UNIVERSITY OF ZAMBIA

GEOLOGY DEPARTMENT, SCHOOL OF MINES

GGY3051: ENGINEERING GEOLOGY

INTRODUCTION TO ROCKS

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Learning objective

Participants should be be able to identify and describe rocks by

Major geological classifications of rock types and groups.

Definition of rock:

- In geology, **rock** is a naturally occurring **solid aggregate of one or more minerals or mineraloids:**
    - ❖The Earth's outer solid layer, the lithosphere, **is made up of rocks**.
- **Rocks** have been used by **mankind throughout history:**
    - ❖From the Stone Age - rocks have been used for tools and construction materials.
    - ❖The **minerals and metals found in rocks -**have been essential to human **civilization**.

There are three major groups of rocks that have bee defined:

i. Igneous Rocks,

ii. Sedimentary Rocks, and

iii. Metamorphic Rock.

The **scientific study** of these rocks is a branch of geology called **petrology.**

IGNEOUS ROCKS

Igneous Rocks - intro

- Igneous rocks are classified into two types according to the settings in which they were formed:

1. **Plutonic or intrusive igneous**

- Formed deep inside the Earth’s crust by the slow cooling and solidification of magma,
- Which results in crystalline materials that are usually coarse grained, such as **granite, gabbro, syenite, and diorite**.
- As they rise to the upper crust, they can fragment and incorporate blocks of host rocks, called xenoliths.

Igneous Rocks intro cont’d

2. Volcanic or extrusive igneous rocks

- Formed at the Earth’s surface, around **volcanic vents,**
- by the **ejection of lava**, which may be explosive or not.
- The cooling is usually too rapid to form coarse-grained mineral crystals, thus
- They tend to be glassy or fine-grained crystalline materials.
- Examples include **rhyolites** and **basalts**.

Intro to igeous Rocks cont'd

- Another **type of volcanic rocks** are **pyroclastic rocks**,
- Which originate from the accumulation, subsequent compaction and cementation of fragments of crystal, glass, or rocks ejected from a volcano.
- Despite their igneous origin, pyroclastic rocks are predominantly classified in a similar way to sedimentary rocks:

❖ Based mainly on the size of the constituting fragments.

Introduction to Igneous Rocks cont'd

- In general, unweathered igneous rocks exhibit **high mechanical strength** due to the relative structural homogeneity and
- The strong cohesion of the mineral constituents.
- For **engineering geology purposes,** the smaller grain size usually corresponds to the **greater mechanical strength** of volcanic rocks relative to plutonic rocks,
- Mainly due to their better mineral imbrication and cohesion.

- Although compact volcanic rocks tend to have greater mechanical resistance than plutonic rocks,
- the presence of **vesicles**, **amygdales**, and **columnar jointing** can reduce their strength.
- Larger proportions of quartz in some types of igneous rocks generally confer greater mechanical strength.
- However, this also generally contributes to increased abrasiveness,
- Which leads to increased wear on equipment (drills, crushers, diamond saws, etc.).

- Strong igneous rocks have the best technological charac- teristics for use in construction, and
- Some are also important industrial raw materials.

Composition of igneous rocks

- The magma from which igneous rocks are formed consists mainly of silicon and oxygen,
- And its viscosity is directly proportional to the content of silica (SiO_2).
- Thus, the **constituent minerals of igneous** rocks are **essentially silicates:**

❖ That are forming as the temperature of the magma reaches their respective crystallization conditions.

Composition of igneous rocks cont’d

- In general, the first minerals to crystallize are **iron** and **magnesium silicates**, called mafic or ferromagnesian minerals (generally dark in color),
- whereas as temperature falls, the last are **potassium aluminosilicates**, **muscovite**, and **quartz,** which are called felsic minerals (generally light in color).
- Accessory minerals, such as **zircon**, **apatite,** and **titanite**, are the first to crystallize.

Composition of igneous rocks cont'd

- The crystallization sequence is represented by two series, known as Bowen series, which converge on the crystallization of potassium feldspars, mica (muscovite), and quartz:

❖ **Discontinuous series:** olivine, pyroxenes (augite), amphiboles (hornblende), and micas (biotite)

❖ **Continuous series:** calcic plagioclases followed by sodic plagioclases

Composition of igneous rocks cont'd

- Due to higher temperature and pressure crystallization conditions,
- the ferromagnesian minerals tend to be less stable under shallow crustal and Earth surface conditions and
- May be altered, in terms of **chemical composition** and **crystal structure:**

❖ By an **interaction with late-stage magmatic liquid** (richer in volatiles and/or siliceous materials) or

❖ By an exposure to the **atmospheric elements** (weathering).

