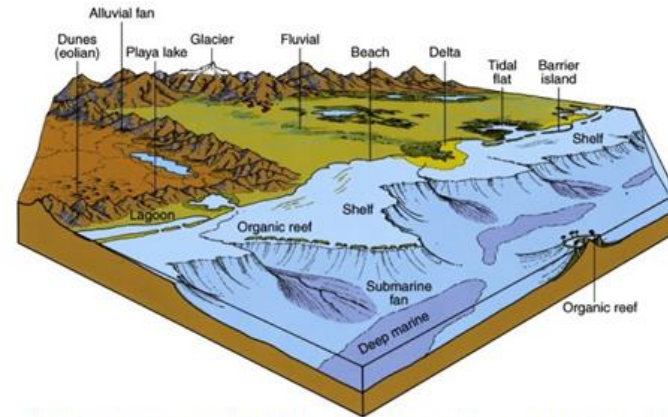
<p><b>PEGMATITE</b>            Environment of formation = intrusive (plutonic)            Texture = very coarse            Grain size = 10mm or larger            Color = light            Density = low            Composition = felsic</p>		<p><b>PHYLLITE</b>            Texture = foliated (mineral alignment)            Grain size = fine to medium            Type of metamorphism = Regional (foliation surfaces shiny from microscopic mica crystals)            Composition = mica, quartz, feldspar, amphibole, garnet</p>	
<p><b>METAMORPHIC ROCKS</b></p>			
<p><b>SLATE</b>            Texture = foliated (mineral alignment)            Grain size = fine            Type of metamorphism = Regional (low grade)            Composition = mica and clay minerals</p>		<p><b>SCHIST</b>            Texture = foliated (mineral alignment)            Grain size = fine to medium            Type of metamorphism = Regional (platy mica crystals visible from metamorphism of clay or feldspar)            Composition = mica, quartz, feldspar, amphibole, garnet</p>	
<p><b>GRANITE</b>            Environment of formation = intrusive (plutonic)            Texture = coarse            Grain size = 1 mm to 10mm            Color = light            Density = low            Composition = felsic</p>		<p><b>GNEISS</b>            Texture = foliated (banding)            Grain size = medium to coarse            Type of metamorphism = Regional (high-grade metamorphism, some mica changed to feldspar, segregated by mineral type into bands)            Composition = mica, quartz, feldspar, amphibole, garnet, pyroxene</p>	
<p><b>DIORITE</b>            Environment of formation = intrusive (plutonic)            Texture = coarse            Grain size = 1 mm to 10mm            Color = medium            Density = medium            Composition = medium</p>		<p><b>HORNFELS</b>            Texture = non-foliated            Grain size = fine            Type of metamorphism = Contact (heat) (various rocks changed by heat from nearby magma/lava)            Composition = variable</p>	

<p><b>QUARTZITE</b>  <b>Texture = non-foliated</b>  <b>Grain size = fine to coarse</b>  <b>Type of metamorphism = Regional or contact (metamorphism of quartz sandstone)</b>  <b>Composition = quartz</b></p>		<p><b>METACONGLOMERATE</b>  <b>Texture = non-foliated</b>  <b>Grain size = coarse</b>  <b>Type of metamorphism = Regional or contact (pebbles may be distorted or stretched)</b>  <b>Composition = various minerals in particles and matrix</b></p>	
<b>SEDIMENTARY ROCKS</b>			
<p><b>MARBLE</b>  <b>Texture = non-foliated</b>  <b>Grain size = fine to coarse</b>  <b>Type of metamorphism = Regional or contact (metamorphism of limestone or dolostone)</b>  <b>Composition = calcite and/or dolomite</b></p>		<p><b>CONGLOMERATE</b>  <b>Texture = clastic (fragmental)</b>  <b>Grain size = pebbles, cobbles and/or boulders embedded in sand, silt, and/or clay</b>  <b>Comments = Rounded fragments</b>  <b>Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks</b></p>	
<p><b>BRECCIA</b>  <b>Texture = clastic (fragmental)</b>  <b>Grain size = pebbles, cobbles and/or boulders embedded in sand, silt, and/or clay</b>  <b>Comments = Angular fragments</b>  <b>Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks</b></p>		<p><b>SILTSTONE</b>  <b>Texture = clastic (fragmental)</b>  <b>Grain size = silt (0.006 to 0.0004 cm)</b>  <b>Comments = very fine grain</b>  <b>Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks</b></p>	
<p><b>SANDSTONE</b>  <b>Texture = clastic (fragmental)</b>  <b>Grain size = sand (0.2 to 0.006 cm)</b>  <b>Comments = fine to coarse</b>  <b>Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks</b></p>		<p><b>SHALE</b>  <b>Texture = clastic (fragmental)</b>  <b>Grain size = clay (less than 0.0004 cm)</b>  <b>Comments = compact may split easily</b>  <b>Composition = mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks</b></p>	