❖ In the latter case, there is a formation of secondary minerals, such as **iron oxides** and **hydroxides**, and **clay minerals.**

Main forms of occurrence of Igneous rocks

- The main forms of occurrence of igneous rocks in the Earth's crust are:

- Batholith
- Stock
- Dike
- Sill.

Main forms of occurrence of Igneous rocks

Batholith: **large-volume** of igneous mass with irregular contours and a **domical top**.

Stock: plutonic igneous mass of **smaller volume**, generally vertical, almost cylindrical bodies.

Dike: result of **rising magma-filled fractures** in crustal rocks.

❖ **The thickness of a dike can range from centimeters to hundreds of meters.**

Sill: An igneous body of tabular format that is concordant (parallel) in relation to bedded host rocks.

❖ Layer of notable uniformity & thickness due to intrusion of magma into bedding planes of sedimentary deposits.

Main forms of occurrence of Igneous rocks

With regard to lava flows, volcanic activity can occur in two ways:

1. **Central eruptions:** these generally form a **cone** on the **surface of the earth,** connected with the volcanic conduit through which **lava**, **gases**, and **pyroclastic materials** are ejected.

2. **Fissure eruptions:** in these, lava escapes through a **network of fractures** in the Earth's surface, generally extending through large areas.

Structures and textures of igneous rocks

- The structural and textural aspects of igneous rocks frequently overlap,
- Structure refers to the **mesoscopic** and **macroscopic** features of rock
- That are more easily observed in the field, and
- Texture refers to **microscopic aspects**, such as the size (granularity) and shape (*euhedral, subhedral and anhedral*) of
- Mineral crystals or grains and the interrelations between them and with any other materials present.

Structures of igneous Rocks

- Igneous rocks are **usually massive in structure**, but
- some have **fluidal**, **vesicular,** or **columnar structure**.

Structures of Igneous Rocks cont'd

Massive Structures:

- Minerals exhibit **no preferential orientation** along specific directions.
- Both in hand samples and outcrops, they have the appearance of a compact rocky mass.
- In the case of plutonic rocks, they may have vertical and sub- horizontal fracturing systems, which arise after magma solidification and favor the breaking of the rock into blocks.

Structures of Igneous Rocks cont'd

Fluidal structures:

- Minerals exhibit iso-orientation as an expression of the **directional movement of the magma** during its emplacement and **prior to its complete cooling**.
- They are **commonly observed in the margins of intrusions** or dikes, near the walls of the host rocks.

Structures of Igneous Rocks cont'd

Vesicular structures:

- **volcanic rocks** may contain a **circular**, **elliptical**, or **irregularly** shaped cavities
- These resulting from the expansion of gases in the lava while it cools, giving the rock a vesicular structure.
- Vesicles tend to be concentrated in the upper portion of the flow due to the tendency of the volatiles to rise.
- In a subsequent stage, these cavities may be filled with secondary minerals or with deuteric minerals arising from the interaction of preexisting minerals with late-stage magmatic solutions, such as quartz (which can form geodes), calcite, zeolites, chalcedony, and chlorite, in which case they are described as amygdaloidal structure.

Structures of Igneous Rocks cont'd

Vesicular structures cont'd:

- In a subsequent stage, these cavities may be filled with secondary minerals or
- with deuteric (alteration) minerals arising from the interaction of preexisting minerals with late-stage magmatic solutions,
- such as quartz, calcite, zeolites, chalcedony, and chlorite, in which case they are described as amygdaloidal structure.

Strucures of igneous strucures

- The term columnar refers to the structure provided by the disposition of the volcanic rock in
- five or six-sided columnar prisms as a result of the lava contracting during its cooling (Fig.1).

Columnar jointing in basalt of stafia island in scotland.

Textures of igneous rocks

- Plutonic rocks:

❖ Exhibit **variable grain size**, usually distinguishable to the naked eye, generating a phaneritic texture (Fig.).

Granitic rock showing massive strucutre and phaneritic texture (bottom left)

Textures of igemnous rocks cont’d

- Volcanic rocks:

- Are so **very fine-grained** that grains are **not distinguishable** to the naked eye,
- which is called an **aphanitic texture**.
- If the lava cools very rapidly, crystalline minerals do not form, and the result is **volcanic glass** and a **vitreous texture**.
- When one mineral is conspicuously larger and stands out in the matrix, this is called a **porphyritic texture**.

Classification of igneous rocks

- Igneous rock classification is **based in two main features**:

1. The modal mineralogy and
2. Grain size,

- This is also a criterion to distinguish **volcanic** from **plutonic rocks** even though there is no specific grain size set for this.

Classification of igneous rocks

- Exceptions are made for glassy or very fine-grained rocks,
- That may be classified on their chemical composition

Classification of igneous rocks

- The most widely adopted classification of igneous rocks is based on the recommendation of **International Union of Geological Sciences (IUGS) in**
- which relative proportions of the essential minerals are plotted in triangular diagrams for each different group of rock – e.g., plutonic, volcanic, or ultramafic.
- These give the root names such as **granite**, **syenite**, **basalt**, **rhyolite**, etc.

Some common igneous rocks

- There is a wide variety of igneous rocks, but for engineering geology, the most common are included in Table 2.

Igneous Rocks, Table 2 Main mineralogy and colors of some common igneous rocks

Essential minerals Rock classification	Qtz, Pl, Kfs (Bt/Hbl)	Kfs (Bt/Hbl) (Aeg) (*Ne/Sdl*)	Pl, Bt, Hbl (Qtz ± Kfs)	Pl, Aug, Op	Ol ± Px (Mag)
Plutonic	Granite	Syenite *Nepheline syenite*	Diorite	Gabbro	Dunite/Peridotite/ Pyroxenite
Volcanic	Rhyolite	Trachyte/ *Phonolite*	Andesite	Basalt	–
Colors	Grey to reddish pink	Pink to reddish brown/grey to dark green	Dark grey/ greenish brown	Dark grey to black	Black to greenish black
Chemical classification (SiO_2 content)	>63% (acidic)	52–63% (intermediate)		45–52% (basic)	<45% (ultrabasic)

Abbreviations: *Qtz* quartz, *Pl* plagioclase, *Kfs* K-feldspar, *Bt* biotite, *Hbl* hornblende, *Aeg* aegirine, *Ne* nepheline, *Sdl* sodalite, *Aug* augite, *Op* opaque minerals, *Ol* olivine, *Px* pyroxene, *Mag* magnetite

Igneous rocks in engineering geology

- The abundance and good physical and mechanical properties (isotropy, mineral cohesion, low porosity, etc.) of igneous rocks, when not fractured or extensively weathered, favor their use in civil works as foundations, crushed rock and as building stone.
- Their appearance also makes them highly valued for use as slabs for covering floors, walls, and facades and as finished or semifinished pieces like counter- tops, wash basins, etc.

- However, before actually using igneous rocks, care must be taken to perform geological and geotechnical fieldworks on the rock mass,
- in order to determine and quantify discontinuities such as **fracture, fault, and other features** that could constitute areas of weakness or percolation/loss of water.

- It is also necessary to perform laboratory physical and mechanical determinations and
- Petrographic analyses in order to check the kind and degree of mineral alteration as
- well as the presence of microdiscontinuities and types of filling materials.
- When using igneous rocks as ornamental stones or as aggregates, the petrographic features are particularly important:

- To check for the presence of unstable, altered, or potentially deleterious minerals
- that could interfere with their aesthetic appearance and durability,
- unless preventive measures are adopted when they are used.

Summary

- Igneous rocks result from **solidification of molten** or partially molten material (magma) generated inside the Earth’s crust.
- According to their formation conditions, they are distinguished in two types,
- **Plutonic or intrusive**, when formed deep inside the crust by the slow cooling and solidification of magma, resulting in crystalline materials, and
- **Volcanic or extrusive** when formed at the Earth’s surface either by flow of lava, resulting in glassy or fine-grained materials due to the rapid cooling, or by fragments of crystal, glass, or rocks explosively ejected from a volcano.

Summary

- **Plutonic** and **volcanic** rocks are classified in terms of their **grain size** and the **predominant mineral** components.
- **Pyroclastic** rocks are predominantly classified in terms of size of the **constituting fragments.**

Summary cont’d

- **Unweathered igneous** rocks usually exhibit **high mechanical strength.**
- For engineering geology purposes, **smaller grain sizes usually correspond to greater mechanical** strength, although the **presence of discontinuities as** cavities, joints, faults, as well as mineral alterations can reduce strength.
- Higher proportions of quartz generally confer greater mechanical strength but may also contribute to increased abrasiveness and wear on equipment.

Summary cont'd

- Good **physical** and **mechanical properties** (isotropy, mineral cohesion, low porosity, etc.) of igneous rocks, **when not fractured** or extensively weathered, favor their use in civil works as **foundations**, **crushed rock**, and **building stones**.
- They are also highly valued **facing**, **flooring**, and other **decorative** uses.