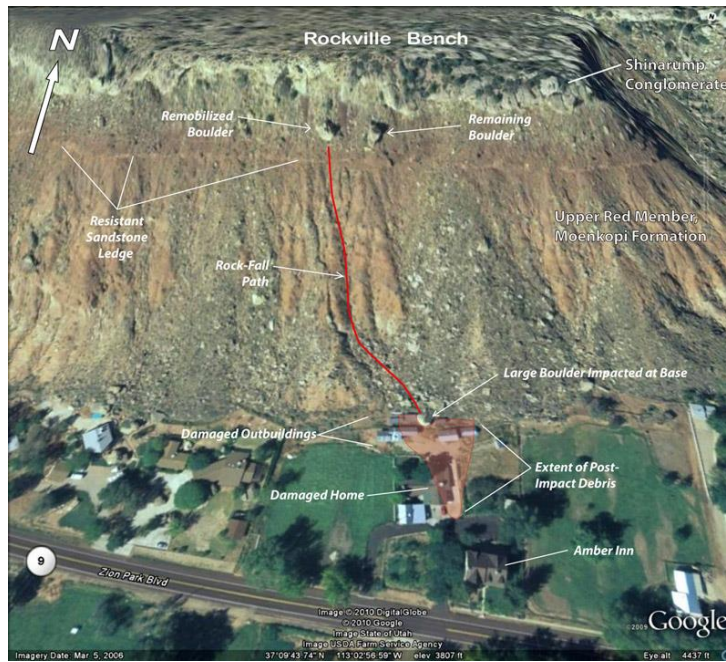




Sequences of sedimentary rock in the Grand Canyon show the characteristic stratification or layering of this rock type (A). The cross section in (B) emphasizes the layering and shows the difference between the sedimentary rocks and the older igneous and deformed metamorphic rocks near the floor of the canyon



The major sedimentary environments on the planets are represented in these idealized diagrams. Sedimentary environments can be divided into four types---(A) Impact produces an ejecta blanket of breccia. (B) Volcanic eruptions produce deposits of volcanic ash that are carried by the wind on planets with atmospheres. (C) Wind transports and deposits sediments in sand dunes and layers of dust, and (D) fluvial marine.