Summary cont'd

- For proper use, it is recommended that careful fieldwork should be undertaken to determine and quantify discontinuities
- such as fractures, faults, and other features that could constitute areas of weakness,
- as well as laboratory physical and mechanical determinations and petrographic analyses to check, for example, for deleterious minerals, types and degree of mineral alteration, microdiscontinuities, and filling materials.

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Sedimentary rocks

Sedimentary Rocks

Definition

Rocks formed from the products of **physical erosion** or **chemical** and **biological processes** at the surface of the Earth, both **on land** and **under water**.

Sedimentary Rocks cont'd

- Sedimentary rocks are formed in four ways:

I. Debris from mechanical erosion of soils & rocks which are transported and deposited as sediments;

II. Chemical & biochemical processes;

III. Particulate material from volcanic eruptions;

IV. Accumulation of organic material mainly from algae and plants.

- **Sedimentary rocks need to be understood in the context of the Earth's dynamic processes:**

❖ The **movement of tectonic plates** give rise to **volcanic activity** and **mountain building**, which are eroded and

❖ The resulting debris are carried to, and **deposited in depressions** in the Earth's surface.

❖ Other sediments are **precipitated directly from water** or arise from **accumulations of organic material** and

❖ others deposited from debris that originated during volcanic activity.

- Whereas **sedimentary** rocks are **less abundant** in the Earth's crust than **igneous** and **metamorphic** rocks,
- They **do cover most of the Earth's surface** and,
- So, they **are of importance to engineering geology** and
- Provide the **main earth resources for building and construction.**

- Many types of sedimentary rocks contain the remains of organisms either in the form of **intact fossils or broken debris**.
- These may be scarce or scattered but in some types of **limestone** may constitute the major part of the rock.
- The **complexity of sedimentary rocks** has led to several systems of **classification.**

Clastic (Epiclastic) Sedimentary Rocks

- **Epiclastic** sedimentary rocks (also known as **terrigenous** or **siliciclastic** rocks) include those that **originated from geological processes** at the surface of the Earth through **erosion**, **transport** of debris, and **deposition** of these as sediments.
- These consist mainly of the mineral **quartz** accompanied by varying quantities of other minerals, notably **feldspar** and **mica**.

Clastic (Epiclastic) Sedimentary Rocks cont'd

- A classification based on **grain size** distinguishes between **clay/mudrock** (finest), **siltstone**, **sandstone**, and **conglomerate/breccia** (coarsest).
- **Sandstones** (arenites) are the most extensively studied **epiclastic rocks**, because of the **importance of porosity** and **permeability characteristics**.
- Some sandstone is sufficiently porous to have **20%** of their volume filled by **oil**, **gas**, or **water,** which **characterizes the**m as **good reservoir rocks**.

- The **mineral compositions of sandstone** vary depending on the **proportions of quartz**, **feldspar,** or **lithic fragments**.
- In accordance with the amounts of these three different components, a sandstone can be a **quartzarenite,** a **feldspathic arenite** **(arkose),** or a **litharenite**.

- **Angularity** of debris also **influences classification** thus;

❖ a **conglomerate** is a sedimentary rock composed by **thick coarse, well-rounded material** (**pebbles & blocks**) with **interstitial sand**,

❖ Whereas **a breccia** has a similar range of **particle size** but the debris is **angular**.

❖ When there are **large quantities of sand** and **mud** forming the **matrix** between **pebbles** and **blocks**, the **rock is called diamictite.**

- The **fine grained clastic sedimentary rocks** are **plastic clay** or, if fissile, **shale**.
- These mainly consist of **clay minerals** and some are important for use in **brick making**, **ceramics**, **creation of impermeable structures**, and **other industrial uses**.
- Sediments that are a **mixture of clay** and **silt** are **referred to as mud**.
- The equivalent rocks are **mudrock/mudstone**.

Chemical and Biochemical Sedimentary Rocks

- Many sedimentary rocks are **formed at the site of deposition by direct precipitation (chemical or biochemical)**, from the **water** and are known as **authigenic**.
- It is difficult to determine if the genesis of some are **purely chemical**, without direct or **indirect biological influence**, such as some **limestone** and **ironstone**,
- but others **are purely chemical such as evaporites**, (salt deposits), deposited from **super-saturated sea** or **lake water**.
- Some ironstone exhibits **rhythmic alternations between iron minerals (mainly hematite), and pure silica**.