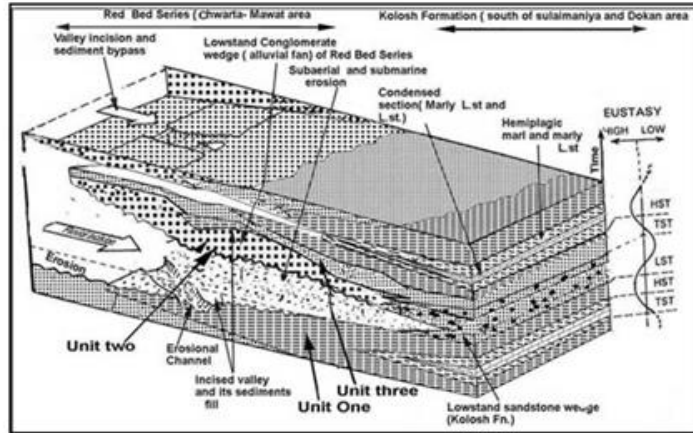


### High rockfall hazard







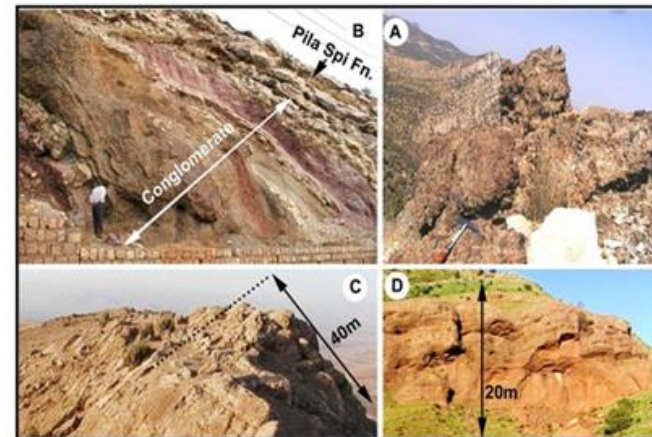
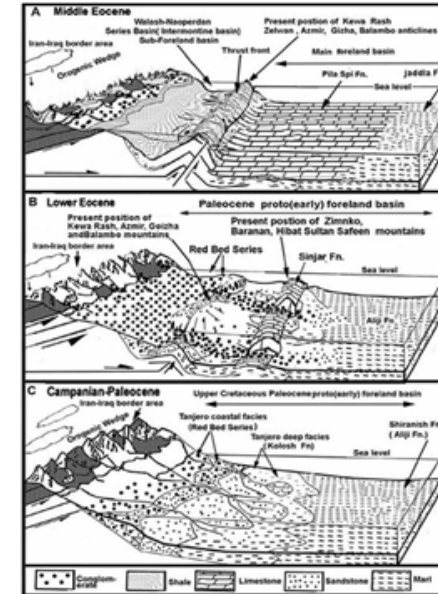


*Chronostratigraphic (Wheeler) diagram which shows two unconformities in the lower part of Red Bed Series (Al-Barzinjy, 2005).*

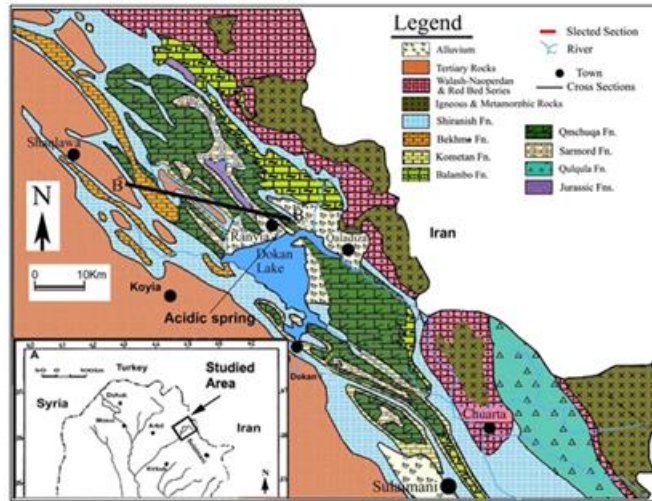
No.	Stratigraphic position of conglomerate	Maximum thickness	Location of the conglomerate as GPS reading	Paleocurrent (measured by imbricated pebbles)
1-	Lower Part of Tanjero Formation	500m	A) N: 35° 39' 13.22" E: 45° 36' 12.76" B) N: 36° 21' 41.28" E: 45° 03' 50.40" C) N: 36° 24' 59.60" E: 44° 57' 06.23"	Southwest
2-	Upper Part of Tanjero Formation	10m	N: 35° 36' 19.35" E: 45° 32' 12.31"	South and southwest
3-	Lower part of Red Bed Series	20m	N: 35° 36' 28.1" E: 45° 32' 13.31"	South and southwest
4	Upper part of Red Bed Series	1000m	N: 35° 22' 12" E: 45° 12' 14"	Southwest
5	Inside Gercus Formation	60m	A) N: 35° 14' 56.82" E: 45° 46' 19.90" B) N: 34° 56' 55.99" E: 45° 45' 08.59"	Southwest
7-	Base of Pila Spi Formation	10m	N: 36° 24' 19.73" E: 44° 20' 49.69"	Not measured
8-	Top of Pila Spi Formation (two beds separated by limestone)	7 m	N: 35° 38' 57.38" E: 44° 57' 16.69"	South and southwest
7-	Base of Fatha Formation	3m	N: 35° 38' 17.01" E: 44° 58' 17.96"	South