Chemical and Biochemical Sedimentary Rocks cont'd

- Several interpretations exist to explain this alternation, some relating to the alternation of climate conditions with proliferation of micro-organisms that promoted hematite precipitation and periods less favourable to life, when the silica precipitated.
- This rock is known as banded iron formation (BIF).

Chemical and Biochemical Sedimentary Rocks cont’d

- Another kind of chemical sedimentary rock is **chert** or **flint** (consisting of micro silica) that sometimes probably originated from precipitation in hot water in springs but, in other cases, during diagenesis (consildation).
- Chert and flint **were important to humanity** in the past because they were a favored rock for **making stone tools**.
- An unusual sedimentary process, related to biochemical processes, is the formation of **calcretes** - a type of **limestone** - **in soils in arid and desert areas.**

Organic Sedimentary Rocks

- Other sedimentary rocks are almost completely formed from **accumulations** of **organic substances**.
- Those consisting of **plant debris** in the form of **unconsolidated peat**, and **lignite to coal (**depending on the **degree of carbonization** due to burial), compression, and heating which drives off water and volatile organic compounds.

Organic Sedimentary Rocks cont'd

- In some circumstances, **organic compounds**, mainly from **plankton**, are present in significant quantities **in pores** and, during diagenesis, **become oil**.
- Such deposits are known as **oil shale.**
- The **oil can be extracted by hydraulic fracturing of these rocks**.
- Both types are **important sources of energy** but **emit large quantities of carbon dioxide during combustion.**

Pyroclastic Sedimentary Rocks

- **Pyroclastic sediments** are produced during volcanic erup- tions.
- Molten **magma is expelled and rapidly solidifies** to form **ash** and **coarser debris**.

Pyroclastic Sedimentary Rocks cont'd

- Although of **igneous origin**, these can be considered as **sediments** because they are **deposited in layers** at the **Earth's surface** and are best classified by grain size:

- **Bombs** (greater than 64 mm),
- **Lapilli** (between 64 and 2 mm),
- **Coarse ash** (between 2 and 0.06 mm) and
- **Fine ash** (less than 0.06 mm) (Tucker 2008).

- Rocks consisting of ash are called tuffs.
- Those consisting of coarse angular debris are volcanic **breccias.**

Sedimentary Rocks Resulting from a Mixture of Processes

- Some sedimentary rocks result from a mixture of processes, for example:

- ❖ Epiclastic sediments mixed with authigenic sediments, such as marl, which is a **mixture of fine grained limestone** and **clay minerals**; and
- ❖ Rocks in which **volcanic ash falls** into **waters** where other sediments are being deposited.

Summary and Conclusion on Sedimentary Rocks

- There are four main processes that form sedimentary rocks:

1. Epiclastic (terrigenous) by erosion, transportation and deposition of clastic sediments,
2. Chemical and bio- chemical, through direct precipitation of the sediment from water,
3. Pyroclastic, from the explosive eruption of volca- noes, and
4. by accumulation of organic material.

After deposition, the sediments are transformed into rock by **diagenetic processes** with the strength of the rock reflecting the degree of compaction and cementation.

Metamorphic Rocks

Metamorphic Rocks

Definition

Rocks derived from other pre-existing rocks that, in the course of geological processes, have **undergone mineralogical, chemical, and structural changes** in the solid state, in response to the changes in physical and chemical conditions existing at depth.

Formation of metamorphic Rocks

- Metamorphism is a process in which **pre-existing** rocks are **transformed** into other rocks by increases in **temperature** and **pressure**.
- The increases in temp & pressure causes changes in the mineral association, texture, and structure. These changes take place in the solid state.
- The composition of the rock resulting from a metamorphic process depends essentially on:

❖ Original **composition,**

❖ the conditions of **temperature** and **pressure**, and

❖ the presence and **activity of fluids**.

Formation of metamorphic Rocks cont'd

- The metamorphic processes range from recrystallization, which involves the increase in size and/or the change in the external form of the original minerals, to
- Metamorphic reactions that result in the development of new minerals in stable equilibrium under the new prevailing conditions.

- The most common minerals in the rocks in the Earth's crust are **plagioclase, K-feldspar, quartz, pyroxenes, amphiboles, micas, and clay minerals**.
- Concerning metamorphic rocks, other minerals are typically represented such as garnet, chlorite, serpentine, epidote, talc, and polymorphs of Al_2SiO_5 (kyanite, sillimanite, and andalusite).

- Metamorphic processes mainly occur in association with tectonic processes at plate boundaries in three major environments: subduction zones, collision zones, and mid-ocean ridges.
- The determining factors for metamorphism are:

❖ **Temperature,**

❖ Pressure,

❖ Presence of fluids, and

❖ Duration of the process.