*Stratigraphic position and geographic location of the dependent (in modification) conglomerates in the present this study.*

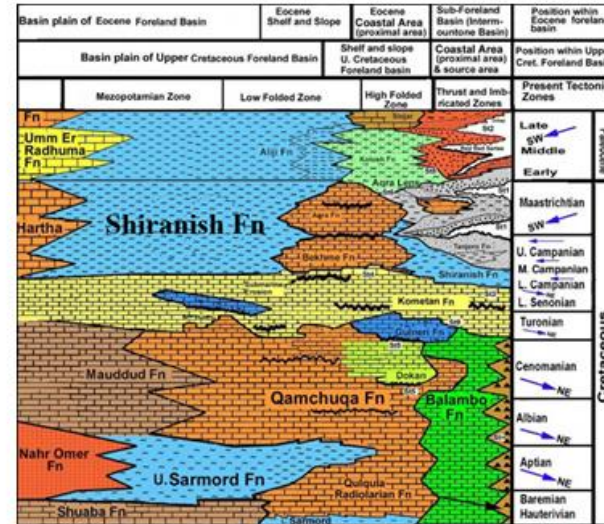
*The conclusions of present study as shown by conceptual models of paleogeography and tectonic evolution of the intermontane basin in Iraq. A: Middle Eocene, B: Lower Eocene, C: Upper Cretaceous and Paleocene.*



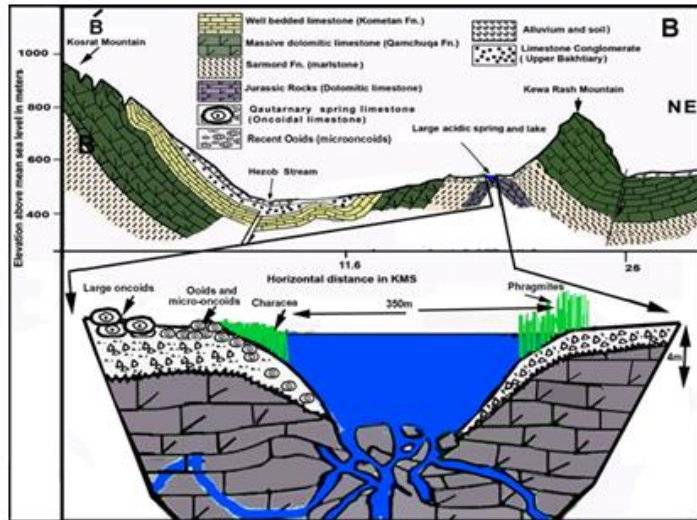
Some of the pebble and boulder temiginous conglomerates at different geographic locations and stratigraphic positions. A and B) At the base of Pila Spi Formation, at 7km to the west of Shaqlawa town and 10km south of Qaradagh town respectively. C) Inside Gercus Formation 15 km south of Zarayeen town. D) In the lower part of the Red Bed Series 5km south of Chuwarta town.



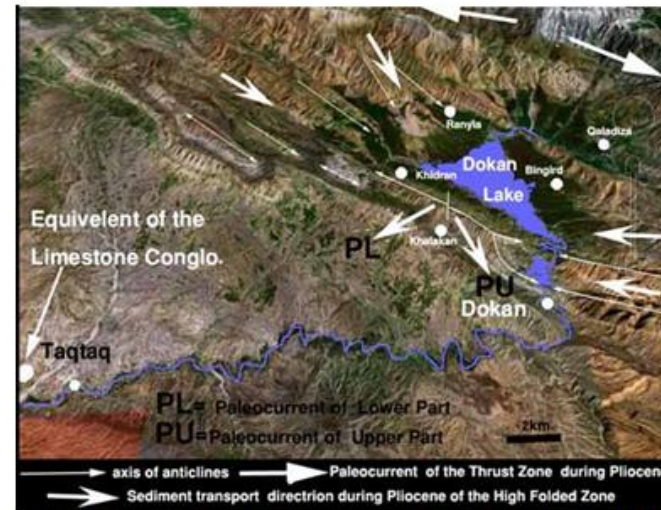
Geological map of northern Iraq (modified from Sissakian, 2000), showing location of the studied section.