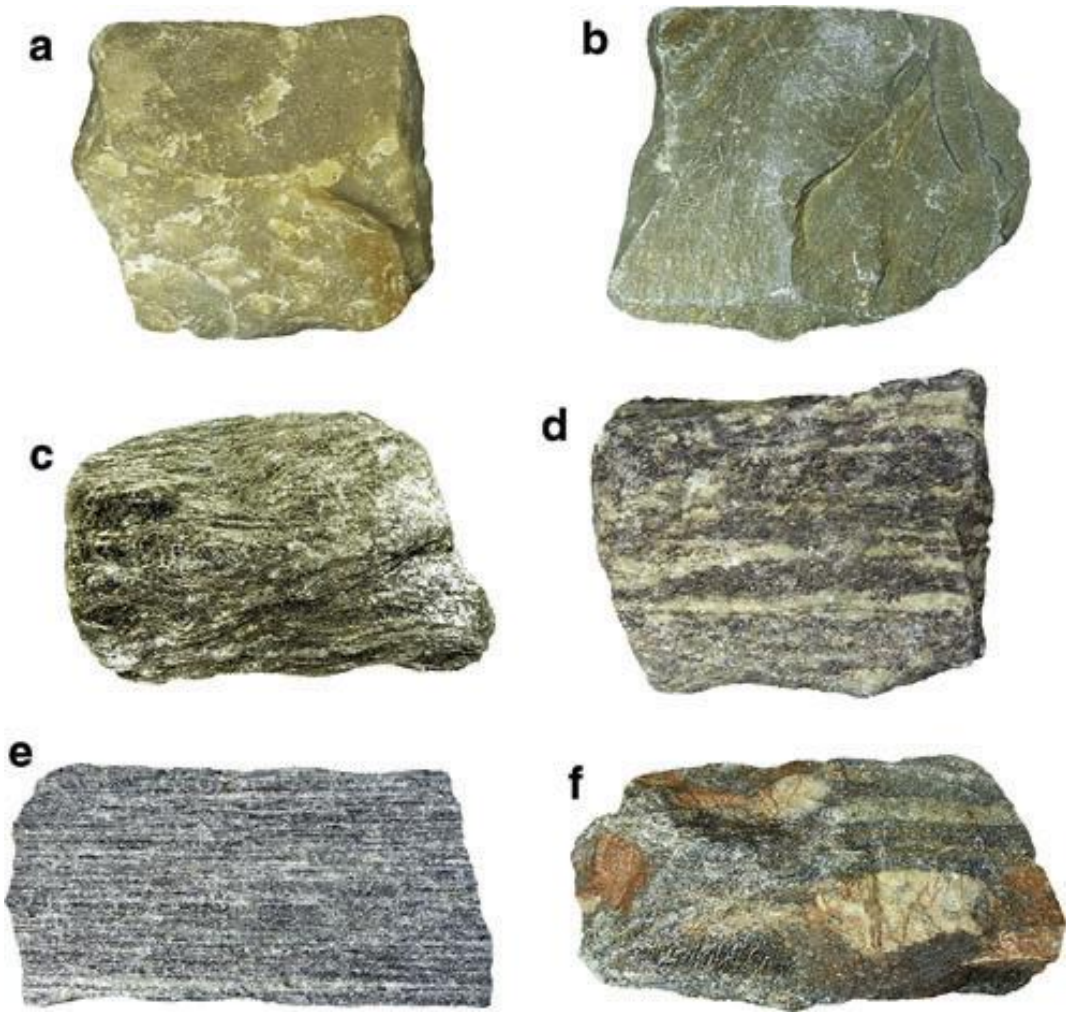
- Temperature is the most important agent, promoting the recrystallization of more stable minerals.
- The heat originates from magma and the geothermal gradient, which is the temperature increase with depth in the crust of the order of 20–30 C/km.
- Metamorphic transformations depend on the precursor rock (or protolith), start at 150–200 C, and end when the rock melts, transforming into magma and then igneous rock.

- Fluids assist the recrystallization of precursor minerals, which occurs due to the migration of ions.
- The main fluid is water with dissolved salts and volatile components.
- In sedimentary rocks, fluids are found within their pores; in igneous and metamorphic rocks, they are present in fractures and faults.
- In metamorphic processes, the water may also originate from the alteration of hydrated minerals (clay minerals and micas) that constitute the original rocks.