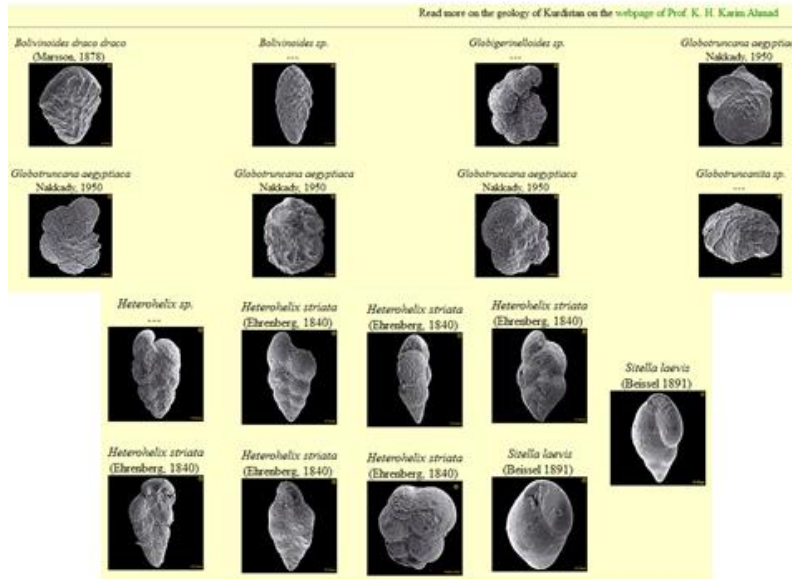
Chronostratigraphic column of Kurdistan redrawn and shown with permission of Prof. K. H. Karim



Schematic geologic cross-section of the studied area passing through Ranyia (Kewa Rash) and part of the Kosrat anticlines. Bottom) Ganau spring cross section (modified from Manmi, 2008).



Google Earth Satellite image showing the studied area and the paleocurrent direction (sediment transport direction) of lower and upper parts of the Dokan Conglomerate in addition to paleocurrent direction of the thrust zone which was either to east or west.



*Fossils from mine (rusty nail for scale-top left)*



*This is a 4 ft cross section of the sandy surface sediment of marine origin. Visible layers containing calcium phosphate, quartz & other minerals.*

*View of the surface, riddled with bones and sharks teeth galore. (shadow of hand for scale)*



*Shells, Sharks  
teeth, Coral &  
Stingray Dental  
Pavements*



*quartz area from the northwest side of the quarry*



*Quartz area with cookeite. Surrounded by feldspar and schorl*



*One of the first quartz pockets. You can see the beginning of a smoky quartz crystal in the hole on the left. Notice the contact with the feldspar and quartz.*

two views of the same smoky quartz crystal overall dimensions are 16cm x 12cm

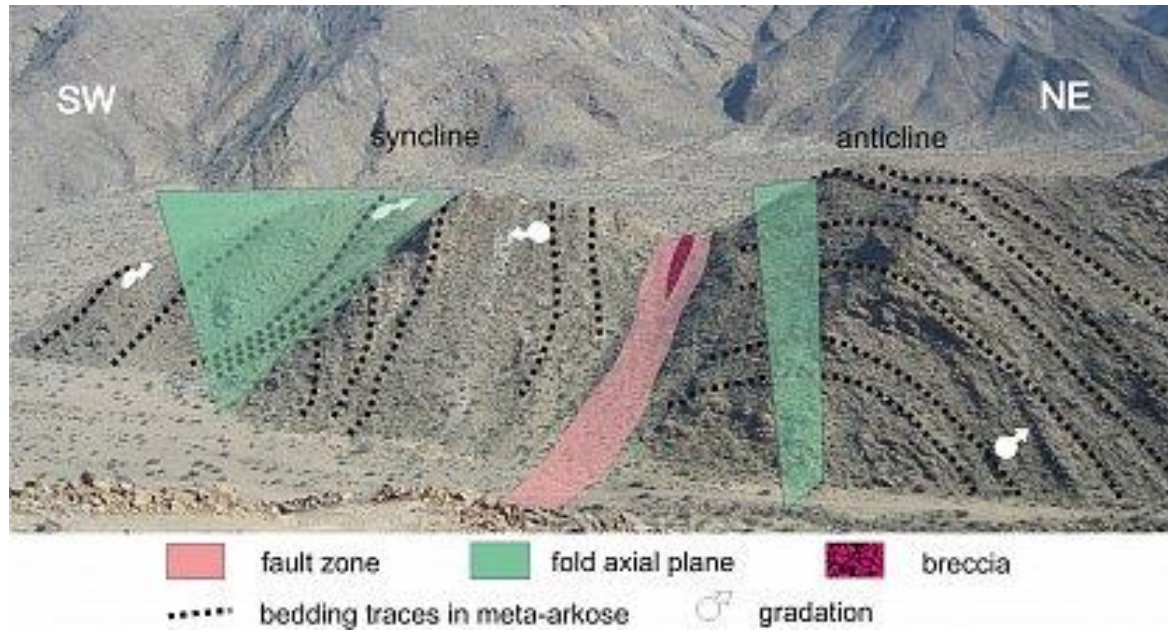
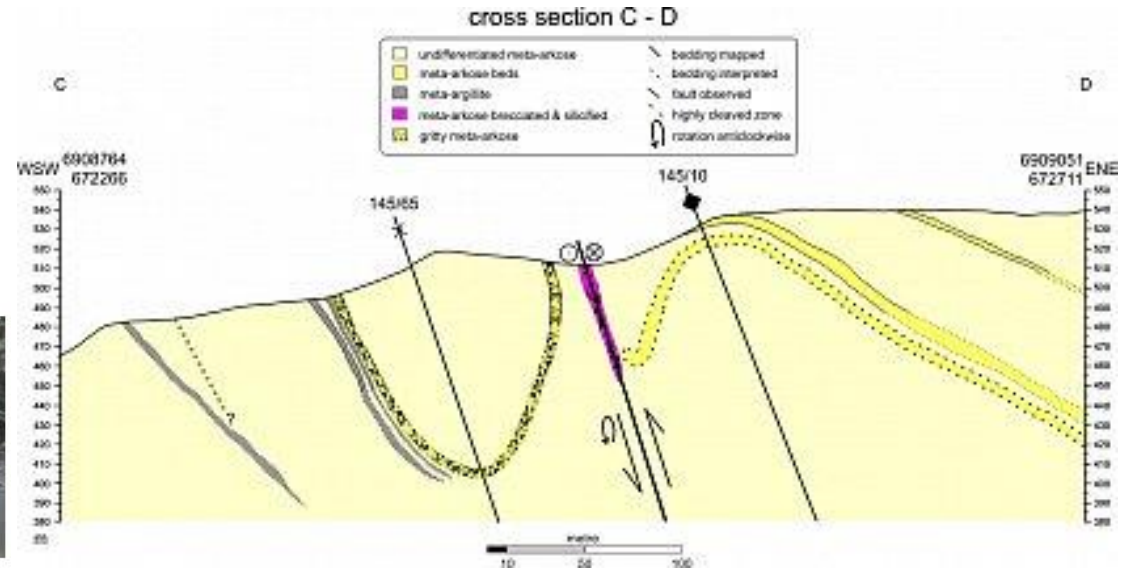
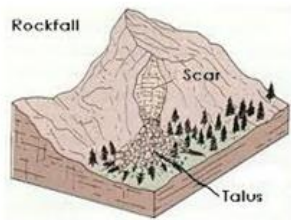
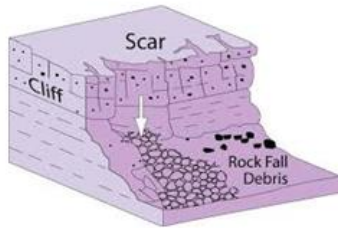


two views of the same smoky quartz crystal overall dimensions are 9cm x 10cm  
note: clear apatite druse on bottom crystal



High rockfall hazard







*Fig. Modified photograph of the eastern part in the mapping area and northern elongation shows synclinal (black hinge line) and anticlinal (red hinge line) structures, which form a dome-and-basin structure; bedding traces in metaarkose dotted, bedding traces are supplied with signs for fining upwards.*

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## Links

1. [http://saturniancosmology.org/files/geology/sect2\\_1a.html](http://saturniancosmology.org/files/geology/sect2_1a.html)
2. <http://eesc.columbia.edu/courses/ees/lithosphere/index.html>
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