- Pressure also plays an important role and increases with depth at a gradient of 1 kilobar for each 3 km.
- There are two types of pressure – lithostatic and directed.
- Lithostatic pressure is the same in all directions in the rock mass, not causing significant mechanical deformation and resulting in essentially equigranular mineral fabrics.
- Directed pressure is generated by the movement of lithospheric plates, acting vectorially and producing deformation and mineral orientation (especially those with tabular or prismatic habits) perpendicular to the maximum pressure.

- Directed pressure is responsible for the formation of **oriented and folded structures**.
- The most common structure of a metamorphic rock is oriented, but massive structures also occur, mainly in mono- mineralic rocks such as **marbles** and **quartzites**.
- Examples of metamorphic structures are: foliated, schistose, gneissic, cataclastic, mylonitic, and relict (Fig. 1).

- Fig. 1 Examples of metamorphic structures:
- Massive (a),
- Foliated (b),
- Schistose (c),
- Gneissic (d),
- Mylonitic (e), and
- Relict (f)



Types of Metamorphism

- There are several types of metamorphism, depending on the predominating agent (temperature or pressure).
- If temperature is dominant, there is contact or thermal metamorphism,
- This occurs when a body of magma intrudes into the parent rock, forming a metamorphic halo at its boundary.
- In this case there is no severe deformation, and the result is a fine-grained rock of massive structure, called hornfels.

- If pressure is more important, there is dynamic or **cataclastic metamorphism**,
- This occurs in the vicinity of shear zones or faults.
- In this case, directed pressure causes movement and ruptures in the crust,
- This produces **mylonites** (in ductile deformation) and **cataclasites** (in brittle deformation), depending on the depth of the crust level where these deformations occur:

- At more surficial (crustal) levels; purely mechanical forces predominate near faults; shear is essentially brittle, causing the fracture and fragmentation of the rock, producing the **cataclasites** and **tectonic breccias**.

- Deeper in the crust, temperature starts to act together with deforming forces, and the shearing process becomes predominantly ductile (Fig. 2),
- This can completely destroy the original textural arrangement of the precursor rocks (igneous or metamorphic), and
- Result in structures with plastic deformation.

Fig. 2: Lenticular deformation of amphibolite in mylonitic gneiss in a shear zone

- If temperature and pressure are equally important,
- there is regional or dynamothermal metamorphism,
- This is responsible for producing large volumes of metamorphic rocks, and
- Associated with the formation of mountains at plate boundaries.
- It occurs over extensive regions and reaches deep crustal levels.
- The resulting rocks tend to be foliated, and the most common varieties are slate, phyllite, schist, and gneiss.

- Two or more successive metamorphic events can occur, that is, polymetamorphism.
- These events may be of a higher or lower grade than the previous metamorphism.
- If temperature and/or pressure increase, there is progressive metamorphism, which forms minerals of higher metamorphic grade in relation to the minerals already present.
- If temperature and/or pressure decrease, there is retrograde metamorphism, which forms minerals of lower metamorphic grade in response to the new physical conditions.

- The minerals that constitute the original rock respond differently to these processes.
- Quartz readily undergoes intracrystalline deformation, showing microscopic deformation.
- After the finalization of forces, recrystallization occurs, and a mosaic of recrystallized grains can occupy the location of what previously was a single grain of quartz.
- The presence of micro defects and very fine quartz grains (<0.15 mm) are criteria for assessing the suitability of crushed rock (coarse and fine aggregate) for use in concrete,

- This is because a direct relationship has been found between these features and the potential for alkali-silica reactions in concrete, forming expansive compounds that could damage and destroy the structures of civil engineering works, such as dams.
- Other minerals, such as feldspars, rarely exhibit intracrystalline deformation,
- In general, only their edges deform and tend to consist of rounded relict crystals (porphyroclasts), also known as augen.

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Classification of Metamorphic Rocks

- Metamorphic rocks can be classified based on three characteristics

❖ Structure,

❖ Mineralogy, and

❖ Their protoliths.

Structural Classification of metamorphic rocks

- The **structural classification** reflects the arrangement and grain size of the constituent minerals, which characterize the metamorphic grade.
- At a low metamorphic grade, the rocks formed are oriented and finely granulated, in which the minerals are not visible to the naked eye.
- They thus have the **foliated** structure of **slate** and **phyllite.**
- At a higher metamorphic grade, the minerals become micaceous or prismatic, resulting in the **schistose** structure which is characteristic of schists.

Structural Classification of Metamorphic Rocks cont'd

- A further increase in the metamorphic grade promotes the segregation of minerals into bands with larger grain size than observed in schists,
- This results in the **gneissic structure,** characteristic of **gneisses**.
- In the higher metamorphic grade **granulite** appears, a rock with **Fe-Mg silicates** (dominantly pyroxene).

Structural Classification of Metamorphic Rocks cont'd

- In fault regions with a strong action of directed pressure, **mylonitic** or **cataclastic structures** form, with elongated or fractured mineral grains, respectively.
- **Migmatitic** structure is peculiar to a hybrid rock, consisting of igneous and metamorphic portions due to **partial melting** and may or may not exhibit fold features.
- The absence of orientation of the mineral grains results in the **massive structure** that is common in rocks of a **high metamorphic grade.**

Mineralogical classification of metamorphic rocks

- The mineralogical classification is most commonly used for **monomineralic rocks**, and the presence of orientation is associated with the constituent mineral.
- Marble, quartzite and amphibolite are some examples of rocks in this category.
- Classification based on the protolith is used when the rock retains relict structures that allow the original rock to be recognized, usually in rocks of a low metamorphic grade. Their names have to include the prefix meta, for example, metaconglomerate.

Classification of metamorphic rx based on protolith

- Classification based on the protolith is used when the rock retains **relict structures** that allow the original rock to be recognized, usually in rocks of a low metamorphic grade.
- Here, the names of the rocks have to include the **prefix meta**, for example, **metaconglomerate**.

Some Types of Metamorphic Rocks

- Slates, phyllites, and schists: characterized by high content of micaceous minerals and well-developed foliation.
- These are the metamorphic products of pelitic sedimentary rocks consisting mainly of clay minerals or clay or silt-sized grains.

Some Types of Metamorphic Rocks

Slate: very fine-grained rock exhibiting a strong planar orientation, called slaty cleavage.

- It consists mainly of sericite and quartz.
- Its principal characteristic is fissility – the property of a rock to fracture easily along fine cleavage or stratification planes, a property that can favor the occurrence of landslides, slippages, and other phenomena.
- On the other hand, this characteristic favors the extraction of slabs that are widely used as flooring and roofing materials in countries with cold climates because of their mechanical strength (under bending forces) and also thermal insulation able to withstand snow.

Some Types of Metamorphic Rocks cont'd

Phyllite:

- Very fine-grained and strongly foliated rock composed mainly of sericite and quartz, and as accessory minerals graphite, chlorite, feldspars, and other minerals.

Schists:

- medium-to-coarse grained rocks, with minerals generally visible to the naked eye, with strongly planar or linear preferential arrangement.
- They typically consist of phyllosilicates (muscovite and/or biotite) and quartz, usually accompanied by metamorphic minerals characteristic of the P and T ranges in which they formed.

Some Types of Metamorphic Rocks cont'd

Gneisses and migmatites:

- Resistant rocks suitable for most engineering purposes, unless they contain foliation planes (especially rich in micaceous minerals, such as biotite) in quantities and dimensions that can constitute discontinuities or sites conducive to landslides/slippages.

Some Types of Metamorphic Rocks copnt’d

Gneisses:

- usually quartz-feldspathic rocks, medium-to- coarse grained, and showing moderate-to-strong planar orientation provided by the iso-orientation of tabular or prismatic minerals, called gneissic structure or foliation.
- They may be derived either from the deformation of granitic rocks or from the total mineralogical and textural reorganization of rocks, especially pelitic rocks, under high-grade metamorphic conditions (high P and T), resulting in a mineral association of quartz, K-feldspar, and plagioclase, with garnet, cordierite, aluminosilicates, and muscovite.

Some Types of Metamorphic Rocks cont'd

- **Migmatites**:
- Rocks of heterogeneous compositions and structures (called migmatitic), usually medium-to-coarse grained, which often occur in terrains of high metamorphic grade.
- Megascopically, migmatites consist of light-colored (leucocratic) portions of a low-mafic, granitic (quartz- feldspathic) composition interlayed in dark-colored (melanocratic) portions that are generally foliated and have mafic minerals in their composition, with gneissic structures.

Summary – about metamorphic rocks

- Metamorphic rocks are formed from precursor rocks modified by increase of pressure and temperature, leading to changes in the mineral association, in texture, and in the structure of the rock – processes that occur in the solid state.
- Their characteristics depend on the protolith (structure, texture, and composition of the original rock), the combined action of pressure and temperature, or the predominance of one of these factors, the time lapse of the metamorphic processes, and the presence or absence of fluids.
- Examples of metamorphic rocks include slates, phyllites, schists, gneisses, migmatites, marbles, amphibolites, and quartzites.